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MARINE INFRASTRUCTURE DEVELOPER PRIVATE LIMITED (MIDPL)

REVISED MASTER PLAN OF KATTUPALLI PORT

Draft CEIA/EMP Report

Volume II

(Mathematical Modelling Studies and Marine Biodiversity Management Plan)

June, 2023

PREPARED BY

L&T Infra Engineering

NABET ACCREDITED

Certificate No: NABET/EIA/2023/RA 0175

C1161303
RP003, Rev. B

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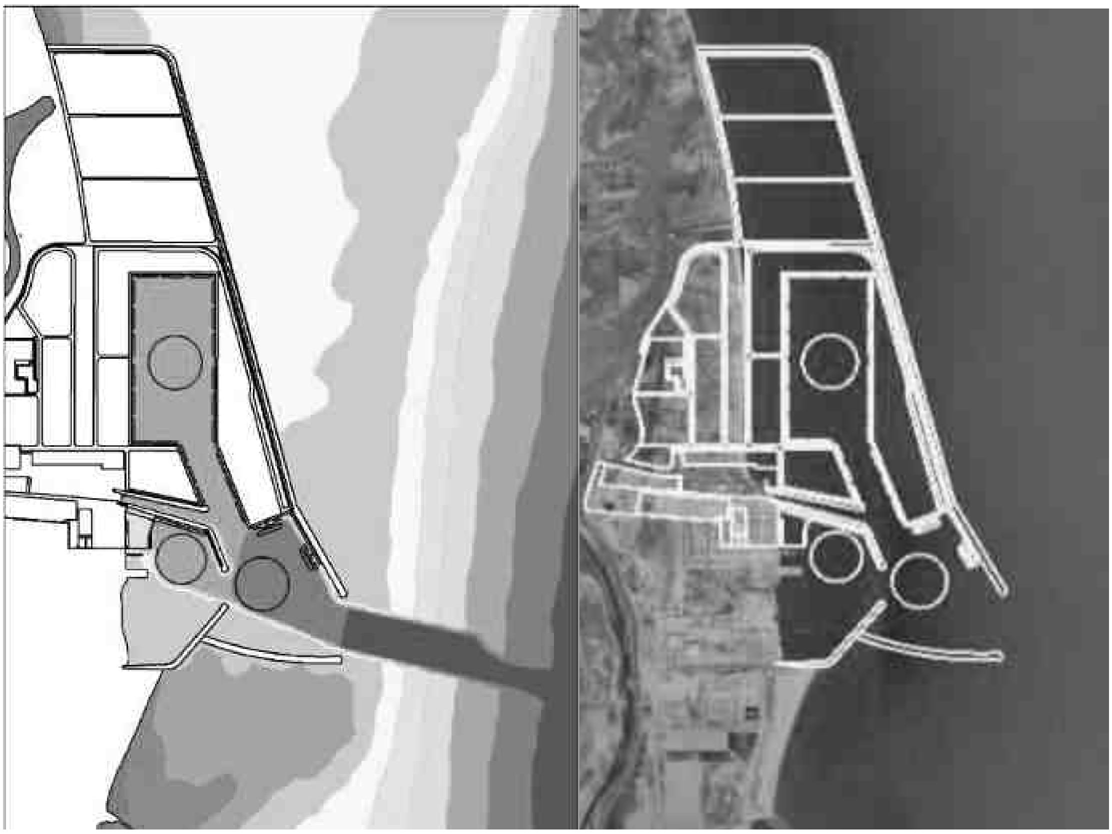

The expert in **WATER ENVIRONM**

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Approved by
Dr. Tirumaleswara Reddy **Technical Director**

Mathematical Modelling studies for Development of Kattupalli Port Master Plan

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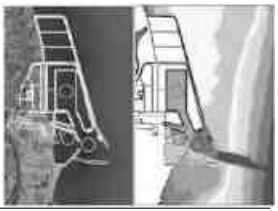

Prepared for ADANI Ports and Logistics

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Project number	63802110
Approval date	11th July 2022
Revision	Final
Classification	Confidential

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EXECUTIVE SUMMARY

The Kattupalli port located north of Chennai has commenced operations since 2012, is developed and operated by Marine Infrastructure Developers Pvt. Ltd. (MIDPL). It is a deep draft port having three berths presently and capable of handling vessels of draft up to 14.50 meters. The expansion of Kattupalli Port is planned to be carried out in a total area of 2120.28 ha which includes 136.28 ha of existing area, 761.8 ha of Government land, 781.4 ha of Private and proposed land reclamation of 440.8 ha.

In this regard, MIDPL has entrusted DHI (India) Water & Environment Private Limited to carry out the mathematical model studies for preparation of Shoreline Management Plan, Wave Tranquillity Studies, Siltation Studies, Tsunami and Cyclone Studies, Flood and Drainage Studies, Intake and Outfall Studies and Oil Spill Modelling Studies.

Coastal process responsible for shoreline management plan were monitored in three phases during the period February 2020 to February 2021. Field measurements on tides, water level, currents, waves, bathymetry, sediment and waves were conducted at selected locations between Ennore Creek and Pulikat Lake. Seasonal variation on water levels, wave, currents and circulation, sediment transport was studied. The measurements indicate that at Kattupalli port, the nature of tide is semi-diurnal type with two high and two low tides in a day. Currents are seasonal, northerly during SW monsoon and southerly during NE monsoon. The wave climate along Kattupalli coast indicates that, almost 80% of waves are coming from E-SE direction and the remaining 20% are from NE-ENE. Most percentage of waves occur in the range of 0.5 to 1.5m and in the period range of 4-10s. Sediment characteristics monitored along Ennore-Pulicat coast indicate that the coarse sediment occupied along the offshore boundary of the shoal and finer sediments adjacent to the shoreline.

Keeping in view of coastal process identified from field investigations, model investigations on hydrodynamical aspects, nearshore wave transformation process, wave tranquillity pattern, sediment transport phenomena, and shoreline changes have been carried out using MIKE 21 state-of-the-art models. The models are calibrated with the field data collected during three phases of the project work. The sediment transport rates with baseline and proposed development were determined. The areas prone to erosion and deposition have been identified. Possible interventions for protection of the erosion hotspots located just immediate north of the proposed development were tested for preparation of shoreline management plan.

The comparison of the simulated and measured water levels and currents are in acceptable range. The maximum current speed observed during spring and neap period at project area is 0.28m/s and 0.10m/s respectively. During SW monsoon a high concentration of wave energy is noticed at south of the Kattupalli port and the coast north of Kattupalli port experiences less energy due to presence of shoals. The waves travel over the shoals, they lose their energy and in turn the wave height reduces. Further, the Pulicat lake mouth situated at 10 km from the proposed master plan boundaries, experiences no changes in the wave climate due to the proposed master plan. The model studies for shoreline changes with the proposed Master Plan indicate that shoreline north of Katupalli port is eroding at the rate of 16m/yr. In order to prevent the erosion along north of Katupalli port, two types of interventions both soft (sand bypassing) and hard measures (groynes) were tested using mathematical model.

- **Option-1: Artificial Beach Nourishment:** From the 15 years shoreline predictions with nourishment quantity of 2MCu.m, the beach fill would be completely lost to sea after 12 years with a rate of 10m/year from the time of nourishment.

- **Option-2: Beach Nourishment and groyne field:** 3km of the shoreline is supplemented by beach nourishment and groyne field (100 to 150m length and spacing as 1 km). The predicted shoreline indicated that the coast is undergoing erosion on its northern side of the end groyne in the order of 8m/year. In order to compensate the loss of north beach of groyne field artificial nourishment of the lost beach is needed. DHI proposes the Option-2, i.e., beach nourishment and groyne field for the present case.

The sedimentation in the approach channel, turning circle and berth pockets of the Master Plan is further assessed using mud transport model. The bed sediment is defined by the sediment mass contained in the layer and by the dry density and erosion properties of the layer. Model results indicate that the average and maximum dredging quantities are 1.2 Mm^3/year and 3.2 Mm^3/year respectively. Two spoil grounds are considered with an area of 1.7Mm^2 and approx.4.5km away from the proposed port location. The disposal of the dredged material would cause a short-term and localised impact on the marine water quality.

As part of the proposed Master Plan development, a 30 MLD seawater desalination plant is proposed by MIDPL in addition to the existing CMWSSB 100 MLD plant. The intake and outfall of both the desalination plants are modelled as connected sink and source. The assessment indicates that the 100 MLD and 30 MLD outlets result in excess salinity below 5 PSU and 1.5 PSU at the point of discharge and 0.1 PSU at the farthest point from the outlet. For 100MLD and 30MLD outlets the excess temperature is comparatively less, and the values are 0.18ºC and 0.07ºC respectively.

A stochastic oil spill assessment is undertaken to assist with oil spill contingency planning for the proposed Master Plan development at Kattupalli port. Oil spill simulation at (i) turning circle, and (ii) SPM location was carried out for gas oil and heavy oil with 15000m^3 of spill quantities. The fate of oil is assessed at the end of 15-day simulation during NE and SW monsoon.

- Spillage occurrence at turning circle is not having any shoreline impact. This was due to the shelter effect of the proposed breakwater and predominant wind direction was from South-East direction. The oil slick was concentrated within the berth area and does not travel far away. For some combination of tide and wind conditions, the oil slick tends to get trapped within the port.
- Spillage occurrence at SPM location was having shoreline impact on the northern side of the proposed development. During the southwest monsoon (June to August), winds from south-easterly was able to move oil very far to the east.

The flood modelling of Ennore creek, Kosasthalaiyar river, its tributary and their floodplains are performed using MIKE FLOOD. The maximum elevation in the port area is 15.78 m and as per the proposed development the land elevation in the port backup area is raised to +4.4 m with respect to MSL. Thus, the model results indicate that raising the port backup area along the riverbanks to the proposed +4.4 m MSL (which is equal to +5 CD) is an effective measure to protect the backup area from flooding.

1 Background

The Kattupalli port located north of Chennai has commenced operations since 2012 is developed and operated by Marine Infrastructure Developers Pvt. Ltd. (MIDPL). It is a deep draft port having three berths presently and capable of handling vessels of draft up to 14.50 meters. The MIDPL has submitted the revised Master Plan for the development of Kattupalli port to Expert Appraisal Committee (Infra-2).

The expansion of Kattupalli Port is planned to be carried out in a total area of 2120.28 ha which includes 136.28 ha of existing area, 761.8 ha of Government land, 781.4 ha of Private and proposed land reclamation of 440.8 ha. In this regard, MIDPL has engaged M/s. DHI (India) Water & Environment Pvt. Ltd., for carrying out the necessary numerical model studies for the proposed master plan.

1.1 Study area

The Kattupalli Port is located north of Kamarajar (Ennore) Port, near Kattupalli village of Ponneri Taluk, Thiruvallur District, Tamil Nadu. The geographic location of the Kattupalli port is at Latitude 13° 18’ 50.35” N and Longitude 80° 20’ 45.68” E. The location map of Kattupalli port and the proposed port expansion layout is shown in Figure 1-1.

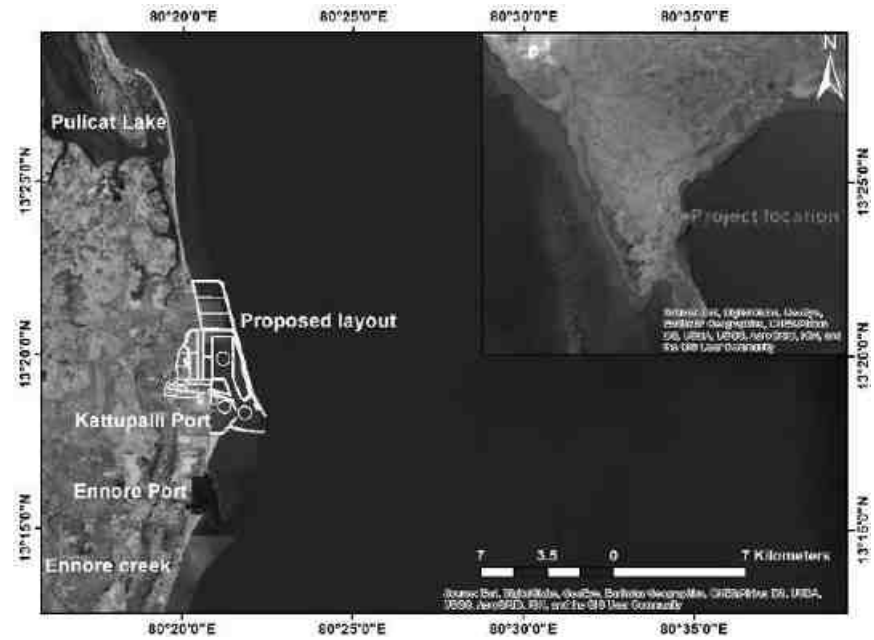


Figure 1-1 Location map of Kattupalli port and the proposed port expansion layout.

1.2 Scope of Work

The scope of works assigned to DHI includes the following:

- Shoreline Management Plan
- Tsunami and Cyclone Studies
- Flood and Drainage Studies
- Siltation Studies
- Wave Tranquillity Studies
- Intake and Outfall Studies
- Oil Spill Modelling Studies

2 Met Ocean Data Analysis

This section describes the analysis of measured data received from client on water levels and currents for Phase-I, Phase-II and Phase-III period. The measurement locations are shown in Figure 2-1 and the parameter specifications are given in Table 2-1. The Temporal variation of these parameters and their features are identified and presented. Further, these measurements form an essential part of calibration and validation of the numerical models.

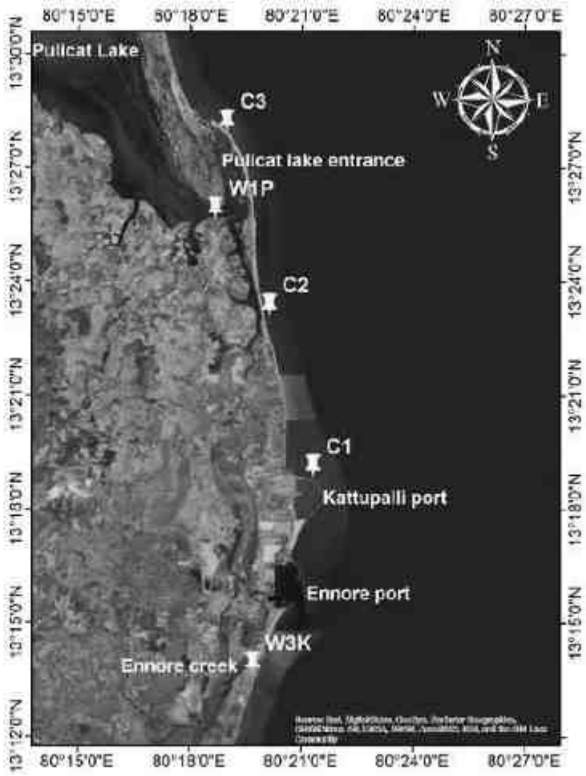


Figure 2-1 Measured data locations

The three Phase of survey is conducted as Phase-I: February-March 2020, Phase-II: September-October 2020 and Phase-III: January-February 2021.

Table 2-1 Details of locations and parameters monitored:

Station ID	WGS84 & UTM-43		Measurement Period			Measured Parameters
	Easting (m)	Northing (m)	Phase-I	Phase-II	Phase-III	
C1	430195	1472484	14/02/2020 to 05/03/2020	10/09/2020 to 30/09/2020	05/01/2021 to 25/01/2021	Current speed, Current direction
C2	428077	1480306	14/02/2020 to 05/03/2020	10/09/2020 to 30/09/2020	05/01/2021 to 25/01/2021	Current speed, Current direction
C3	426032	1489244	14/02/2020 to 05/03/2020	10/09/2020 to 30/09/2020	05/01/2021 to 25/01/2021	Current speed, Current direction
P1	425465	1485014	14/02/2020 to 15/03/2020	10/09/2020 to 10/10/2020	05/01/2021 to 04/02/2021	Water level
P2	421438	1488555	-	10/09/2020 to 10/10/2020	05/01/2021 to 04/02/2021	Water level
K1	427256	1462917	14/02/2020 to 15/03/2020	10/09/2020 to 10/10/2020	05/01/2021 to 04/02/2021	Water level

2.1 Tides

At Kattupalli port, the nature of tide is semi-diurnal type with two high and two low tides in a day. The Naval Hydrographic Chart 3039 provides information on tides and tidal levels with respect to Chart Datum (CD) at Chennai and the levels are reproduced in Table 2-2.

Table 2-2 Various Tidal levels at Chennai

Datum	Notation	Tidal Level (m) w.r.t CD
Mean High High Water	MHHW	1.1
Mean Low High Water	MLHW	0.8
Mean Sea Level	MSL	0.6
Mean High Low Water	MHLW	0.4
Mean Low Low Water	MLLW	0.1

2.2 Water Levels

2.2.1 Phase-I

The Pre-monsoon (2020) water level data is reviewed at two locations inside the Pulicat Lake (W1P) and Ennore Creek (W3K) for a period of 30 days. The data was recorded with respect to Mean Sea Level (MSL) at every 15 minutes interval. Figure 2-2 shows the water level variation at W1P and W3K locations. Maximum tidal range at W1P and W3K are 0.44m and 0.94m respectively. The tide is semidiurnal in nature with a period of 24 hrs and 52min.

The change in water levels is combined due to astronomical tide, wind setup, wave set up, barometric pressure and global sea level rise. The phase of the tide also varies from south to north. The highest water level is seen where the influence of bottom relief and the configuration of the coast are prominent. Asymmetry in water levels is seen at W1P and W3K and it is more predominant during the neap phase of the tide.

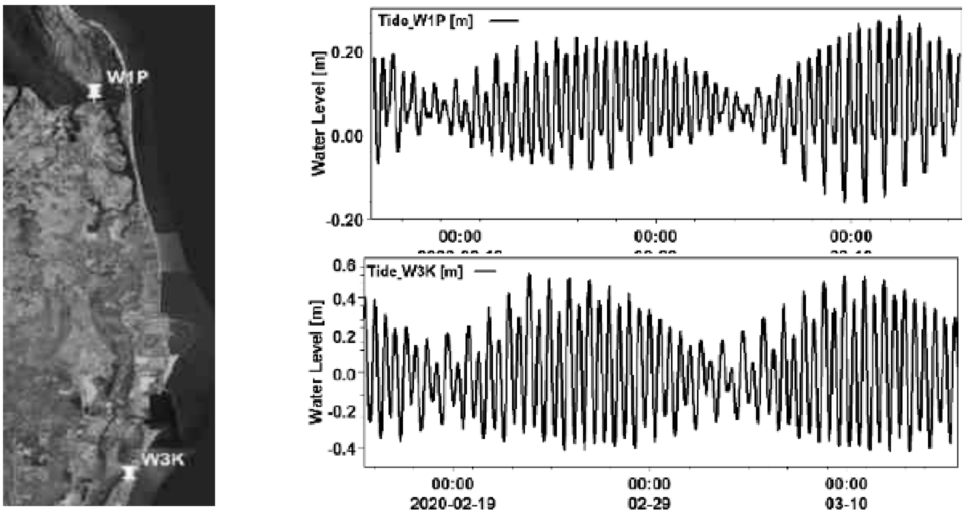


Figure 2-2 Water level variation w.r.t MSL at W1P and W3K Locations for Phase-I

2.2.2 Phase-II

The Post-monsoon (2020) water level data is reviewed at three locations inside the Pulicat Lake (P1 and P2) and Ennore Creek (K1) for a period of 30 days. The data was recorded with respect to Mean Sea Level (MSL) at every 15 minutes interval. Figure 2-3 shows the water level variation at P1, P2 and K1 locations. Maximum tidal range at P1, P2 and K1 are 0.43m, 0.45m and 1.3m respectively. The tide is semidiurnal in nature with a period of 24 hrs and 52min.

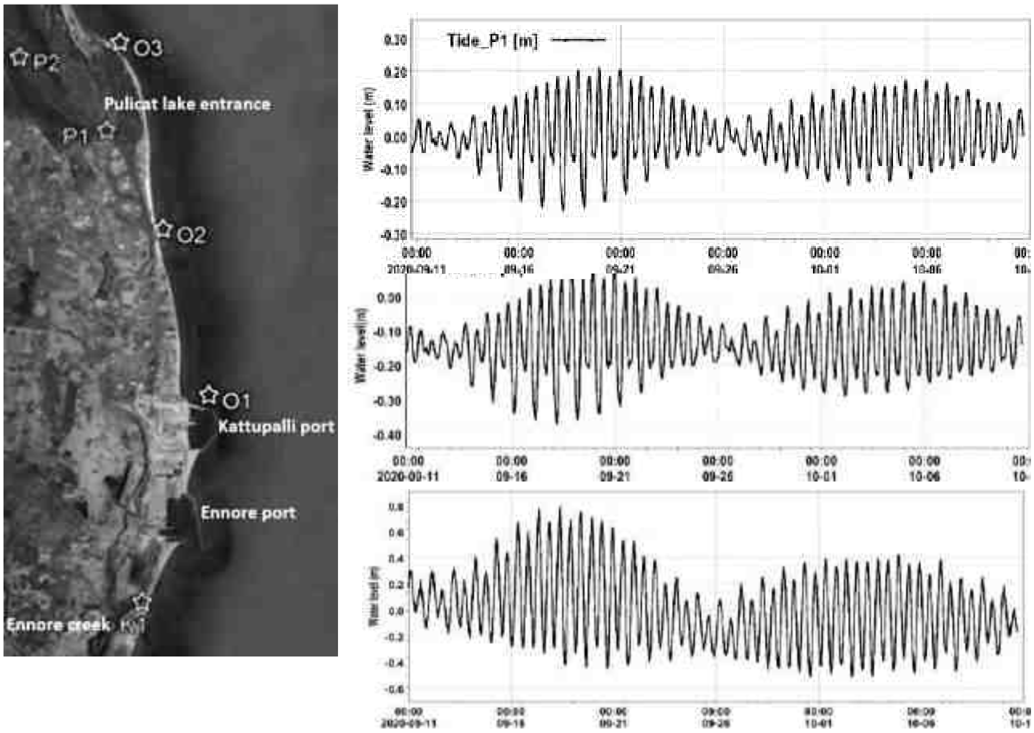


Figure 2-3 Water level variation w.r.t MSL at P1, P2 and W3K Locations for Phase-II

2.2.3 Phase-III

The Pre-monsoon (2021) water level data is reviewed at three locations inside the Pulicat Lake (P1 and P2) and Ennore Creek (K1) for a period of 30 days. The data was recorded with respect to Mean Sea Level (MSL) at every 15 minutes interval. Figure 2-4 shows the water level variation at P1, P2 and K1 locations. Maximum tidal range at P1, P2 and K1 are 0.59m, 0.41m and 0.41m respectively. The tide is semidiurnal in nature with a period of 24 hrs and 52min.

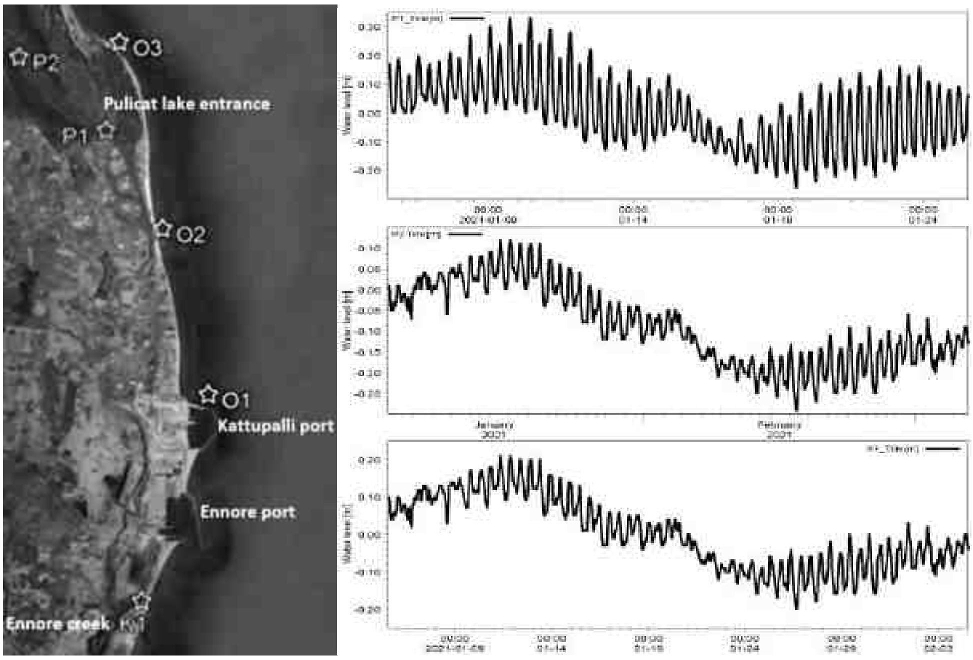


Figure 2-4 Water level variation w.r.t MSL at P1, P2 and W3K Locations for Phase-III

2.3 Currents

2.3.1 Phase-I

Pre-monsoon currents (Phase-I) in the project area are primarily forced by tide and wind components. Major driving mechanism of current variability is attributed to wind in the Bay of Bengal, which reverses with monsoon. It has also been reported that periods of peak monsoon do not coincide with times of maximum current speed.

Figure 2-5 shows the variation of current speed at all the measured locations (C1, C2 and C3) during the measurement period. Maximum current speed at C1, C2, and C3, are 0.17m/s, 0.25m/s, 0.27m/s respectively. The mean current speeds are 0.04m/s, 0.07m/s, and 0.09m/s.

The current direction at C1, C2 and C3 is represented as current roses in Figure 2-6. The current direction at C1, which is immediate north of Kattupalli Port north breakwater is aligned in NW and SE direction. At C2 between Kattupalli port and Pulicat creek, the currents are shore parallel and predominantly northwards. At C3, near Pulicat creek, the currents are aligned in NW direction. The current data indicates that nearshore currents coincide with coastal currents and its direction is northerly during pre-monsoon. But at station C1, which is immediate north of Kattupalli port, is influenced by breakwater, do not show any particular trend in the direction.

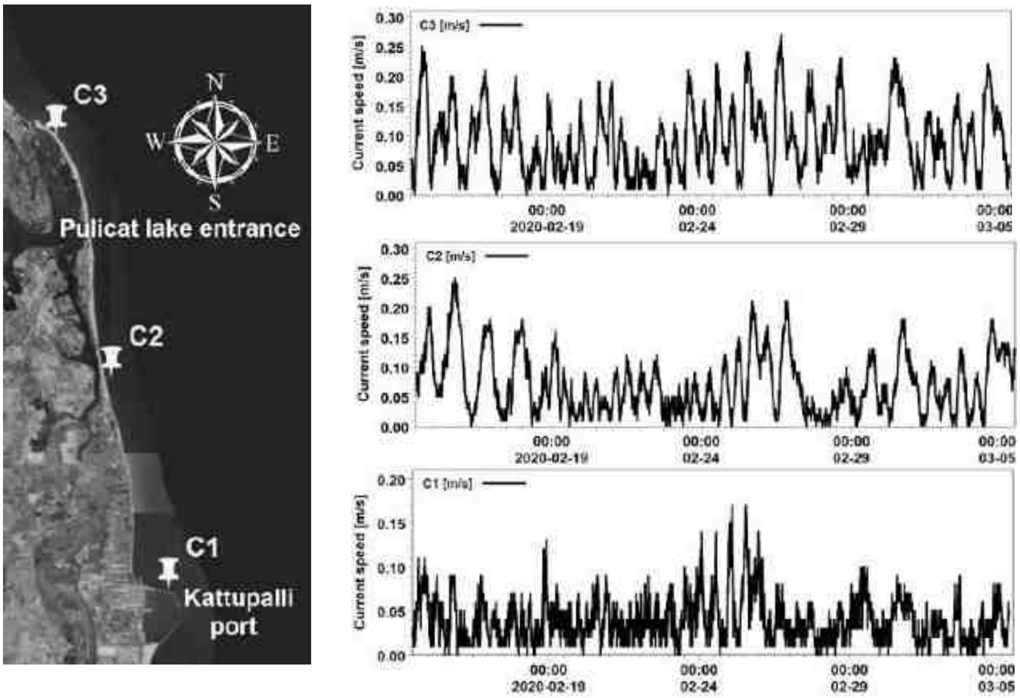


Figure 2-5 Measured current speed at C1, C2 and C3 locations for Phase-I

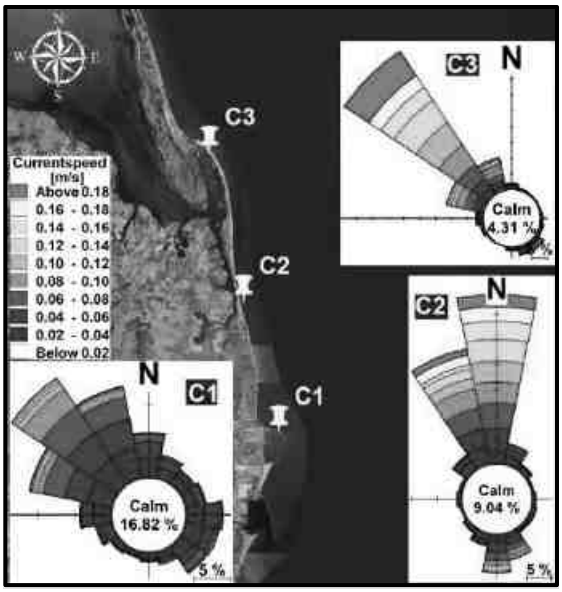


Figure 2-6 Measured current direction at C1, C2 and C3 locations for phase I

2.3.2 Phase-II

Post-monsoon (Phase-II) currents in the project area are primarily forced by tide and wind components. Major driving mechanism of current variability is attributed to wind in the Bay of Bengal, which reverses with monsoon. It has also been reported that periods of peak monsoon do not coincide with times of maximum current speed.

Figure 2-7 shows the variation of current speed at all the measured locations (C1, C2 and C3) during the measurement period. The Maximum current speed at C1, C2, and C3, are 0.24m/s, 0.28m/s and 0.35m/s respectively and the corresponding mean current speeds are 0.06m/s, 0.06m/s, and 0.07m/s.

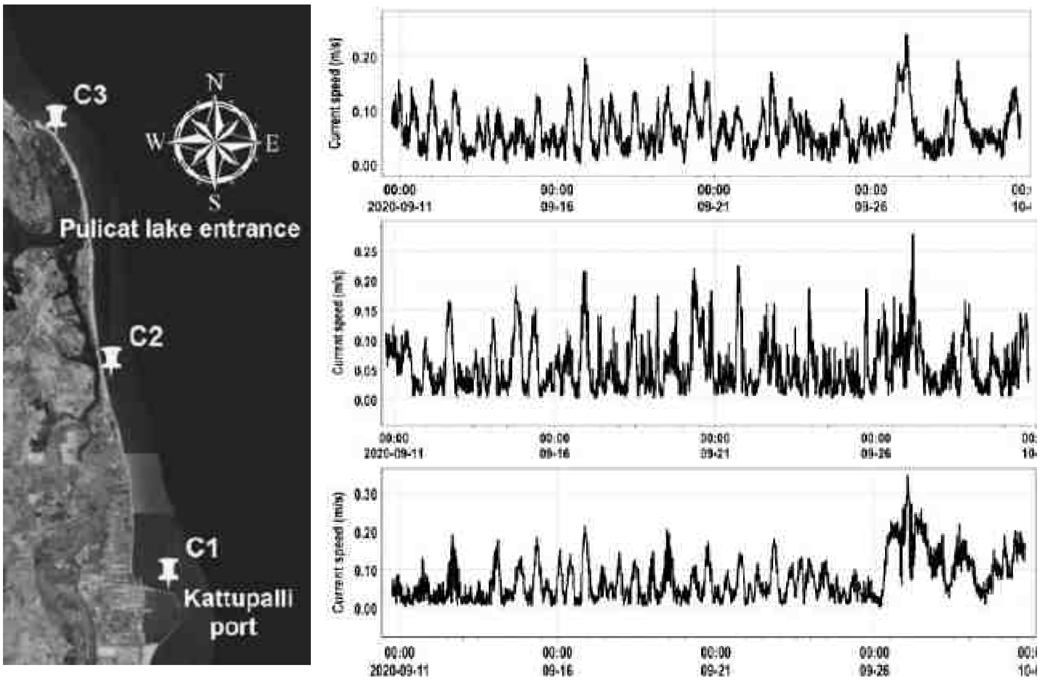


Figure 2-7 Measured current speed at C1, C2 and C3 locations for Phase-II

2.3.3 Phase-III

Pre-monsoon (Phase-III) currents in the project area are primarily forced by tide and wind components. Major driving mechanism of current variability is attributed to wind in the Bay of Bengal, which reverses with monsoon. It has also been reported that periods of peak monsoon do not coincide with times of maximum current speed.

Figure 2-8 shows the variation of current speed at all the measured locations (C1, C2 and C3) during the measurement period. The Maximum current speed at C1, C2, and C3, are 0.42m/s, 0.47m/s and 0.47m/s respectively and the corresponding mean current speeds are 0.15m/s, 0.13m/s, and 0.19m/s.

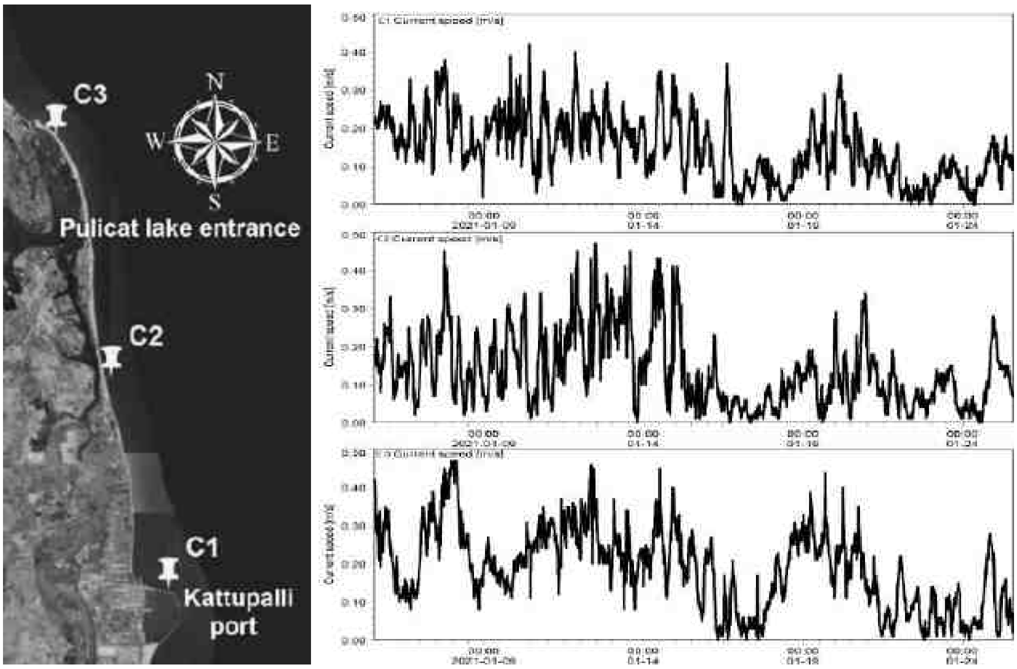


Figure 2-8 Measured current speed at C1, C2 and C3 locations for Phase-III

2.4 Waves

The annual distribution of wave hindcast by National Institute of Ocean Technology (NIOT) indicates that during November and December, the waves are mostly from northeast (30^0-90^0) direction and during the rest of the period the waves are from southeast direction (150^0–180^0). Percentage distribution of wave directions along Kattupalli coast indicates that almost 80% of waves are coming from E-SE direction and the remaining 20% are from NE-ENE. Most percentage of waves occur in the range of 0.5 to 1.5m and in the period range of 4-10 sec shown in Figure 2-9.

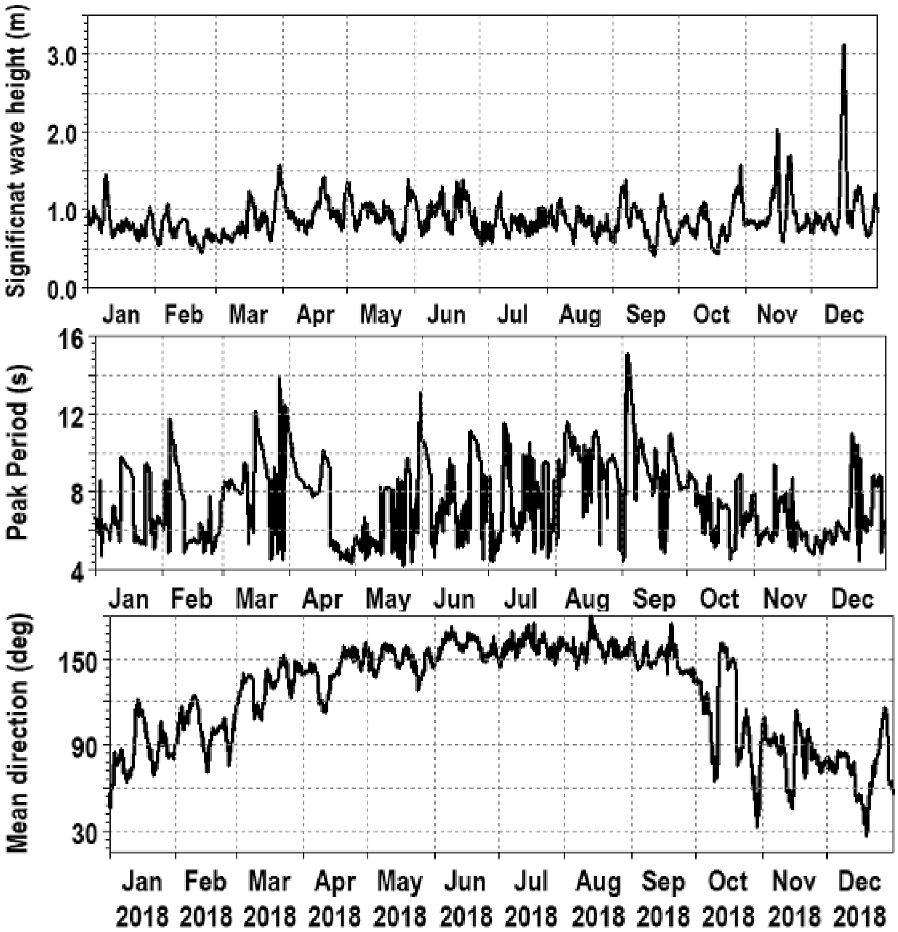


Figure 2-9 Hindcast wave climate at 30m water depth for the period Jan-Dec 2018

2.5 Bathymetry

Seabed information from Ennore to Pulicat creek is mapped using the single beam echosounder (Figure 2-10). The data is collected for the area 30km alongshore (north to south) and 10km at cross shore (east to west). The data is collected from 1m below low water level up to a water depth of 35m with respect to Chart Datum. The spacing between the main lines is 100m and the corresponding cross lines is considered as 500m.

The bathymetry data reveals more variation in the cross-shore direction than the alongshore direction in the coastal environment. Also, the seabed at Kattupalli Port is complex with varied slope between Ennore Creek and Pulicat Creek. The slope at the south of Ennore port is relatively steep (1 in 300) at Ennore Creek, while the slope on the north of Kattupalli port is flat (1 in 500) with submerged shoals extending in north-easterly direction.

Further, the bathymetry data reveals the submerged shoals, which is a morphological feature formed along 10m water depth contour at the waterfront of the proposed project site. These shoals are formed due to unbalanced sand movement along the coast over decades due to regional longshore flow generated by SW and NE monsoon waves. However, it's existence gives sheltering to the coast from energetic cyclone and tsunami waves.

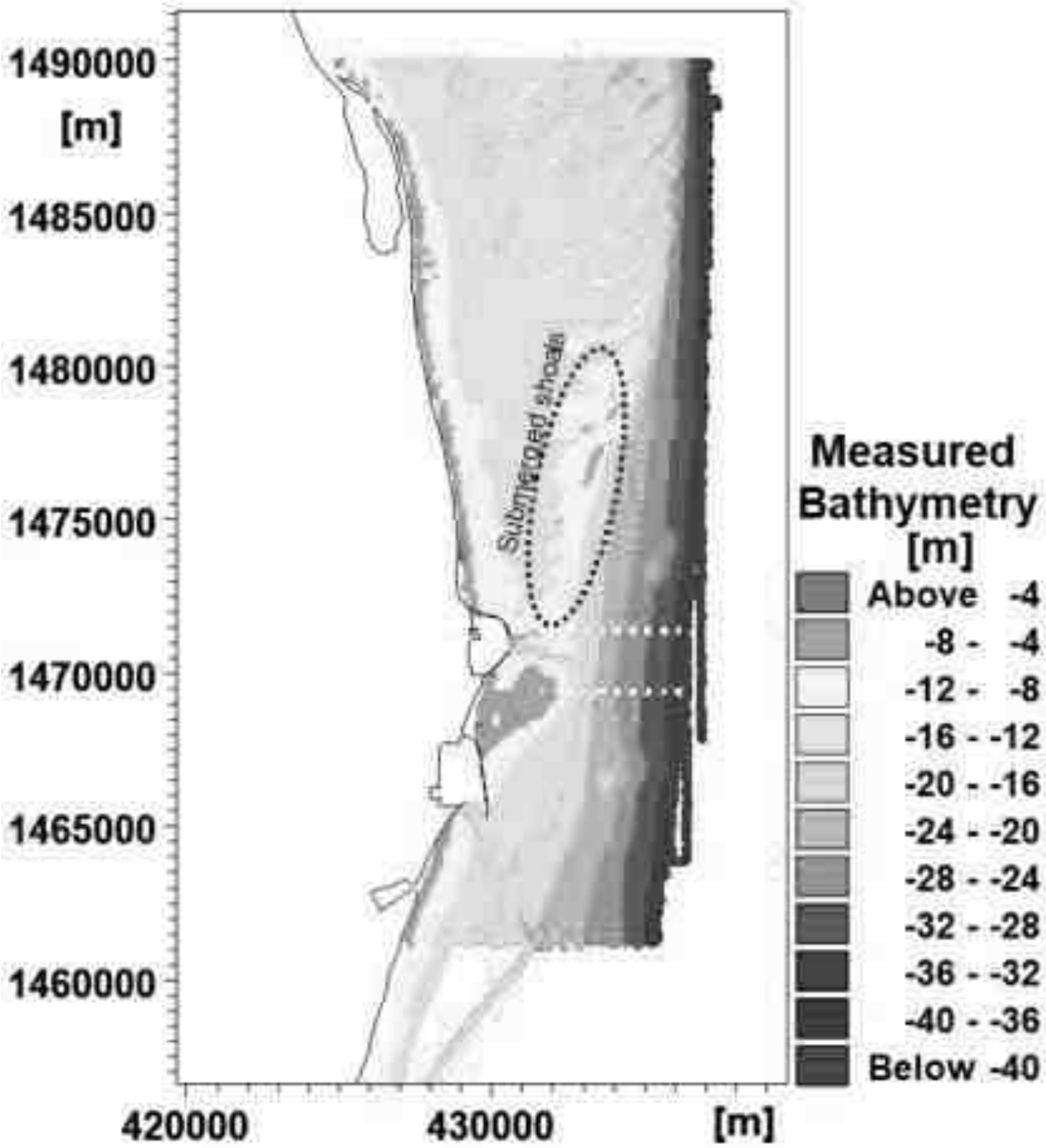


Figure 2-10 Measured Bathymetry data: Ennore to Pulicat Creek

2.6 Seabed sediments

The seabed sediments are collected using Van Veen grab sampler in 2km grid spacing between Ennore and Pulicat area during the period from 15/02/2020 to 24/02/2020. The location map of the seabed sediment samples with grain size is shown in Figure 2-11. The samples are analysed for particle size distribution using sieve analysis. The mean grain size for the model input is considered as 0.31 mm.

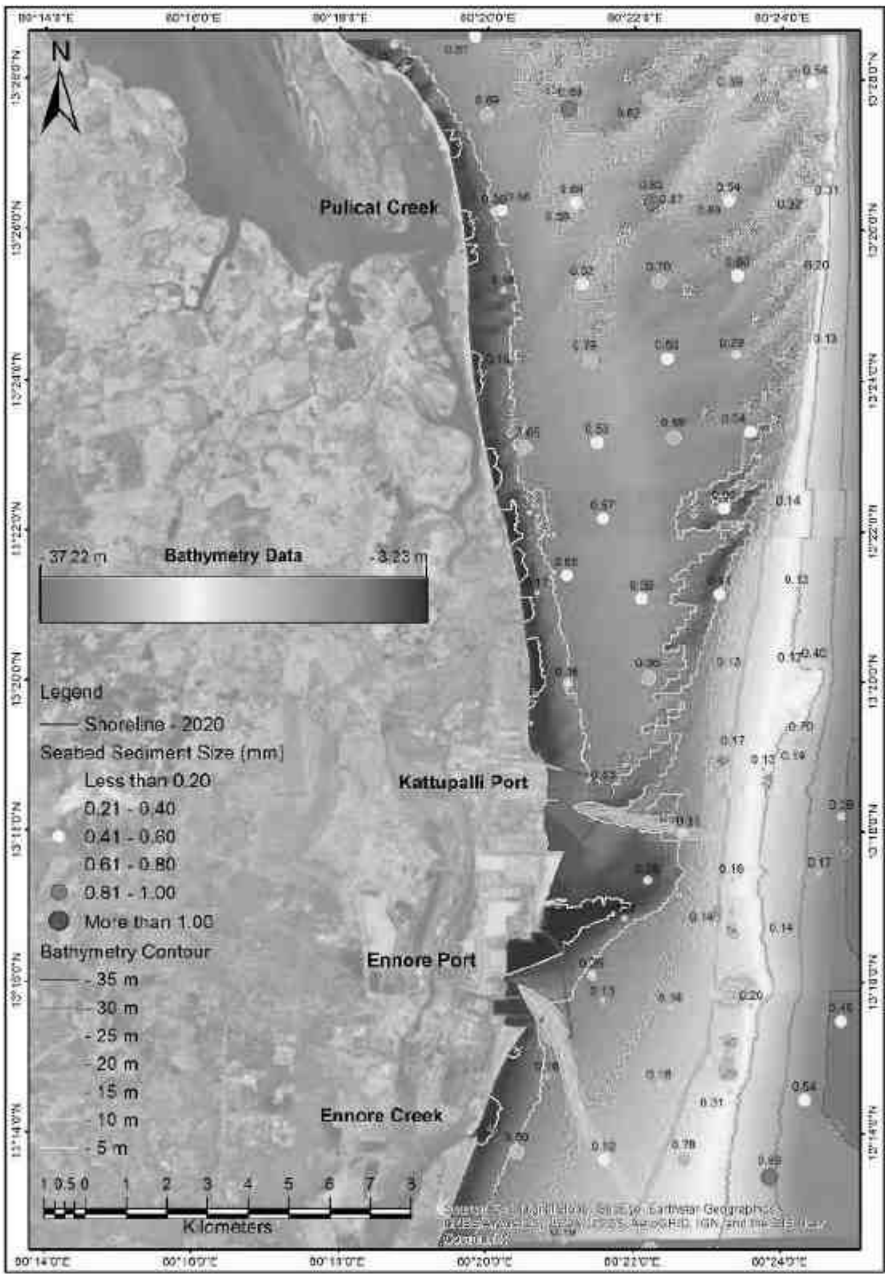


Figure 2-11 Location map of the seabed sediment samples collected

2.7 Suspended Sediments for Phase-I, Phase-II and Phase-III

Surface, mid and near bottom water samples are collected at off Kattupalli port using 1 litre Niskin water sampler for assessing the total suspended solids concentrations. The sampling is conducted at 5 stations named as TSS1, TSS2, TSS3, TSS4 and TSS5 for the Three Phases (Phase-I, Phase-II and Phase-III). The samples are collected at hourly interval for 12-hour duration during spring and neap day of pre and post monsoon period. The Location map with measured TSS value for Phase-I of spring and neap periods are depicted in Figure 2-12 and Figure 2-13. Similarly for phase-II is depicted in Figure 2-14 to Figure 2-17. For Phase-III the samples are collected at hourly interval for 12-hour duration during spring (06 Jan 2020 & 7 Jan 2021) and neap (13 Jan 201 & 14 Jan 2021) and TSS values are provided in a tabular form in Annexure-1.

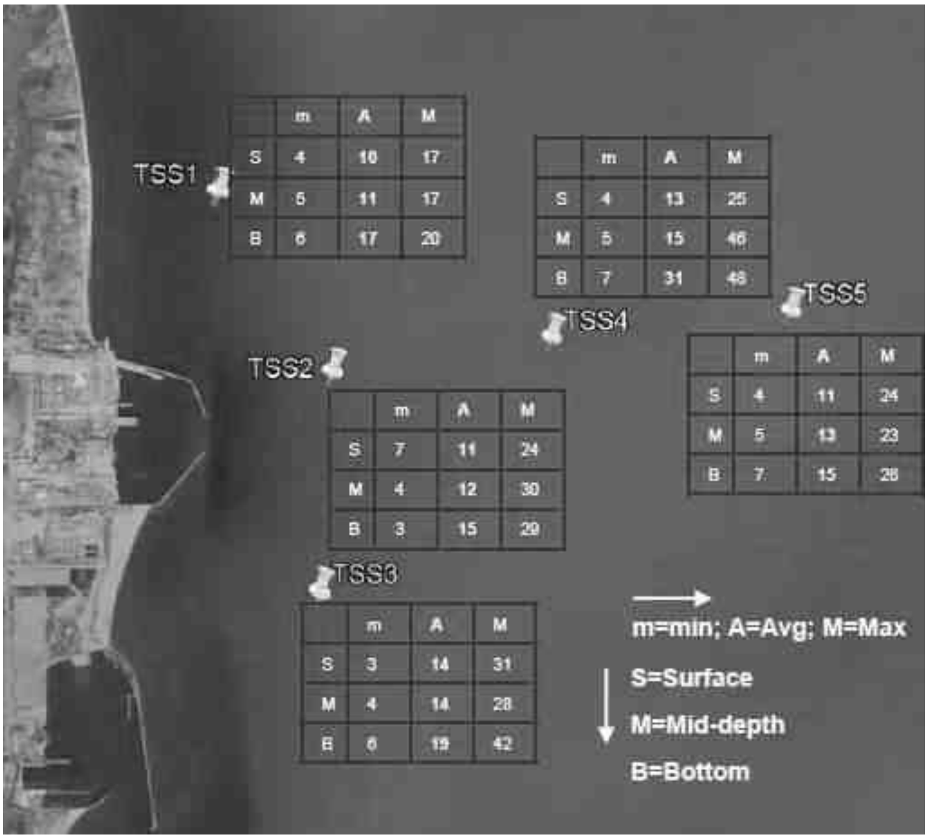


Figure 2-12 Total Suspended Solid Concentration: Pre monsoon Spring period (23 Feb 2020)

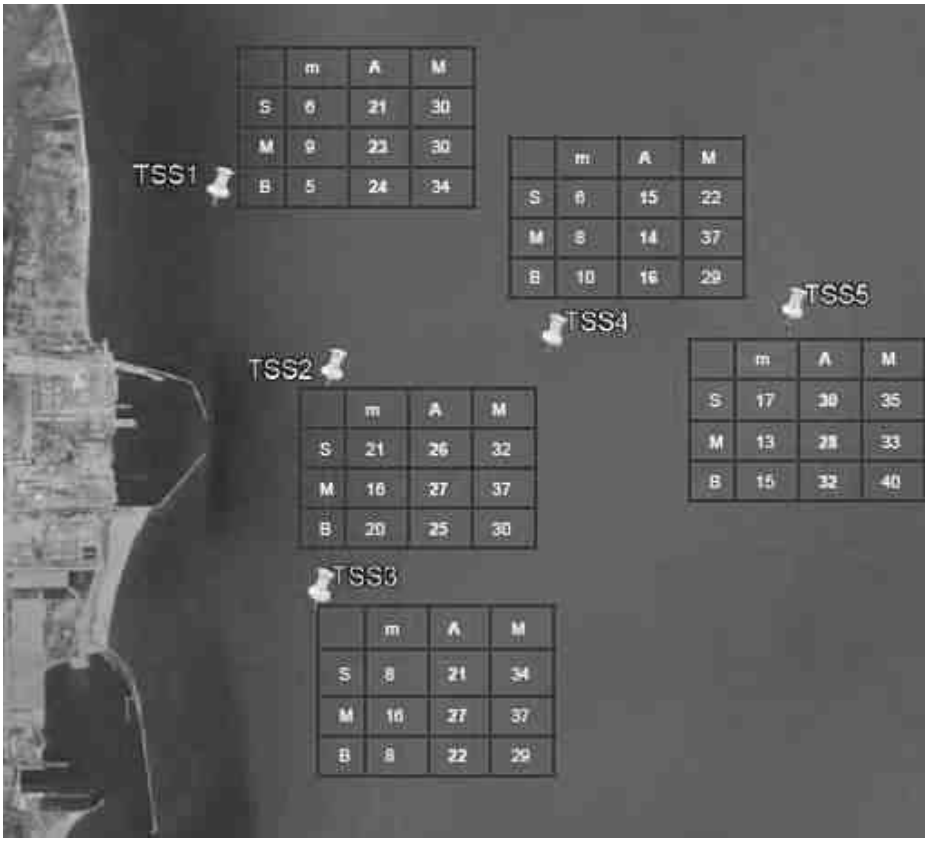


Figure 2-13 Total Suspended Solid Concentration: Pre monsoon Neap period (04 March 2020)

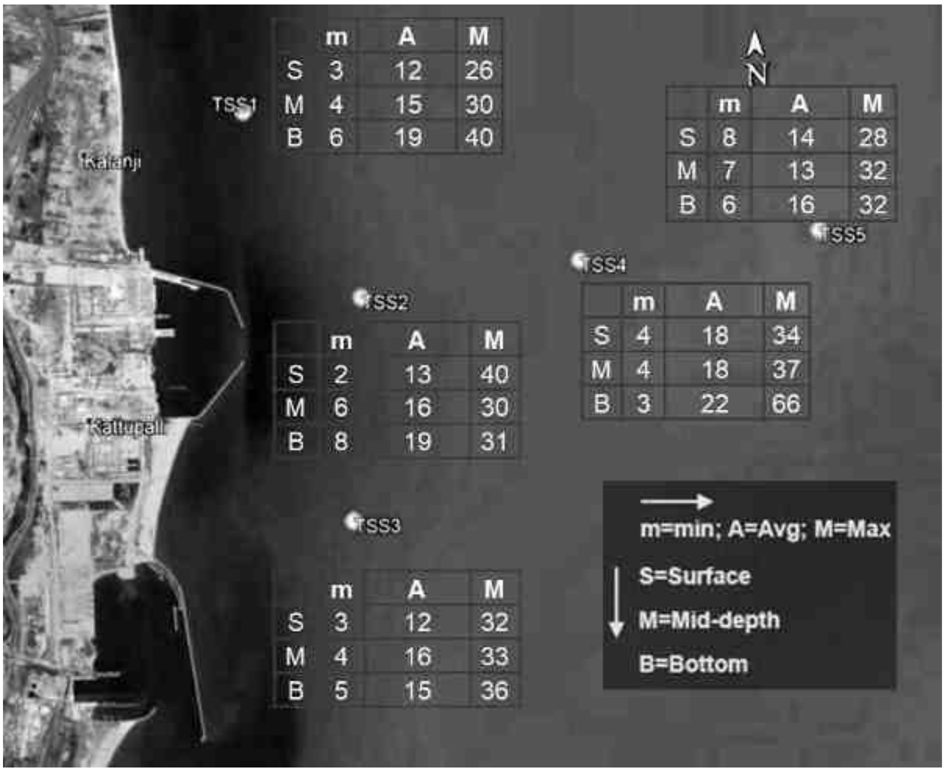


Figure 2-14 Total Suspended Solid Concentration: post monsoon Neap period (11 Sep 2020)

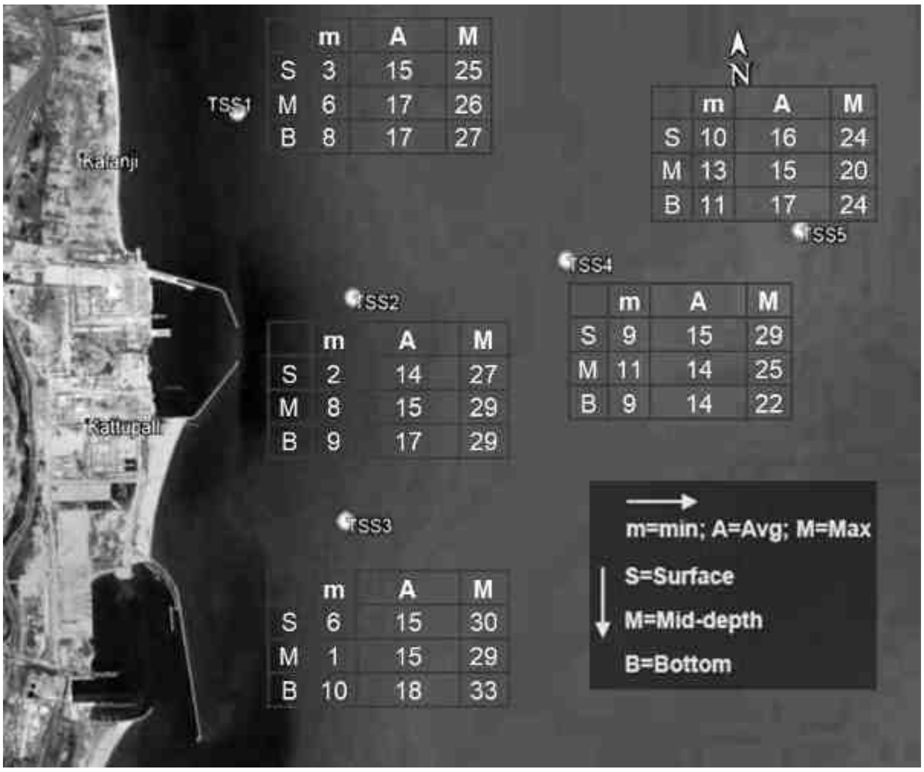


Figure 2-15 Total Suspended Solid Concentration: post monsoon Neap period (12 Sep 2020)

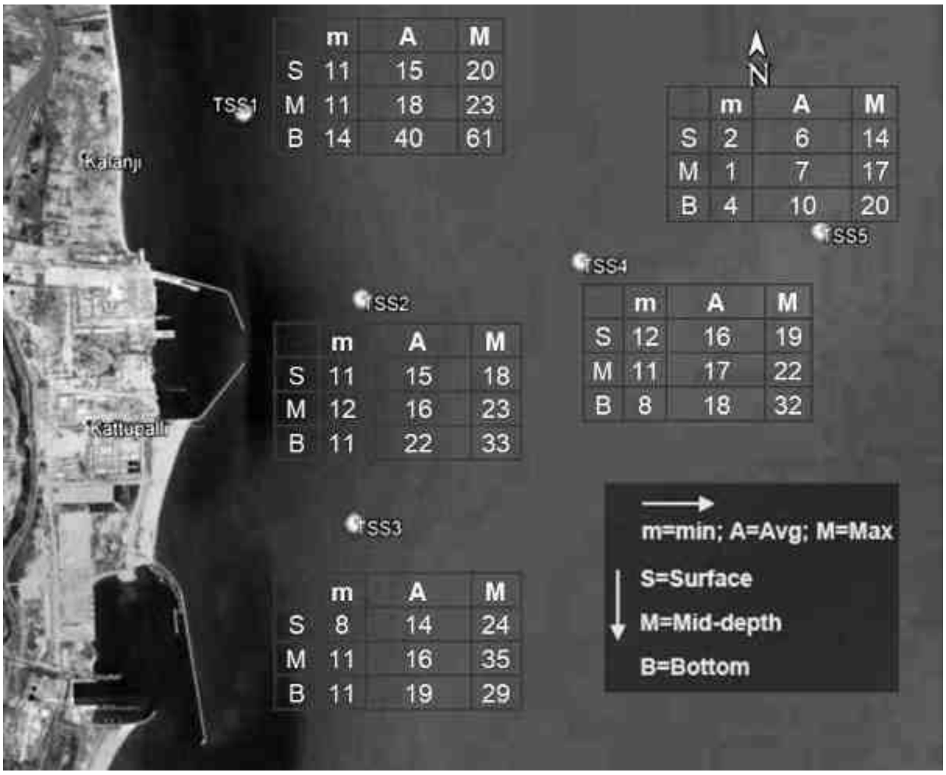


Figure 2-16 Total Suspended Solid Concentration: post monsoon Spring period (18 Sep 2020)

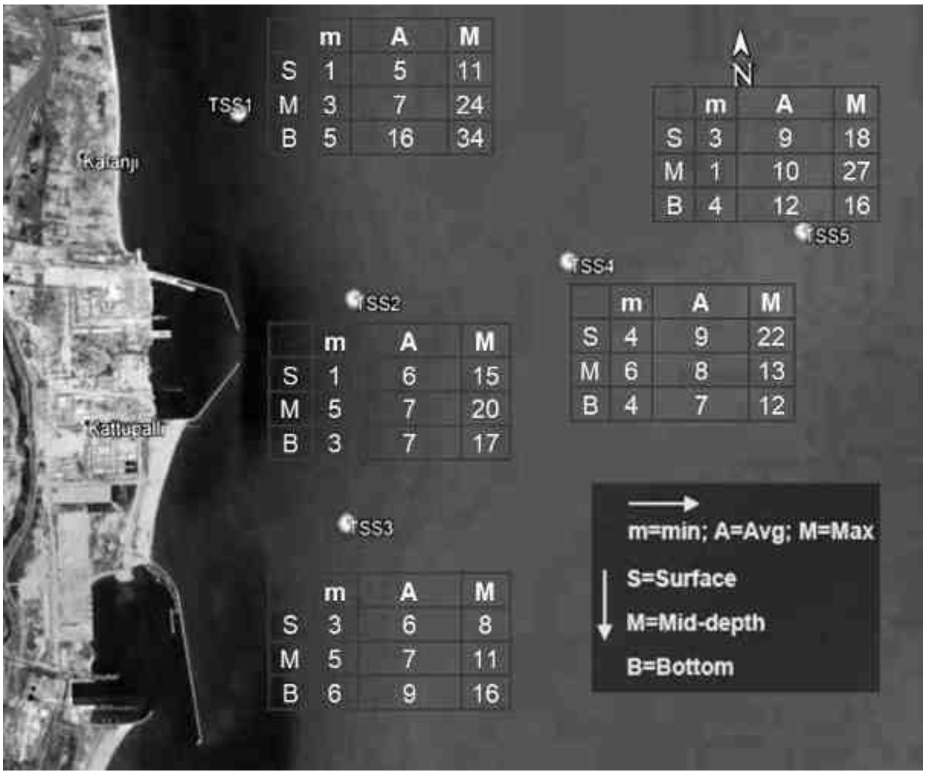


Figure 2-17 Total Suspended Solid Concentration: post monsoon Spring period (19 Sep 2020)

3 Hydrodynamic Modelling

In order to simulate water levels and current pattern along Ennore to Pulicat creek with the baseline and proposed Master plan, the hydrodynamic modelling is carried out using DHI's MIKE21 FM (Flexible Mesh) HD model. The model simulates 2D free-surface flows by solving the depth-averaged Navier-Stokes equations and is applicable to simulate hydrodynamic processes in lakes, estuaries, bays, coastal areas and seas. The FM module of MIKE 21 is based on Flexible Mesh approach using triangular and quadrangular elements for addressing geometrical flexibility to complex coastlines, like an archipelago, lagoons, estuaries etc. Inputs include bathymetry, bed resistance, wind velocities and hydrographic boundary conditions (e.g., tides and inflows).
The following effects can be included in the model:

- Wind shear stress at the surface
- Bottom shear stress
- Barometric pressure gradients
- Coriolis force
- Turbulent viscosity
- Sources and sinks
- Flooding and drying

Calibration parameters include Manning's *n* and eddy viscosity coefficients.

3.1 Bathymetry

The model domain used for 2D hydrodynamic modelling covers the region 80°16.748'E–13°1.298'N and 80°30.837'E–13°39.367'N, Pulicat lake on the northwest and Bay of Bengal on the East. The bathymetry data is assembled from several primary and secondary sources covering the areas Ennore creek and Pulicat lake. Ennore creek and Pulicat lake are surveyed by NIOT and shared the data to DHI. Nearshore bathymetry data is also surveyed and provided the data to DHI. The Offshore extent of the model domain uses bathymetry from C-map source. The different data sources are merged, aligned, gridded and quality controlled before proceeding for simulation.

About 32751 elements with various mesh resolutions have been produced. It features higher resolution in areas where the kinetic power density is high, and lower resolution in areas where the currents are weaker. The unstructured mesh triangles in coarse areas have a maximum element area of 500Km^2 and in the shallow areas 800m^2. The coastline is defined throughout as an impermeable, zero normal velocity boundary, while the bottom is a non-slip, impermeable boundary with bed resistance specified by a quadratic drag coefficient of 0.01.

Figure 3-1 shows the measured bathymetry and C-Map data for the open coast area. Similarly, Figure 3-2 shows the measured bathymetry at Pulicat lake and Ennore creek. Figure 3-3 represents the overall bathymetry generated using above bathymetry information for the hydrodynamic simulations and the zoomed view of model domain with layout.

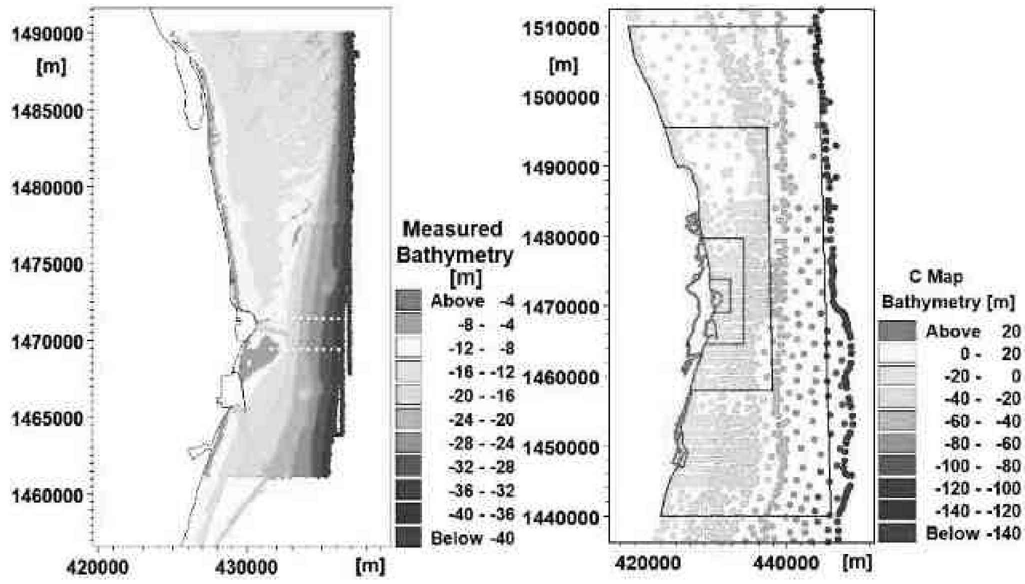


Figure 3-1 Measured nearshore bathymetry (Left), C-Map bathymetry along the coast (Right)

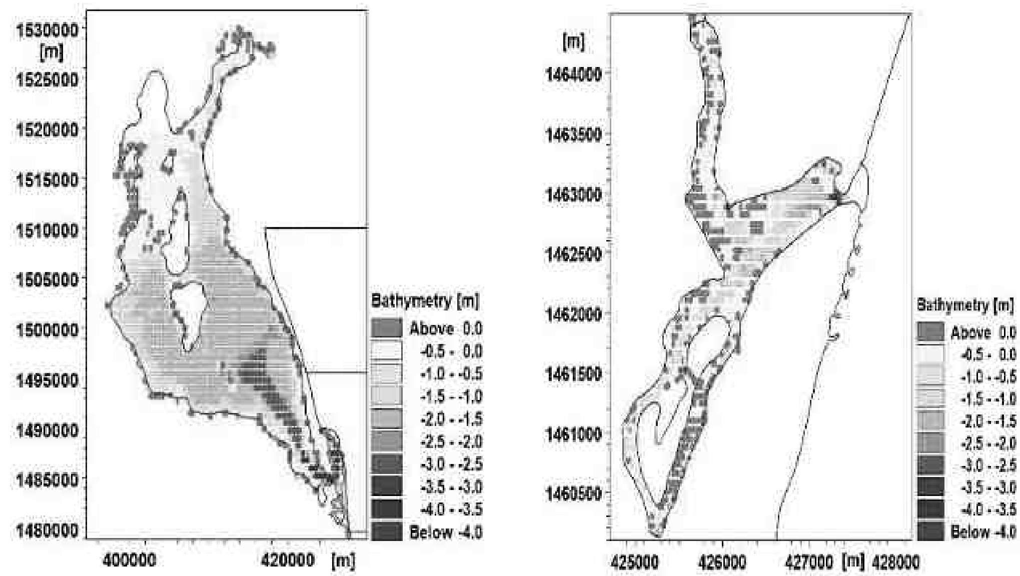


Figure 3-2 Measured bathymetry Pulicat lake (Left), Ennore Creek (Right)

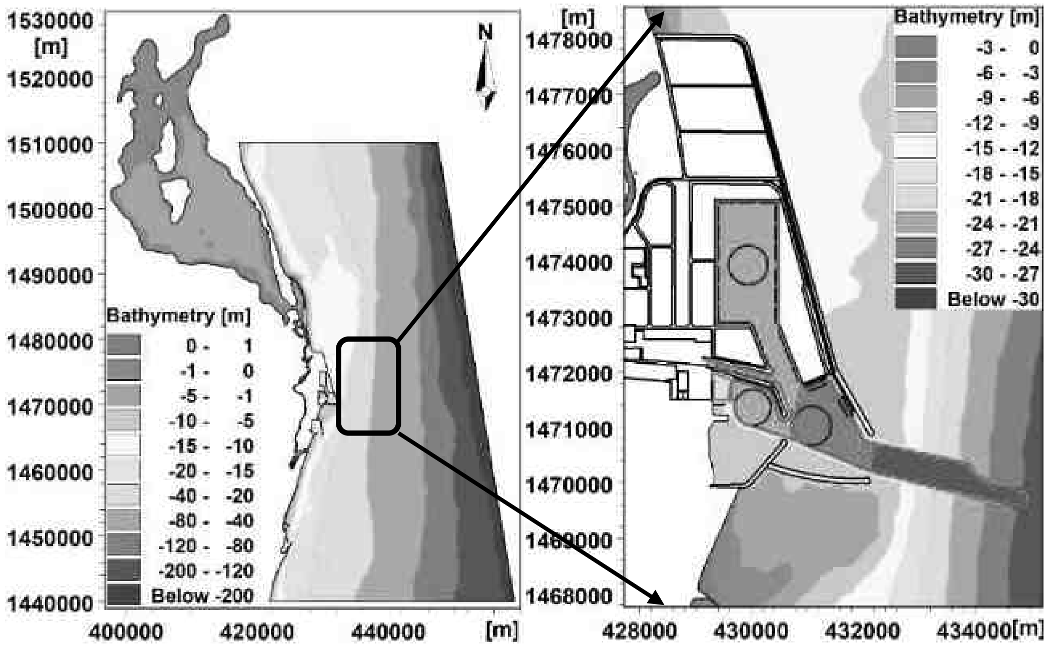


Figure 3-3 Model domain showing overall bathymetry (Left), Zoom-in view with Layout (Right)

3.2 Model Calibration (Phase-I)

The model is calibrated against the measured water level and currents (Figure 2-1) collected for pre-monsoon season (Feb-Mar 2020). Bed resistance and eddy viscosity is readjusted to achieve the best match between prediction and measurements.

3.2.1 Water Level

The comparison of measured and modelled water levels at W3K is shown in Figure 3-4. simulated water levels are having a good agreement with the measured data in terms of amplitude and phase. The comparison of the simulated and measured water levels is in the acceptable range with Index of agreement as 0.93.

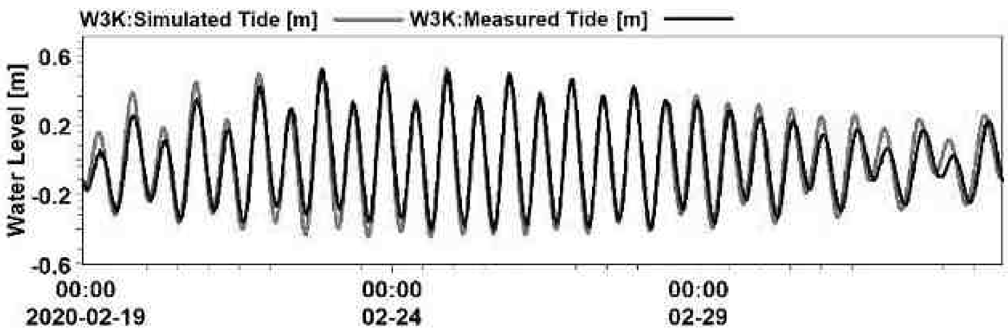


Figure 3-4 Comparison of measured and simulated water level at W3K for Phase-I

3.2.2 Current Speed

The depth averaged current speed obtained from the model are compared with measured current speeds at C1, C2 and C3 (Figure 3-5 to Figure 3-7). While the current speed agrees comparatively well throughout the time period, there is a minor phase and amplitude difference between measurements and model results. This difference could be due to the boundary conditions and the changes in the bathymetry.

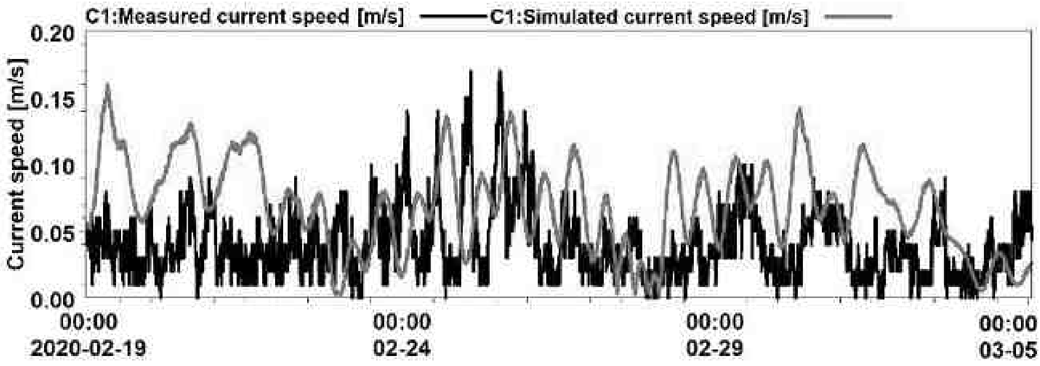


Figure 3-5 Comparison of measured and simulated current speed at C1 location for Phase-I

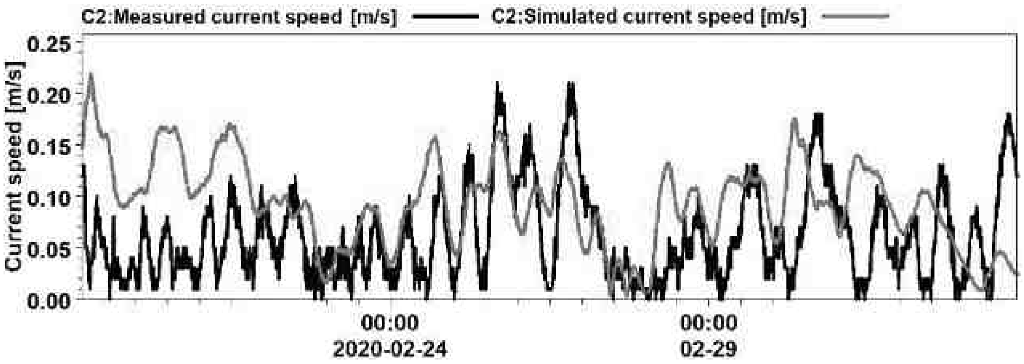


Figure 3-6 Comparison of measured and simulated current speed at C2 location for Phase-I

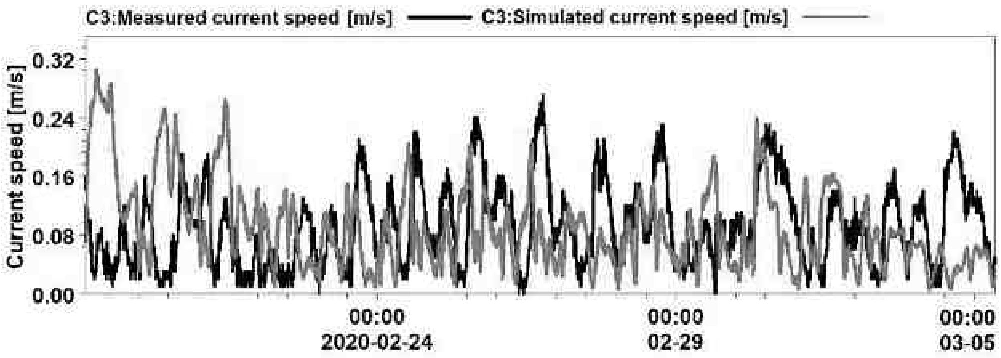


Figure 3-7 Comparison of measured and simulated current speed at C3 location for Phase-I

3.3 Model Validation (Phase-II)

The model is validated against measured water level and currents (Figure 2-1) collected for the post-monsoon season (September-October 2020). Bed resistance and eddy viscosity are adjusted to achieve the best match between prediction and measurements.

3.3.1 Water Level

The comparison of measured and modelled water levels at K1 is shown in Figure 3-8. The simulated water levels are having a good agreement with the measured data in terms of amplitude and phase.

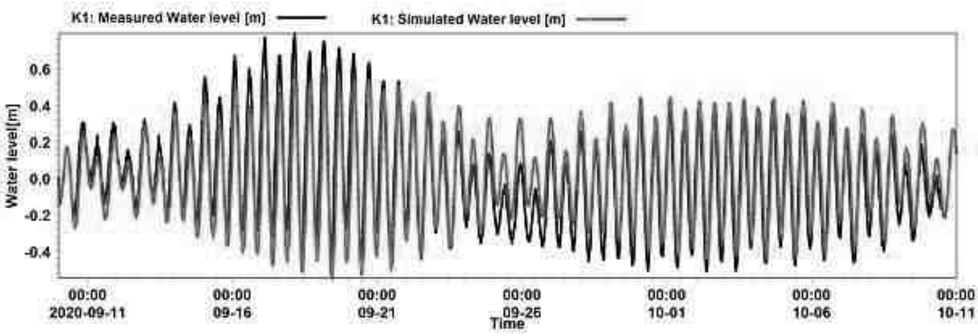


Figure 3-8 Comparison of measured and simulated water level at K1 for Phase-II

3.3.2 Current Speed

The depth averaged current speed obtained from the model are compared with measured current speeds at C1, C2 and C3 (Figure 3-9 to Figure 3-11). While the current speed matches comparatively well throughout the time period, this difference in phase and amplitude could be due to the boundary conditions and the changes in the bathymetry.

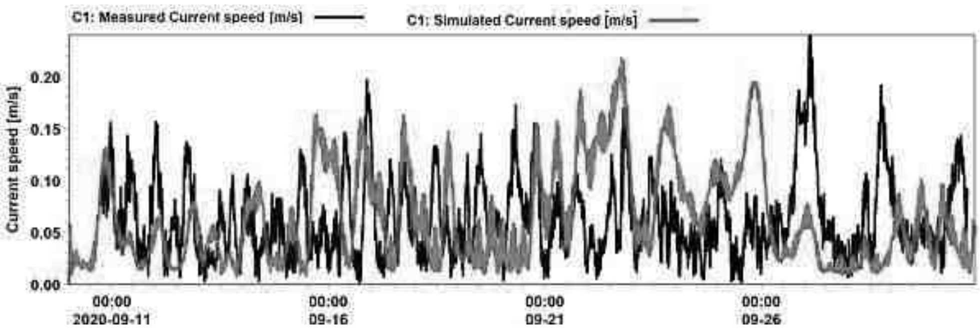


Figure 3-9 Comparison of measured and simulated current speed at C1 location for Phase-II

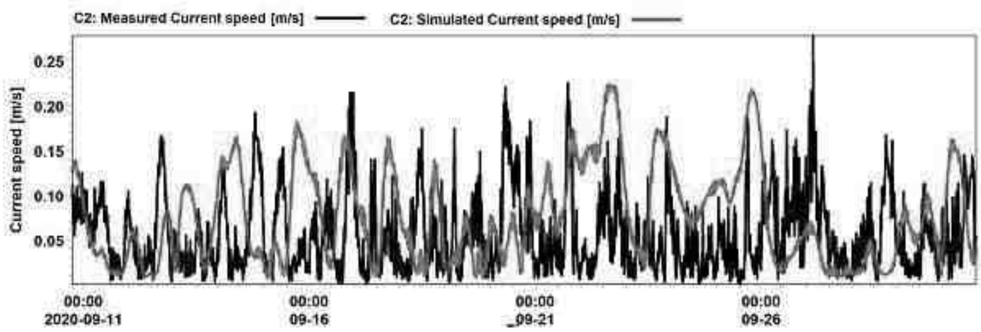


Figure 3-10 Comparison of measured and simulated current speed at C2 location for Phase-II

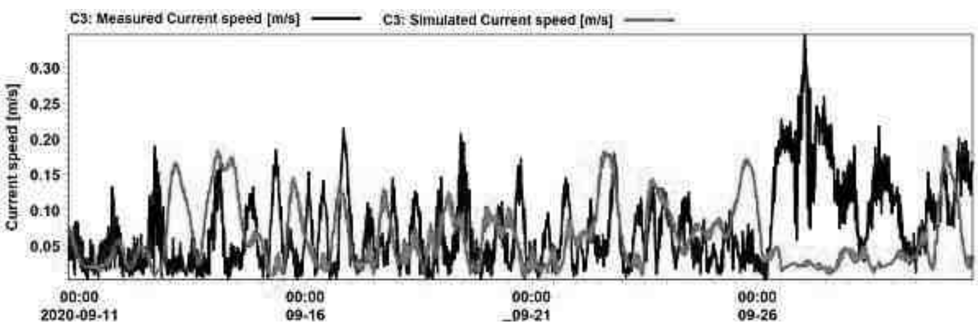


Figure 3-11 Comparison of measured and simulated current speed at C3 location for Phase-II

3.4 Model Validation (Phase-III)

The model is validated against measured water level and currents (Figure 2-1) collected for the pre-monsoon season (January-February 2021). Bed resistance and eddy viscosity are adjusted to achieve the best match between prediction and measurements.

3.4.1 Water Level

The comparison of measured and modelled water levels at P1 is shown in Figure 3-12. The simulated water levels are having a good agreement with the measured data in terms of amplitude and phase.

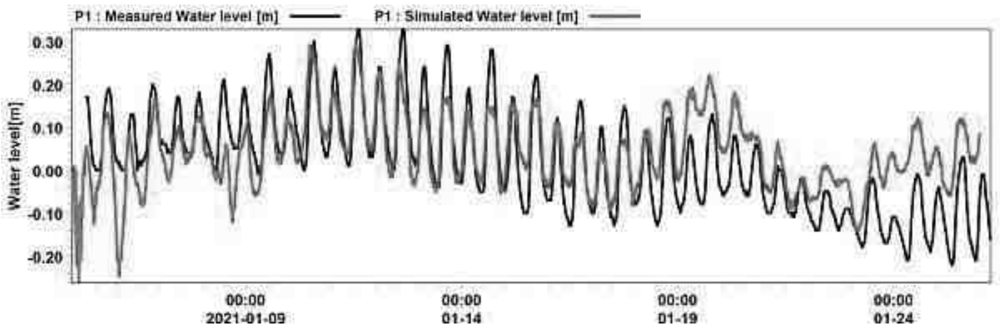


Figure 3-12 Comparison of measured and simulated water level at P1 for Phase III

3.4.2 Current Speed

The depth averaged current speed obtained from the model are compared with measured current speeds at C1, C2 and C3 (Figure 3-13 to Figure 3-15). While the current speed matches comparatively well throughout the time period, this difference in phase and amplitude could be due to the boundary conditions and the changes in the bathymetry.

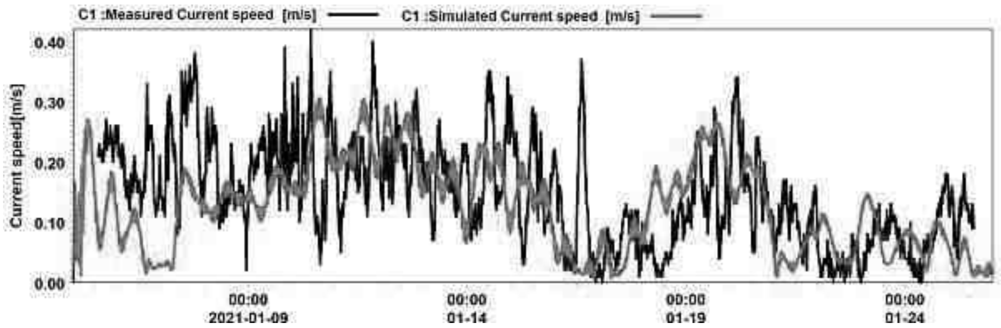


Figure 3-13 Comparison of measured and simulated current speed at C1 location for Phase-III

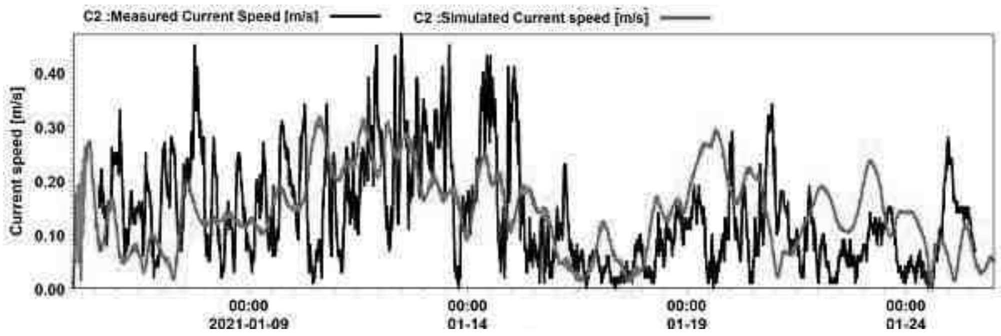


Figure 3-14 Comparison of measured and simulated current speed at C2 location for Phase-III

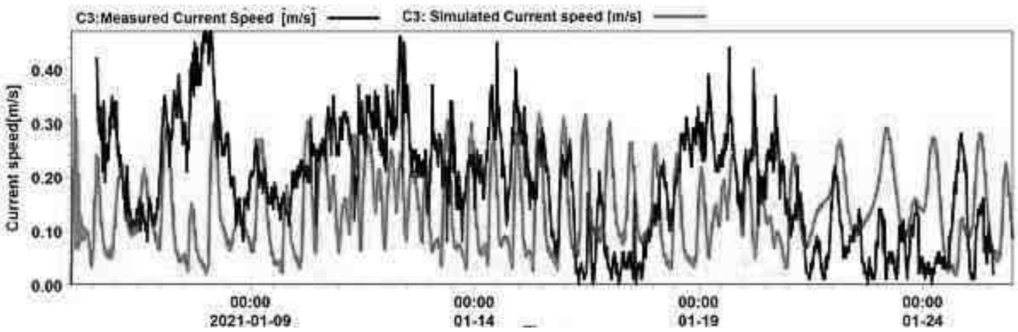


Figure 3-15 Comparison of measured and simulated current speed at C3 location for Phase-III

3.5 Model Results

Depth averaged current speed and direction during spring and neap tides with baseline and layout condition is shown in Figure 3-16 and Figure 3-17. Similarly zoomed view of the area is shown in Figure 3-18 and Figure 3-19. The Maximum current speed observed during spring and neap period at study area is 0.28m/s and 0.10m/s respectively. The two major forcing functions, i.e., tide and wind, influence the direction of current. The circulation around Kattupalli Port is influenced by the north and south breakwaters and presence of the shoals at offshore.

Further, the current magnitude inside the Kattupalli port area is insignificant with the baseline and proposed Master Plan layout.

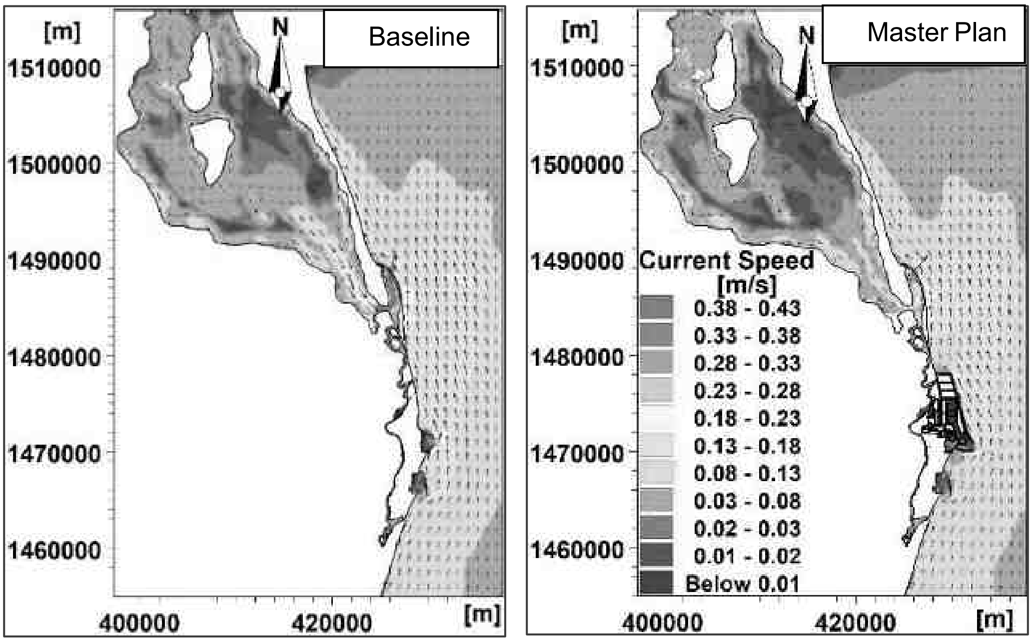


Figure 3-16 Depth averaged current during spring tide: Baseline (Left), Layout condition (Right)

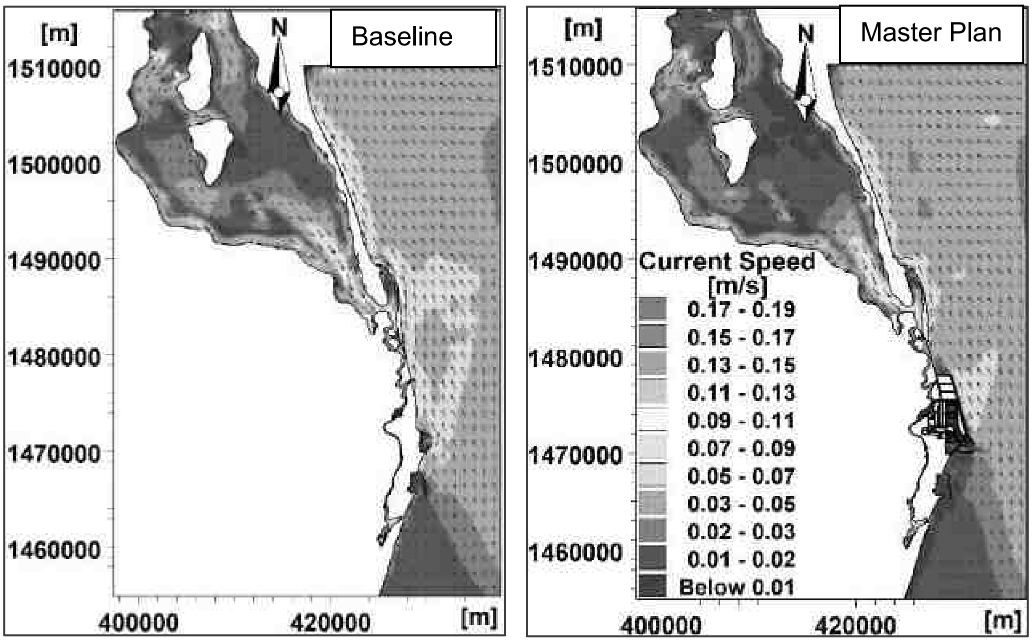


Figure 3-17 Depth averaged current for Neap tide: Baseline (Left), Layout condition (Right)

Water level variations are not subjected to any changes between baseline and proposed Master Plan along the Ennore to Pulicat coastline. The tide at various locations at the study area suggests that the tidal variations are semidiurnal with identical water level fluctuations both at Ennore and Pulicat regions. The tidal range is in the order of 0.5 m. Comparison of tide measurements at foreshore regions of Ennore Creek and Pulicat lake inlet/mouth reveals no appreciable difference between water levels, which indicate that the entire region is experiencing identical tidal conditions. However, a phase lag of 10 to 15 minutes is observed between Pulicat and Ennore Creek. Results indicate that the tide is propagating from south to north with the high water being observed first at Ennore and after 10 to 15 minutes at Pulicat.

The shoals at Ennore are naturally formed, the shore parallel shoals extend up to a length of about 14 km with widths varying between 500 m to 1500 m and depths varying between 3 m to 6 m. In the study area, these shoal plays a significant role in dissipating wave energy and reducing the erosion rate on the north side of the northern Ennore breakwater.

The simulation explicitly shows that the circulation pattern remains the same at the Ennore shoal and at Pulicat inlet/mouth area. There are minor variations in the direction of current flow in front of the proposed masterplan configuration and there is no impact to the Ennore shoal area. Pulicat lake is situated at a distance of 10 km from the proposed masterplan, found that there is no effect to Pulicat lake circulation after modelling the layout in the hydrodynamic model. The model simulation shows that, in both the baseline and layout conditions, the position of the barrier island in the Pulicat lake mouth is remain unchanged.

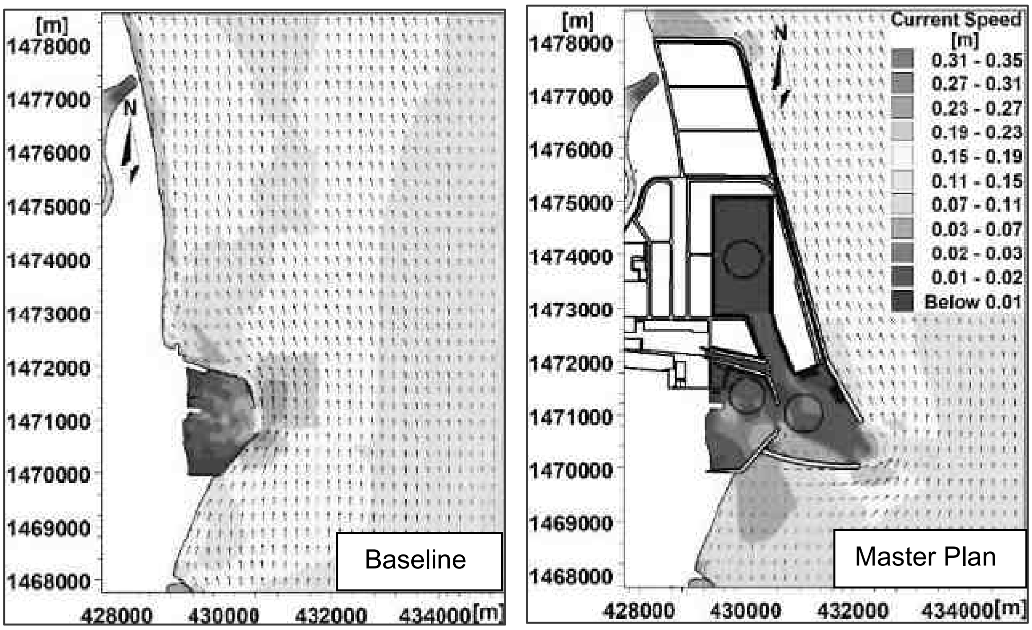


Figure 3-18 Depth averaged current for spring period: Baseline (Left), Layout condition (Right)

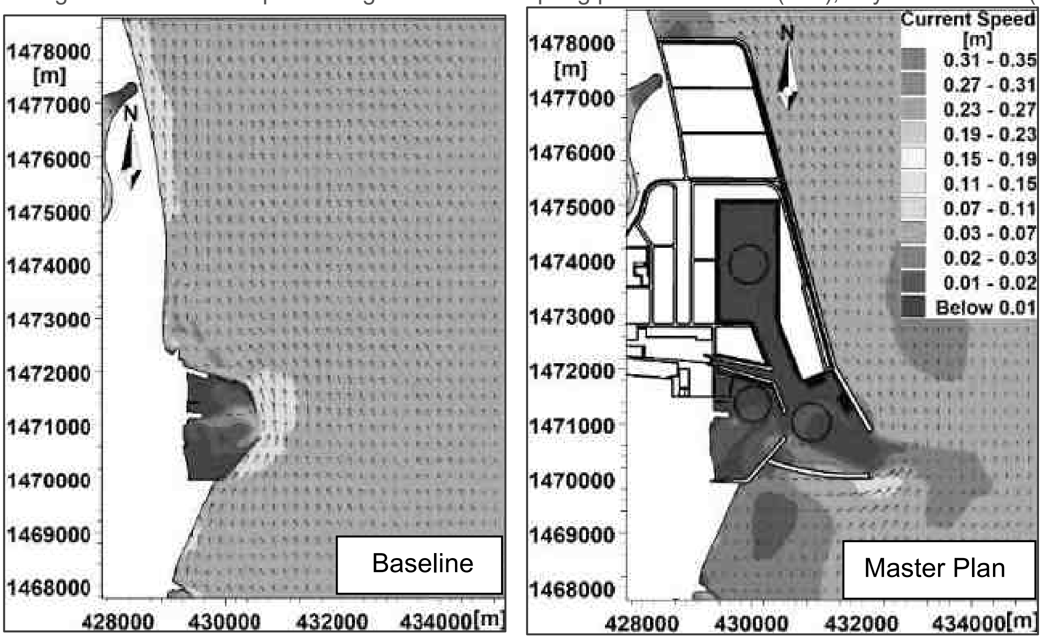


Figure 3-19 Depth averaged current for Neap period: Baseline (Left), Layout condition (Right)

4 Wave Transformation Modelling

MIKE 21 Spectral Wave (SW) FM model is used in order to predict the annual wave climate along Ennore to Pulicat creek. The spectral wave model is based on an unstructured, cell-centred finite volume method and uses an unstructured mesh in geographical space. This approach, which has been available from DHI now for more than a decade and which is thus fully matured, gives the maximum degree of flexibility and allows the model resolution to be varied and optimised according to requirements in various parts of the model domain.

4.1 Bathymetry

The model domain for wave propagation and transformation is chosen accordingly to transform the offshore wave fields at 30m depth provide by client. The model extent and bathymetry used for baseline and layout wave modelling is provided in Figure 4-1.

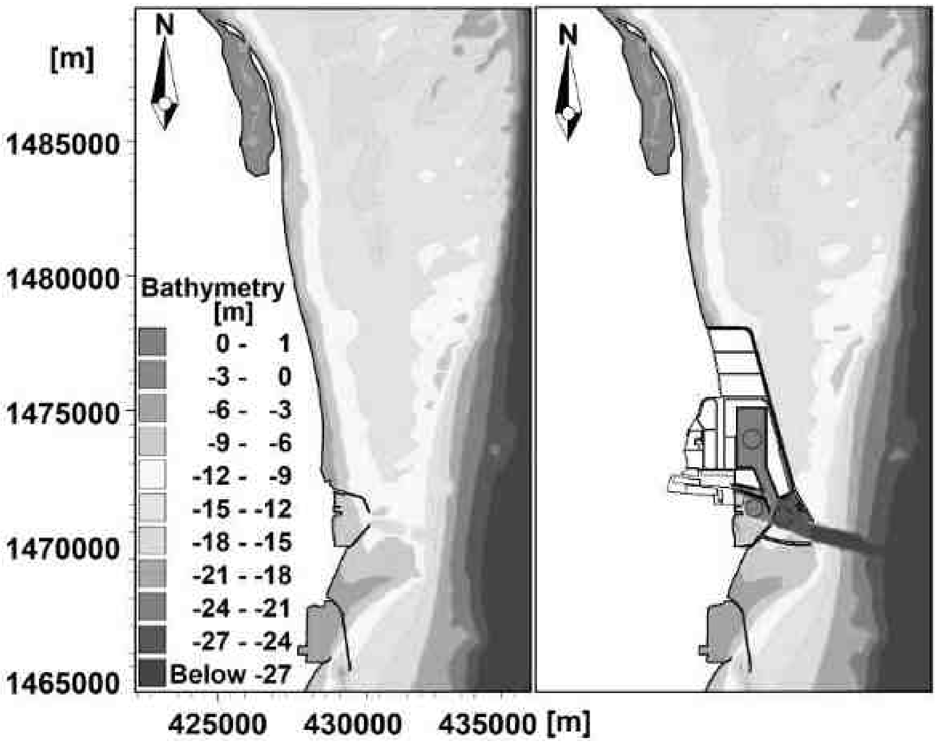


Figure 4-1 Bathymetry used for SW Modelling - Baseline (Left), Layout condition (Right)

4.2 Boundary Conditions

Wave boundary conditions are obtained at 30m water depth (13°17'40.57"N 80°24'18.39"E), provided by the client, which is a hindcast model developed by NIOT at a regional scale. The parameters include significant wave height, peak wave period, mean wave direction at every 6-hr interval. Time series of significant wave height, peak wave period and mean wave direction used for the model simulation is depicted in Figure 4-2.

The annual distribution of wave hindcast indicates that during Nov-Dec the waves are mostly from northeast (30^0 -90^0) in other months 150^0 – 180^0. Percentage distribution of wave directions indicates that almost 80% of waves are coming from E-SE direction and the remaining 20% are from NE-ENE. Most percentage of waves occurs in the height range 0.5 to 1.5m and in the period of 4-10 sec.

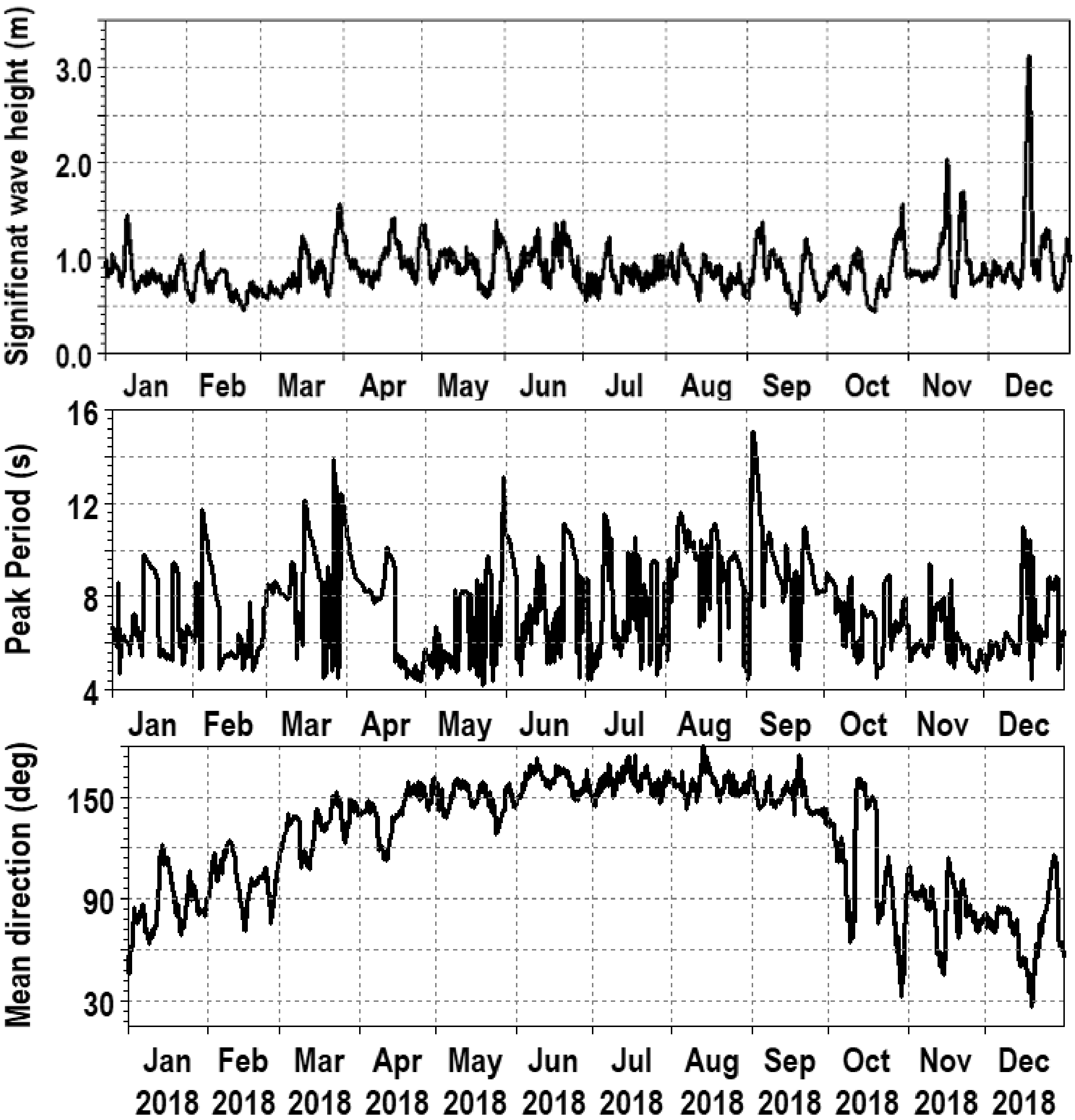


Figure 4-2 Hindcast wave climate at 30m water depth for the period Jan-Dec 2018

4.3 Model Results

Figure 4-3 and Figure 4-4 shows the spatial variation of significant wave height (1.3m) and peak wave period (16 Sec) for baseline and layout conditions. The colour variation indicates the magnitude, and the vectors indicate the direction of an incoming wave. A high concentration of wave energy is noticed at south of the Kattupalli port during SW monsoon.

The coast north of Kattupalli port experiences less energy due to presence of shoals. The waves travel over the shoals, they lose their energy and in turn the wave heights reduce. About 0.2 to 0.4 m difference in wave height has been observed between the eastern and western side of Ennore shoals. From the model, the significant wave height (Hs) has been considerably reduced up to 0.4 m after the wave crosses the shoals while travelling east to west towards the shore. The overall analysis of offshore wave data at Ennore and Pulicat also indicates a similar trend in wave height distribution, whereas the comparison between offshore and nearshore region indicates change in wave distribution due to wave transformation from deep water to shallow water.

The analysis of results produced for baseline and layout conditions indicates similar wave pattern, except a shadow zone with less wave energy formation immediately north of the northern breakwater for the master plan layout. Further, the Pulicat lake inlet/mouth is situated approximately at a distance of 10 km from the proposed master plan boundaries, experiences no changes in the wave climate due to the proposed master plan, observed from the model results. The impact of master plan on wave climate further north of proposed master plan towards Pulicat inlet/mouth is remains same in comparison to baseline conditions. It indicates that the proposed development will not cause any alterations to the Pulicat inlet/mouth and to the barrier island.

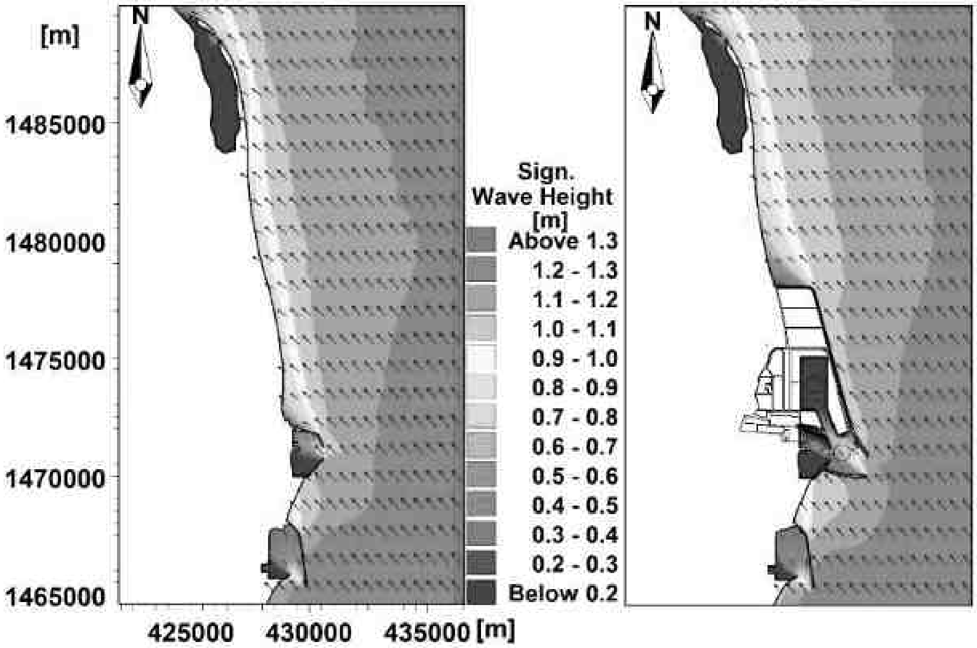


Figure 4-3 Significant wave height for pre-monsoon. Baseline (Left), Layout condition (Right)

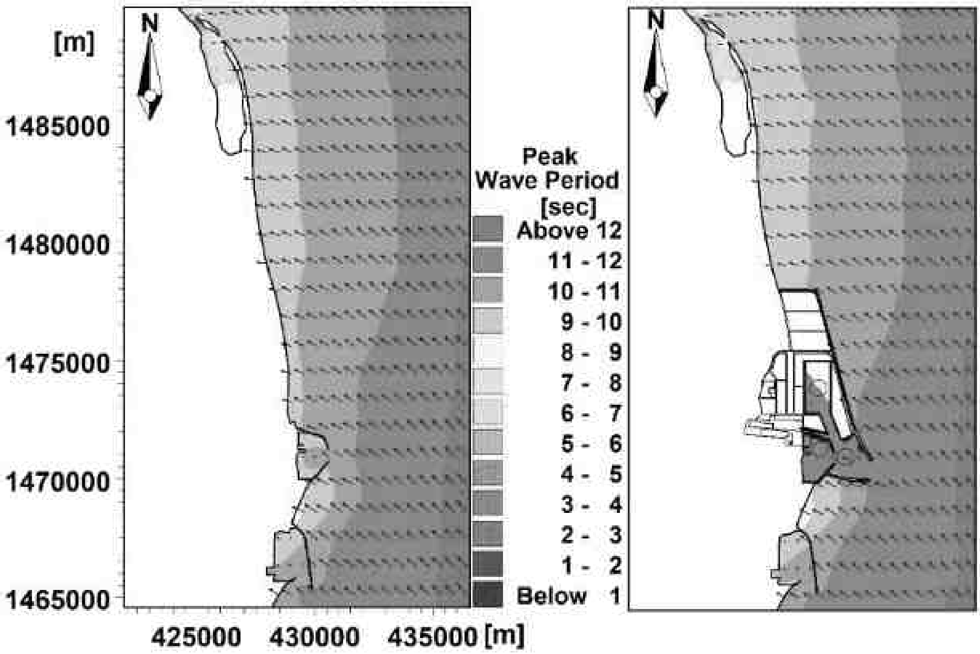


Figure 4-4 Peak wave period for pre-monsoon. Baseline (Left), Layout condition (Right)

5 Historical Shoreline Changes: Remote Sensing

The satellite images are downloaded for 20 years from 2000-2020 to estimate the historical shoreline changes. The shorelines from each image are digitised using GIS techniques to estimate the changes. The Littoral Process FM modelling system is used to predict coastline for 15 years with the proposed Master plan.

5.1 Methodology

The transect lines from Ennore to Pulicat creek are demarcated at every 1 Km interval. These transect lines started from 13°11'3.19"N, 80°19'2.48"E and ended at 13°32'33.46"N, 80°16'36.38"E. A total of 43 transect lines are digitized in GIS and named as T01 to T43 (Figure 5-1). These transect lines demarcates the entire study area into 6 zones, as well as erosion / deposition analysis from 2000 to 2020. The area of erosion and deposition between each transect along the coastline is calculated and mapped using ArcGIS 10.7 software. The transect wise total area of erosion and deposition from 2000 to 2020 (pre-monsoon and post-monsoon) is extracted and analysed for statistics.

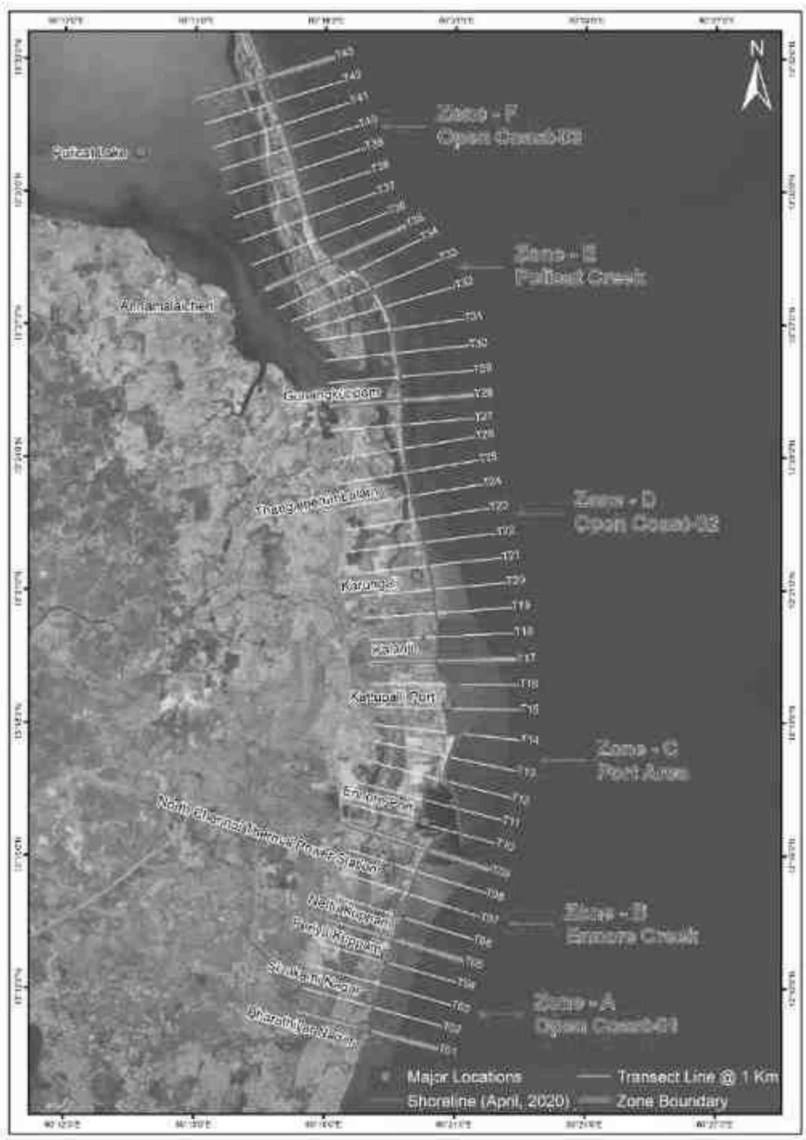


Figure 5-1 Study area with demarcation of zones

The Satellite data geo-processing is performed in the following way to estimate the historical shoreline changes:

- The raw data is acquired from USGS and Image processing software has been used for loading and viewing the raw satellite imagery and geo-referencing processes.
- Ground Control Points (GCP's) are collected from Survey of India (SOI) at 1: 50,000 scale toposheet.
- Using ground control points (GCP's) from Survey of India (SOI) toposheet, the satellite imagery has been geo-positioned / geo-referenced in required projection and datum as per the standard process of the image processing software.
- The projection system as Universal Transverse Mercator (UTM), zone 44, Datum as World Geodetic System 1984 (WGS-84) has been used for better calculation and verification of distances between utilities, shoreline, area and the span length.
- Nearest Neighbourhood method has been taken for the transformation of the raw satellite data to geo-referenced satellite data.

5.2 Data sources

The Landsat-5 TM (30 m spatial resolution), Landsat-7 ETM+ PAN sharpened imagery (15 m spatial resolution) and Landsat-8 OLI PAN sharpened imagery (15 m spatial resolution) from 2000 to 2020 have been used to obtain information on base mapping, erosion / deposition area mapping, land use / land cover mapping, shoreline change mapping of area from Ennore – Pulicat Creek.

The Landsat-5's Thematic Mapper (TM) has seven spectral bands with 30 m spatial resolution, except Band 6 thermal band (120 m spatial resolution). Landsat ETM+ has information in 8 bands of electromagnetic radiation. Landsat-7 ETM+ image in PAN mode has the best spatial resolution which was merged with image from band-2, band-3 and band-4 using a principal component image merge algorithm. The resultant image had a spatial resolution of 15 m and a spectral resolution of 3 bands.

The Landsat-8 satellite has two main sensors, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). OLI collects images using nine spectral bands with 30 m spatial resolution except for band 8 PAN with 15 m spatial resolution. TIRS collects images using two spectral bands with 100 m spatial resolution. Landsat-8 OLI PAN sharpened imagery has been generated by using band-3 (green), band-4 (red), band-5 (NIR) and band-8 (PAN) in ArcGIS 10.7 software.

5.3 Shoreline change analysis and mapping

Shorelines have been delineated by on-screen digitization in a GIS platform using ArcGIS 10.7 software at a scale of 1:1000. Multi-temporal satellite remote sensing data i.e. Landsat series satellite imagery (Landsat-5 TM, Landsat-7 ETM+, Landsat-8 OLI) from USGS have been used to digitization of shoreline from 2000 to 2020. By overlaying this database locations of shoreline shifting will be identified. The resultant shapefiles are superimposed to demarcate union wise erosion and deposition areas. The erosion and deposition areas are identified. The total area of erosion and deposition from all the unions are calculated using ArcGIS software. Quantitative data generation and thematic maps has been produced outlining hot spots of high erosional reaches of shoreline. A flow chart for the methodology of quantifying the shoreline is shown in Figure 5-2.

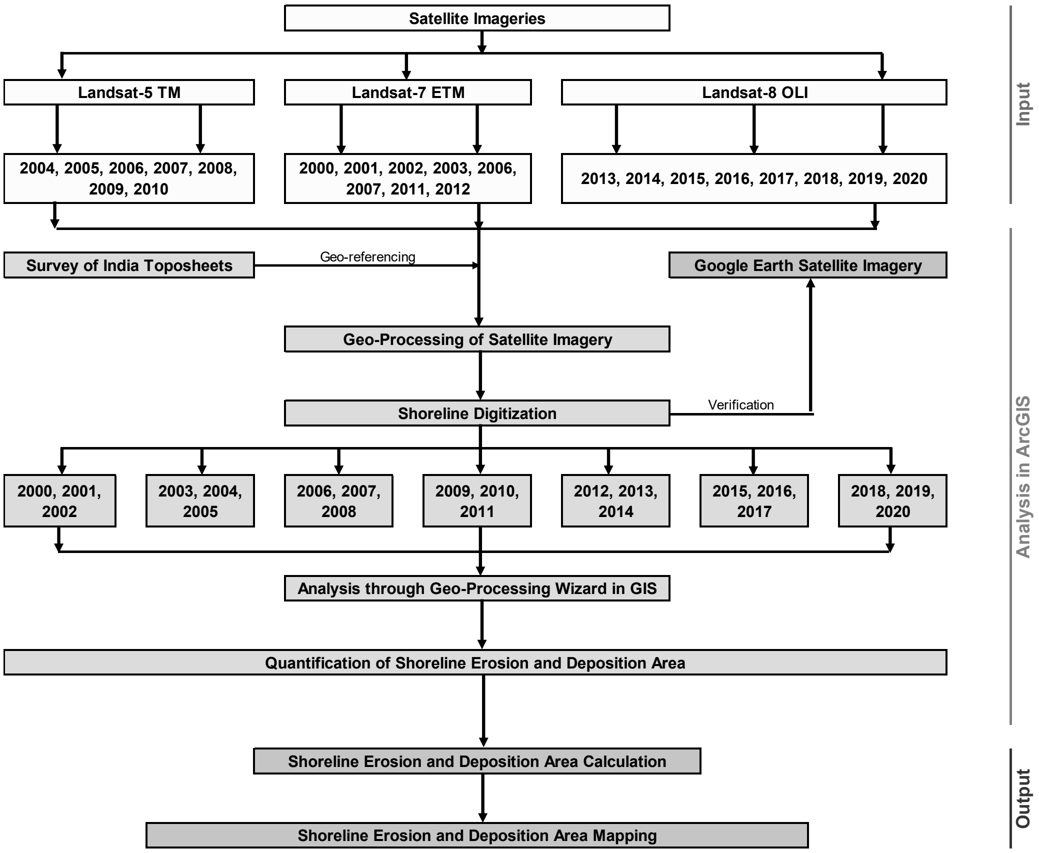


Figure 5-2 Flow chart for the quantification of shoreline erosion and deposition areas

5.4 Results

The zone wise shoreline changes are presented in Figure 5-3 and the observations are as below:

Zone-A Open Coast: This coastal stretch is mostly protected by seawall and groynes. It is noticed that the erosion / deposition pattern and shoreline changes are not showing any trends, because the coast is protected by long seawall parallel to the coastline and series of groynes perpendicular to the coast.

Zone-B Ennore Creek: Southern side of Ennore Creek is well protected by seawall and groynes. In the northern side the of Creek, North Chennai Thermal Power Station is located. Locations where the seawall and groynes are located, erosion / deposition patterns are not showing any trends. But at Ennore Creek mouth, the erosion / deposition is predominant. Towards the north of Ennore Creek, the shoreline is advancing. Deposition is more predominant at the Ennore port, because the port development has caused significant changes in the surrounding regions.

Zone-C Port Area: In this stretch of the shoreline, two ports i.e. Ennore Port and Kattupalli Port are situated between two coastal inlets viz. Ennore inlet and the Pulicat inlet/mouth. It is noticed that the south side area of Ennore Port is more predominant for deposition and erosion, and it is active since 2007, and continuous till 2020. The coast located between two ports i.e. Ennore and Kattupalli has shown no significant changes, and that coast is stable. The north side of Kattupalli Port, where erosion is more predominant, and it is active after the construction of Kattupalli Port. These changes started during the construction stages of the port affecting the coast of north side of the port.

Zone-D Open Coast-02: This area is located just north side of the Kattupalli Port, which is of sandy beaches, and where erosion is more predominant. The erosion is active after the construction of Kattupalli Port. It is clearly seen that, the tendency of erosion and deposition is decreasing, while moving from Kattupalli Port towards Pulicat Creek.

Zone-E Pulicat Creek: This coastal stretch is located where Pulicat Creek is situated. The area where mouth of Pulicat Creek is located, there shoreline changes are more predominant, and shoreline is very dynamic due to the inlet migration. In comparison to erosion, the sand deposition is more in this stretch of coastline.

Zone-F Open Coast: This coastal stretch consists of mostly sandy beaches. The coast just north of Pulicat Creek is more dynamic because the coast is located nearby the mouth of Pulicat Creek. Therefore, the shoreline is more-or-less stable.

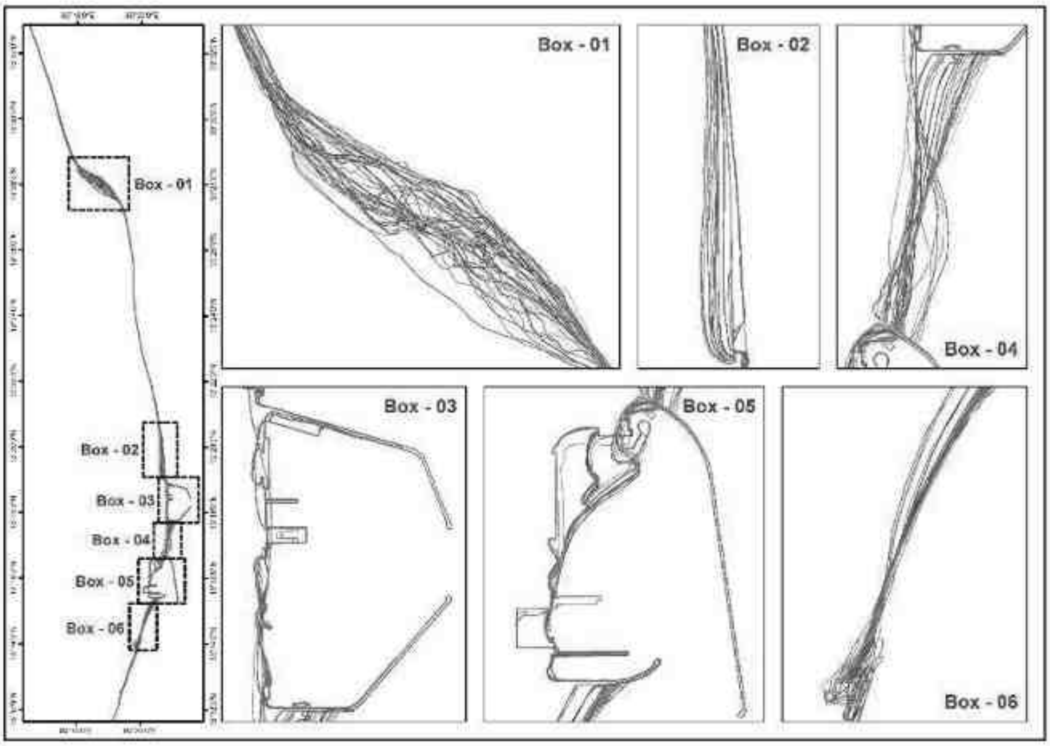
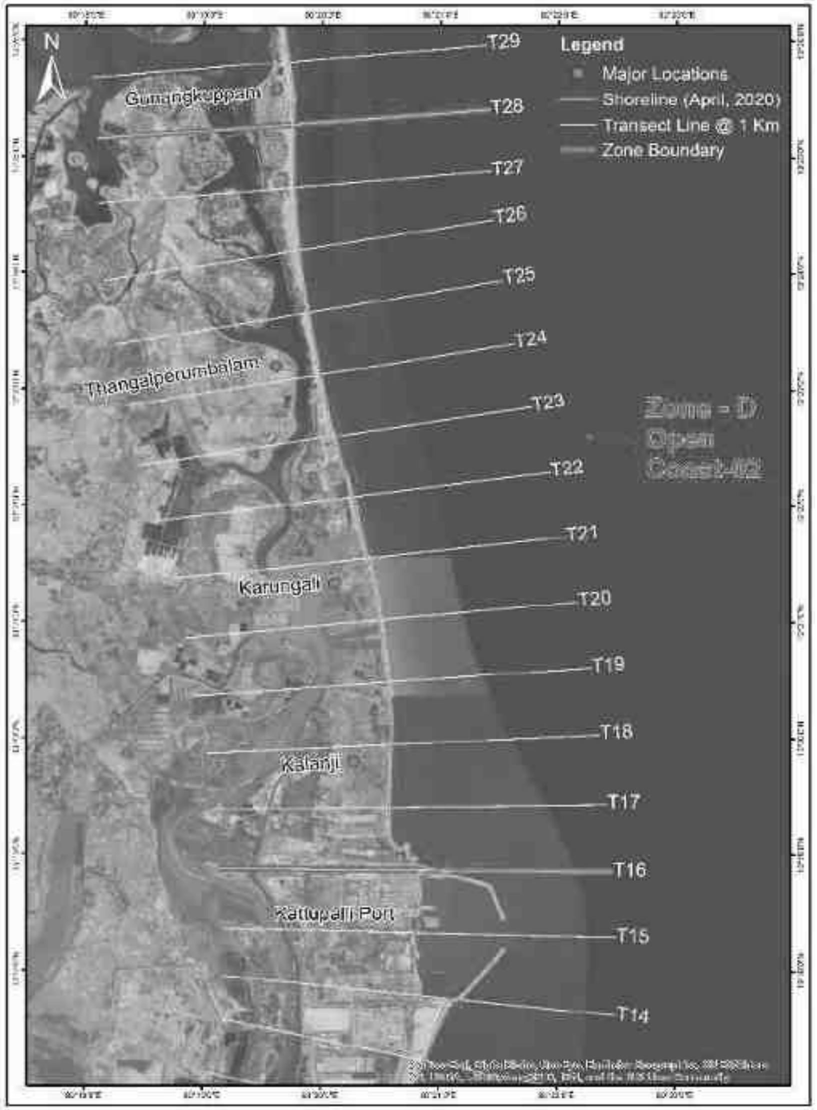


Figure 5-3 Visual interpretation of shorelines on Landsat satellite imageries: 2000 – 2020

The detailed shoreline change analysis for Zone-D is presented in Figure 5-4, indicates that the maximum shoreline changes are around 303m for the 1km stretch of shoreline immediate north of the port. The maximum shoreline erosion is around 198m at 2km from north of the port and around 31m at 3km from north of the port breakwater. Thereafter, the shoreline is stable and subjected to no erosion and deposition.



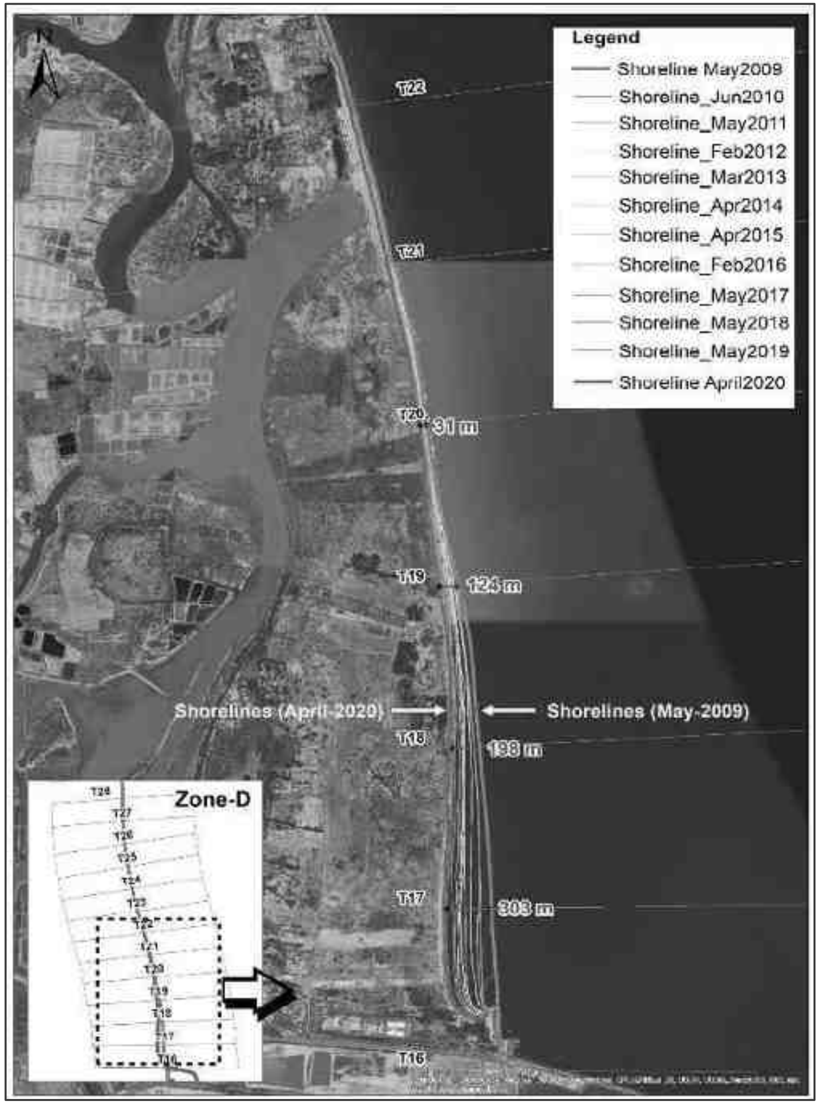


Figure 5-4 Shoreline changes immediate north of Kattupalli Port: 2009-2020

6 Shoreline Change Prediction: LITPACK

The shoreline change rate is predicted using numerical model techniques. Littoral processes FM is a numerical model capable of simulating littoral drift and coastline evolution in areas with non-cohesive sediment and quasi-uniform beaches in which the flow and transport can be assumed to be primarily in the longshore direction. The model has the capacity to simulate the influence of structures like groyne, breakwater, jetties etc., on shoreline evolution.

In the coastal zones, the sand movement is primarily controlled by nearshore currents and wave breaking. The key source of sediment movement is the action of waves, when it triggers sediment movement and generates a strong local current as waves eventually break. This longshore current will bring suspended sediment alongshore with appropriate velocity. The subsequent transportation of longshore sediments depends on the height of the wave, wave period, and the direction of breaking waves. In deciding the quantity of sediment placed in suspension, breaker height is essential and breaker direction is important in determining the longshore transport direction.

Depending on the various seasons the wave climate changes and the same is reflected in the sediment transport pattern. The waves approaching from the NE quadrant are responsible for the southerly sediment movement and the wave approaching from the SW quadrant is responsible for the northerly sediment movement.

6.1 Data Basis and Model Input

The littoral sediment at a given location moves up and down the coast depending on the attacking angle of the incoming waves with respect to the coastline normal. The net sediment transport rate is the difference in the transport in the two directions within a year, while the gross transport is the sum of the transport magnitudes in the two directions. The long-term morphological stability is generally governed by the annual net sediment transport rate while the gross sediment transport rate may cause significant temporary morphological changes (the gross transport is important for example in relation to backfilling of navigation channels and inlet stability). The long shore transport is up and down the coast and often takes place during different stages of the season. The seasonal changes in the direction of the littoral drift are typical in a monsoon climate. The model predicts variations in shoreline position and littoral transport within a stipulated period under the combined action of waves and currents. Hence, the input data required for the model are

1. Cross-shore profile
2. Initial shoreline position along the coast
3. Wave climate
4. Cross shore distribution of Sediment
5. Wave driven, Tidal and Ocean Currents
6. Water level

The cross-shore profiles and the shoreline position used in coastline evolution model are derived from bathymetry data used in the hydrodynamic and wave model studies. The breaking waves in the surf zone are the main source of turbulent kinetic energy, which can bring and maintain the sediments in suspension. The required annual wave climate for study area is obtained from the fair-weather analysis from spectral wave model. Currents forced by the waves, tides, winds, large-scale pressure systems, etc. are factors that influence the sediment transport capacity and the transport of suspensions. The shape of the cross-shore profile together with the water levels determines the cross-shore "distribution" of the surf zone, and the sediment properties are naturally important for sediment in suspension.

The factors listed above are used by LITPACK model to calculate the long-shore sediment transport and the coastline evolution. In the following, these factors are described in more detail with emphasis on available data.

6.1.1 Initial coastline and Profiles

The cross-shore distribution of the transport within the surf zone is highly dependent on the shape of the profile. For given wave conditions, the shape of the cross-shore profile determines the surf-zone properties, i.e., where, and how violently the waves break, the width of the breaking zone, etc. For example, a steeper beach profile leads to a more rapid loss of energy due to wave breaking and larger driving forces for sediment transport. For sandy beaches, the main factors determining the shape of the cross-shore profile are related to the sediment properties, the wave climate, and the tidal variation.

The model is simulated for the baseline conditions of the shoreline during 2020 and shoreline changes with the presence of existing features. For this study, starting from south of Ennore creek to the north of Pulicat lake bar inlet/mouth along 35km coastal stretch has been considered as shown in Figure 6-2. The initial shoreline is digitised from satellite image of Sentinel of the month January for the year 2020. Coastline from south of Ennore creek to Chennai port is not included in the present shoreline change assessment as this stretch of shoreline is completely protected by sea wall and groynes. The longshore transport and shoreline changes along this stretch is almost negligible.

Three cross-shore profiles were derived from the bathymetry and topography information and the coordinate of each cross section is determined from the 8m contour as shown in Figure 6-1. All the cross-shore profile drawn to same length and perpendicular to shore. Since the surf zone bathymetry data and topographic data is not available, it is assumed that dune height of 3m and interpolated with the existing bathymetry. The 3m contour has been demarcated in the google image where there is permanent feature like vegetation or change in land use are appeared.

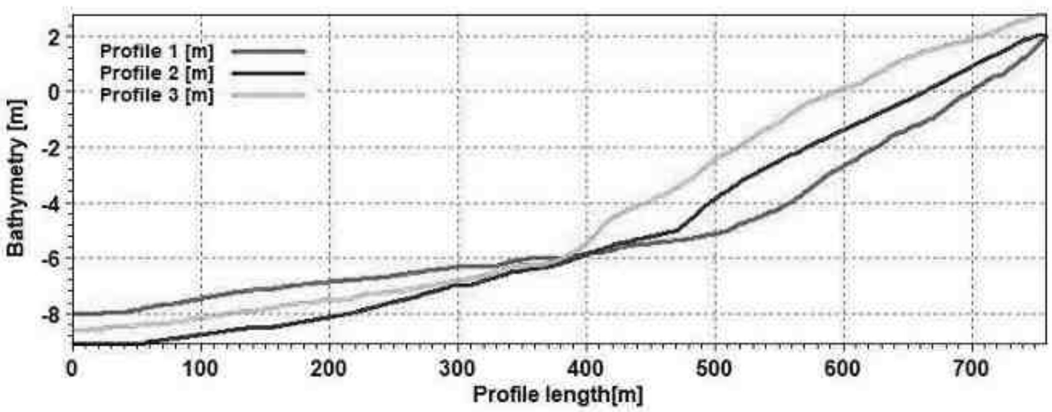


Figure 6-1 Cross section of the three profiles considered for the Littoral Process FM Model

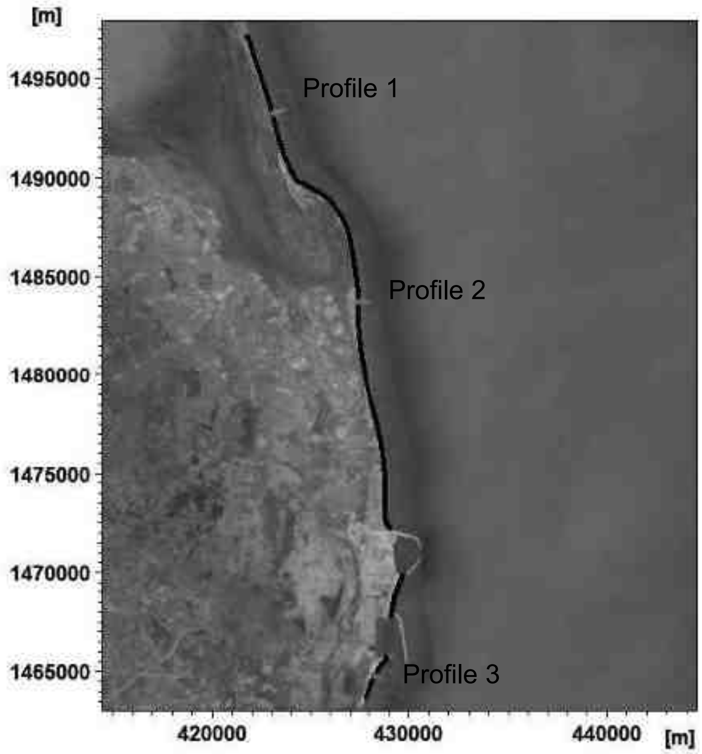


Figure 6-2 Shoreline (black line) and location of profiles (red lines) considered for model studies

6.1.2 Wind

The wind and the variations in atmospheric pressure are responsible for the generation of waves, wind set-up and storm surges as well as wind generated currents. Furthermore, wind has a direct impact on the morphology of coastal areas through Aeolian transport of sand on the beach and in the dunes.

The shift in the wind directions leads to the monsoons or the monsoon wind climate. Monsoons are wind systems that show a pronounced seasonal trend in direction. South-west monsoon occurs during the summer months and the north-east monsoon during the winter months.

Besides the large-scale atmospheric circulations, local pressure differences are influencing the local wind fields, where the wind speed mainly depends on the gradients of the pressure. Low pressure systems are generating extratropical cyclones.

In addition to larger scale events which, in a statistical sense, occur randomly, the existence of sea breezes and land breezes with daily period are common phenomena. The sea has a higher capacity of heat absorption and storage than the neighbouring land masses. During daytime, the surface of the land warms up faster than the surface area. Warm air over the land is rising and causes a local low-pressure area. As a result, we have wind from the sea (sea breeze) with a maximum in the afternoon. During the night, the land masses are cooling down faster than the water masses. If the surface water temperature is higher than the surface temperature of the land, warmer air over the sea is rising and causes a local low. Therefore, wind from land (land breeze) is blowing during the night with a maximum before sunrise.

6.1.3 Waves

Waves are often the most important and decisive parameters for coastal morphology and for coastal engineering structures. The term sea state covers the wind induced sea waves (sea) and the so-called swell waves (swell). The swell waves in many cases the most important in the coastal processes during the moderate sea states because the swell height increases drastically in the nearshore zone due to shoaling which means that the swell is dominating the wave breaking process. Swell waves are often relatively long, of moderate height, regular and unidirectional. Swell waves tend to build up the coastal profile to a steep shoreface. Sea waves are referred to as short-crested. Wind waves tend to be destructive for the coastal profile because they generate an offshore movement of sediments, which results in a generally flat shoreface and a steep foreshore.

The boundary wave climate for the year 2020 is considered as variable wave climate which is obtained from the spectral wave model at 14m water depth. The reduction factor is given as 0.5. The typical wave rose plot for the year of 2020 is presented in Figure 6-3 which indicates that most of the wave occurrence is from SE direction.

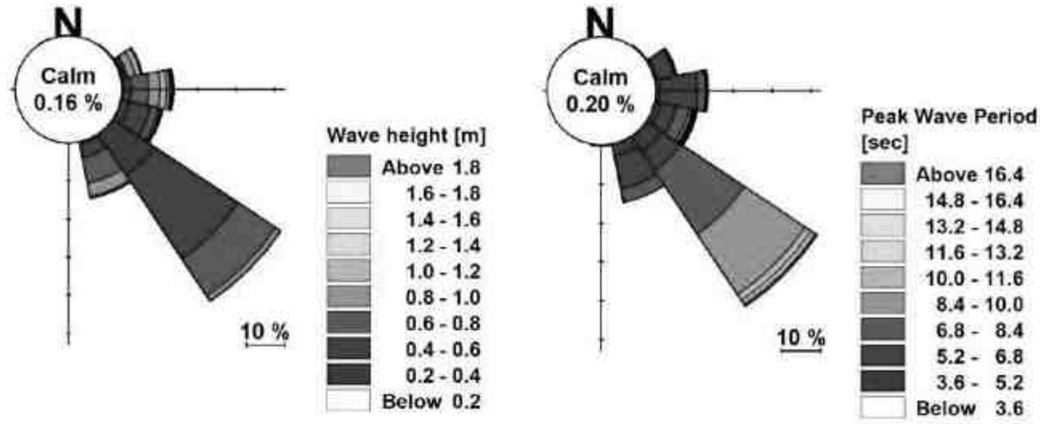


Figure 6-3 Wave climate at 14m depth from SW model.

6.1.4 Water Levels

Tidal ranges for locations along the Chennai coast are considered. The Mean High High Water (MHHW) at Chennai is 0.5 m above MSL. Mean High High Water is the average height that the tide reaches on a Spring Tide. Spring tides basically occur when there is a new moon or a full moon. Spring tides rise furthest up the shore at high tide and go out furthest at low tide (i.e. maximum tidal range occurs).

6.1.5 Wave driven, Tidal and Ocean Currents.

The currents within the surf zone are driven mainly by waves, while tidal and ocean currents are dominating outside the surf zone. The wave driven currents are calculated by the model using Battjes and Janssens breaking theory, while other "external" currents must be specified as input to the model with a direction and a magnitude on a certain water depth as the main input parameters. The expected magnitude of combined tidal and ocean currents within the surf-zone is small, and experience shows that the wave driven currents completely dominate in the surf zone where they are at the maximum, while the tidal currents are stronger in deeper water where the resistance is smaller.

6.1.6 Sediment Property

National Institute of Ocean Technology collected seabed surface sediment samples at 150 locations spread over the model domain at 2km grid spacing is shown in Figure 6-4. The samples are analysed for particle size distribution using sieve analysis. The mean grain size for the model input is considered as 0.31 mm. The final EIA report on the development of shipyard cum port complex at Kattupalli indicates that the sub-soil profile of top layer is coarse dense sand overlying a layer of loose fine silty sand. This layer covers a relatively soft clay layer. The underlying layer consists of stiff clay or dense cemented clayey sand layer. There is little difference between the northern and southern parts of the area.

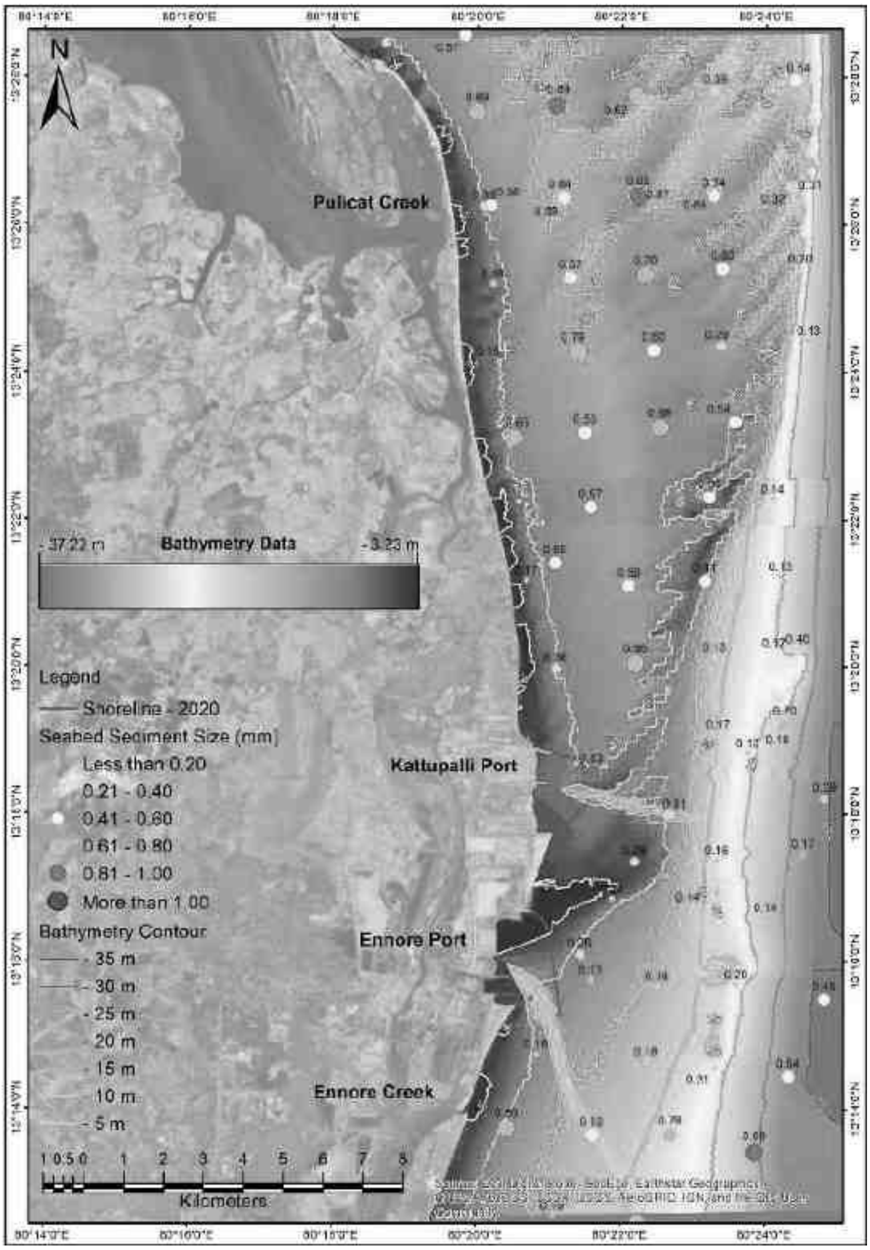


Figure 6-4 Spatial distribution of the sediment size d50

6.2 Results

The model is simulated with the shoreline as base (2020) and shoreline evolution under the presence of Master Plan layout structures. The shoreline changes are predicted for 1- year, 5-years, 10-years and 15-years subjected to the development of Master Plan.

6.2.1 Littoral Drift

The littoral drift along the Ennore-Pulicat coast is calculated for a shoreline orientation of 170-degree N using three profiles. The cross-shore distribution of the littoral transport is shown in Figure 6-5 to Figure 6-7. As per the convention, the northward drift is considered drift -ve and the southward drift is considered to be drift +ve. It is observed that net movement is always towards north.

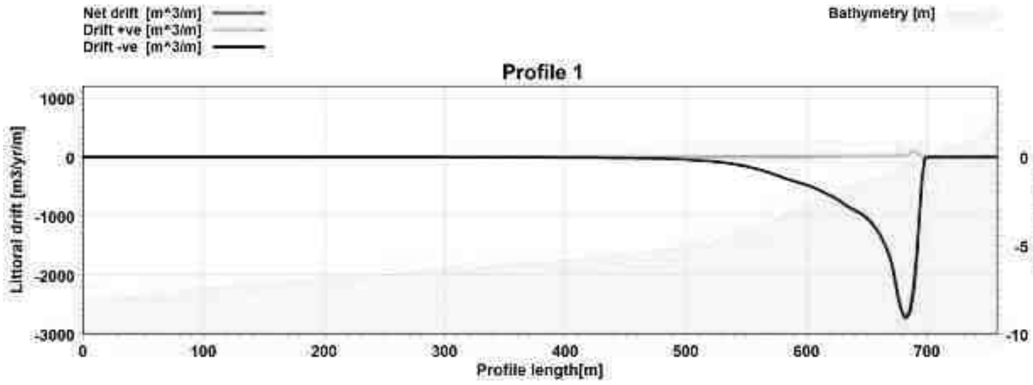


Figure 6-5 Littoral drift along the cross-shore profile 1

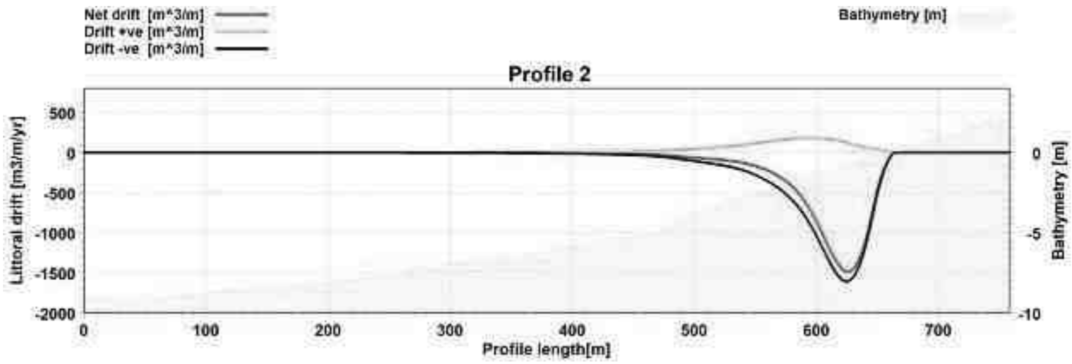


Figure 6-6 Littoral drift along the cross-shore profile 2

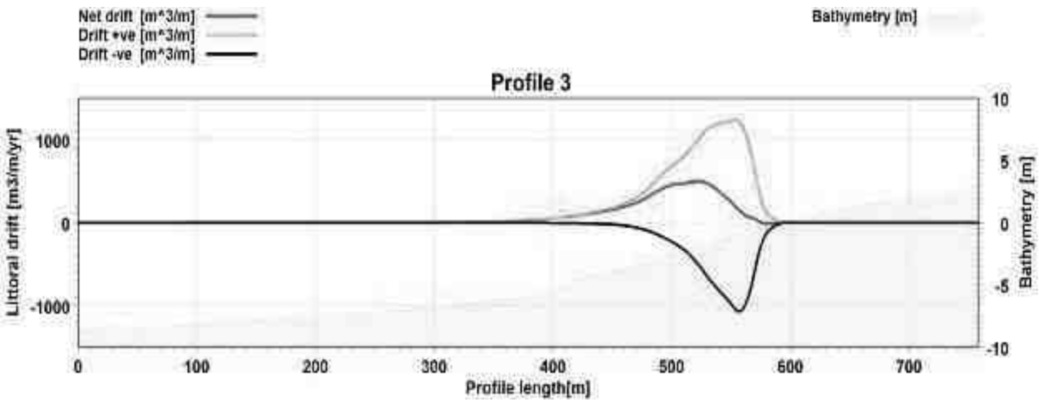


Figure 6-7 Littoral drift along the cross-shore profile 3

6.2.2 Longshore sediment transport

Shoreline behaviour due to the construction of proposed master plan breakwaters is studied using a site-specific shoreline change model for the coastline of approximately 35km. The one-year prediction based on the 2020 wave climate reveals that, the shore oscillates with alternatively erosion/deposition trends depending on the local currents due to wave breaking.

Since the coastal stretch considered for the study is long, it is divided into zones based on the significance of the area and the results are represented as zone wise. The zone wise division considered is represented in Figure 6-8. Totally six zones are considered is as follows

Zone 1: North to the Pulicat lake mouth
Zone 2: Pulicat lake mouth
Zone 3: Open coast
Zone 4: North of Kattupalli port
Zone 5: Small Coastal stretch in-between Kattupalli and Ennore port
Zone 6: South of Ennore port

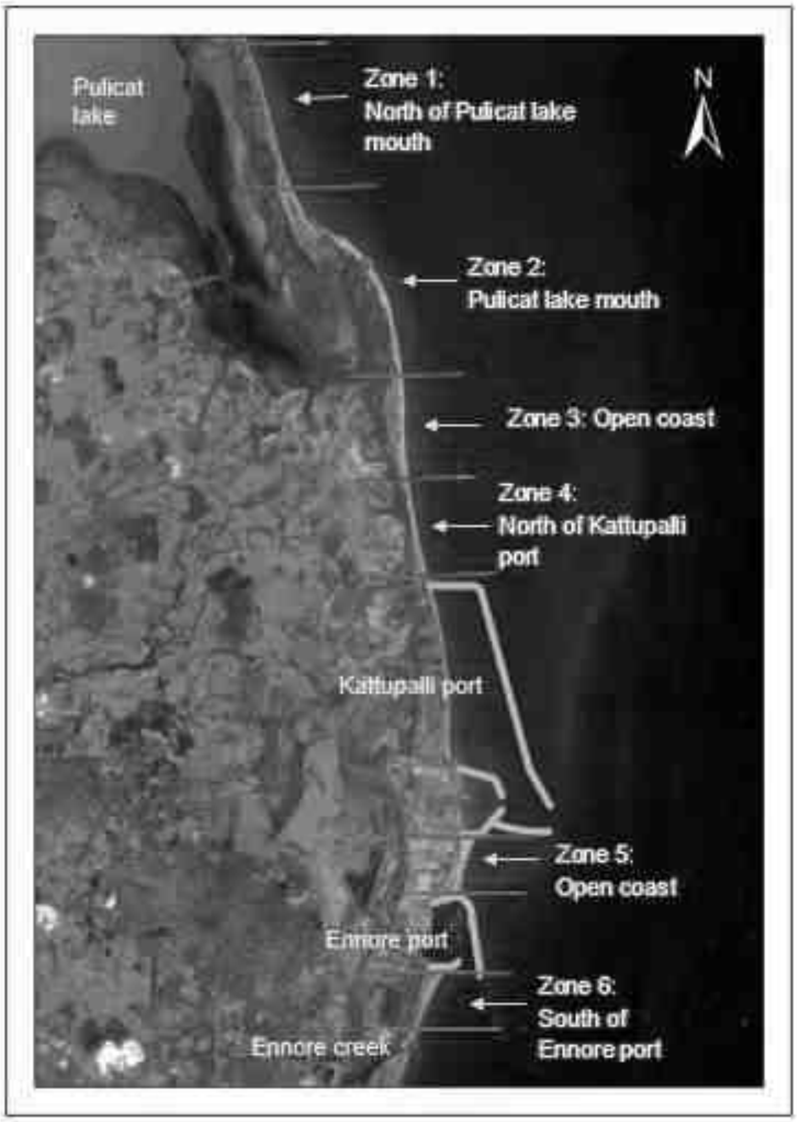


Figure 6-8 Zone wise division of the considered coastal stretch

Zone 1 North of Pulicat lake mouth

This zone covers the shoreline extending 8 kms from the mouth of Pulicat lake. This coastal stretch is observed to be most stable with no dynamic changes during 15 years of the study. The shoreline change is represented in Figure 6-9.

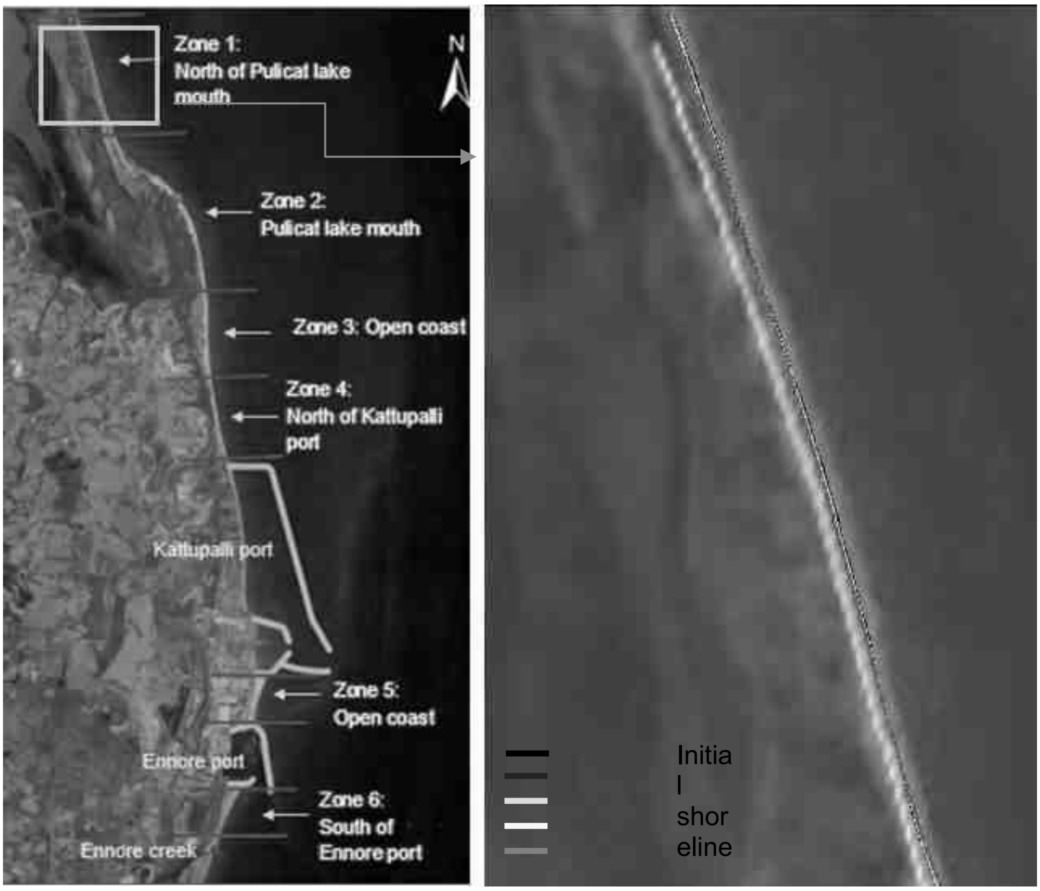


Figure 6-9 Shoreline change in the Zone 1 for 15 years under layout condition

Zone 2 Pulicat lake mouth

This coastal stretch covers entire Pulicat lake mouth and the small coast extending to the south of it. This coastal stretch is observed to be very dynamic. In the mouth region, southern part is observed to be eroding whereas northern part is observed to be accreting. It is represented in the Figure 6-10.

This trend will vary based on the changes in seasonal wind and wave directions. Since the net littoral movement is observed to be towards north, the accretion of the northern end of the mouth can be understood.

The coastline orientation also plays the major role whereas the convex shaped coastline is eroding, and the materials are observed to be deposited in concave shaped coastline in the northern part of mouth region which can also be well observed. Other parts in this zone are observed to be more stable.

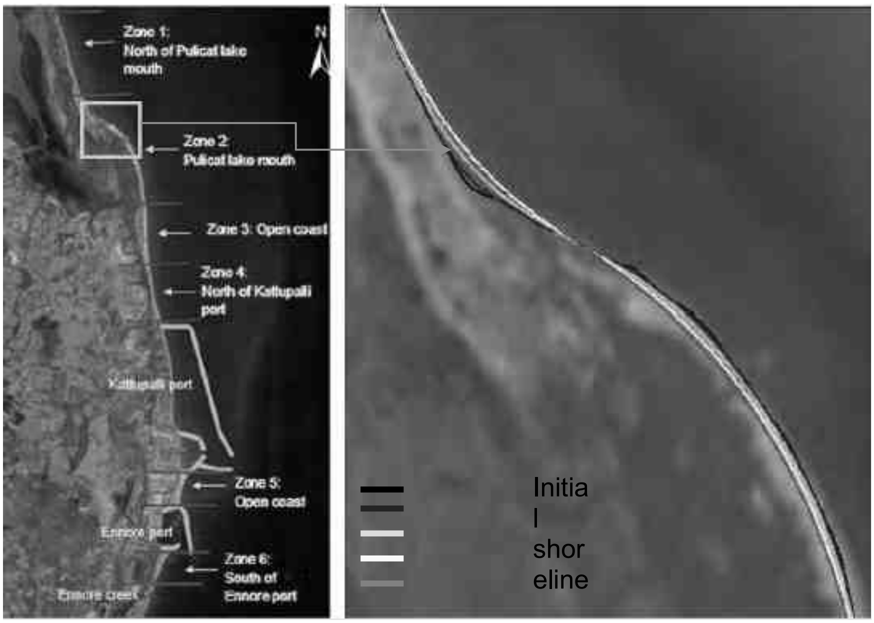


Figure 6-10 Shoreline change in the Zone 2 for 15 years under layout condition

Zone 3 Open coast

This is a coastal stretch which has no natural interventions like estuary, creek, and man-made structures. It is an open coast, and it is not entirely a straight coast. The straight part of the coast is almost stable whereas the part which is not straight is observed to be undergoing erosion. This can be attributed to the fact that the influence of coastline orientation and it will be varying for the changing wave and current directions. The eroding coastal stretch in this zone can be viewed in the Figure 6-11.

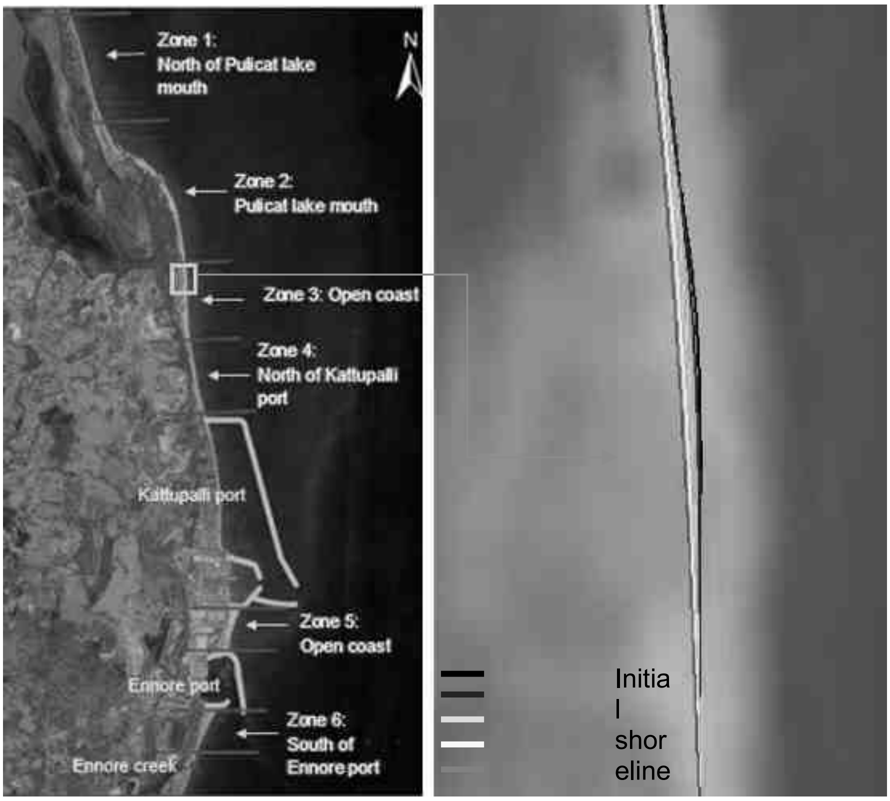


Figure 6-11 Shoreline change in the Zone 3 for 15 years under layout condition

Zone 4 North of Kattupalli port

This zone covers the coastal stretch extending 5km from the proposed northern breakwater of Kattupalli port under layout conditions. It is observed that the coastal stretch immediately 1km to the north of northern breakwater will undergo erosion. The tendency and the extend of erosion are directly proportional to the increase in the number of years. It is noted that an erosion of 117 m is observed immediately near to the northern breakwater. From 15 years estimation, approximately, 84 m of erosion is observed at 300m distance, 50 m of erosion at 500 m distance and 4 m of erosion at 1km distance from the northern breakwater. After the first 1km stretch, the coast is mostly observed to be stable, and it is not dynamic in nature. The coastal stretch is represented in Figure 6-12.

Table 6-1 Rate of prediction of Erosion North of Kattupalli port

Distance from North breakwater	1year	5 years	10 years	15 years
	Erosion in meters			
Immediate north	33	68	100	117
250m North	3	31	52	85
500 m north	No Change	5	22	50
750 m north	No Change	No Change	7	18
1km north	No Change	No Change	No Change	4

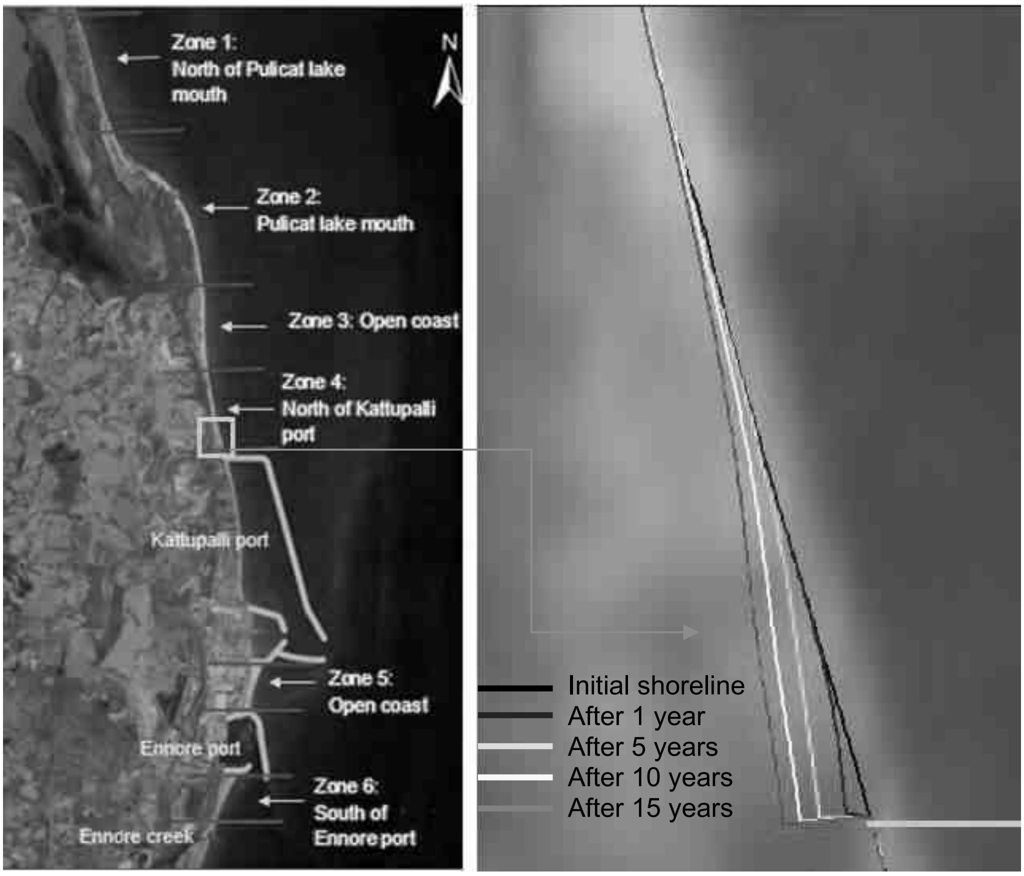


Figure 6-12 Shoreline change in the Zone 4 for 15 years under layout condition

Zone 5 Open coast

This zone covers the small coastal stretch which lies between Ennore and Kattupalli port. It is well protected between the breakwaters of the above-mentioned ports. The shoreline in this zone is observed to be accreting on both the ends and eroding in the middle. This shore is oscillatory in nature mostly due to the varying seasonal wave and wind directions. The entire coastal stretch in this zone is well represented in the Figure 6-13.

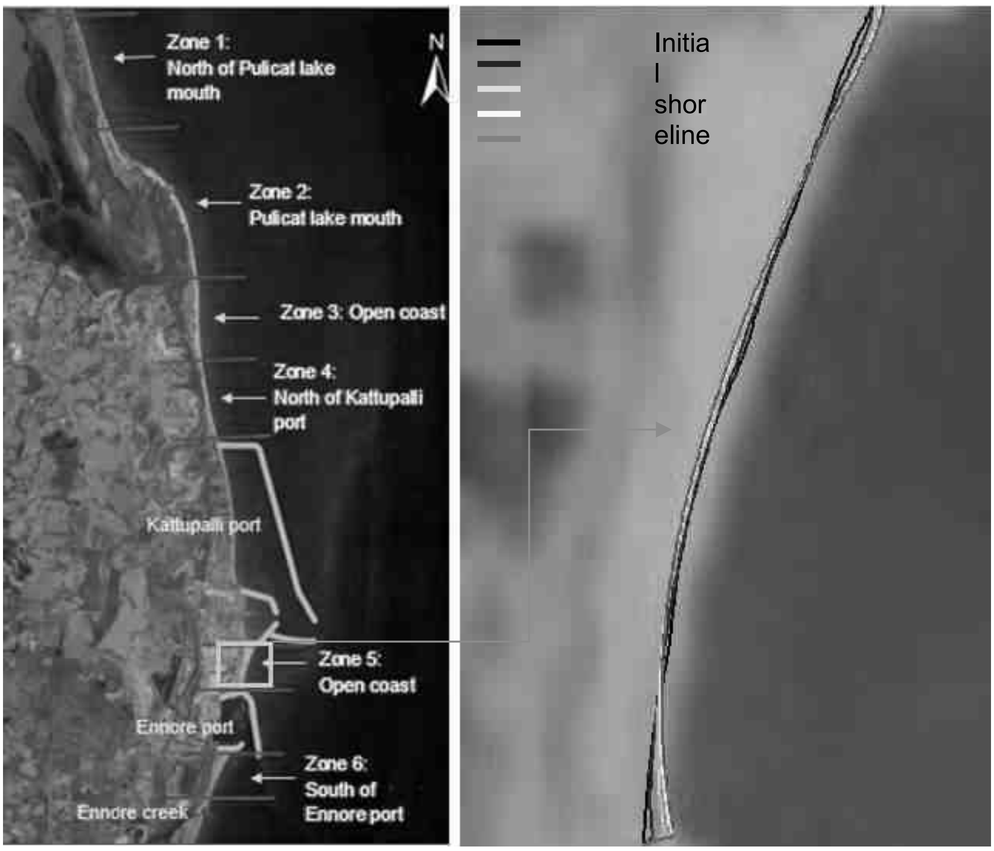


Figure 6-13 Shoreline change in the Zone 5 for 15 years under layout condition

Zone 6 South of Ennore port

This zone consists of a coastal stretch from the Ennore creek to the southern breakwater of Ennore port. The shore immediate south to the southern breakwater of Ennore port is observed to be eroding and erosion is observed to be increasing for the increasing number of years. This erosion trend decreases and stops approximately at the 800m distance from the Ennore port and then the coast is appeared to be accreting till the end. From the littoral drift result shown in Figure 6-7, the profile considered in this zone shows the net littoral drift is in southern direction, which is the nature this shoreline. The entire coastal zone 6 is represented in the Figure 6-14.

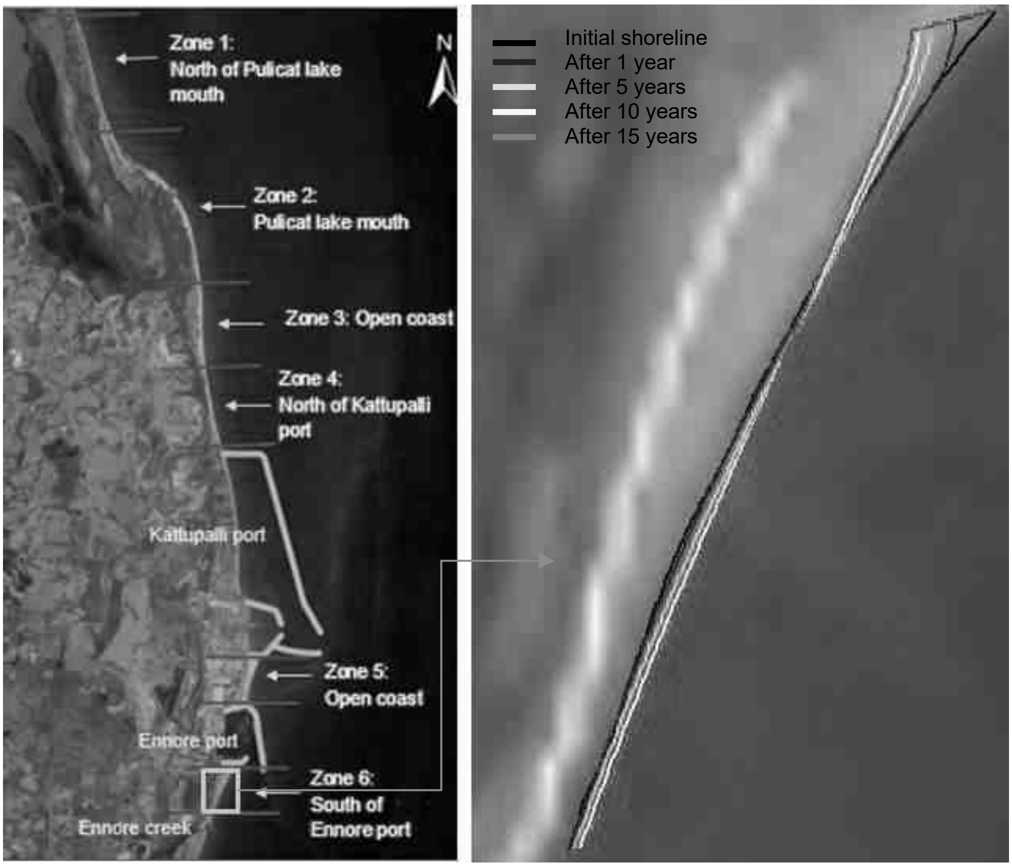


Figure 6-14 Shoreline change in the Zone 6 for 15 years under layout condition

Under varying annual wave conditions, the model predicted the littoral drift for one to 15 years is given in Table 6-2. The prediction clearly indicates that the coast will undergo erosion in the immediate north with the proposed Master Plan layout. The northernly movement of 0.46 million cu.m and southernly movement of 0.06 million cu.m is anticipated for 1-yr with the proposed development. The net drift is towards the north with a quantity of 0.39 million cu. m in one year. For 15 years assessment the northerly movement is 5.1 million cu.m and southerly movement is 0.45 million cu.m. After 15 years the shoreline erosion is 117 m, predicted immediate north of the proposed northern breakwater (Figure 6-12).

Table 6-2 Longshore sediment transport and rate for different scenarios

Scenario	Structure	Longshore sediment Transport (m^3)			Sediment transport rate [m^3/s]	
		Northerly Drift	Southerly Drift	Net Drift	Northerly	Southerly
1 year	Existing Facilities	-458329	66043	-392286	0.82	0.22
1 year	Proposed Facilities	-367070	69830	-297240	0.82	0.23
5 years		-1764412	237554	-1526858	0.82	0.23
10 years		-3477689	365349	-3112340	0.82	0.23
15 years		-5139085	448683	-4690402	0.82	0.23

From the model results, the following points are observed from the shoreline change prediction:

- Northward movement of sand in the order of 458329 m^3 and southward movement of sand in the order of 66043 m^3 is noticed with the baseline conditions for 1 year.
- Northward movement of sand in the order of 367070 m^3 and southward movement of sand in the order of 69830 m^3 is noticed with proposed port facilities for 1 year.
- Northward movement of sand in the order of 1764412m^3 and southward movement of sand in the order of 237554 m^3 is noticed with proposed port facilities for 5 years.
- Northward movement of sand in the order of 3477689 m^3 and southward movement of sand in the order of 365349 m^3 is noticed with proposed port facilities for 10 years.
- Northward movement of sand in the order of 5139085 m^3 and southward movement of sand in the order of 448683 m^3 is noticed with proposed port facilities for 15 years.

7 Shoreline Management Plan

Shoreline Management Plans (SMP) are high-level, non-statutory documents which form part of the strategic framework for the protection of coastal communities. The SMP records the natural coastal processes, land use and the environment by providing a detailed understanding in the coastal zone of existing and planned infrastructure and any problems such as erosion or the community needs.

Wind, waves, and currents in combination with the local water levels are the main driving factors for the development of the coasts. These factors have been summarized as met ocean forcing.

The purpose of Shoreline Management Planning (SMP) is to identify the resources and assets in the coastal area now and in the future and through that minimise negative consequences from the interaction between various interests, i.e. coastal protection.

7.1 Environmental condition

The input environmental data required for the model are cross-shore profile, initial shoreline position along the coast, sediment size, annual wave climate etc.

7.2 Interventions

The model studies for shoreline change for the proposed Master Plan indicates that the first 1km north coast of Kattupalli is eroding, at the rate of 8m/yr. In order to prevent the erosion in north coast, two types of interventions and the consequent impacts on shoreline management along the coast both soft (sand bypassing) and hard measures (groynes) are tested with appropriate model simulations.

7.2.1 Option-1: Artificial Beach Nourishment

Soft engineering measures such as beach nourishment are widely used for shore protection due to lack of negative impacts like erosion and advantage over hard measures (seawalls and groynes) in terms of performance, aesthetics, and restoration of natural beach. Figure 7-1 shows a broad classification of sand nourishment based on cross-shore dimension.

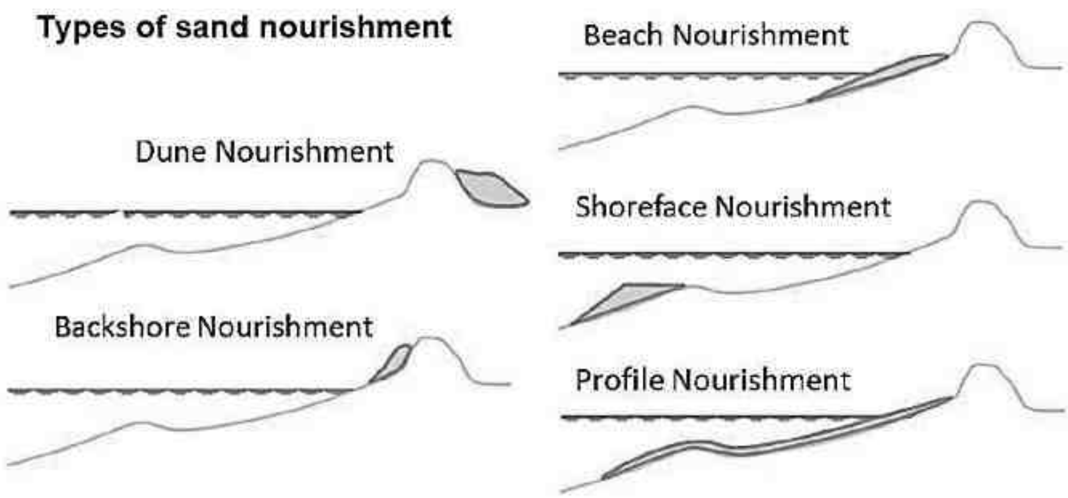


Figure 7-1 Types of sand nourishment

Beach nourishment is not a complete coastal protection measure, as the beach will normally be flooded during extreme events allowing erosion of the coast, but it will support possible coastal protection measures. When performing beach nourishment, the borrow sand must be similar to the native sand to adjust smoothly towards the natural profile. It may be an advantage to use slightly coarser sand than the natural beach sand, as this will enhance the stability of the steeper profile. Finer sand will very quickly be transported to deeper water and will thus not contribute directly to a wider beach.

Another mitigation measure is to consider in relation to minimising the impact of nourishment on the port operations. Hence it is to perform the nourishment during the southwest monsoon, so that the possibility of material entering the entrance channel can be avoided.

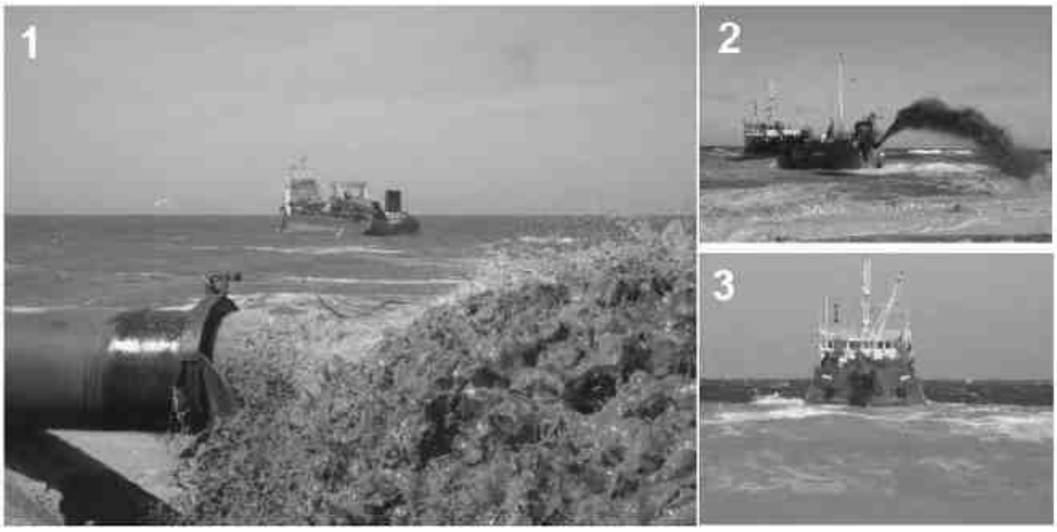


Figure 7-2 Nourishment methods in practice. 1: Beach nourishment by pipe discharge. 2: Foreshore nourishment by bow pumping and 3: Shoreface nourishment by split barge

At Ennore Port, the backshore nourishment is implemented. The material dredged from Ennore port as capital dredging (3.5M Cu.m) can be transported through pipeline to the north of the port. Out of total quantity dredged, 0.7 M Cu.m can be placed over the existing beach inorder to rise the berm height from 2.5 to 6m above mean sea level and the rest is spread over the nearshore to widen beach by 500m. The fill started supplying material to the downdrift coast, from the inception of the project henceforth 250m wide beach is lost between 2000 and 2004, forming a steep cut at the beach fill location.

To find suitability of nourishment at Kattupalli, similar method applied and tested using numerical models. The overall performance of the beach fill to protect the downdrift coast appears satisfactory at Kattupalli. Two Million Cu.m of the dredged material is used for nourishing 1km of the beach immediate after the northern breakwater of proposed port development. Figure 7-3 shows the 15 years shoreline changes with nourishment quantity of 2MCu.m of dredged material. Predictions made using numerical models indicated that at the end of 15 years, it is observed that a large quantity of nourishment will be lost to the sea. The threat will increase with increase in years and the investment made will be under threat if no intervention is planned after that. To mitigate the impact of beach nourishments on intertidal sandy beaches and to assure a swift recolonization of the nourished beach by the original sandy beach community, the use of same size of sediment that resembles the initial beach sediment, is therefore strongly recommended.

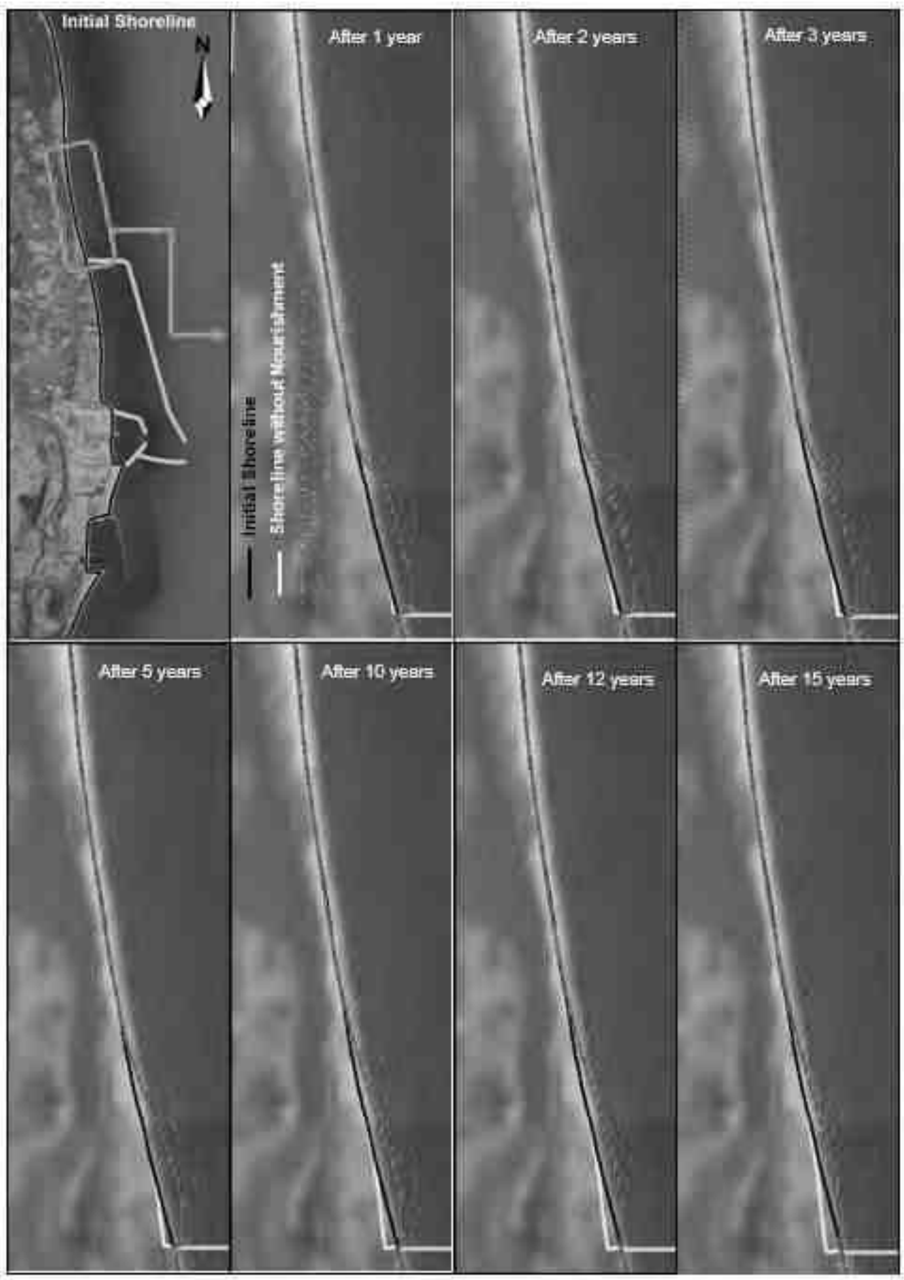


Figure 7-3 Shoreline changes in 15 years (with and without nourishment)

The demerits of the beach nourishment is a chance of washing out of the nourished materials when the extreme weather condition (Tsunami and Cyclone) occurs.

7.2.2 Option-2: Beach Nourishment with groyne field

Groynes are coastal structures oriented approximately shore-normal and built of similar material as seawalls. They form a cross-shore barrier that traps sand which moves alongshore, thereby increasing the width of the beach on the upstream side. Hence, they function best on beaches with a predominant alongshore transport direction.

Groynes are built to serve three purposes. 1) to build or widen beach, by trapping sand, 2) to stabilize a beach, which is subject to excessive storms or periods of episodic erosion and 3) to reduce or prevent the movement of littoral materials out of an area.

Along Ennore to Pulicat coast even though there is predominant alongshore sediment transport but at immediate north of port there is considerable onshore/offshore movement of sediment. The suitability of groynes to arrest erosion north of port, groyne field is considered and the resulted effect along the shore is studied with the help of numerical models.

Simulations on effectiveness of groyne structure under different wave directions indicate that the groyne effect is completely negligible, when waves approach the coast from East direction i.e. parallel to coastline. It is evident from the studies that the bypassing of sediment to north of the proposed development is not possible due to presence of entrance channel on southern side of the port, which will act as sediment trap. The model results indicate that the wave heights on the downdrift side is drastically reduced, and the wave induced current strength is decreased and considerable amount of sediment is accumulated.

Under varying annual wave conditions, the predicted shoreline for 15 years is assessed using three groynes of varying size (100 to 150m length) and the spacing is one km (Figure 7-4) and the 3km of the shoreline is protected by beach nourishment along with groyne field. The predicted shoreline indicated that the coast is undergoing erosion on its northern side of the last groyne, in the order of 3.6m/year, even though the beach was built with the groyne field. To compensate the loss of north beach of groyne field artificial nourishment is needed. The first one km coastline immediate after the northern breakwater is nourished with 2M Cu.m dredged material to overcome the erosion and 0.5M Cu.m sand from the maintenance dredging should be used for nourishment in alternative years.

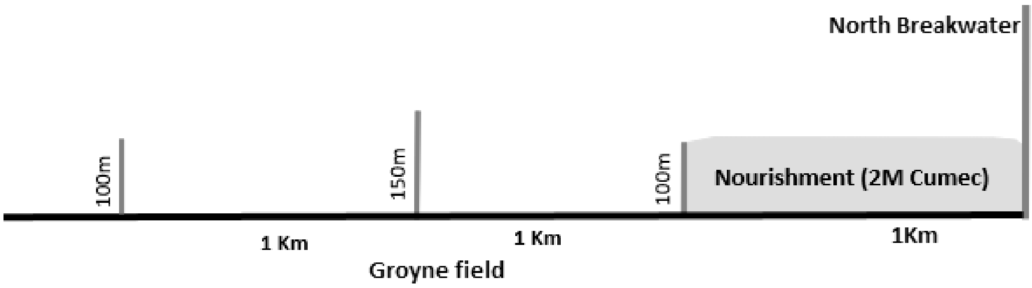


Figure 7-4 Nourishment with three groynes to protect the shoreline on the north of proposed port

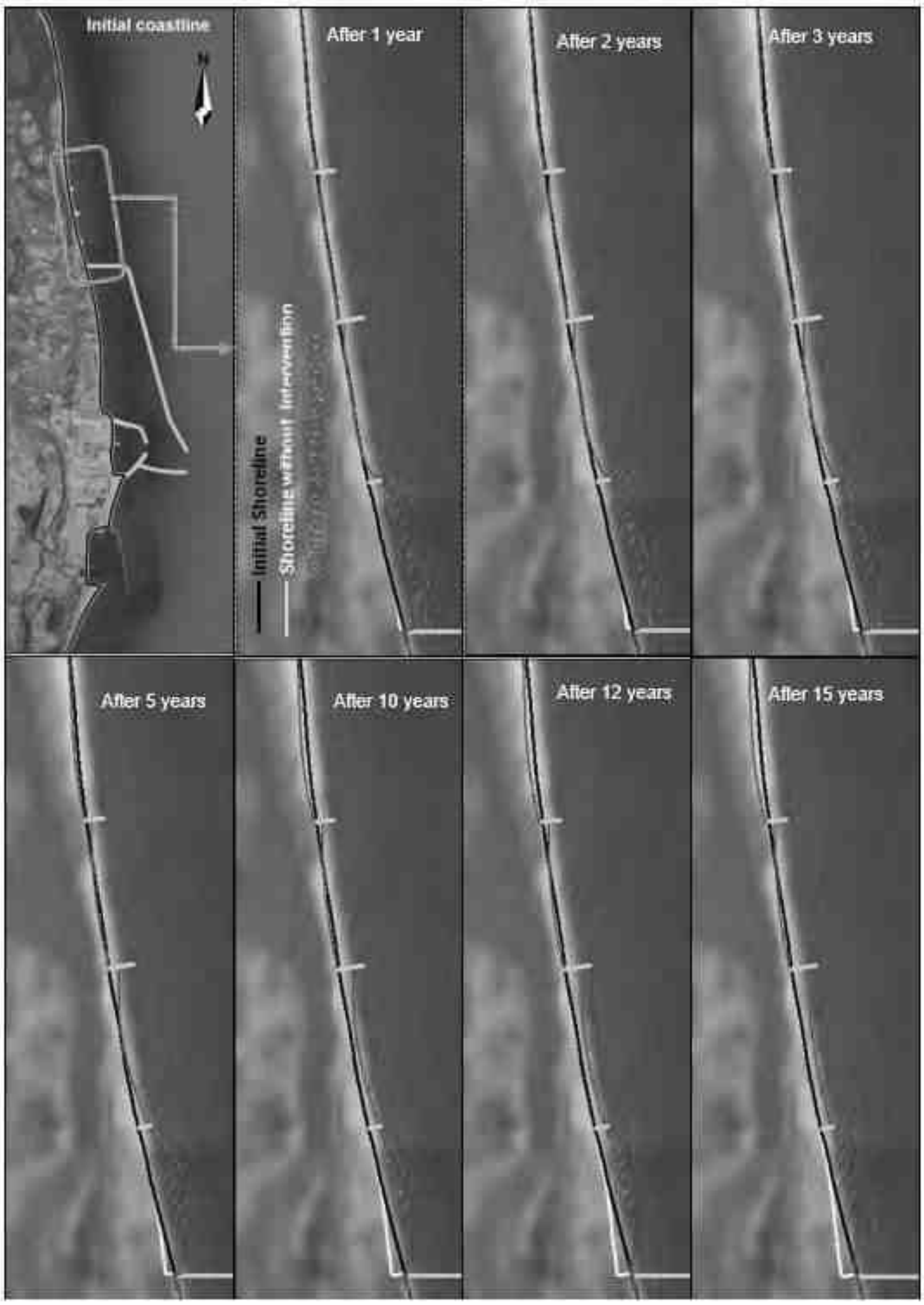


Figure 7-5 Shoreline changes over 15 years with option-2 (nourishment with groyne field)

The Figure 7-5 shows the shoreline change in 15 years after introducing the groyne field with 2M Cu.m nourishment immediate after north of the proposed port facility along with 0.5M Cu.m. nourishment in alternate years. The shoreline is well protected up to 3km from the north of proposed breakwater, but there is significant shoreline erosion further north of the groyne field in the order of 55m over 15 years duration.

7.3 Recommendations

The information from hydrodynamic conditions (tide, wave, current and water level), shoreline changes and sediment characteristics are used to estimate the sediment quantity for the coastal stretch from Ennore creek to Pulicat creek.

The model results with the proposed master plan and without any shoreline protection measures indicates that the shoreline erosion is up to 1 km on the northern side of the port with a rate of erosion 8m/year. To prevent the loss of land, DHI has assessed the performance of artificial nourishment combined with groyne field on the northern side of the proposed master plan.

The model analysis indicates that the beach fill (with a length of 1000m, width of 200m with a transition length of 800m) will reduce the impact of erosion on the adjacent coast. Predictions further indicates that this nourished material would be completely lost to sea after 15 years from the time of nourishment, will be an economical loss. The rate of erosion with the proposed beach fill is in the order of 5m/yr and the zone of erosion is shifting further north.

To avoid the quick flow of nourished sand towards north due to littoral transport, implementation of three groynes on the northern side of the beach fill is proposed. The length of the first and last groin is 100m and the middle groin is 150m, the distance between the groins is 1 km. Following the implementation of beach fill along with groyne field, the rate of erosion is reduced to 3.6 m/year, but the erosion extent shifted further 3 km from the proposed development. This would be minimized with additional nourishment of 0.5 million Cu.m of sand at every alternate year to protect the area immediate north of the groin filed.

Overall, the extent of erosion is limited to 3km north of the proposed groyne (last). Thereafter the coastline is stable and not subjected to any erosion. The Pulicat lake mouth is further 7 km north from the erosion region hence, it will have no impact either from the proposed Master plan development or from the proposed shoreline protection measures (beach fill along with groyne field). The groyne field will also help to keep the nourished material on the beach during extreme weather conditions such as tsunami and cyclones. DHI proposes the Option-2 beach nourishment with groyne field for this case.

Table 7-1 Shoreline Trend with various interventions

Scenarios	Erosion Rate in meter/year
Master Plan without any shore protection	8
Master Plan + beach nourishment	5
Master Plan + beach nourishment + groyne field	3.6

8 Tsunami Modelling

The historical tsunamis are generated in Bay of Bengal and Indian Ocean, three of them are simulated to predict the water levels and currents at the proposed port development.

For the modelling of tsunami, the static vertical tectonic displacement is used as initial wave heights. Tsunami models assume that the water motion occurs instantaneously. In other words, the initial tsunami wave is assumed to be of the same shape as the seafloor deformation.

8.1 Earthquake Parameters

For calculating the initial vertical displacement due to the earthquake, various earthquake parameters is considered, such as the initial rupture time, dip angle, strike angle, slip angle, latitude and longitude, most importantly the moment magnitude of the earthquake and the type of fault mechanism.

However, in this study, the fault parameters of the earthquakes considered for the generation of 2004 Sumatra Tsunami is from Stephen et. al. (2007) and similarly fault parameters for 1881 and 1941 earthquakes are from Usha et. al. (2011). The fault parameters are listed in Table 8-1.

Table 8-1 Fault parameters for 1881, 1941 and 2004 Earthquakes in the Bay of Bengal.

Parameters	1881 Car Nicobar	1941 Andaman	2004 Sumatra				
			Fault-1	Fault-2	Fault-3	Fault-4	Fault-5
Longitude [Deg]	92.43	92.5	95.10	93.90	93.41	92.10	92
Latitude [Deg]	8.52	12.1	2.50	4.33	5.80	9.10	10.50
Magnitude [Mw]	7.9	7.7	9.3				
Slip [m]	5	5	18	23	12	12	12
Fault length [km]	200	200	220	150	390	150	350
Fault width [km]	80	80	130	130	120	95	95
Strike angle [Deg]	350	20	323	348	338	356	10
Dip angle [Deg]	25	20	12	12	12	12	12
Rake angle [Deg]	90	90	90	90	90	90	90
Focal depth [km]	15	30	25	25	25	25	25

8.2 Model Setup

8.2.1 Bathymetry

The model that covers Bay of Bengal, Andaman Sea, and Laccadive Sea has been used in the study. The model covers tsunami generation and its propagation area. The dedicated model coverage is shown in Figure 8-1. About 147801 elements with various mesh resolutions have been produced. The resolution of the bathymetries is varied from 100m to 25km, respectively.

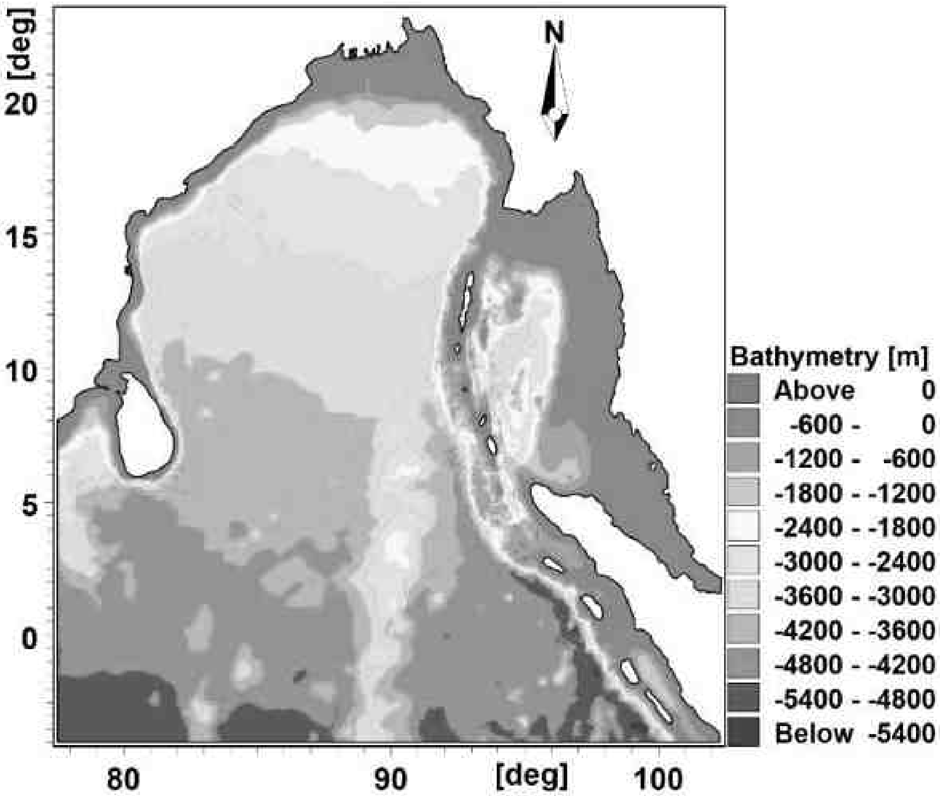


Figure 8-1 Domain used for Tsunami Modelling.

8.2.2 Initial Water Elevation

Tsunami is caused by the vertical displacement of the water column along the fault line. The elevated water is subjected to the action of gravity, which induces a series of waves (collectively known as the tsunami). The resulting wave train travels away from the source at a given speed, which in general, is determined by the length of the waves and the local water depth.

The initial surface elevation along the fault (responsible for the onset of the tsunami wave train), constitute the main input to the MIKE21 HDFM. The initial surface elevation was generated by MIKE21 Bathymetry Adjustment Tool.

8.3 Results

The model results show the generation and propagation of the tsunamis considered. The total duration of all simulations considered to be 5 hours from the initial rupture time.

Figure 8-2 shows the 2004 Sumatra tsunami propagation after 30min, 60min and 120min from the initial rupture. Figure 8-3 and Figure 8-4 shows the predicted maximum surface elevation and current speed along Ennore to Pulicat lake with baseline and proposed master plan layout.

Further, water levels and current speeds are extracted at Kattupalli port entrance, Ennore and Pulicat creek entrance as shown in Figure 8-5 and Figure 8-6 respectively. The maximum water level predicted at the existing and proposed port entrance is 2.18m and 2.23m. The corresponding current speed at existing and proposed port entrance is estimated to 3.1m/s and 3m/s respectively.

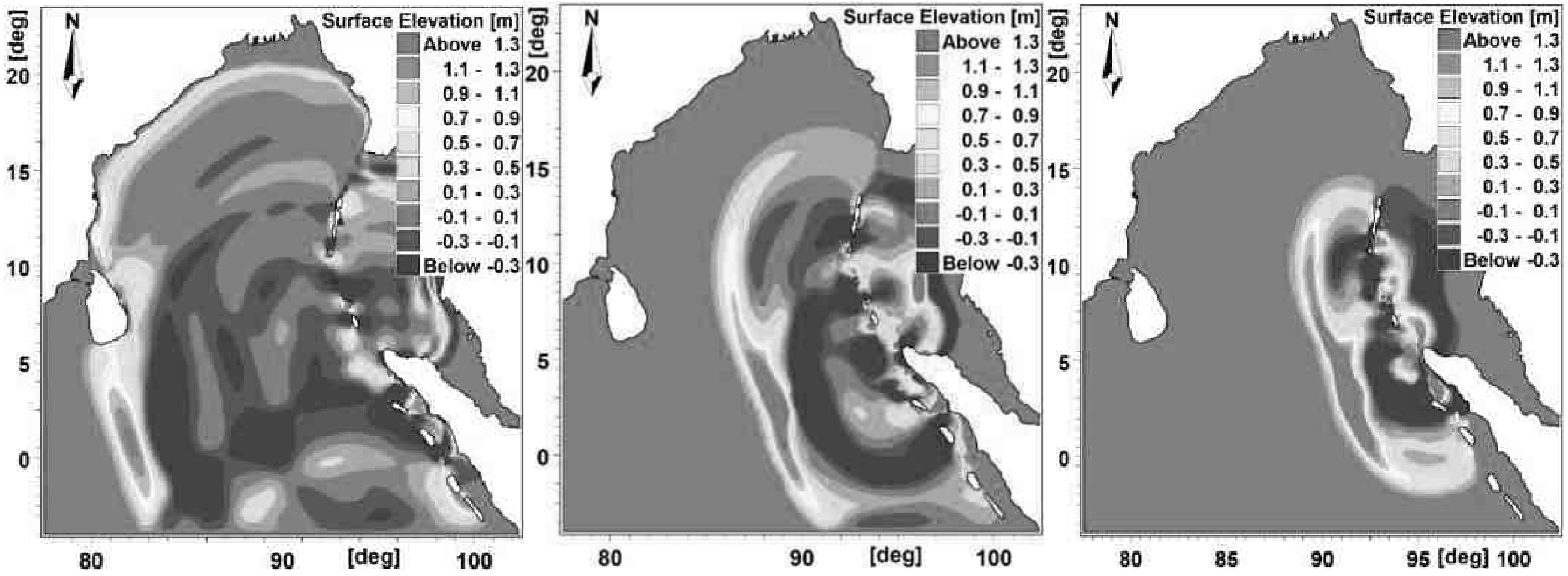


Figure 8-2 2004 Sumatra Tsunami propagation after 30, 60, and 120 minutes from origin

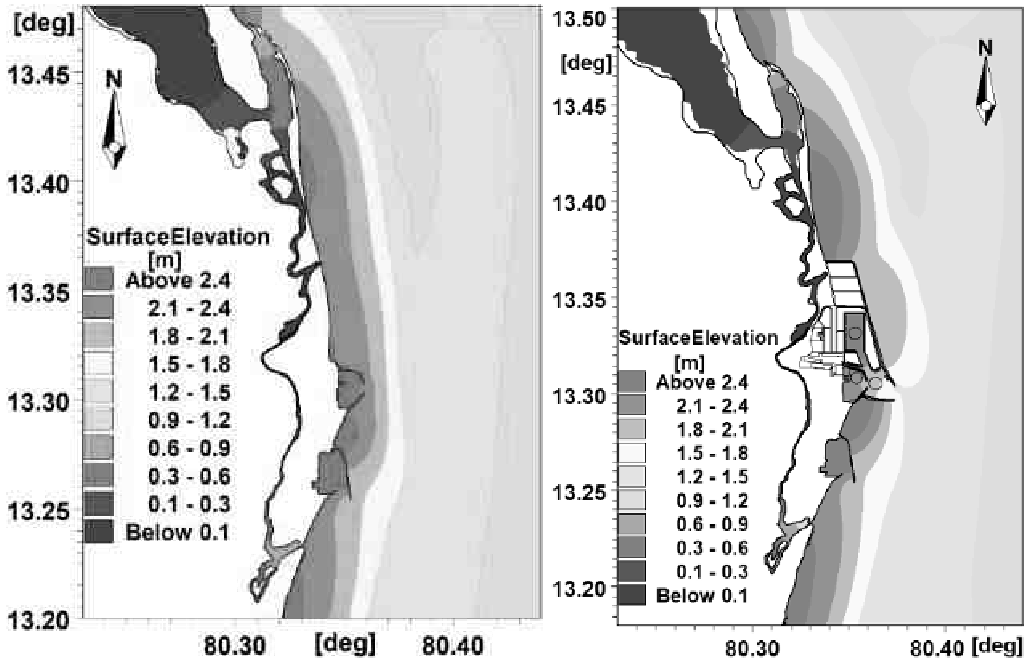


Figure 8-3 Water level induced by 2004 tsunami along Ennore to Pulicat Lake (Baseline and Layout conditions)

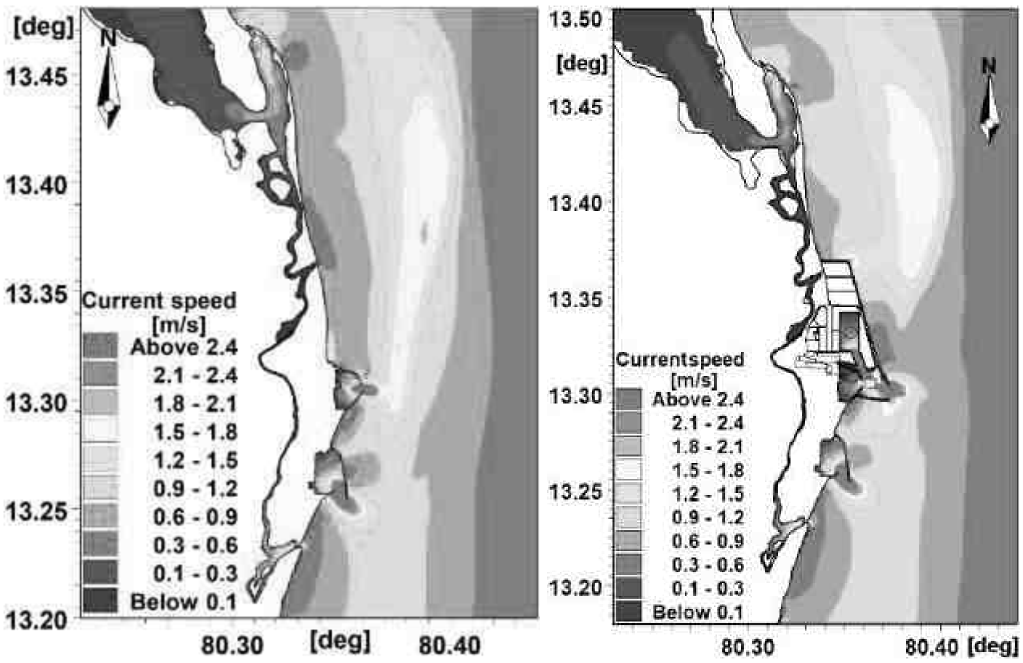


Figure 8-4 Current speed induced by 2004 tsunami along Ennore to Pulicat Lake (Baseline and Layout conditions)

The water level and current speed produced by 2004 tsunami along Ennore to Pulicat region are not having any significant differences between baseline conditions and proposed master plan layout. This indicates that the proposed master plan is not causing any impact to Ennore shoals and also to the adjacent Ennore creek and Pulicat mouth. The surface elevation and current speed at different extraction locations along the study area are listed in Table 8-2 and Table 8-3.

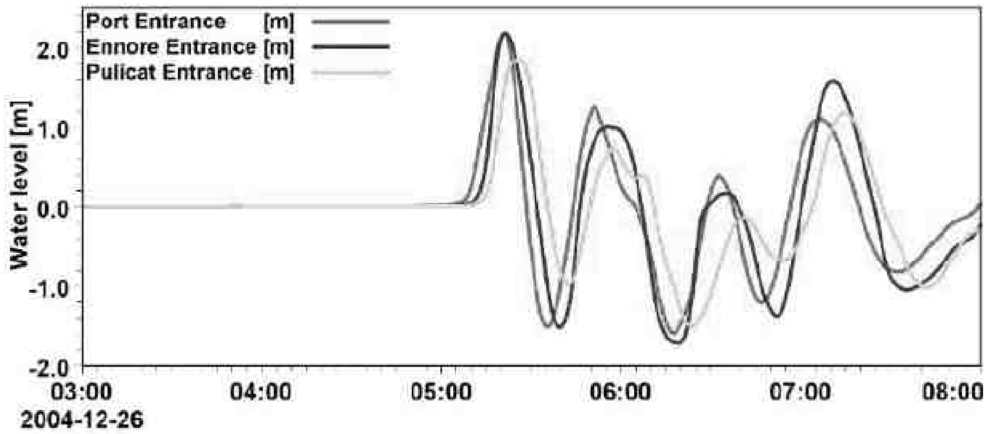


Figure 8-5 Tsunami induced surface elevation along the study area from 2004 Sumatra Tsunami

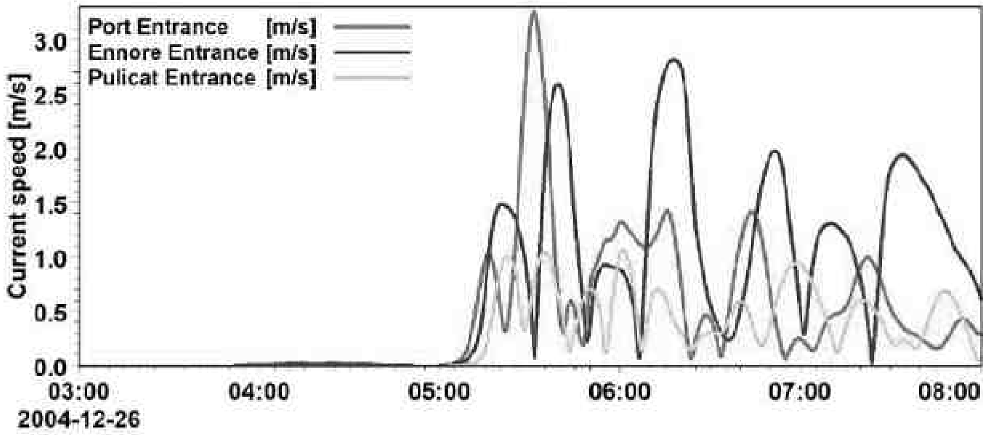


Figure 8-6 Tsunami induced current speed along the study area from 2004 Sumatra Tsunami

Table 8-2 Location details and surface elevation for selected points

Location			Surface Elevation[m]		
Name	Long [Deg]	Lat [Deg]	1881 Car Nicobar	1941 Andaman	2004 Sumatra
Ennore Creek Entrance	80.362	13.305	0.44	0.22	2.18
Kattupalli Port Entrance	80.331	13.233	0.47	0.21	2.18
Pulicat Lake Entrance	80.317	13.474	0.41	0.23	1.85

Table 8-3 Location details and current speed for selected points

Location			Current Speed [m/s]		
Name	Long [Deg]	Lat [Deg]	1881 Car Nicobar	1941 Andaman	2004 Sumatra
Ennore Creek Entrance	80.362	13.305	0.6	0.18	3.26
Kattupalli Port Entrance	80.331	13.233	1.0	0.46	2.81
Pulicat Lake Entrance	80.317	13.474	0.4	0.14	1.07

The above results indicated that the intensity of inundation decreased along Ennore to Pulicat due to the presence of submerged shoals north of Kattupalli Port, which served as wave dampers in reducing wave energy. If the proposed development caused any alternations to these shoals, then the tsunami wave would have significant impact to this particular stretch of coast, but which is not the likely scenario with the proposed master plan. Hence, it is concluded that the proposed master plan is not causing any changes to the Ennore shoal and in turn these shoals are still acting as barrier in protecting the coast during tsunami and cyclone events.

9 Cyclone Modelling

9.1 Tropical Cyclone Tracks

The number of cyclones that have occurred within the vicinity of 100 km radius of the proposed project location for the period of 1970 to 2018 from (Cyclone eAtlas) India Meteorological Department (IMD, India) is shown in Figure 9-1.

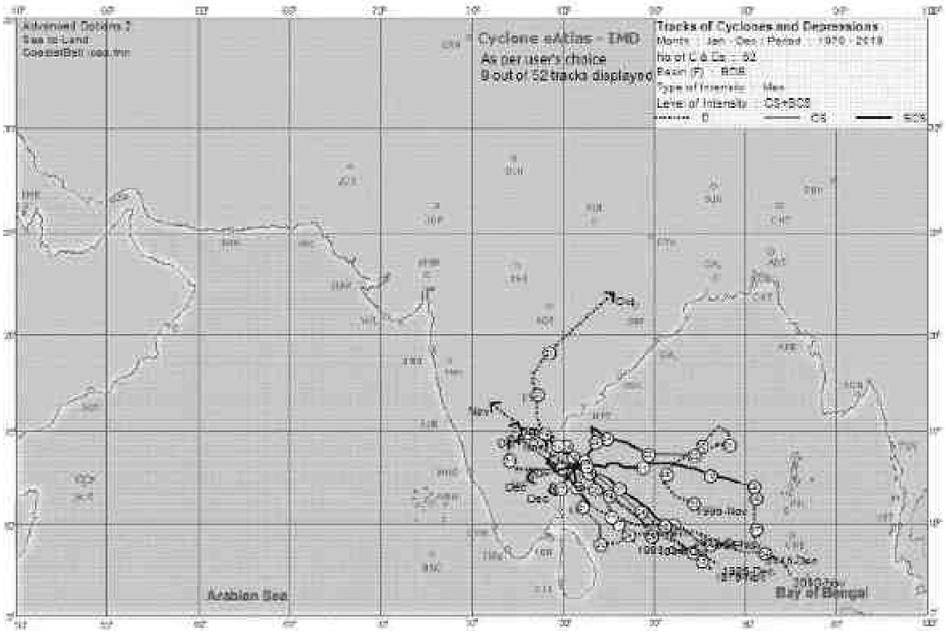


Figure 9-1 Tracks of the cyclones in the vicinity 100 to the study area from 1970 to 2018

For model simulations, nine (9) cyclonic events are selected for simulation. The year of cyclone crossing and the maximum wind speed of selected cyclones is given in Figure 9-2. From the IMD storm track data, cyclonic stages, maximum wind speed of the system, pressure drop, radius to maximum wind are retrieved and estimated.

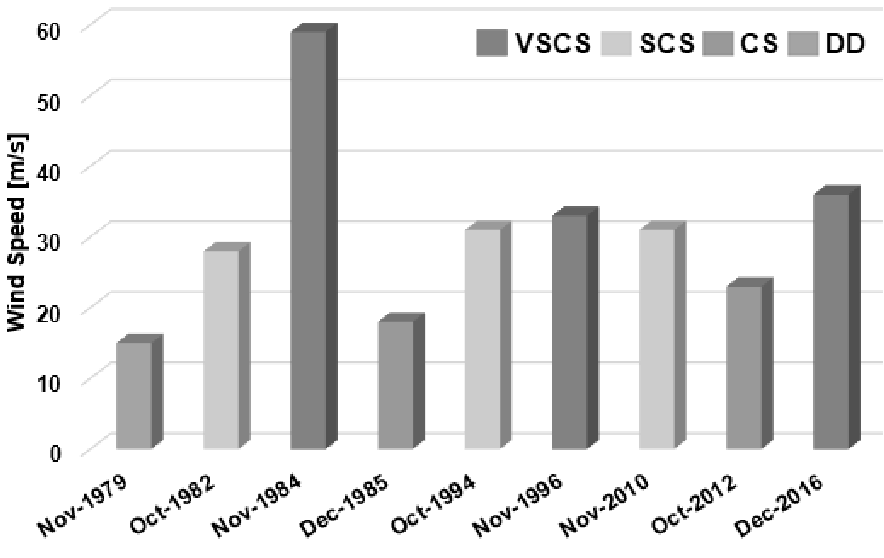


Figure 9-2 Storms crossed within 100 km radius of Kattupalli Port during the period (1970–2018)

9.2 Storm Surge Modelling

9.2.1 Wind and Pressure fields

The wind field and pressure field of 2016 Vardah cyclone generated using MIKE 21 Cyclone wind field generation tool is represented in Figure 9-3. The maximum wind speed observed is 71m/s.

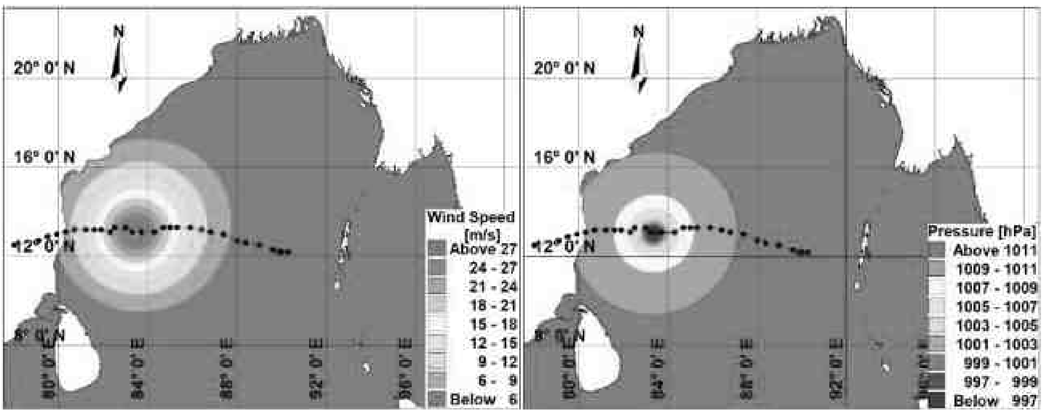


Figure 9-3 Wind and Pressure field map for 2016 Vardah Cyclone.

9.2.2 Model results

The results obtained from MIKE 21 HD storm surge simulation for 2016 Vardah cyclone with baseline and layout is presented in Figure 9-4 and Figure 9-5. The timeseries results of storm surge and current speed at the study area is presented in Figure 9-6 and Figure 9-7 for Vardah cyclone. The storm surge map shows that there is one meter surge occurring along the Kosasthalaiyar river and Pulicat lake. The storm surge and current speed for the 9 cyclones at the study area are extracted and presented in Table 9-1.

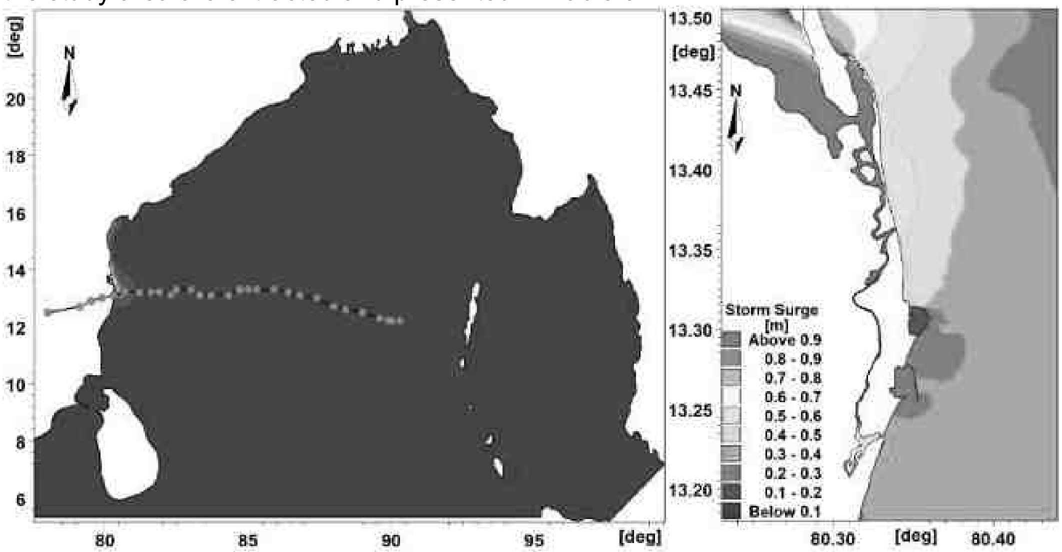


Figure 9-4 Snapshot of simulated storm surge during 2016 Vardah cyclone (Baseline)

At Kattupalli Port location, the December 2016 Vardah cyclone has caused a maximum surge height of 0.78m and a maximum current speed of 2.74 m/s.

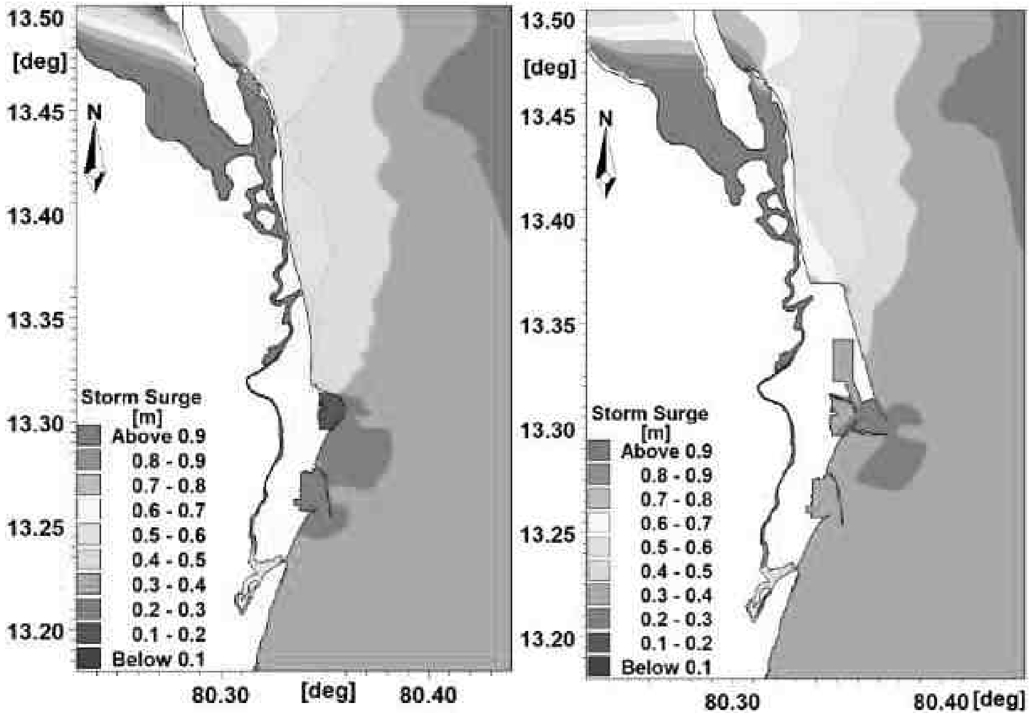


Figure 9-5 Storm surge during 2016 Vardah cyclone (Baseline and Layout)

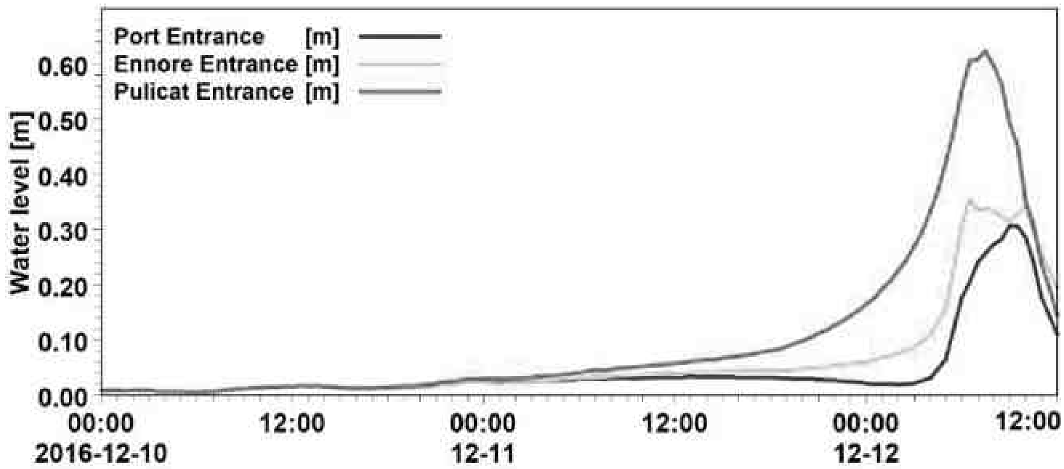


Figure 9-6 Predicted surge at different locations for 2016 Vardah cyclone

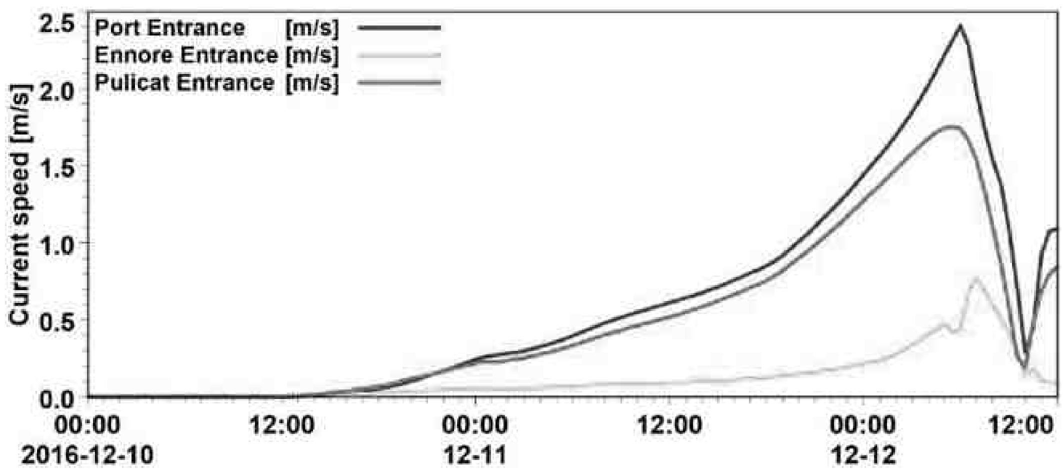


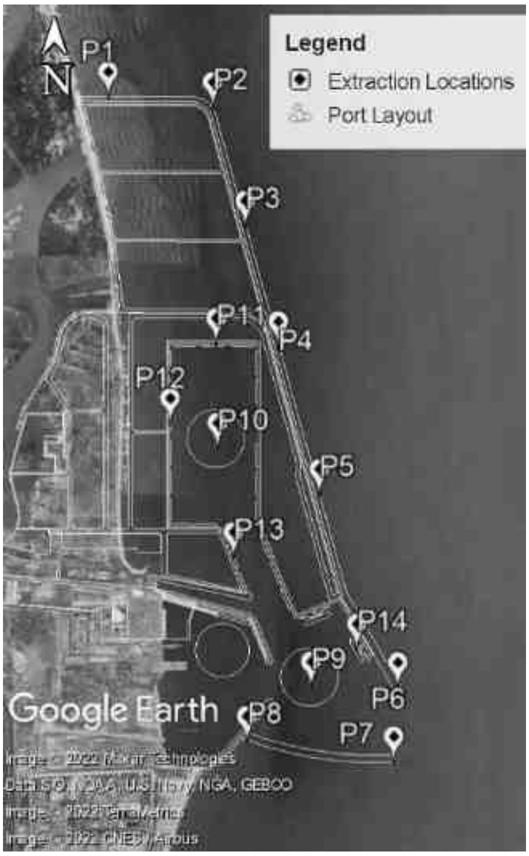
Figure 9-7 Current speeds at selected locations for 2016 Vardah cyclone

Table 9-1 Maximum storm surge at project location for the modelled cyclones

S. No	Month & year	V max m/s	Nature of the cyclone	At the study area	
				Storm Surge [m]	Current Speed[m/s]
1	November-1979	15	DD	0.03	0.35
2	October-1982	28	SCS	0.18	1.35
3	November-1984	59	VSCS	0.73	2.63
4	December-1985	18	CS	0.13	1.07
5	October-1994	31	SCS	0.47	1.38
6	November-1996	33	VSCS	0.39	1.83
7	November-2010	31	SCS	0.18	0.89
8	October-2012	23	CS	0.15	0.62
9	December-2016 (Vardah cyclone)	36	VSCS	0.78	2.74

The Storm wave heights at different chainage of breakwater, turning circle and berths are shown in Table 9-2 Storm wave table at different chainage of breakwater, turning circle and berthsTable 9-2.

Table 9-2 Storm wave table at different chainage of breakwater, turning circle and berths



Location	WGS 1984 UTM-44		Storm Wave height [m]
	Easting [m]	Northing [m]	
P1	428635	1478030	3.6
P2	429911	1477900	4.0
P3	430305	1476460	4.1
P4	430703	1475000	4.1
P5	431200	1473210	4.5
P6	432153	1470870	4.1
P7	432103	1469970	4.4
P8	430315	1470220	2.7
P9	431096	1470880	2.8
P10	429960	1473770	0.6
P11	429946	1475040	0.6
P12	429385	1474070	0.6
P13	430153	1472450	1.5
P14	431654	1471340	1.5

9.3 Storm Wave Model results

The results obtained from MIKE 21 SW Storm Wave simulations for 2016 Vardah cyclone is presented in Figure 9-4. The significant wave height at the entrance of the existing port

(Baseline) is presented in Figure 9-6. For the rest of the cyclones, it is presented in Table 9-3. The maximum wave height estimated at Kattupalli port due to 2016 Vardah cyclone is 5.15m.

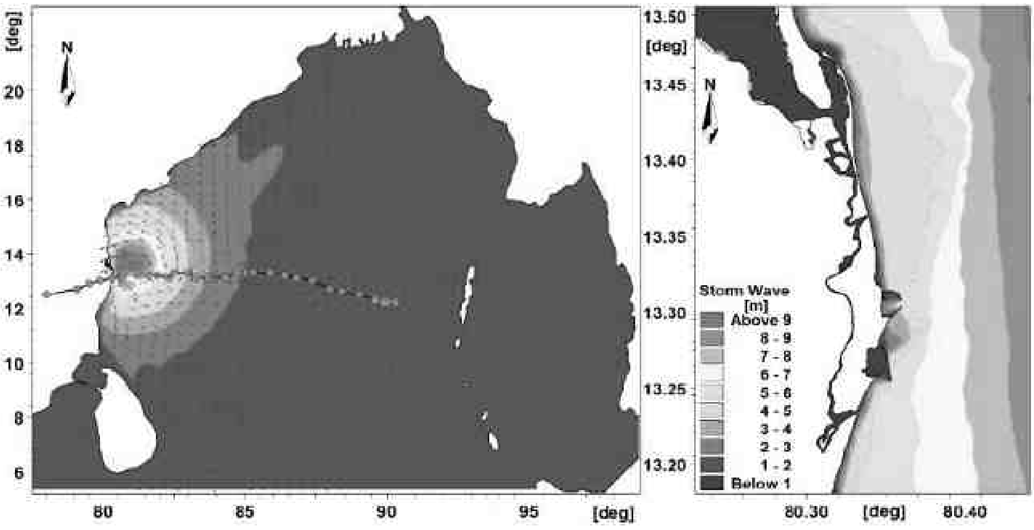


Figure 9-8 Simulated storm wave during 2016 Vardah cyclone (Baseline)

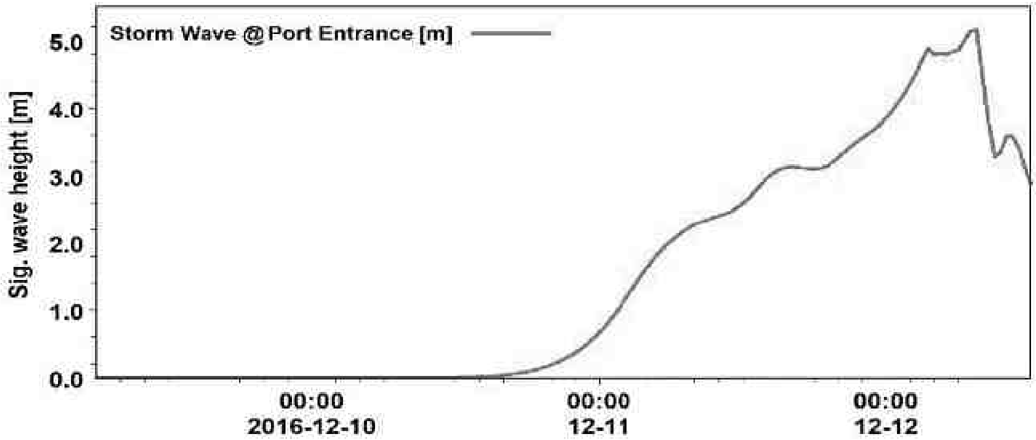


Figure 9-9 Wave height at the entrance of the existing port during 2016 Vardah cyclone

Table 9-3 Maximum storm wave at existing port entrance for the modelled cyclones

S. No	Month & year	V max m/s	Nature of the cyclone	Storm wave at port entrance [m]
1	November-1979	15	DD	0.72
2	October-1982	28	SCS	2.25
3	November-1984	59	VSCS	4.40
4	December-1985	18	CS	1.74
5	October-1994	31	SCS	3.76
6	November-1996	33	VSCS	2.84
7	November-2010	31	SCS	2.52
8	October-2012	23	CS	2.48
9	December-2016 (Vardah cyclone)	36	VSCS	5.15

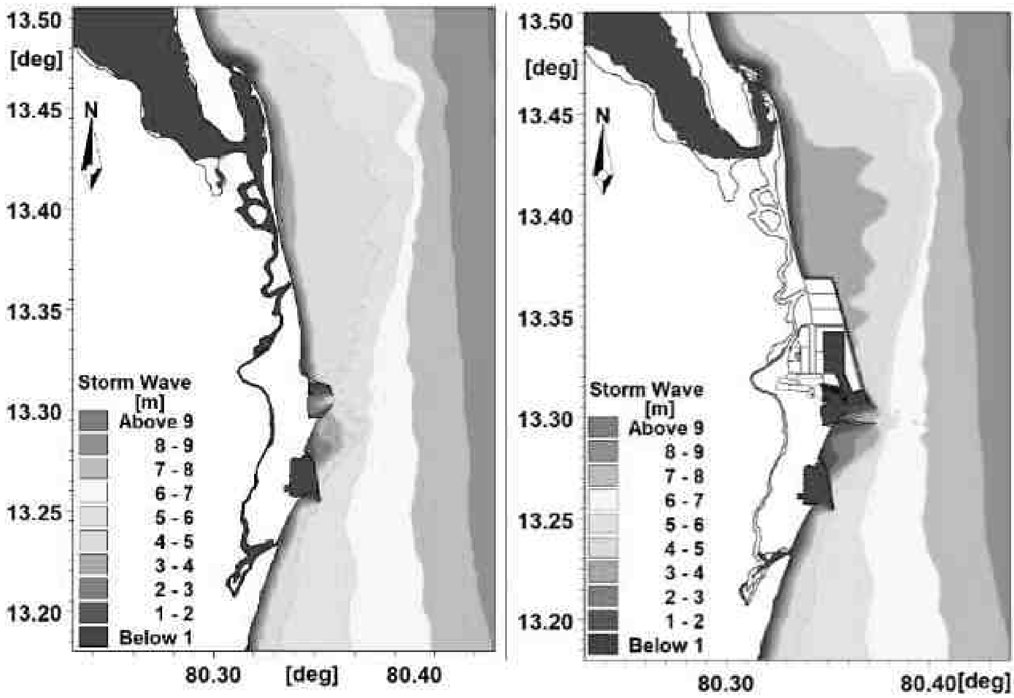


Figure 9-10 Storm waves during 2016 Vardah cyclone (Baseline and Layout)

The hydrodynamic and spectral wave modules of DHI's MIKE 21 FM modelling system have been applied in a coupled fashion to compute the surge levels and wave heights along the coastal stretch of Kattupalli for the nine historical cyclone conditions.

Model results are presented in the form of two-dimensional maps of maximum surge level and significant wave height calculated over the course of each of the historical storms. Time series of storm surge, storm current and significant wave height are extracted from the model results at three selected positions along the study area and presented graphically.

The above results indicated that the proposed master plan development has not caused any changes to submerged shoals in terms of surge height and storm wave and these shoals are still acting as barrier in protecting the coast during cyclone events.

10 Drainage Pattern Study

This chapter explains about the drainage pattern of Ennore Creek, Pulicat lake and Buckingham Canal. The location of these area is shown in Figure 10-1. The overland drainage pattern is based on the topography of an area. A watershed boundary defines the drainage or catchment areas that contribute to a specified outlet channel, such as a creek or river (Bhola, 2012). Drainage morphometry provides quantitative description of the drainage system. Linear, areal and relief aspects of morphometric parameters are analysed and shown in Table 10-1, which is helpful to know about the channel networks, slope, flow direction, drainage pattern, runoff and flooding characteristics of the Ennore Creek and Pulicat lake.

Ennore Creek

The total area of the Ennore creek is 2.25 km^2 which is 20 km North of Chennai. The creek is nearly 400 m wide and is elongated in northeast-southwest direction. It’s north-south channels connecting to the Pulicat Lake in the north and to the Kosasthalaiyar River in the south. The Kosasthalaiyar backwater channel, which connects the creek to Pulicat, is marked as Kosasthalaiyar in the Survey of India (SoI) Toposheet (Shanthi & Gajendran, 2009).

Contribution of total flow to Ennore Creek is from Kosasthalaiyar river (surplus from Poondi reservoir), surplus water from Redhills, industries effluent, outflow from Pulicat lake (through Kosasthalaiyar backwater channel), few canal outflows (such as Kuruvimedu Kalvai) on the west, discharge from north Buckingham canal and inflow from the sea during tides. Figure 10-2 shows the Ennore creek and its inflow.

Pulicat Lake

Pulicat lake is the second largest brackish water body in India. It acts as a barrier to retain flood water during riverine and coastal floods. The seasonal rivers that flow into Pulicat lake are Araniyar at the southern tip, Gummidipoondi in the middle, the Kalangi River at the northwest, and few smaller streams. There are two openings in the Pulicat lake which exchange water to the sea, zone at south near Pulicat and another smaller one which remains often closed at north of Sriharikota boundary. The southern mouth opens during northeast monsoon (November- January) when the freshwater flow into the lake is large (Indomer Coastal Hydraulics (P) Ltd., 2018) and one outlet at the south which drains water to the Kosasthalaiyar backwater channel. The North Buckingham canal passes through Pulicat lake and it reaches the creek. Figure 10-2 shows details of the Pulicat lake.

Buckingham Canal

The Buckingham canal which runs along the east coast from Kakinada in the Andhra Pradesh up to Marakanam near Pondicherry in the south. It flows through the Pulicat lake and emerges at its southern end near the Pulicat Town. The canal is designed in such a way to collect water from various large and small rivers, and artificial canals along its path. In case of heavy rain in the region between Creek and Pulicat, it acts as the flood observer. The flood water received in Kosasthalaiyar river is drained into the sea through Ennore creek. The rest of the flood water after discharging through the Ennore creek, flows along this segment towards the Pulicat lake. Therefore, the backwater channel of Kosasthalaiyar river and the Buckingham Canal running side by side plays a limited role in receiving the flood and discharging into sea (Indomer Coastal Hydraulics (P) Ltd., 2018).

Figure 10-1 Location of study area

Table 10-1 Morphological parameters of River Basins

Parameters of different aspects	Reference	Araniyar (Ends at Kosasthalaiyar backwater)	Kosasthalaiyar (Ends at Creek)	Pulicat lake
Area (km^2)		1610.70	3832.70	3287.70
Perimeter (km)		360.54	498.16	371.47
Basin length (km)		91.76	117.88	76.23
Longest flow length (km)		136.17	175.74	125.21
Total Length L (km)		1717.55	3841.65	4025.70
Effective Basin width, Rb		11.83	21.81	26.26
Stream order		6	7	6
Form factor, Rf	Horton (1945)	0.09	0.12	0.21
Shape factor Rs		11.51	8.06	4.77
Circularity ratio Rc	Strahler (1964)	0.16	0.19	0.30
Elongation ratio Re	Schumn(1956)	0.33	0.40	0.52
Drainage Density (1/km)	Horton (1945)	1.07	1.00	1.22
Relief		365.00	438.00	259.00
Relief ratio (%)	Schumm(1963)	2.68	2.49	2.07
Ruggedness number, Rn		342.29	436.98	211.52

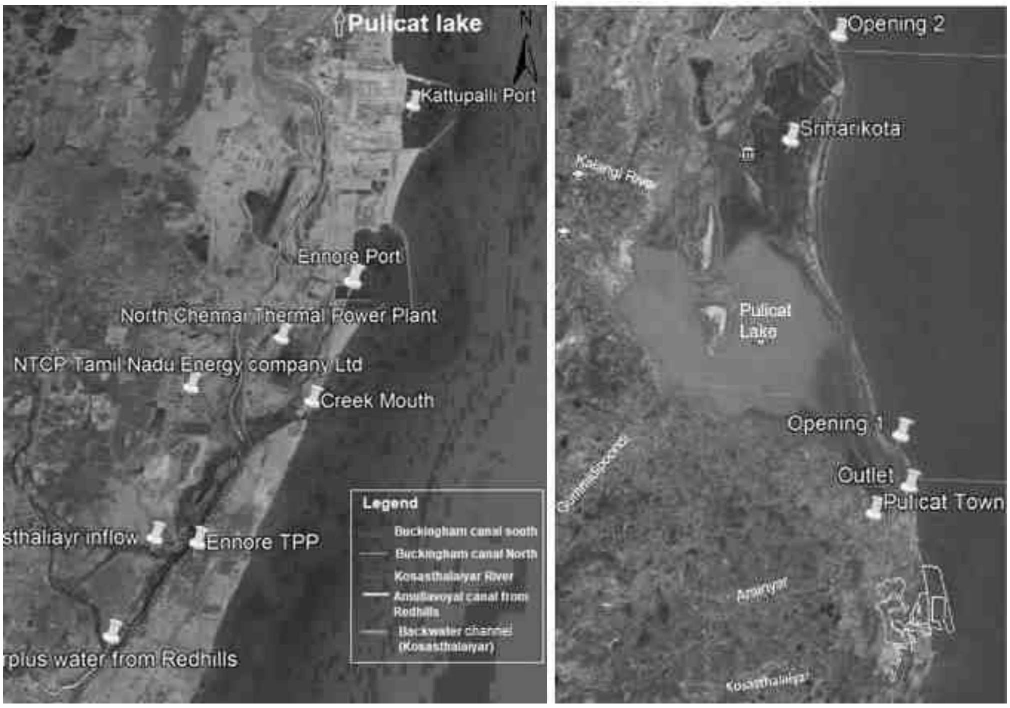


Figure 10-2 Flow into Ennore Creek (Left), and Flow into Pulicat Lake (Right)

10.1 Methodology

Shuttle Radar Topographic Mission's (SRTM) Digital Elevation Model (DEM) of 30 m resolution is obtained for the three river basin areas and CARTOSAT DEM of 10 m is acquired from Ennore creek to Pulicat creek. These two datasets are processed using ArcGIS. The processed 30 m DEM is used for the evaluation of linear, areal and relief aspects of morphometric parameter. Figure 10-3 shows the workflow of the drainage pattern study and the morphometric parameters of the three basins are presented in Table 10-1.

The surface elevation of the entire basin varies from 0 to 1035m (with respect to MSL) which is shown in Figure 10-4 and the highest elevation within the Kattupalli port boundary is 16m (refer Figure 10-8).

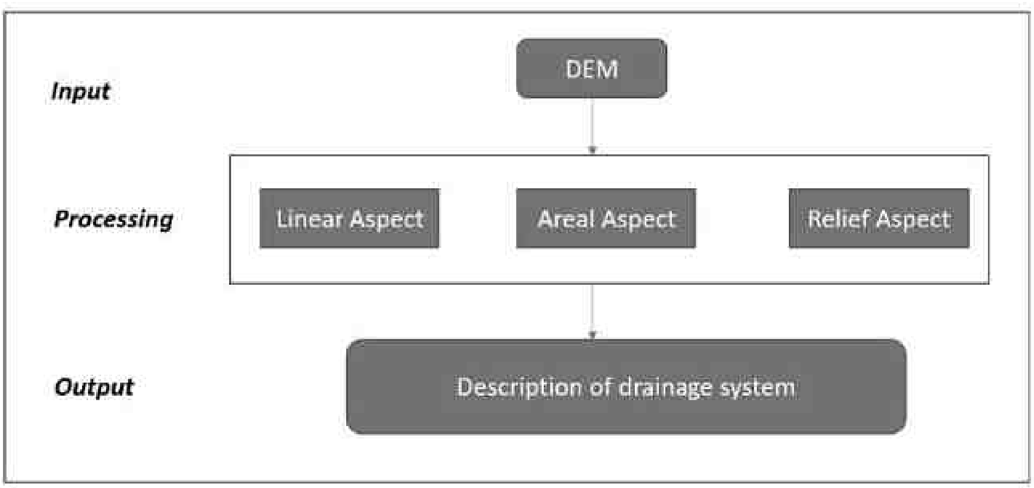


Figure 10-3 Workflow for drainage pattern study

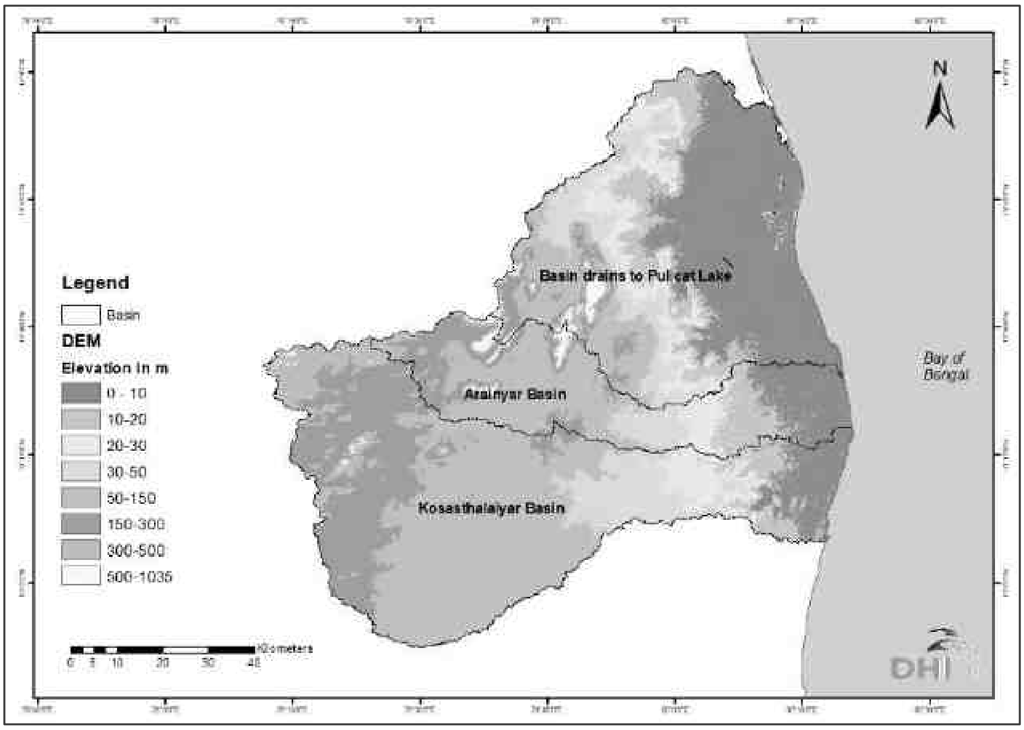


Figure 10-4 Topography of Kosasthalaiyar basin, Araniyar basin and Pulicat Lake basin

Strahler method of stream ordering is a method for classifying the types of streams based on their number of tributaries. The smallest tributaries are referred to as first-order streams, while the largest river is referred to as higher order, as illustrated in Figure 10-5.

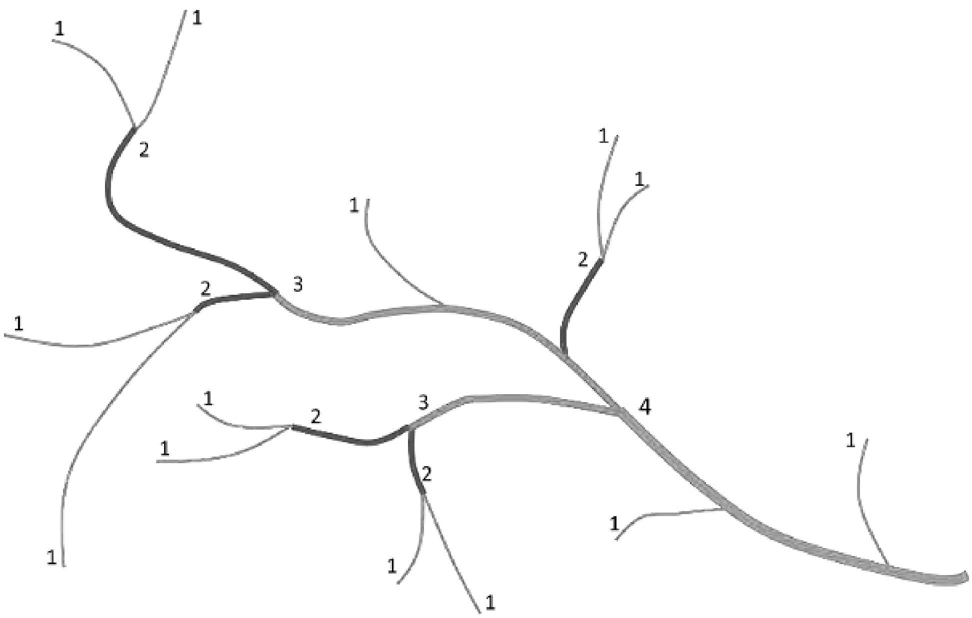


Figure 10-5 Strahler method of stream ordering

Drainage density (Dd) is the expression of the closeness of spacing of channel within a basin as per Horton (1945). Dd is measured as the ratio of the total length of streams irrespective of stream order to the per unit area of the basin. Drainage density and stream order, of the Kosasthalaiyar basin, Araniyar basin and Pulicat lake basin are shown in Figure 10-6 and Figure 10-7.

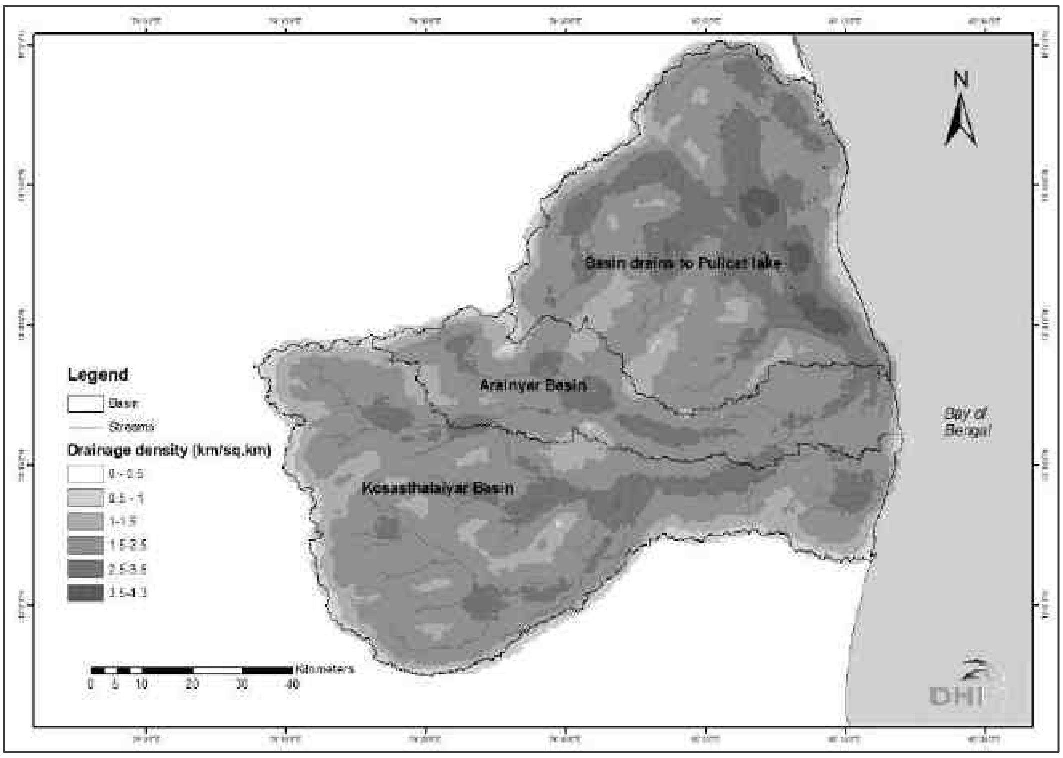


Figure 10-6 Drainage density map of the study area

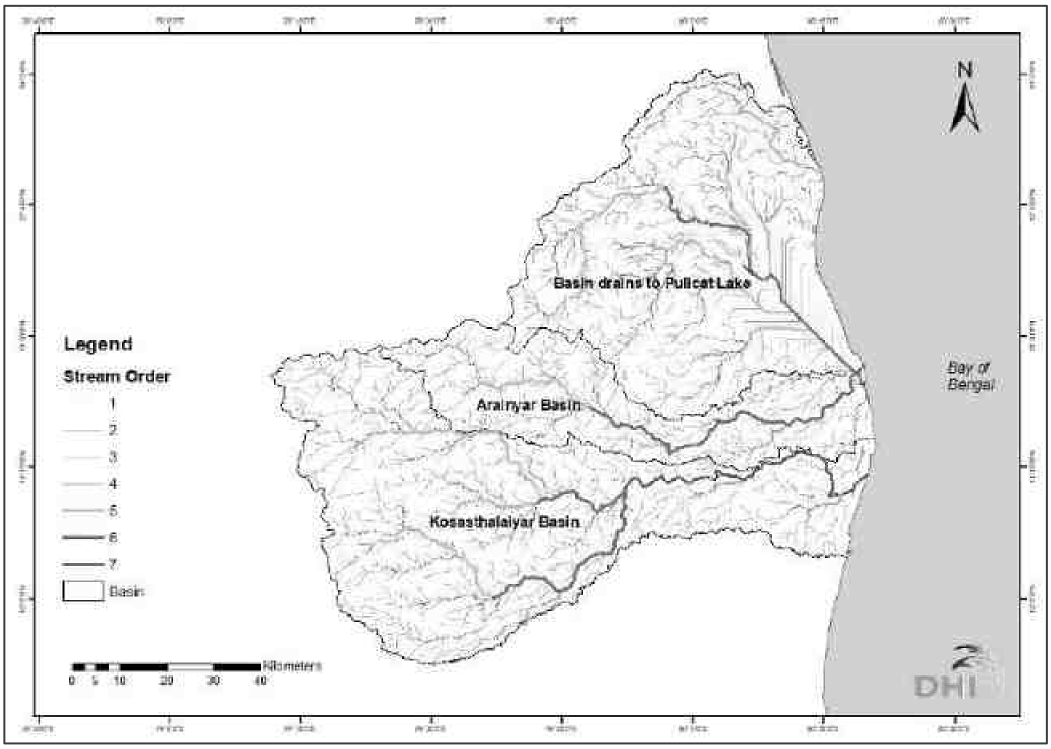


Figure 10-7 Stream order of the study area

Figure 10-8 shows the elevation, stream orders and drainage density around the Master plan of the Kattupalli port area.

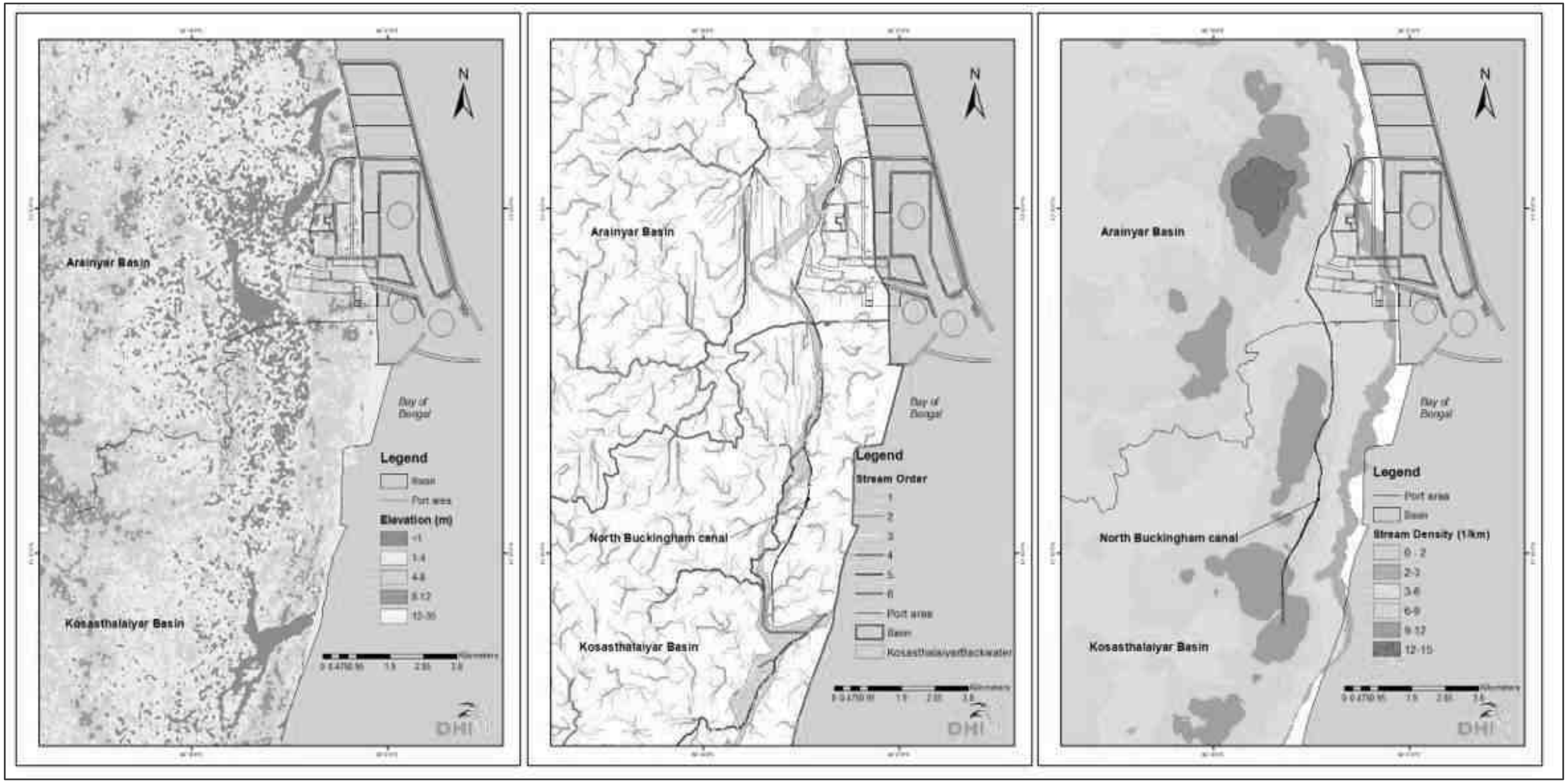


Figure 10-8 CARTOSAT Digital Elevation Model, stream order and drainage density of the port area

10.2 Inference

Kosasthalaiyar basin is designated as the seventh stream order; Araniyar and Pulicat basin (basin contributing to Pulicat) as sixth order. Small stream orders such as first and second are predominate in the vicinity of the Kattupalli port area.

There are 4 types of drainage patterns based on their flowing pattern namely dendritic, trellis, radial and rectangular. The study reveals that the Kosasthalaiyar and Araniyar basin exhibits dendritic pattern of drainage.

The literature states that elongation ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9~0.10), oval (0.8~0.9), less elongated (0.7~0.8), elongated (0.5~0.7), and more elongated (less than 0.5).

The three study area basins are elongated in nature. The smaller value of form factor in Araniyar and Kosasthalaiyar basin indicates that it is more elongated watershed and have flow for longer duration. As the runoff is more for the one with the smallest circulatory ratio, Pulicat basin has quick runoff.

The drainage density is estimated to be nearer to 1 for all basins, which indicate the existence of permeable rock and soil, and vegetation. The calculated value indicates Pulicat basin might have some erosion compared to others. The basin relief indicates runoff, sediment transport and overall steepness of the drainage basin. The relief ratio of the river basin indicates that the discharge capability of watershed is high.

11 Flood Model Study

The scope of the flood modelling study is to analyze flood events and develop flood protection measures or flood mitigation strategies to minimize significant destruction of infrastructure.

Two types of mathematical models are generally applied to the analysis of the flows and morphology of a river. These are one-dimensional (1D), along the reach of the *river*, and two-dimensional (2D) in *plain*. While the two-dimensional model has the advantage that it can predict the flow paths in the floodplain, it takes more computational time. A coupled 1D & 2D model is applied here to understand the hydraulic behaviour of the Kosathalaiyar River, Ennore Creek and their floodplains, to determine the flood paths along the proposed Kattupalli port expansion area.

The baseline scenario represents the current condition, and the future scenario represents proposed expansion of Kattupalli port with increase in the ground elevation. These two scenarios are simulated for peak flood event combined with tidal variations in the vicinity of project area.

The following sections of this chapter describe the methodology and process adopted to set up the baseline model, and the results of the simulation.

11.1 Methodology

The modelling of Ennore creek, Kosasthalaiyar river, its tributary and their floodplains are performed using DHI's in-house software package, MIKE FLOOD.

MIKE FLOOD consists of a coupled 1D model called MIKE HYDRO RIVER and a 2D model called MIKE 21 FM. The detailed procedure of modelling is illustrated in Figure 11-1.

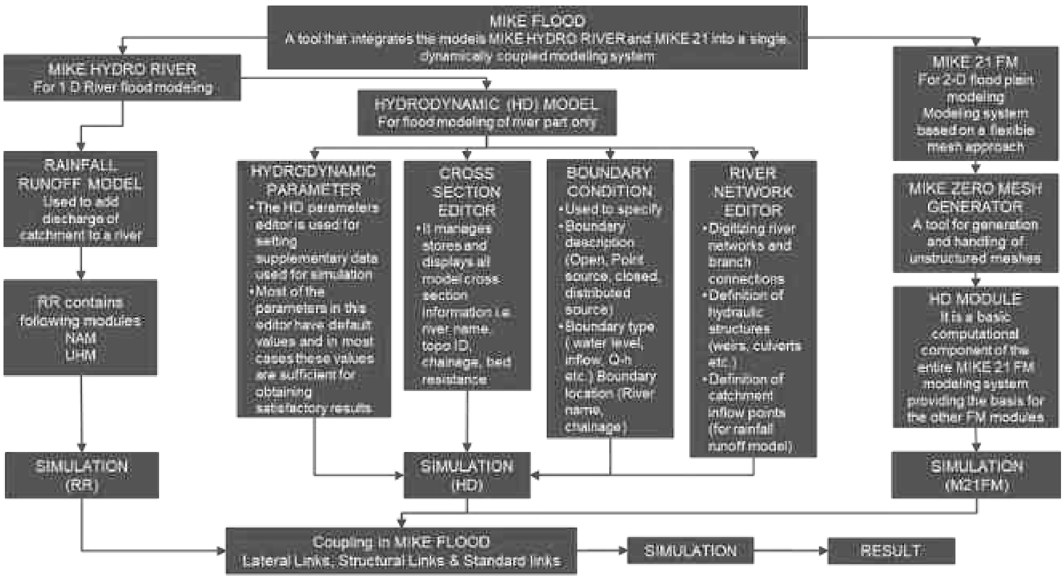


Figure 11-1 Methodology for flood modelling

11.2 1D River Model

MIKE Hydro River is a model system for one-dimensional (1D) networks such as river and channel networks. The model solves the one-dimensional shallow water equations (Saint

Venant equations). Inputs for the one-dimensional model include rainfall, cross-sections in rivers and channels, upstream- and downstream boundary conditions (water level or discharge time series) and structures. The output of the model gives the details about the water level, velocity, and discharge at selected points in the network.

11.2.1 Data collection

The primary data required for the 1D model are:

- **Rainfall details** – By applying statistical analysis on rainfall data collected over a long duration (DHI Library), the rainfall pattern can be analysed, and the intensity and duration of high return period events can be computed. This rainfall data is also useful for modelling/computing the discharge from the catchment to the river for a particular rainfall event. In this model we use the observed rainfall from November-December 2015 as this rainfall was determined to be a very rare 100-year rainfall.
- **River network** – obtained from the drainage pattern study (Chapter 2)
- **River cross sections** – are obtained from Digital Elevation Models as described in the following sections. A 10 m DEM CARTOSAT DEM was purchased from National Remote Sensing Center (NRSC) used for the areas close to the port, and a 30m SRTM DEM was used for all the river basin areas.
- **Tide** – Tide data corresponding to the extreme flood event of 2015 is downloaded from Chennai port, the nearest C-MAP station and used as the tidal boundary.

11.2.2 Model Setup

The model setup of Kosasthalaiyar River and Ennore creek is developed using MIKE HYDRO RIVER (One dimensional) to simulate flow and water level along its length. The key components the hydraulic model is:

- River alignment (.shp format)
- River cross sections at various chainages (surveyed cross sections for baseline, and designed cross sections for proposed scenarios)
- Boundary conditions (a) discharge entering the rivers and (b) tidal water level at the mouth
- Roughness coefficient

11.2.2.1 River network and cross sections

The river network is setup using the river drainage patterns of Gummidipoondi, Araniyar, and Kosasthalaiyar rivers. These rivers are selected for the modelling since they all drain into the sea via Ennore Creek and therefore can impact flooding around the port area. Buckingham canal has also been included starting from the emergence of the canal near the outflow point of Pulicat lake until the confluence of the canal with Cooum river at the southern boundary of the model. Figure 11-2 is screenshot of the model domain showing the network.

Gummidipoondi River drains into Pulicat Lake. Araniyar river drains into the southern end of Pulicat lake and joins a stream which connects Pulicat Lake with Ennore Creek. The port lies beside this stream and this stream is crucial to the flood scenario around the port area. Buckingham canal flows parallel to this stream (between the stream and the coast) until Ennore Creek where it merges with the sea. South of the creek, Buckingham canal re-emerges from Kosasthalaiyar river and continues to traverse south parallel to the coast until it meets Cooum river. The entire canal extends from Kakinada in Andhra Pradesh to Villupuram district of Tamil Nadu over a distance of 797 km.[1] Note that for the present study

[1] Long live the canal: An ambitious plan to revive the Buckingham Canal. (2017). The Hindu. Retrieved from https://www.thehindu.com/news/national/andhra-pradesh/long-live-the-canal/article19429503.ece

the extent of Buckingham canal considered in the model is pertaining to the proposed development.

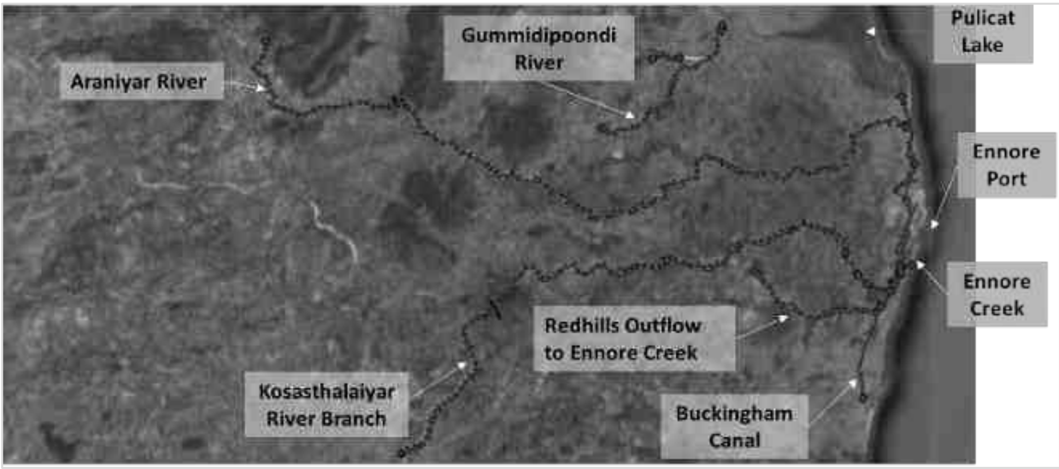


Figure 11-2 Network of major rivers nearby Ennore Creek, Kattupalli Port and Pulicat Lake

The cross sections of the river have been extracted using Digital Elevation Models (DEM) from 2 sources:

- For the area close to the creek, 10m resolution CARTOSAT DEM is purchased from National Remote Sensing Centre (NRSC) and used. The extent of the 10m CARTOSAT DEM with respect to the river network can be seen in Figure 11-3.
- For all the remaining areas, 30m SRTM DEM is obtained from United States Geological Survey (USGS) where it is publicly available for download.

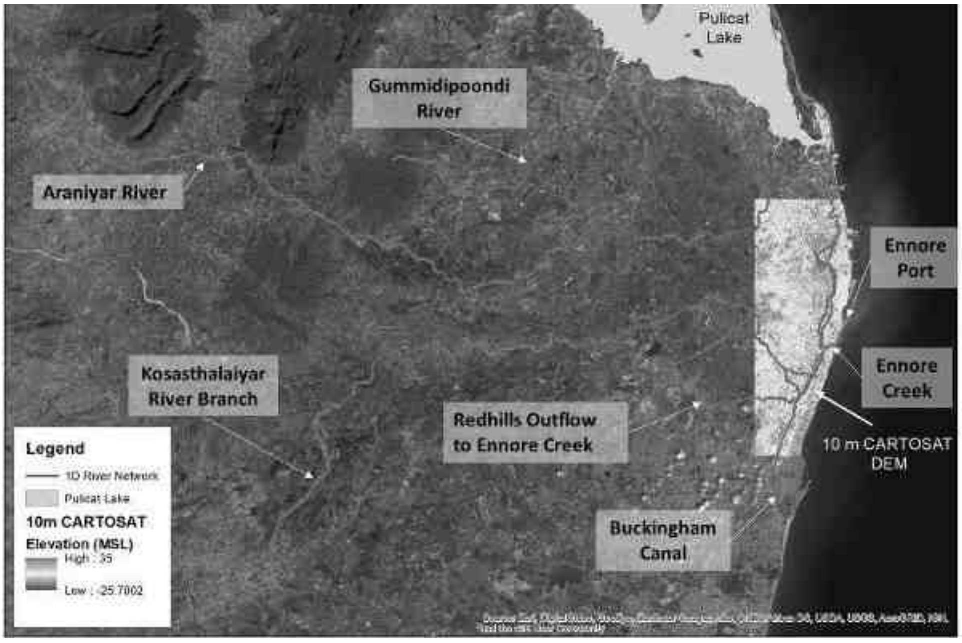


Figure 11-3 River network with 10m CARTOSAT DEM. Remaining areas with 30m SRTM DEM.

11.2.3 Boundary Conditions

Boundary conditions are applied into the river to account for dam releases along the river and catchment runoff entering the river. At the downstream end, Gummidipoondi river freely discharges into Pulicat lake. A tidal boundary is applied at Ennore creek and at the confluence of B-canal with Cooum river in the southern boundary of the model.

The excess water from Pulicat lake flows into a stream which connects Araniyar river to Ennore creek. Figure 11-4 shows the locations where the boundary conditions are applied with ID numbers from 1 to 8. Table 11-1 presents details about the boundaries marked in the figure using the same ID numbers.

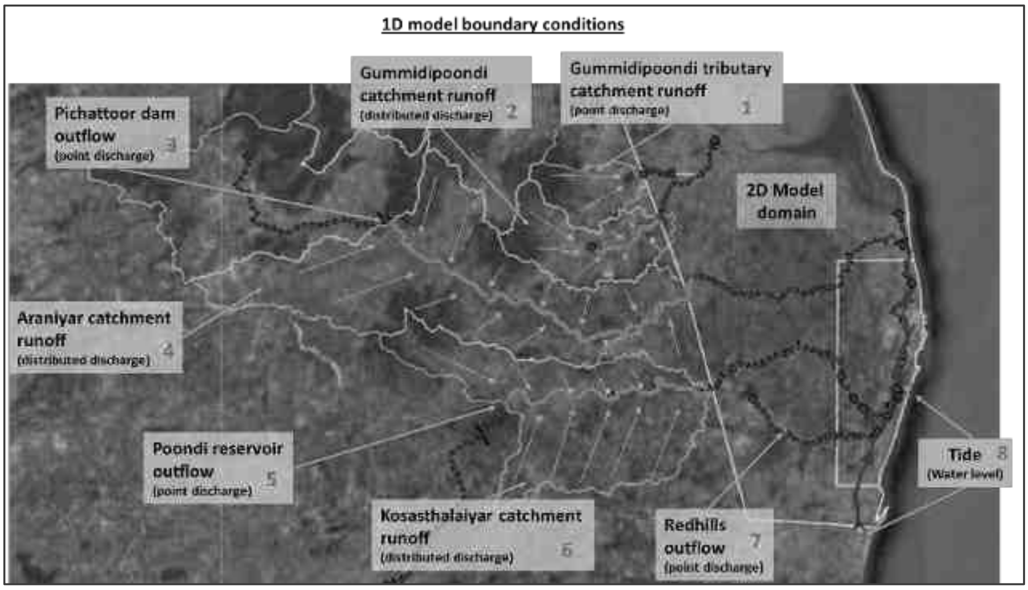


Figure 11-4 1D model boundary conditions (light blue line= flow direction; red line = distributed catchment runoff boundaries; pink polygons = sub-catchments; yellow polygon = 2D model domain)

Table 11-1 Details of boundary conditions

Boundary ID	River/Location	Description	Boundary type	Reference
1	Gummidipoondi Tributary	Catchment runoff (till 2D model domain)	Point discharge	Obtained from NAM (rainfall-runoff) model
2	Gummidipoondi river	Catchment runoff (till 2D model domain)	Distributed discharge	Obtained from NAM model
3	Araniyar	Outflow from Pichatur Dam	Point discharge	Newspaper article (Thanthi News, 2015)
4	Araniyar	Catchment runoff (downstream of reservoir till 2D model domain)	Distributed discharge	Obtained from NAM model
5	Kosasthalaiyar	Poondi Reservoir Outflow	Point discharge	DHI Library and 2015 flood assessment report (IISc, 2016)
6	Kosasthalaiyar	Catchment runoff (downstream of reservoir till 2D model domain)	Distributed discharge	Obtained from NAM model
7	Kosasthalaiyar	Redhills reservoir outflow to Ennore Creek	Point discharge	DHI Library and 2015 flood assessment report (IISc, 2016)
8	Ennore Creek	Tide	Water level	C-MAP data from MADRAS
	B-canal southern limit in model	Tide (since it is merging with Cooum river near the mouth)	Water level	C-MAP data from MADRAS

11.2.3.1 Gummidipoondi

The discharge hydrograph for Gummidipoondi river and its tributary are obtained by simulating a rainfall runoff model (NAM). The hydrographs for the tributary and main river (numbers 1 and 2 in Figure 11-4) is shown in Figure 11-5.

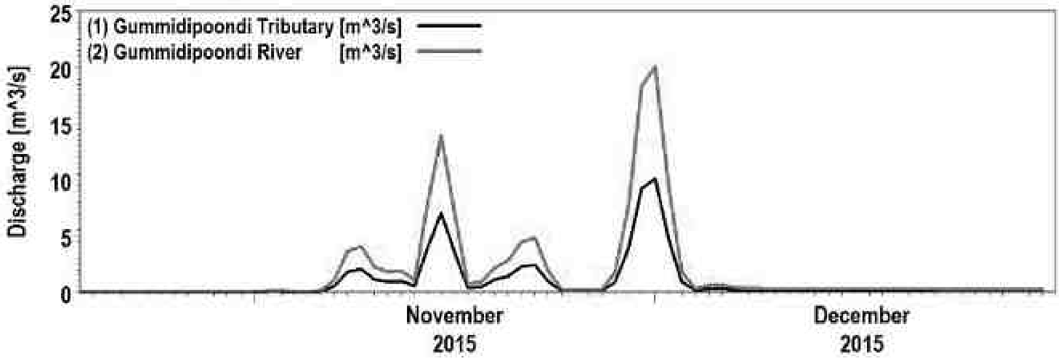


Figure 11-5 Discharge from Gummidipoondi Tributary and River catchment runoff

11.2.3.2 Araniyar River

The discharge data from Pichatur dam (boundary ID 3, Figure 11-4) for 2 days during 2015 flood are obtained from published sources (Thanthi, 2015). The normal discharge from this dam for remaining days is set to 2 m^3/s[2].

The discharge hydrograph for Arani River catchment runoff (boundary ID 4, Figure 11-4) are obtained by running a rainfall runoff model (NAM). The catchment used for the NAM model is the intermediary catchment downstream of Pichatur dam and until the 2D model domain. The two hydrographs for Arani River are shown in Figure 11-6.

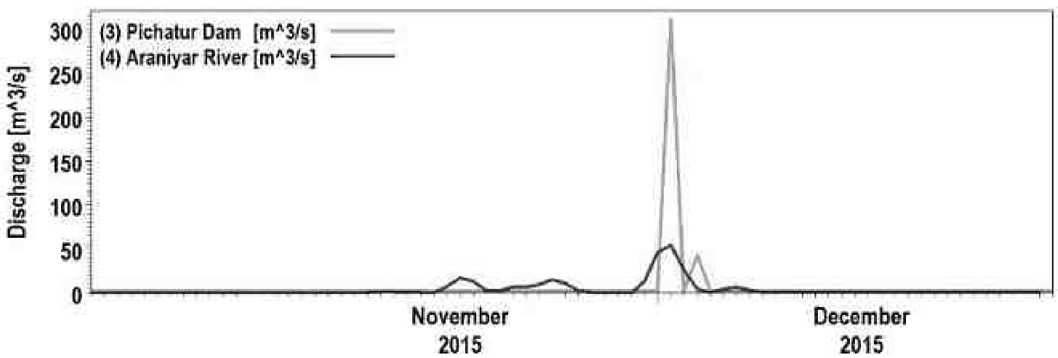


Figure 11-6 Discharge from Pichatur Dam outflow and Araniyar River catchment runoff

11.2.3.3 Kosasthalaiyar

Three boundary conditions are added into Kosasthalaiyar river:

- Poondi reservoir outflow (boundary ID 5, Figure 11-4)
- Kosasthalaiyar river catchment runoff for the intermediary catchment from downstream of Poondi till the 2D model domain (boundary ID 6, Figure 11-4).
- Redhills reservoir outflow (boundary ID 7, Figure 11-4)

[2] ARANIAR RESERVOIR PROJECT. (n.d.). Retrieved August 21, 2020, from https://irrigationap.cgg.gov.in/wrd/static/approjects/aranair.html

The three hydrographs are plotted in Figure 11-7.

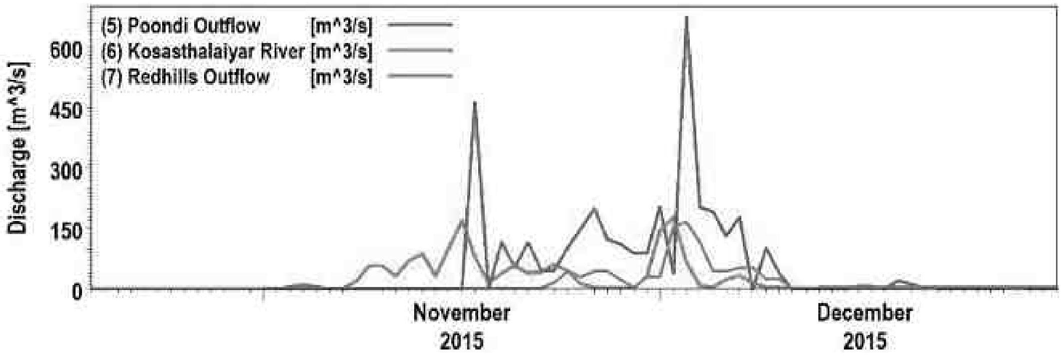


Figure 11-7 Discharge from Poondi Reservoir outflow; Kosasthalaiyar River catchment runoff and Redhills outflow to Ennore

11.2.3.4 Tide

The tidal boundary condition (marked as ID 8 in Figure 11-4) is applied at Ennore creek and Buckingham canal at the confluence with Cooum river mouth.

For this purpose, the tidal water levels from the closest C-MAP station – MADRAS – are downloaded for November and December 2015. The tidal boundary time series is as shown in Figure 11-8. The tide ranges from 0.8m to -0.45m with respect to mean sea level.

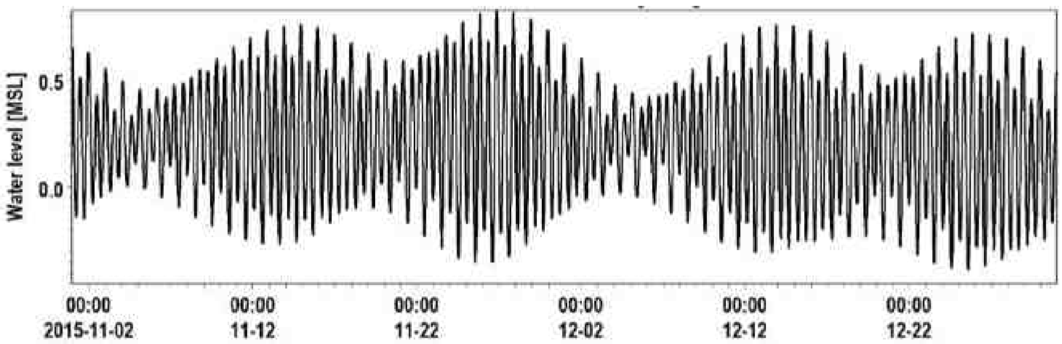


Figure 11-8 Tide data with respect to Mean Sea Level (MSL)

11.2.4 Roughness coefficient

The resistance to the flow in the river is typically estimated by calibration with the observed discharge and water level data available between the model stretch, i.e. reservoir water spread length. Since no such intermediate data is available to calibrate the model, standard values from the literature have been used.

The roughness values that have been used in the model based on the type of land-use or channel lining material are listed in Table 11-2.

Table 11-2 Roughness coefficients used in the model (USACE, 1995)

Type of channel	Manning's 'n' value	Manning's 'M' value
Natural channels with no boulders and scattered bush with weeds	0.03	33.33
Floodplains with mature row crops	0.035	28.57
Floodplains with mature field crops	0.04	25
Channel with dry rubble or riprap or stone-pitching on one side	0.022	45.45
Concrete lined channel	0.018	55.56

11.3 2D Surface Model

The 2D modelling is carried out using MIKE 21 Flow Model FM, which is a modelling software based on a flexible mesh approach. It is used for flood modelling, estimating the flood depths in the study area.

The Hydrodynamic Module used for flood modelling is based on the numerical solution of the shallow water equations - the depth-integrated incompressible Reynolds averaged Navier-Stokes equations. Thus, the model consists of continuity, momentum, temperature, salinity, and density equations. In the horizontal domain both Cartesian and spherical coordinates can be used.

The spatial discretization of the primitive equations is performed using a cell centred finite volume method. The spatial domain is discretized by subdivision of the continuum into non-overlapping element/cells. In the horizontal plane an unstructured grid is used comprising of triangles or quadrilateral element.

An approximate Riemann solver is used for computation of the convective fluxes, which makes it possible to handle discontinuous solutions. For the time integration an explicit scheme is used.

11.3.1 Model setup

The 2D model setup mainly consists of a Digital Elevation Model (DEM) in the study area. 10m CARTOSAT DEM from NRSC are used for 239 km^2 in the vicinity of the port area (refer Figure 11-3 for extent of DEM) and 30m SRTM DEM from USGS is used for the remaining area.

A flexible triangular, computational mesh is created for the model domain, which is shown in Figure 11-9.

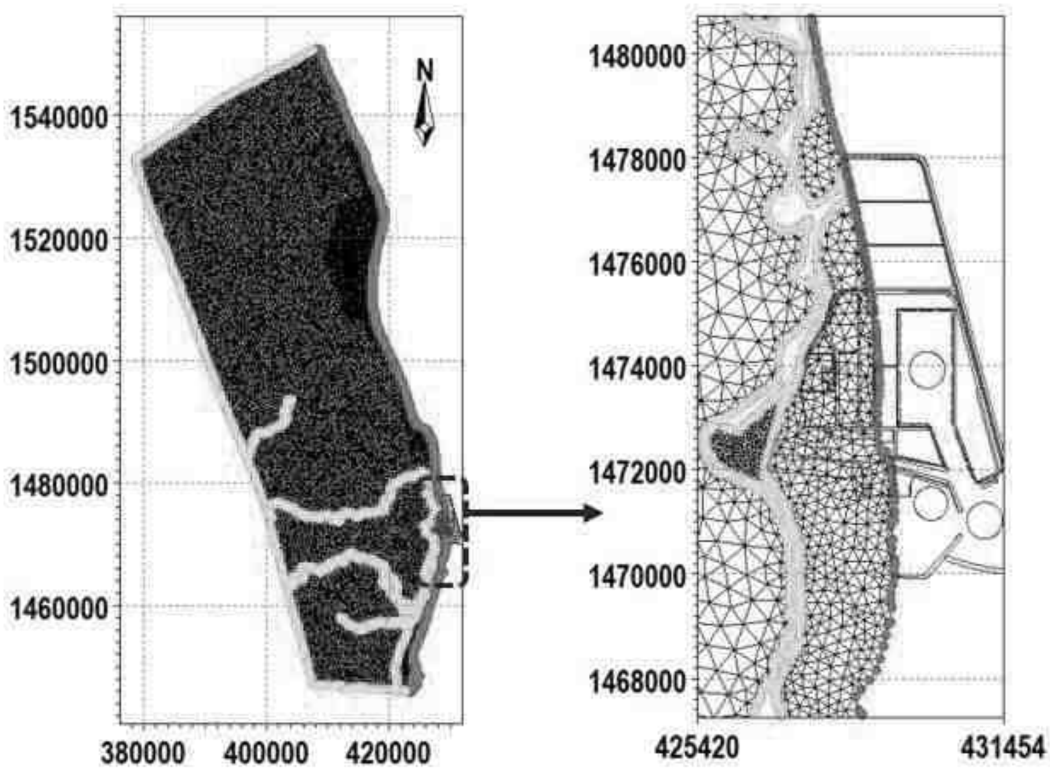


Figure 11-9 Left: Flexible mesh used for model domain, Right: Zoom-in mesh in the port area

11.3.2 Initial conditions and boundary conditions

The Surface Elevations (SE) with 0m total water depth or dry throughout the model domain is considered as the initial condition for the hydrodynamic flow model which is shown in Figure 11-10. The Land boundary condition on the north, south and west side of the model domain assumes zero flow condition. The uniform Manning number of 28.57 is used for the entire domain (refer Table 11-2).

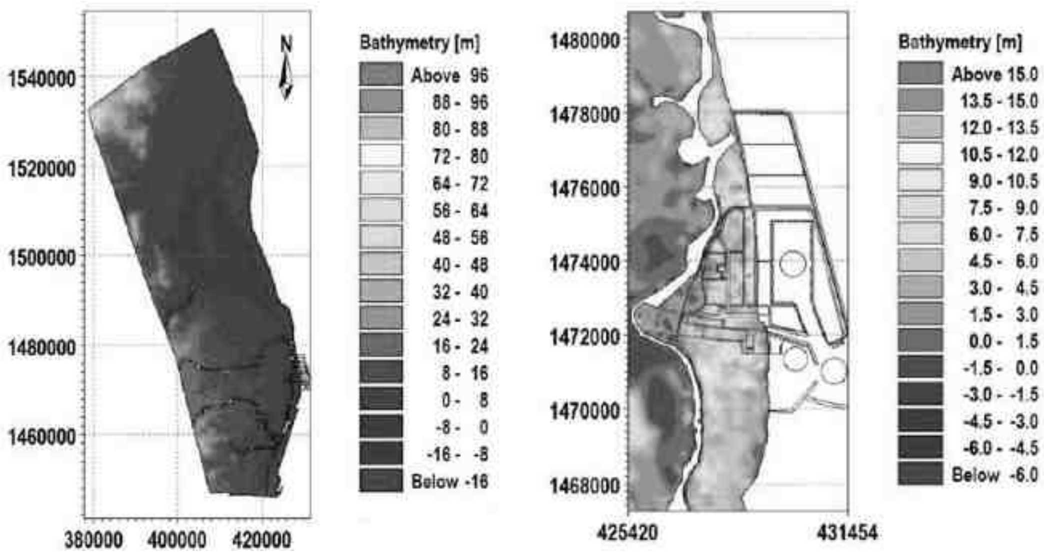


Figure 11-10 Surface Elevation (SE) as the initial condition for the Hydrodynamic flow model

As the storm intensity of 2015 flood event is greater than 24 hour-100-year return period storm intensity, modelling is carried out for 2015 flood event to estimate the maximum flooding depths in the port area. Figure 11-11 shows the daily rainfall data.

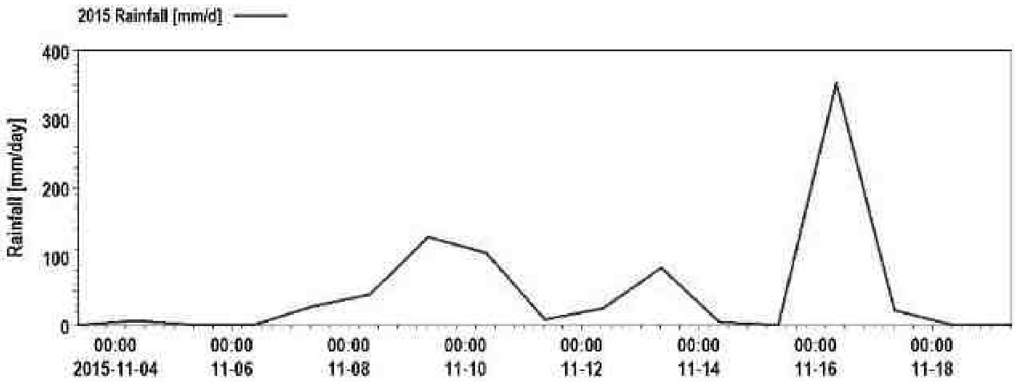


Figure 11-11 Rainfall applied on the model domain -2015 flood event

11.4 Coupled Flood Model (1D & 2D)

MIKE FLOOD is a product that integrates the 1-dimensional model MIKE HYDRO River, MIKE 11, MIKE URBAN (MOUSE) and the 2-dimensional model MIKE 21 into a single, dynamically coupled modelling system.

Using a coupled approach enables the best features of both the 1-dimensional and the 2-dimensional models to be utilised, whilst at the same time avoiding many of the limitations of resolution and accuracy encountered when using 1D or 2D separately.

In the present case, MIKE FLOOD is used to couple the 1D MIKE HYDRO RIVER and the 2D MIKE 21FM models.

11.4.1 Model Setup

The 1D model (MIKE HYDRO River) and the 2D model (MIKE 21 FM) are coupled using MIKE FLOOD. MIKE FLOOD has several types of links to couple the 1D and 2D.

In this case, lateral links are used to couple the left and right banks of the 1D river to the 2D surface. A lateral link allows a string of MIKE 21 cells/elements to be laterally linked to a given reach in MIKE HYDRO River, either a section of a branch or an entire branch. Flow through the lateral link is calculated using a structure (weir) equation.

This type of link is particularly useful for simulating overflow from a river channel onto a flood plain. Figure 11-12 shows the application of lateral links.

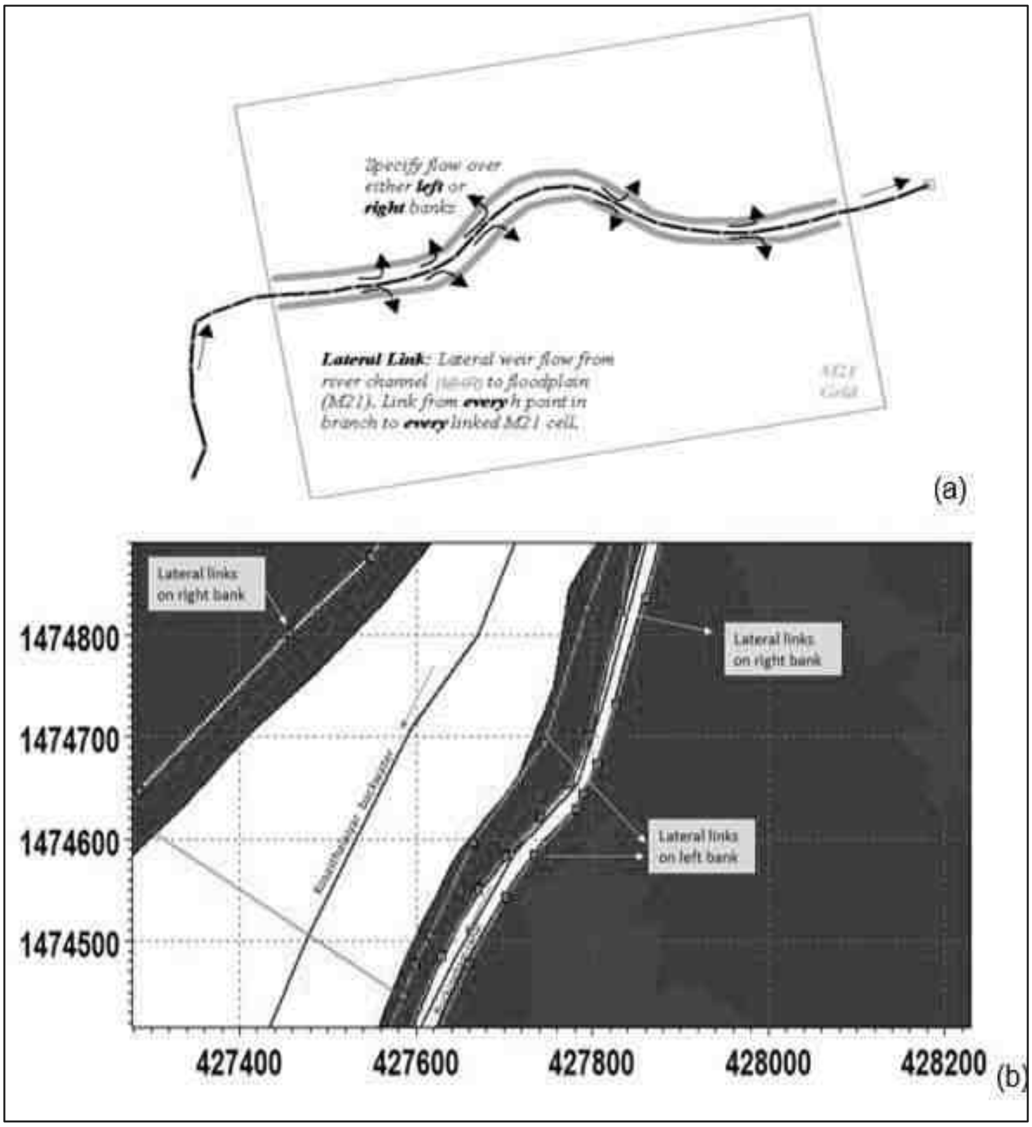


Figure 11-12 a) Application of lateral links b) Lateral links of zoomed area near port

Figure 11-13 shows the entire MIKE Flood model extent and sub-set of study area developed using two way coupling and the lateral links used to couple the 1D and 2D.

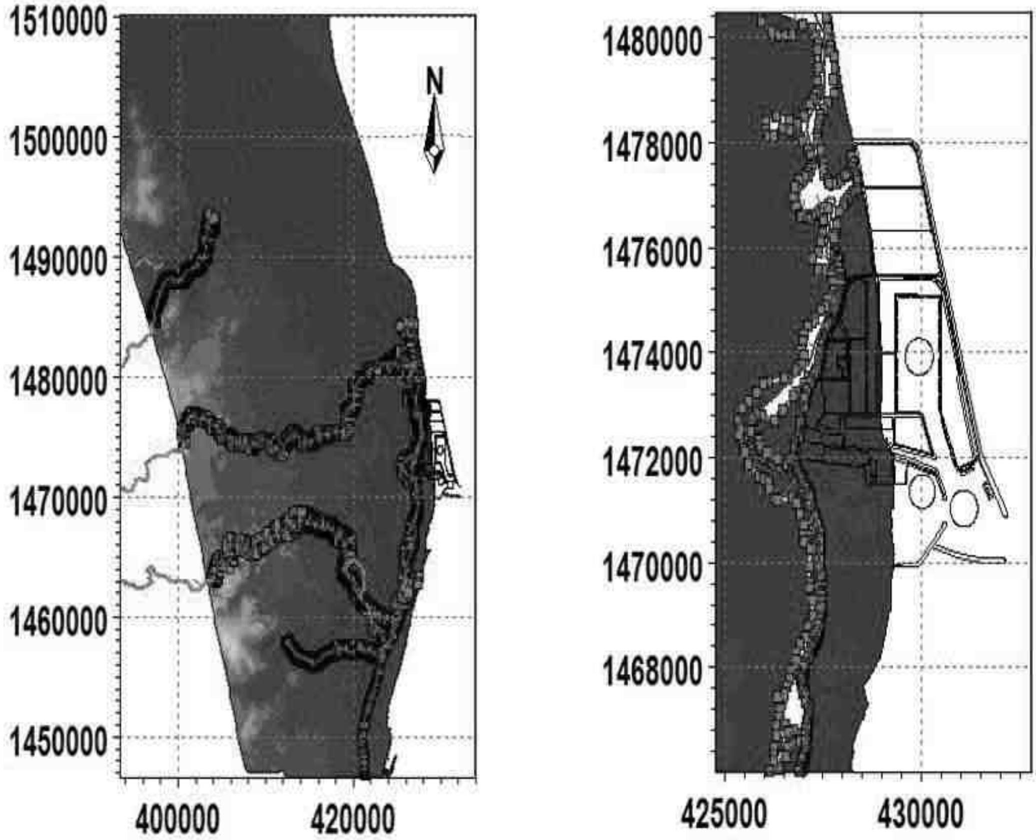


Figure 11-13 MIKE FLOOD two way coupling setup showing lateral links, Left: Entire Model domain; Right: Zoomed to port area

11.4.2 Model Scenarios

The flood model is carried out for baseline condition and future scenario for 4 days from 14 Nov to 18 Nov 2015. Baseline model is performed by considering the existing ground condition and future scenario includes the development activities in the port area. The model setup for both is same. Bathymetry for the 2D model is updated to incorporate the port plan as provided by the client for future scenario.

Baseline

CARTOSAT DEM values are used as surface elevation in the port area. The maximum elevation in the port area is 15.78 m. Kosasthalaiyar backwater and north Buckingham canal passes through this area. The flood plain on the left bank (western part of the Port) has lower elevation compared to the right bank.

Future scenario

The future scenario considers the situation where the land elevation in the port backup area is raised to +4.4 m with respect to MSL, as per the requirement of the client. The comparison of surface elevation for baseline condition and future scenario is shown in Figure 11-14.

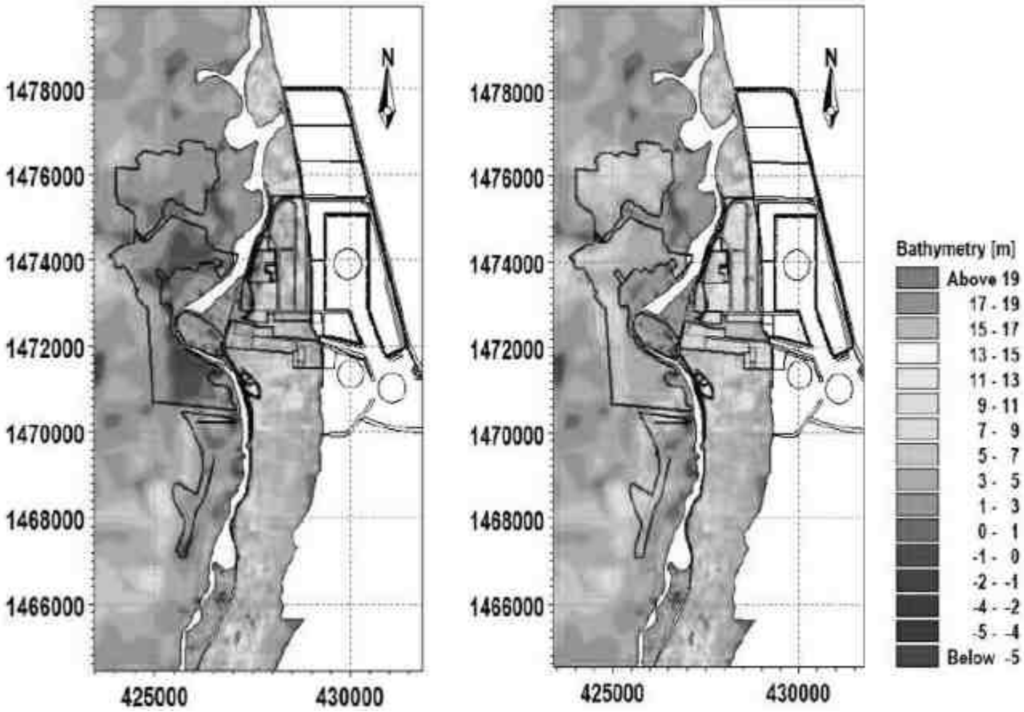


Figure 11-14 Surface elevation in the port area for baseline and future scenario

11.5 Coupled Model Results

The coupled (1D & 2D) model results provide the inundation depth and extent of flood in the port area, and flood level in the river. High flood level in the river means that the water continues to flow out of the river which induces flooding in the flood plain.

Baseline Scenario

The simulated maximum water level profile i.e., High Flood Level (HFL) along the Kosasthalaiyar backwater river and Buckingham canal in the port area is shown in Figure 11-15 for baseline condition. This shows that the water level in the channel is higher than the existing bank level. When this occurs, the flood water from the river will flow laterally onto the floodplain following the gradient of the DEM and result in inundation of the floodplain.

Note: It is assumed that flow direction is from Pulicat lake to Ennore creek. Dotted black line = left riverbank; Solid black line = right bank; Blue shaded area = maximum water level condition

The inundation depth and current speed in the vicinity of the port area induced by the 2015 flood event with baseline configuration is shown in Figure 11-16 and Figure 11-17. It is observed from the model that the maximum water depth is 3.5 m near the meandering area of the Kosasthalaiyar river where multipurpose area for the port is expected. The west side of the port (right bank of the river) is heavily flooded, where depth is varying between 1.8 m and 3.5 m. Because of the existing high ground elevation, flooding has minimal impact on the eastern part of the port (left bank of the river) compared to other area. The current speeds are low in this area, less than 0.2 m/s, presumably due to the flat terrain.

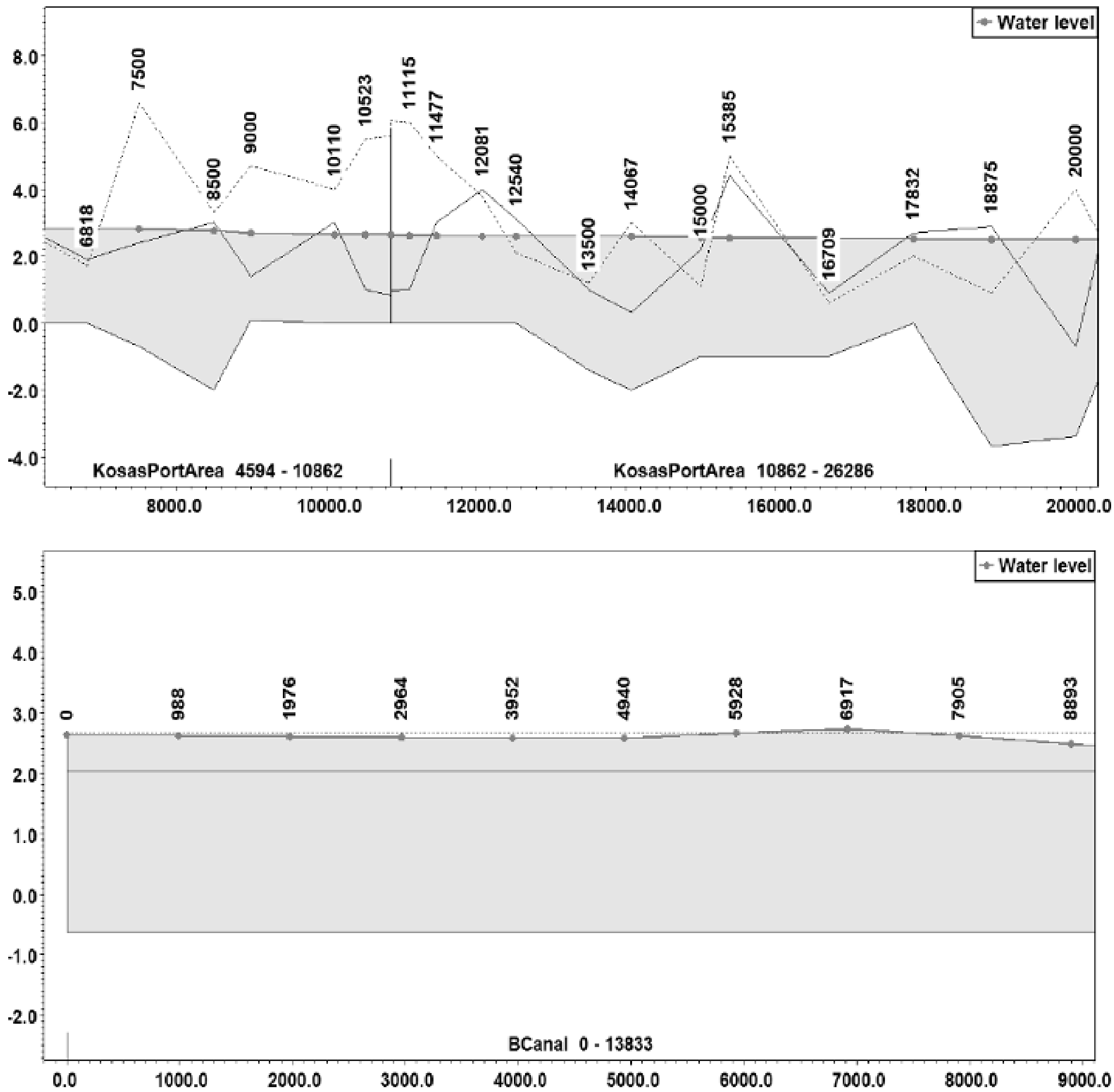


Figure 11-15 Water level profile of Kosasthalaiyar and Buckingham canal-Baseline condition

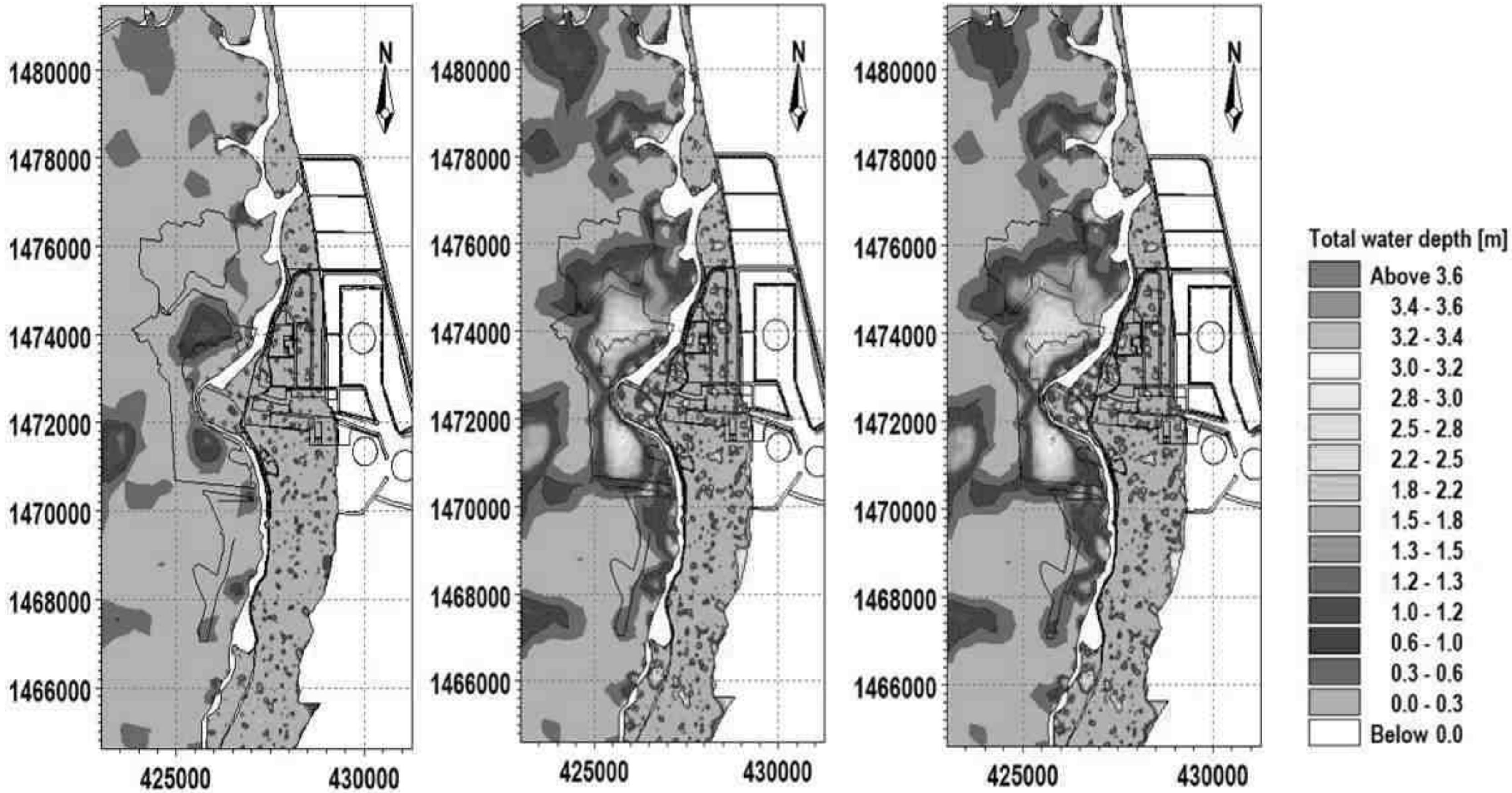


Figure 11-16 Flood inundation depth from 16 Nov 2015 to 18 Nov 2015 - Baseline condition

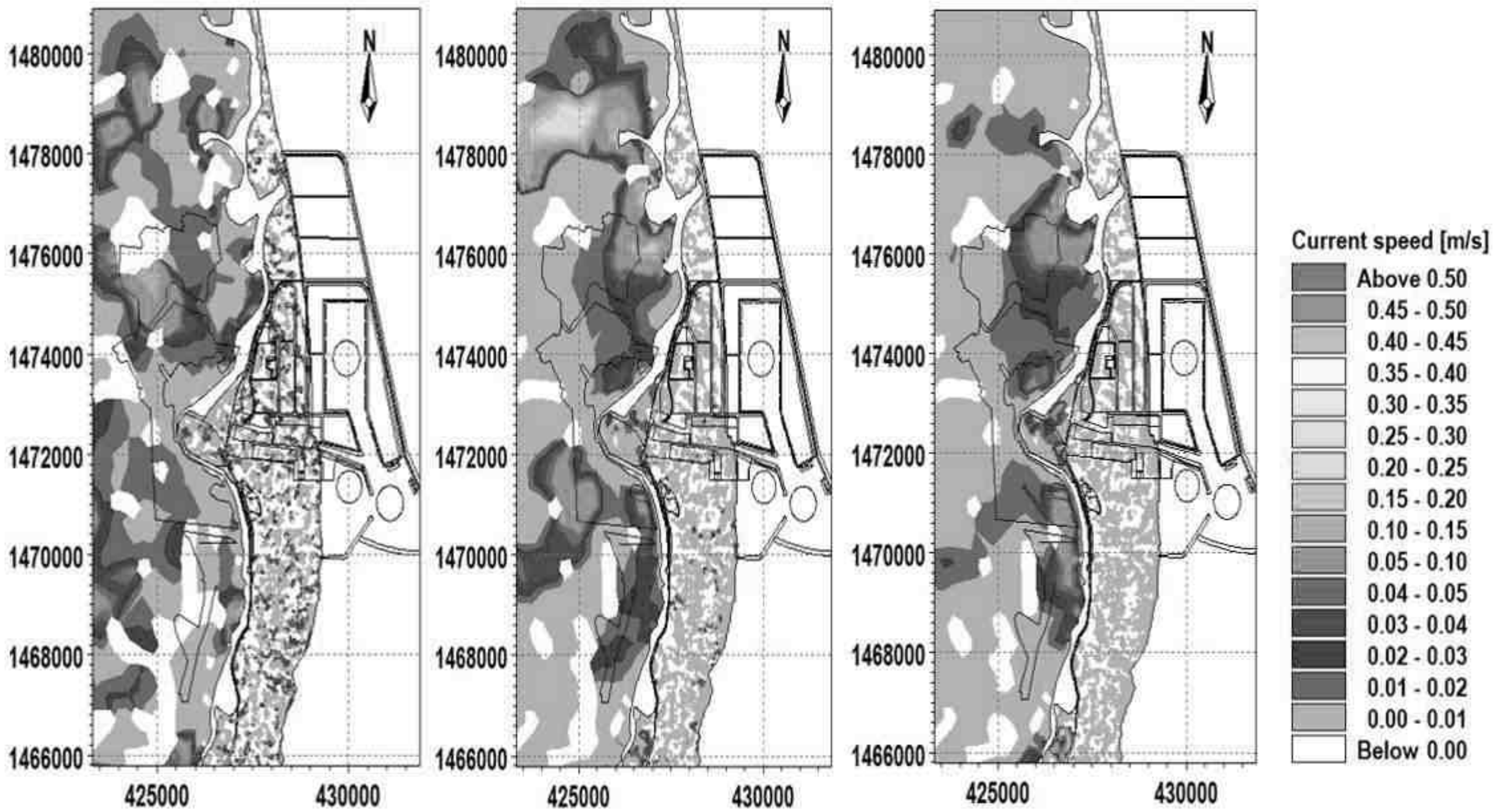


Figure 11-17 Current speed from 16 Nov 2015 to 18 Nov 2015 - Baseline condition

Future Scenario

The simulated maximum water level profile i.e., High Flood Level (HFL) along the Kosasthalaiyar backwater river and Buckingham canal is given in Figure 11-18 for future scenario. The inundation depth and current speed with the proposed development of the port area is shown in Figure 11-19 and Figure 11-20.

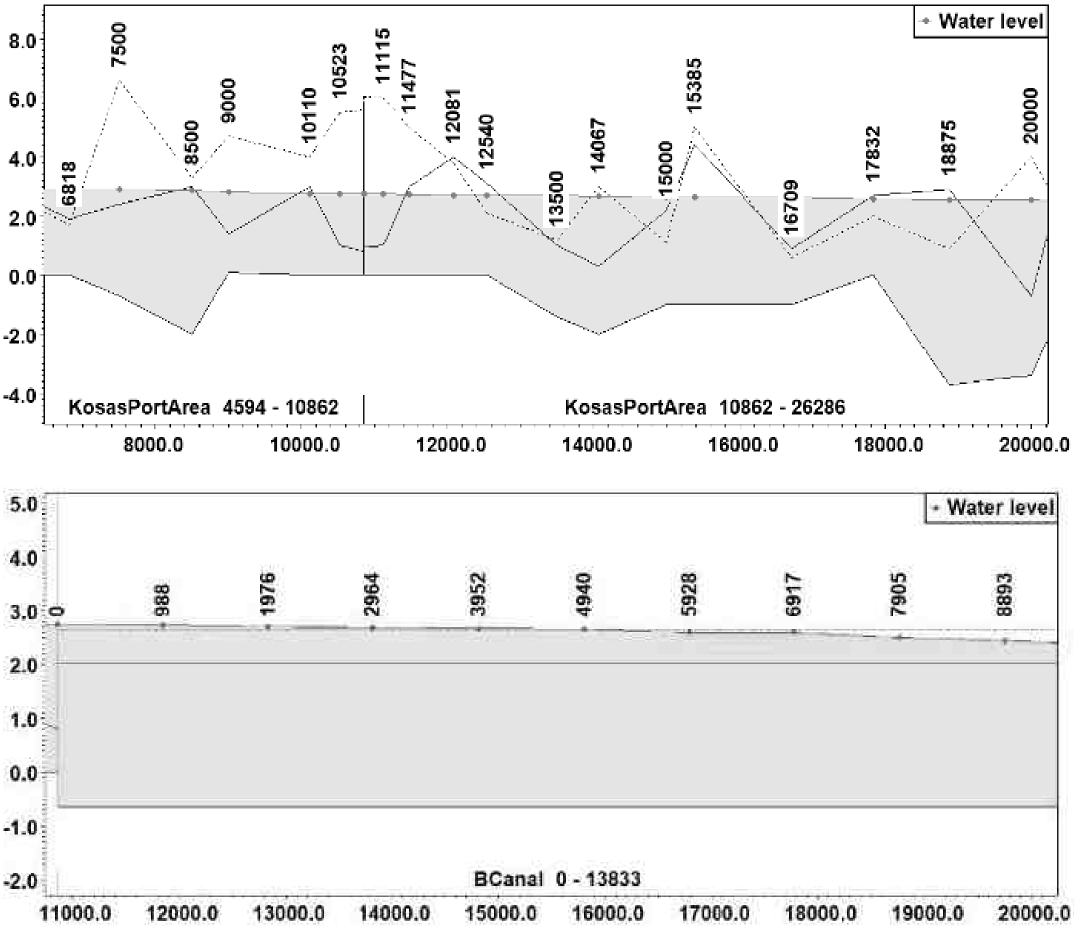


Figure 11-18 Water level profile of Kosasthalaiyar and Buckingham canal – Future Scenario

Note: Assuming that flow direction is from Pulicat lake to Ennore creek. Dotted black line = left riverbank; Solid black line = right bank; Blue shaded area = maximum water level condition

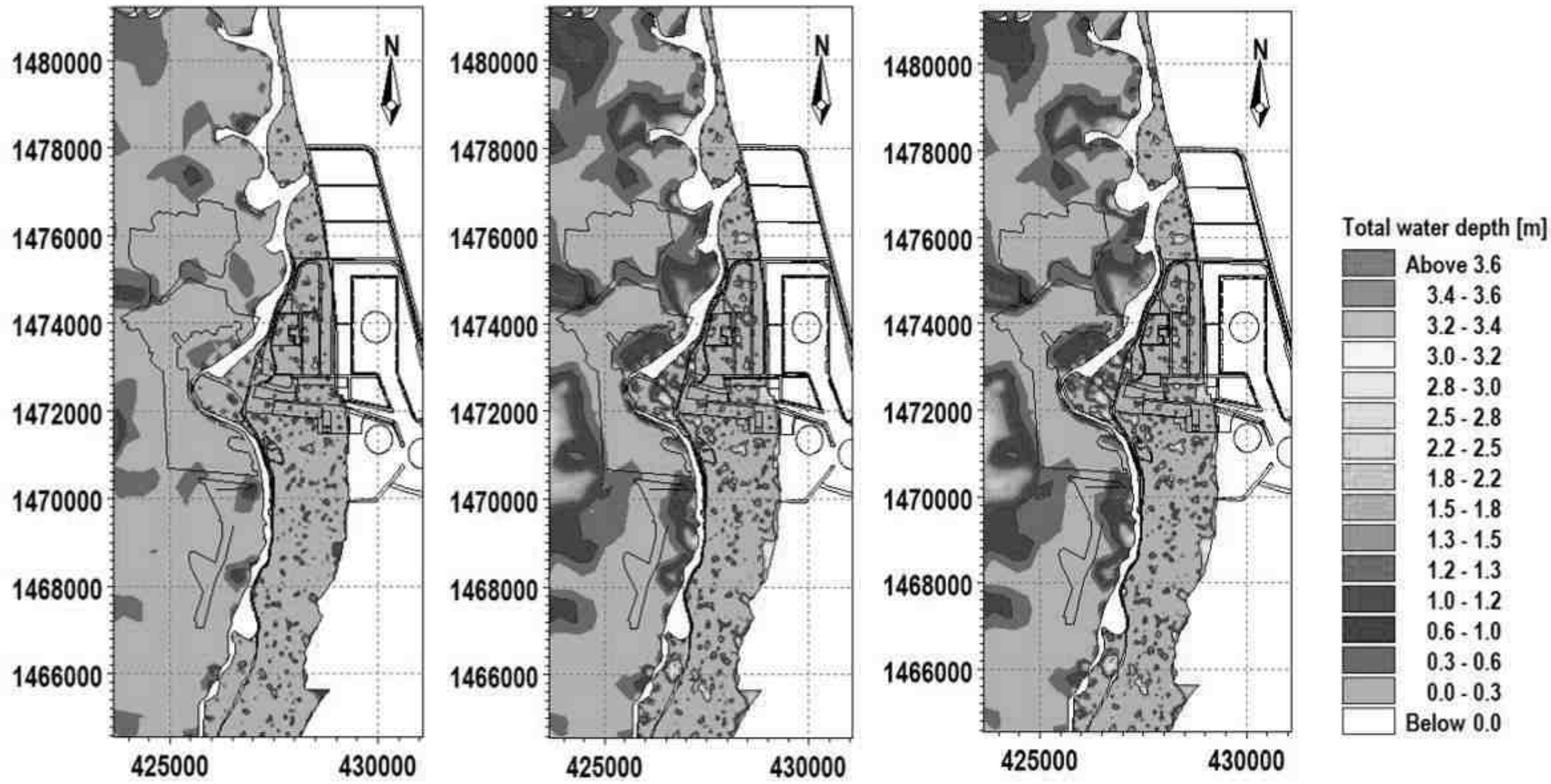


Figure 11-19 Flood inundation depth from 16 Nov 2015 to 18 Nov 2015 – Future Scenario condition

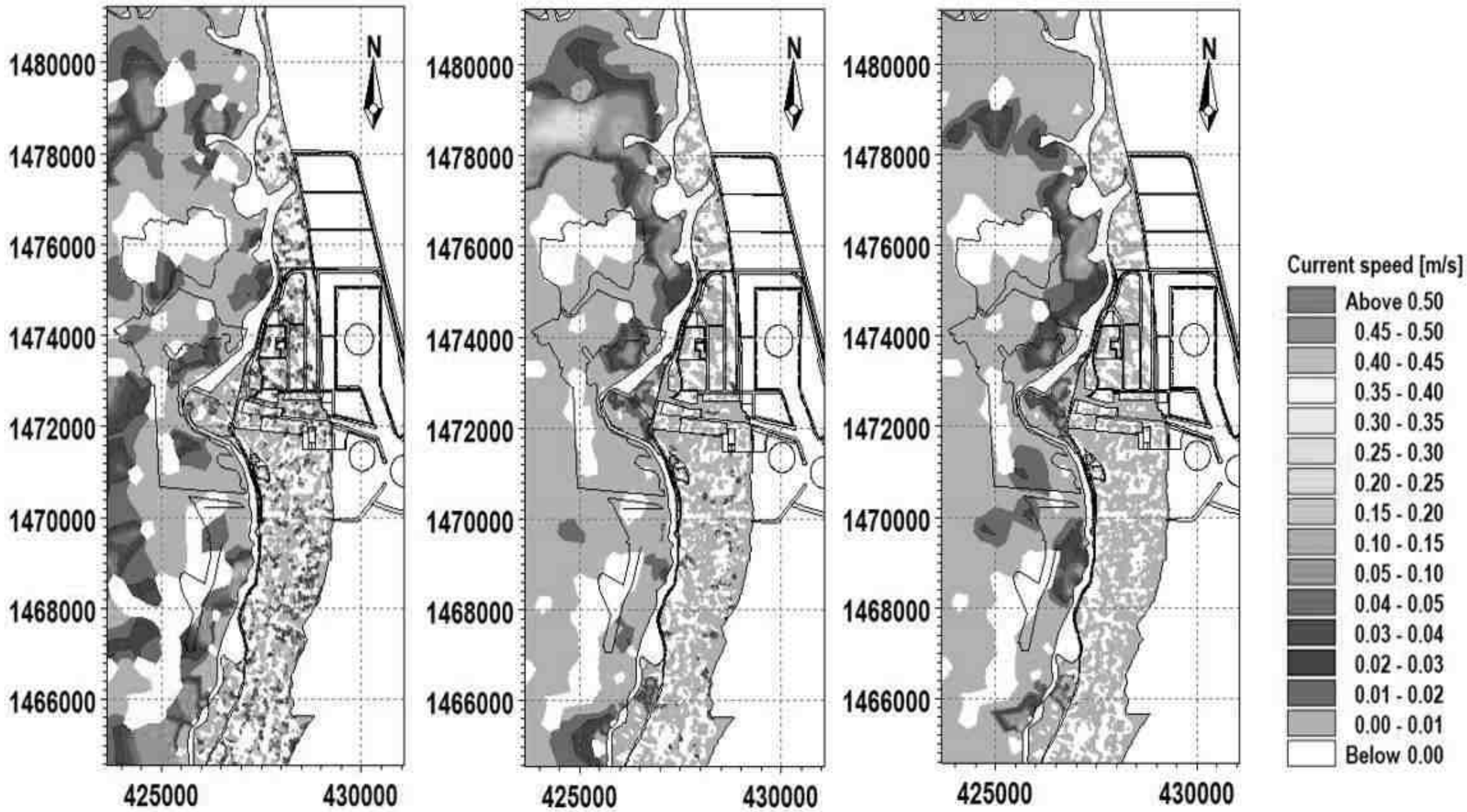


Figure 11-20 Current speed from 16 Nov 2015 to 18 Nov 2015 – Future Scenario condition

The comparison of the flood inundation depth between baseline and future scenario is shown in Figure 11-21 for the 2015 event.

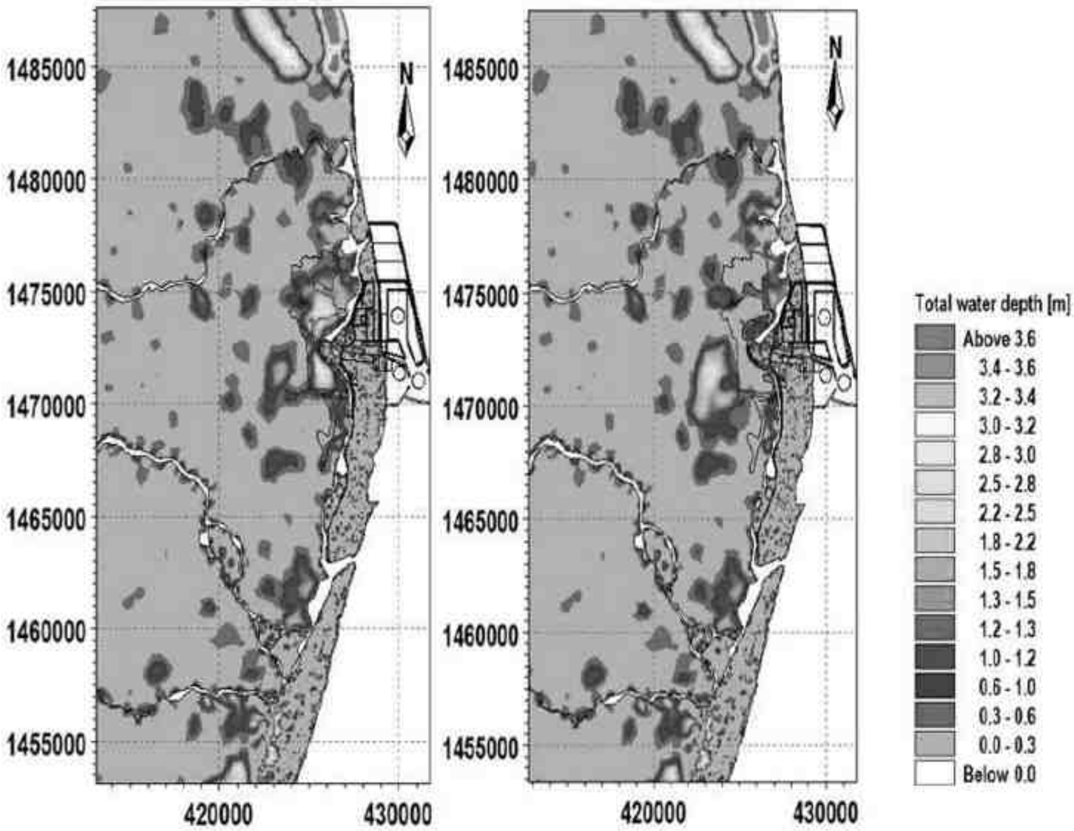


Figure 11-21 Comparison of flood extent between baseline and future scenario

From the results shown in Figure 11-15, the HFL in the Kosasthalaiyar river and B-canal in the vicinity of the port backup area is approximately 3 m with respect to MSL. Based on the CARTOSAT elevation data, the port backup area alongside the river has a low elevation ranging from -2 to +3 m with respect to MSL (Figure 11-14). Thus, it noticed that the inundation depth with the baseline scenario reaching up to 3.6 m above MSL particularly along the banks of the river as seen in Figure 11-16. The inundation is severe around the meandering portion of the river. Current speeds are low in these area, less than 0.2 m/s, presumably due to the flat terrain. These values may change subject to change in the bathymetry of the area.

For the future scenario, the elevation of the port backup area is raised to +4.4 m above mean sea level. The HFL in Buckingham canal is slightly higher in the future scenario than the baseline scenario. The raising of the port backup area is seen to be effective since the flooding of the backup area along the riverbanks reduces significantly and flood depths are reduced to under 0.3 m (Figure 11-19).

Thus, the modelling study carried out shows that raising the port backup area along to riverbanks to the proposed +4.4 m MSL (which is equal to +5 CD) would be an effective measure to protect the backup area from flooding. However, as seen in Figure 11-21, the flooding increases in the area just west of the elevated backup area.

11.6 Storm Water Management Plan

Natural drainage of the surrounding area of Kattupalli Port shall be diverted through river/B'canal to Ennore creek. The port area shall be developed at proposed FGL in flood modelling report by DHI. Kattupalli port back up area shall be divided into sub catchment area and different outfalls at nearest point into the River/Creek. Based on the sub catchment area, outfall drains are proposed to carry storm water discharge from port area and discharging into sea.

11.6.1 Assumptions

The following are the assumptions considered for the storm water design:

- Rainfall intensity is considered as 35 mm/hr based on IRC- SP-13, for Chennai
- The port development is at raised level as per flood modelling report
- Diversion of outside natural streams (i.e. River/Creek) is not considered in internal storm water drainage system
- Final outfall shall be discharged into the Sea / creek
- Outfalls will be constructed in phased manner as per development of internal plots
- External main storm water drains shall be proposed along main roads
- Main drain from sub-catchment area shall be connected to final outfall and lateral shall be connected to main drain

11.6.2 Drainage Pattern and Catchment Area Analysis of Port Backup Area

The masterplan of the proposed Kattupalli Port has been divided into 15 sub-catchments to lay out a stormwater drainage plan for the area as shown in Figure 11-22.

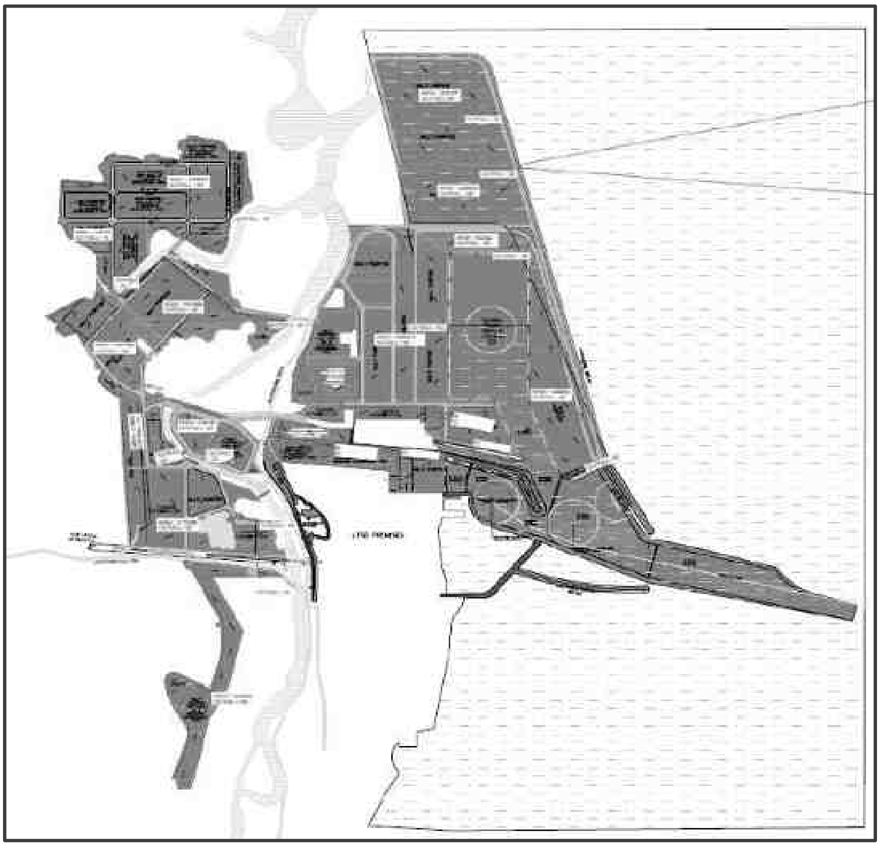


Figure 11-22 Masterplan showing flow-directions (black arrows) and stormwater drains (red lines)

Area description	Tributary Area on section		Net Tributary Area		Intensity of storm (mm/h)	Design runoff (m3/s)	Outfall Description
	Type 1 (Ha)	"C" Coefficient	Section (Ha)	Cumulative (Ha)			
Area 1A	74.68	0.75	56.01	56.01	35.00	5.45	Outfall-1A in the river
Area 1B	276.67	0.75	207.50	207.50	35.00	20.17	Outfall-1B in the river
Area 2A	167.40	0.75	125.55	125.55	35.00	12.21	Outfall-2A in the river
Area 2B	130.73	0.75	98.05	98.05	35.00	9.53	Outfall-2B in the river
Area 2C	71.96	0.75	53.97	53.97	35.00	5.25	Outfall-2C in the river
Area 2D	75.81	0.75	56.86	56.86	35.00	5.53	Outfall-2D in the river
Area 2E	211.63	0.75	158.72	158.72	35.00	15.43	Outfall-2E in the river
Area 3A	203.23	0.75	152.42	152.42	35.00	14.82	Outfall-3A in the river
Area 3B	206.95	0.75	155.21	155.21	35.00	15.09	Outfall-3B in the river
Area 3C	435.88	0.75	326.91	326.91	35.00	31.78	Outfall-3C in the river
Area 3D	60.24	0.75	45.18	45.18	35.00	4.39	Outfall-3D in the river
Area 3E	169.50	0.75	127.12	127.12	35.00	12.36	Outfall-3E in the river
Area 3F	114.15	0.75	85.61	85.61	35.00	8.32	Outfall-3F in the river
Area 3G	177.51	0.75	133.13	133.13	35.00	12.94	Outfall-3G in the river
Area 4A	121.94	0.75	91.46	91.46	35.00	8.89	Outfall-4A in the river
Area 1A	74.68	0.75	56.01	56.01	35.00	5.45	Outfall-1A in the river

Table 11-3 Sub-catchment area and storm water flow calculation

The outlets drain the storm water from the proposed backup area either into the river (for port area on the west of the river) or directly into the sea (for port areas east of the river).

Based on the type of land use, runoff coefficient is decided. A summary of the sub-catchment areas, their runoff coefficients and design runoff are given in Table 11-3.

Port back up yard storm water drains are of RCC channel with minimum of 600 mm to maximum shall be as per design flow and 1:500 longitudinal slopes. Roadside drains are provided within utility corridor on road. Minimum velocity 0.60 m/s and maximum velocity 2.5 m/s shall be considered in design of the drains. The road crossing shall be proposed by RCC box drain or RCC Hume pipes.

During construction of the port, for temporary drainage and ease movement, temporary storm water drains, and culverts are proposed. These drains will be stone pitched drains with bottom width of 0.5m. Refer Figure 11-23 for a typical section of a pitched drain.

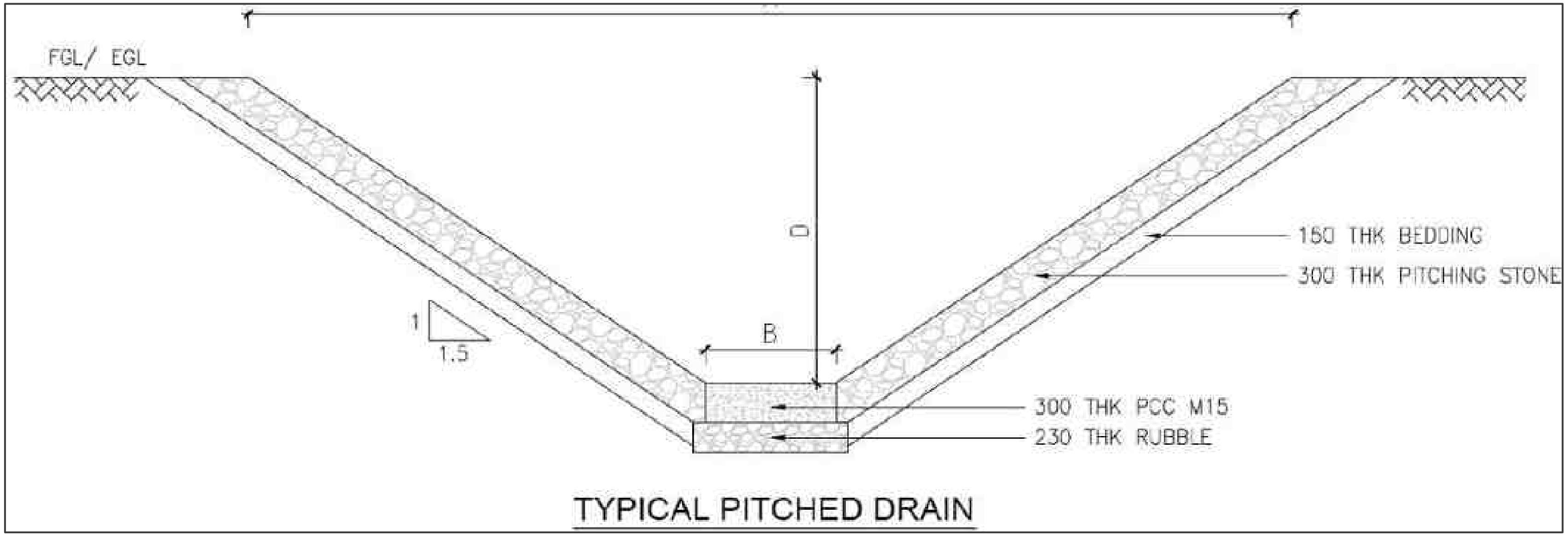


Figure 11-23 Typical cross section of a pitched drain

11.6.3 Drainage Pattern and Catchment Area Analysis on Westside of Port Backup area

During reconnaissance survey in the study area and using satellite imagery, an existing open channel was found which drains the overflow from a lake to the west of the proposed port backup area into the Kosasthalaiyar backwater river. The alignment of the drain is shown in Figure 11-24. The Figure 11-25 shows the alignment of the identified drain with respect to drainage pattern lines (from the drainage pattern study) and baseline/layout inundation results.

Figure 11-24 Existing drainage canal alignment (red line) with respect to port boundary (black line)

As seen from the figures, the existing drain alignment falls within the natural drainage pattern of the flood waters in this area and as such it is recommended that drain should be retained for management of inundation along the western periphery of the port.

It is further recommended that the open drain channel must be extended until the river along the main road which passes through the port backup area as shown in Figure 11-26. The canal segment which enters the backup area must be integrated with the storm water drainage network of the port.

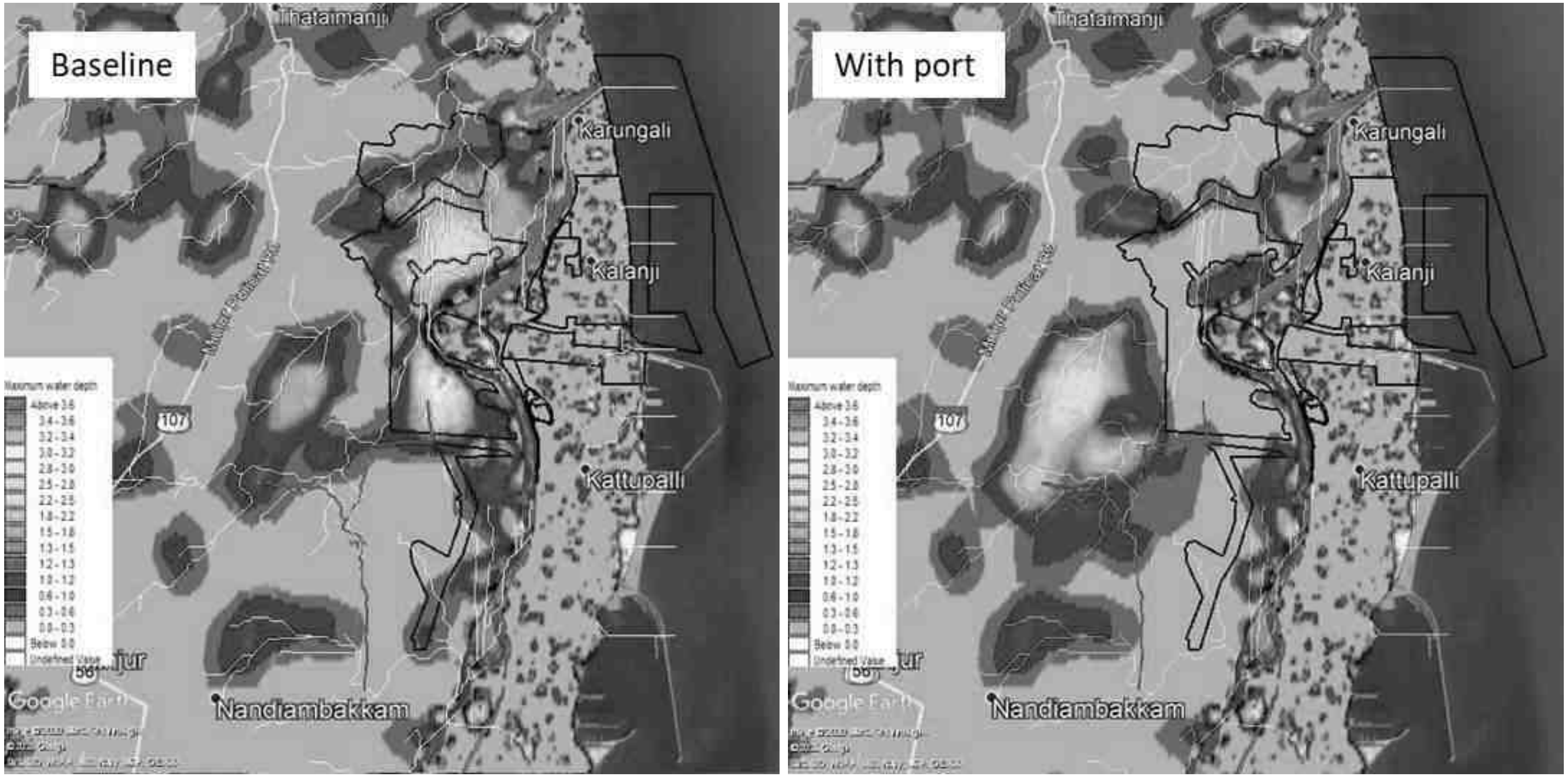


Figure 11-25 Existing drainage canal alignment (red lines), drainage pattern (white lines) with respect to port boundary (black line) and model inundation extent

Figure 11-26 Open channel extension (yellow line) to the river along the road

11.7 Recommendations

Flood model studies indicate that the raising of proposed Master Plan backup area of the port to +5m CD is effective in protecting the port infrastructure from the overtopping of the river during a 100-year rainfall event of 24-hour duration.

Locations where the embankments of the Kosasthalaiyar backwater river and B-canal are damaged must be identified and strengthened to reduce overtopping from the banks.

Locations where the banks are not continuous or have breaches/gaps must also be identified and continuous embankments of the river and B-canal must be ensured.

The proposed Master Plan development area has been divided into 15 sub-catchments and a Storm Water Drainage network plan must be laid out to drain the storm water from the port area into the river/canal or the sea. The port backup area will be raised, and the flow directions will be ensured into the drains.

The existing open channel towards the western side and periphery of the port backup is recommended to be retained for mitigation of flooding in this area. The de-silting of this canal is important to have a quick recession of flood water. The open channel must also be extended as suggested in the previous section and integrated with the Storm Water Drainage network of the port area.

12 Ship Tranquillity Study

The present chapter assess the wave disturbance in the basin and berthing area of the proposed Kattupalli Port Master Plan using DHI's Boussinesq Wave model. BW is phase resolving, two dimensional Boussinesq-type wave model for calculation and analysis of short- and long-period wave disturbance in ports and harbours. MIKE 21 BW can also be used for modelling of surf zone dynamics and swash zone oscillations.

The present model is based on the numerical solution of the enhanced Boussinesq equations formulated by (Madsen & Sørensen, 1992).The model has been extended into the surf zone by inclusion of wave breaking and moving shoreline. This module can reproduce the combined effects of most wave phenomena of interest in port, harbour and coastal engineering. These include:

- Shoaling
- Refraction
- Diffraction
- Partial reflection and transmission
- Non-linear wave-wave interaction
- Frequency spreading
- Directional spreading

Phenomena such as wave grouping, generation of bound sub-harmonics and super-harmonics and near-resonant triad interactions are implicitly captured using MIKE 21 BW.

In this study the MIKE 21 BW model applies the wave spectral input from spectral wave model and carry out a highly detailed time-domain wave transformation analysis into the entire port accounting for both sea and swell wave energy.

12.1 Model Setup

The numerical parameters and model parameters used for the modelling can be seen in Table 12-1. The numerical scheme for the discretization of the convective terms used is 'Central differencing with side-feeding'. A time extrapolation factor of 1 is used in the entire domain to reduce the numerical instabilities that occur when wave breaking is included. One-hour simulation period was considered for the present study.

Table 12-1 Model Parameters used in the Boussinesq Wave model

Parameter	Value
Spatial Resolution Δx = Δy	5m
Time step Δt	0.25sec
Courant Number	0.80
Bottom Friction - Manning Number	32
Eddy Viscosity - Smagorinsky	Constant, Velocity based
Wave Breaking	Included
Type of roller celerity	3 - Directional
Half-time for cut-off roller	2.4sec
Slot friction coefficient	0.1

12.2 Bathymetry Data

The entire computational domain is discretized with a Cartesian grid with an extent of 8450m by 14500m. Bathymetry data for the entire domain is employed from the survey data provided by the client.

A depth cut-off was used at a depth of 32m in the entire domain. This is required for the internal wave generation boundary that can only be applied correctly along a constant depth. It was also done to reduce the computational time from resolving large water depths, where the non-linear wave transformation will be minimal.

Figure 12-1 shows the bathymetry considered for the BW model and the extraction locations for the wave disturbance coefficient.

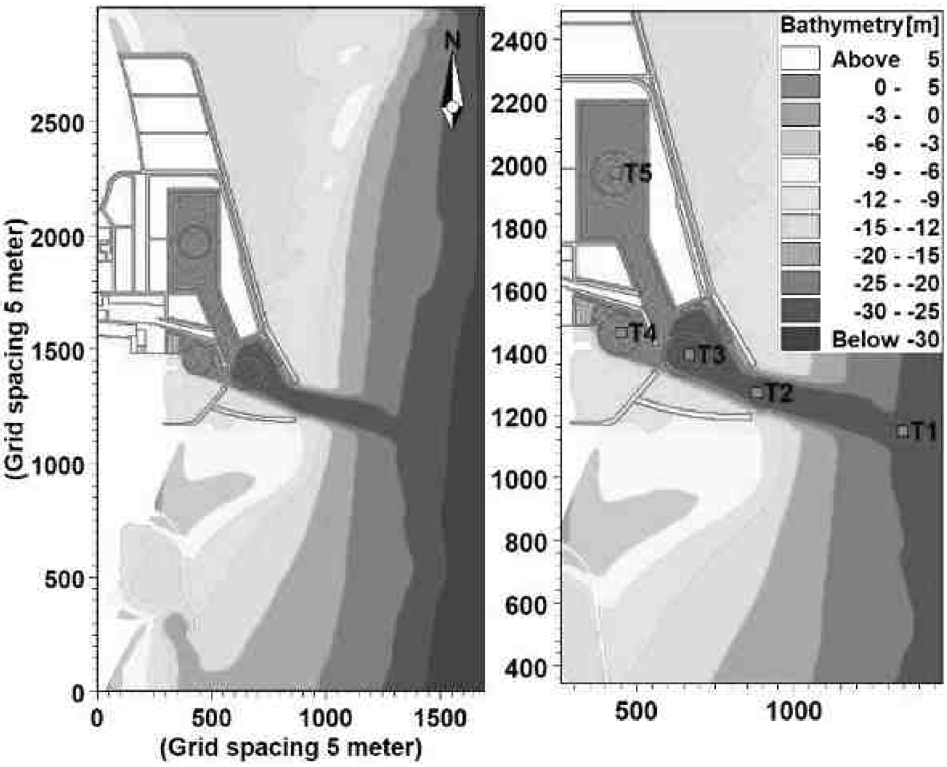


Figure 12-1 Left: Bathymetry used for Harbour Tranquillity Study, Right: Zoomed bathymetry with extraction locations

12.3 Wave Reflection: Porosity and Sponge Layer Maps

All model boundaries are made wave absorbing, meaning that all wave energy reaching these model boundaries (offshore and coast) are absorbed to avoid waves being reflected into the model domain.

Along the breakwater and revetments, partial wave reflection is applied. For the structures being important for the wave disturbance in the harbour, the reflection properties are estimated and modelled based on the actual structure type and the wave conditions. The variation in reflection is mainly due to variation in wave height/steepness.

The Porosity and sponge layers considered for the wave tranquillity study is illustrated in Figure 12-2.

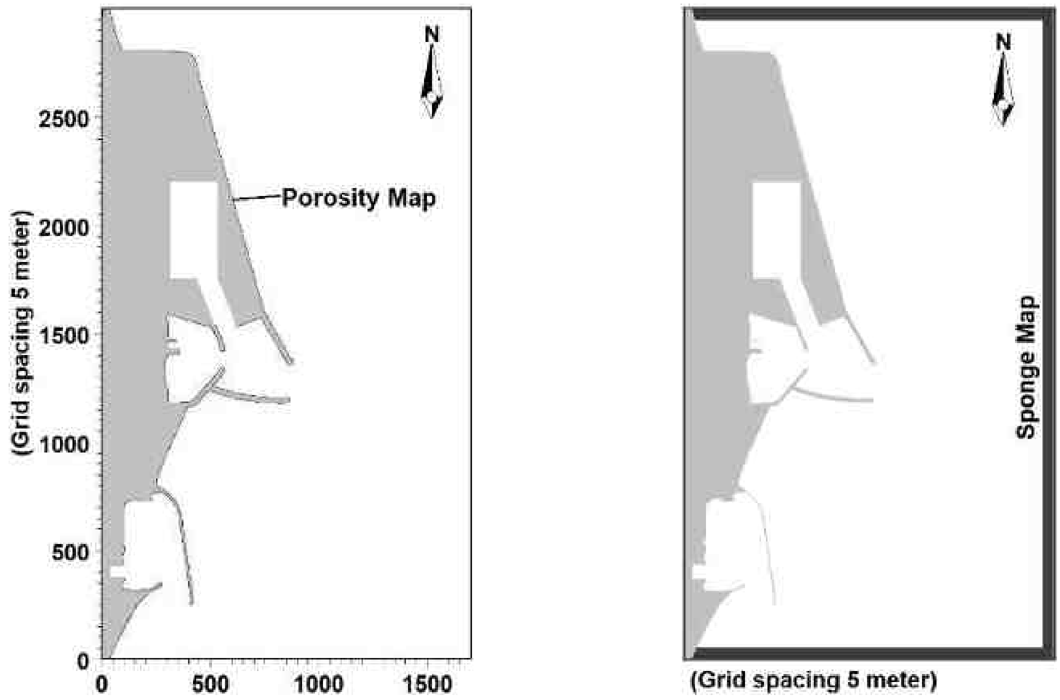


Figure 12-2 Porosity and sponge layer for the wave tranquillity study

12.4 Boundary conditions

Based on the one year (2018) hindcast wave transformation result, scatter analysis has been carried out on the modelled offshore wave conditions at -30 m CD. The scatter tables are presented in Table 12-2 and Table 12-3.

Based on the analysis, the following wave periods and wave directions are included in the scope of wave disturbance simulations to cover the relevant operational wave conditions:

- Significant wave height: 1m and 2.5m
- Peak wave periods: 8s and 12 s
- Mean wave directions: 45°N, 90°N, and 135°N

Directional irregular waves with a significant wave height of 1 m and 2.5m, peak wave period and mean wave direction are applied for defining the incident wave conditions. The waves are defined using a standard JONSWAP spectrum and directional spreading of 30° has been used in defining the wave spectrum.

12.4.1 Offshore Wave Condition

The wind-wave climate at offshore condition, as evident in Figure 12-3 shows that the largest monsoon waves reaching the -30 m CD water depth range between 1.0 and 3.0 m during the northeast monsoon, when the site is exposed to the prevailing wind and wave directions. During the southwest monsoon the wave conditions are more benign, with the significant wave height dropping below 2 m.

The wave rose for the offshore wave conditions at -30 m CD is presented in Figure 12-4. It can be observed that the offshore waves are majorly coming from the NE to SE sectors.

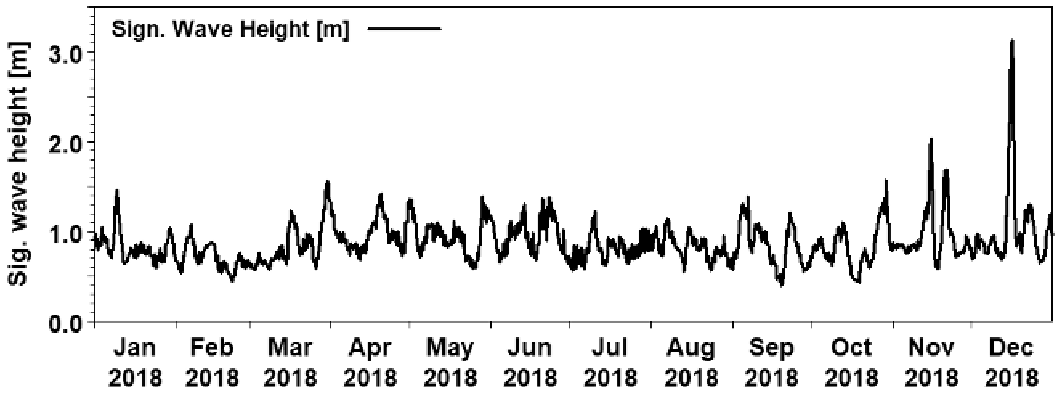


Figure 12-3 1-year (2018) hindcast wave conditions at -30 m CD.

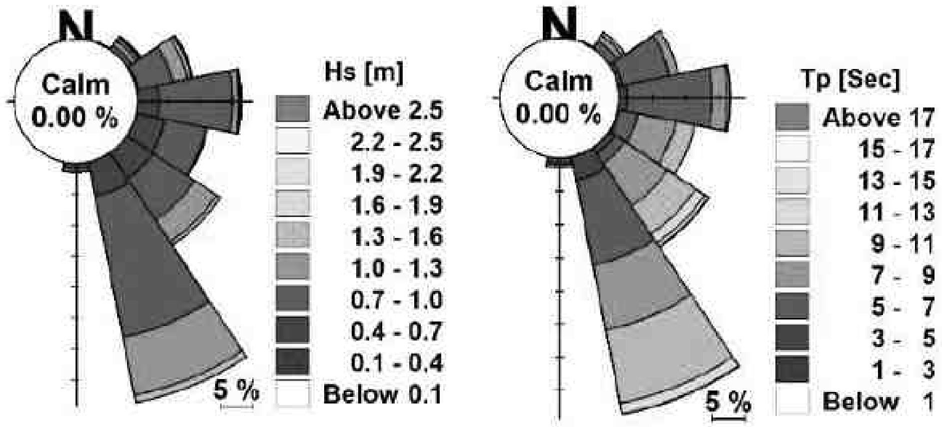


Figure 12-4 1-year (2018) wave rose for offshore wave conditions at -30 m CD

Table 12-2 Scatter data: Significant wave height and mean wave direction at -30 m CD

Hs (m)	MWD [° N]								Total [%]
	22.5	45	67.5	90	112.5	135	157.5	180	
0.1	-	-	-	-	-	-	-	-	0
0.4	-	-	-	-	-	-	-	-	0
0.7	-	-	1.44	5.27	3.36	6.78	2.88	0.07	19.79
1	**0.55**	**0.96**	**13.15**	**6.58**	**5.89**	**19.04**	**11.03**	-	**57.19**
1.3	0.14	2.19	1.85	0.34	0.82	9.73	3.49	-	18.56
1.6	0.21	0.62	0.41	0.14	-	1.37	0.55	-	3.29
1.9	-	0.21	0.07	0.14	-	-	-	-	0.41
2.2	-	0.14	0.14	-	-	-	-	-	0.27
2.5	-	**0.14**	-	-	-	-	-	-	0.14
2.8	-	0.14	-	-	-	-	-	-	0.14
3	-	0.21	-	-	-	-	-	-	0.21
Total [%]	**0.9**	**4.61**	**15.62**	**7.2**	**6.71**	**30.14**	**15.07**	-	100

Table 12-3 Scatter data: significant wave height and peak wave period at -30 m CD

Hs (m)	Peak wave period [Sec]							Total [%]
	0-3	3-6	6-9	9-12	12-15	15-18	18-21	
0.1	-	-	-	-	-	-	-	-
0.4	-	-	-	-	-	-	-	-
0.7	-	5.1	12.3	2.3	0.1	-	-	19.8
1	-	**19.8**	**23.8**	**12.8**	**0.7**	**0.1**	-	57.2
1.3	-	4.9	6.0	6.8	0.8	0.1	-	18.6
1.6	-	0.9	1.4	0.7	0.3	-	-	3.3
1.9	-	-	0.3	0.1	-	-	-	0.4
2.2	-	-	0.3	-	-	-	-	0.3
2.5	-	-	0.1	0.1	-	-	-	0.1
2.8	-	-	0.1	0.1	-	-	-	0.1
3	-	-	-	0.2	0.0	-	-	0.2
Total	-	**30.8**	**44.3**	**23.0**	**1.9**	**0.1**	-	100

Table 12-4 shows the run matrix of BW model for the present study. These data are arrived based on the scatter data analysis. Model with 1m wave height considered as case-1 and 2.5 is case-2 respectively.

Table 12-4 BW simulation matrix

Run ID	Case	Peak Wave Period (sec)	Wave Direction (Degrees from, North)	Significant Wave Height (m)
BW01	Case-1	8	45	1
BW02		8	90	1
BW03		8	135	1
BW04		12	45	1
BW05		12	90	1
BW06		12	135	1
BW07	Case-2	8	45	2.5
BW08		8	90	2.5
BW09		8	135	2.5
BW10		12	45	2.5
BW11		12	90	2.5
BW12		12	135	2.5

12.5 Results

The solutions to the flux-based equations in the BW model give various types of output results such as wave disturbance and deterministic parameters corresponding to three predominant directions.

12.5.1 Wave Disturbance Coefficients

The key output from the wave penetration modelling is the significant wave height in the model basin with the given Master layout. As the incident wave height at the offshore model boundary was 1 m, the values can also be regarded as the wave disturbance coefficients, defined as the wave height relative to incident wave height (i.e. model boundary wave height).

The model results with the Master plan are presented in the following section as wave disturbance coefficient, which is defined as the ratio of wave height at a given location to the incident wave height or the wave height at the model boundary. For instance, a predicted wave disturbance coefficient of 0.5 would indicate a reduction of the incident wave height by 50%.

Wave disturbance coefficient at five (5) extraction locations with all modelled wave conditions are provided in Table 12-5 and Table 12-6. Similarly Contour plots of the wave disturbance coefficients for all modelled wave conditions are depicted in Figure 12-5 to Figure 12-8.

Generally, it is observed that the wave disturbance coefficients near the breakwater and at the berths are in the less than 30% of the incident offshore significant wave heights for waves coming from all direction.

Table 12-5 Wave disturbance coefficients for operational condition (Case-1) at study area

No	Easting [m]	Northing [m]	Wave Disturbance Coefficients					
			BW01	BW02	BW03	BW04	BW05	BW06
T1	434537	1469818	0.69	0.83	0.61	0.88	1.00	0.91
T2	432214	1470434	0.55	0.67	0.42	0.64	0.70	0.47
T3	431140	1471032	0.20	0.31	0.30	0.44	0.31	0.33
T4	430049	1471384	0.10	0.17	0.14	0.18	0.17	0.15
T5	429961	1473936	0.12	0.13	0.20	0.25	0.20	0.22

Table 12-6 Wave disturbance coefficients for extreme condition (Case-2) at study area

No	Easting [m]	Northing [m]	Wave Disturbance Coefficients					
			BW07	BW08	BW09	BW10	BW11	BW12
1	434537	1469818	0.69	0.80	0.60	0.87	1.00	0.89
2	432214	1470434	0.50	0.63	0.40	0.65	0.67	0.44
3	431140	1471032	0.17	0.29	0.28	0.40	0.29	0.29
4	430049	1471384	0.07	0.14	0.11	0.15	0.14	0.12
5	429961	1473936	0.03	0.03	0.04	0.05	0.05	0.04

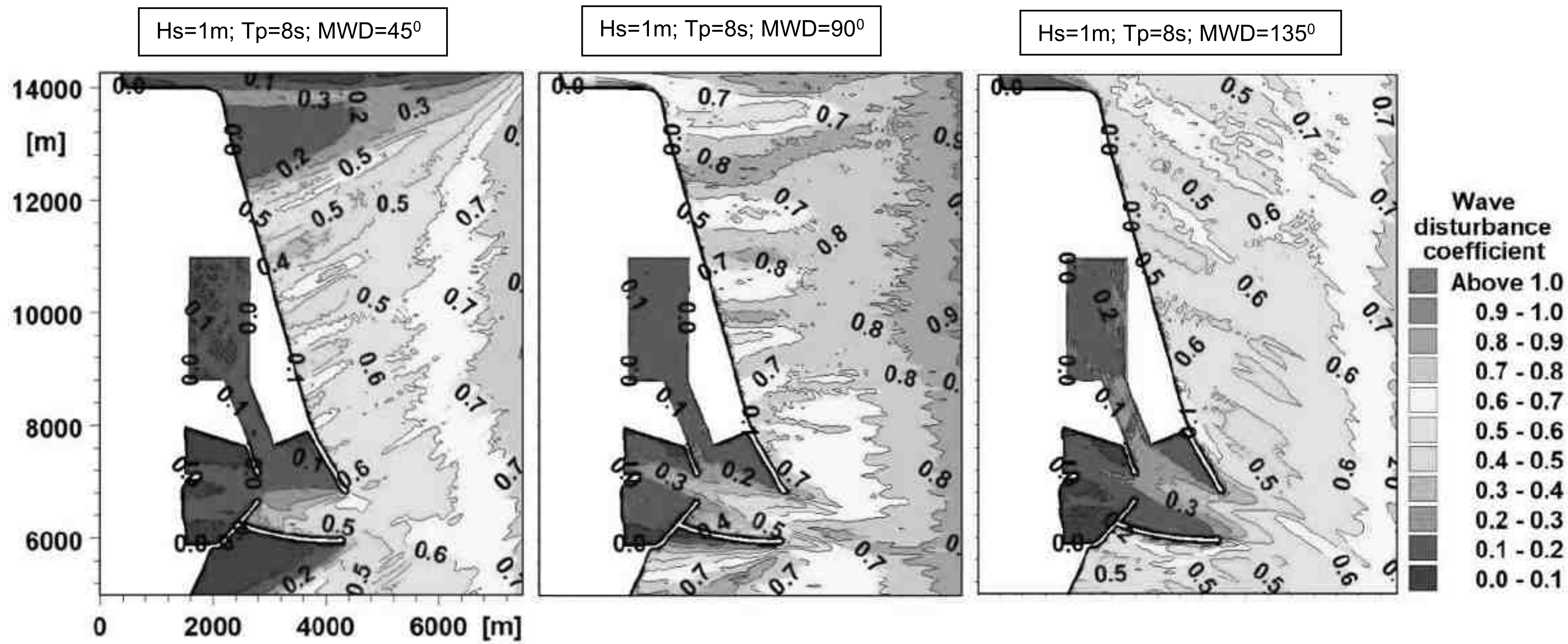


Figure 12-5 Contour plot of wave disturbance coefficient for operational condition (Case-1)

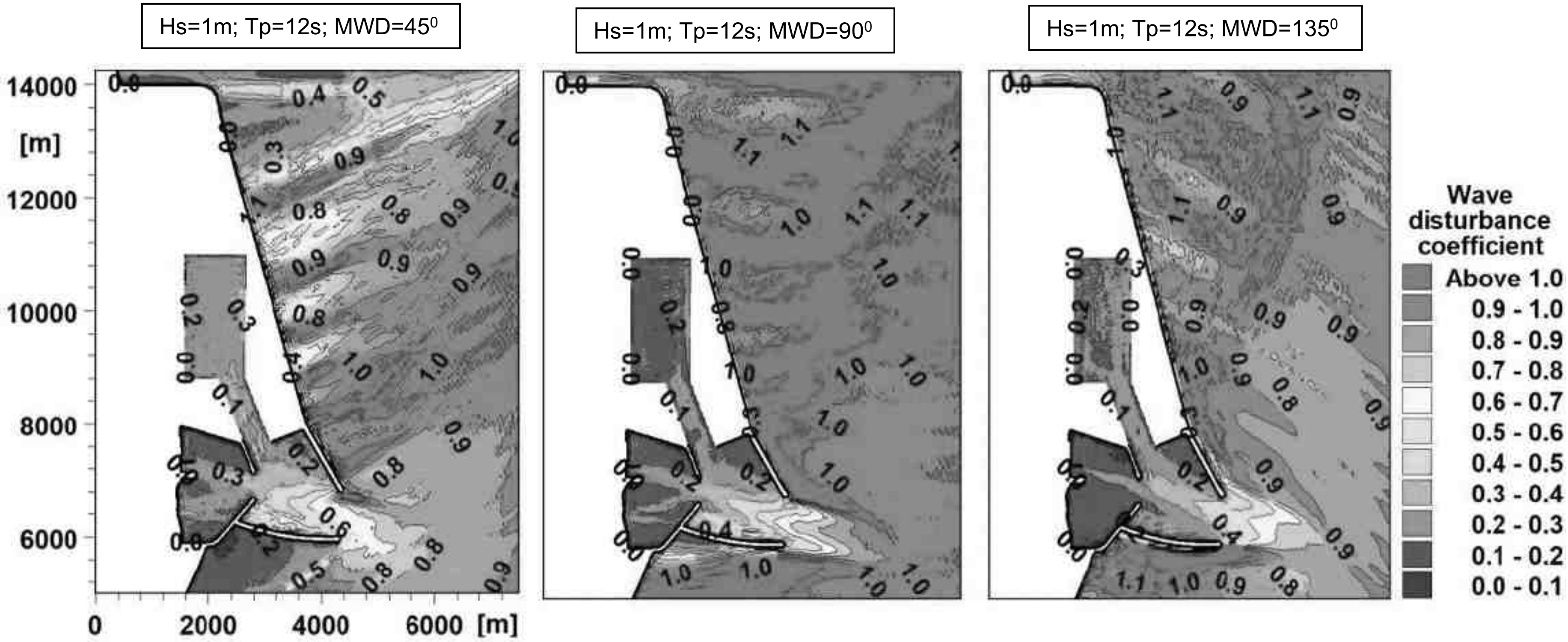


Figure 12-6 Contour plot of wave disturbance coefficient for operational condition (Ccase-1)

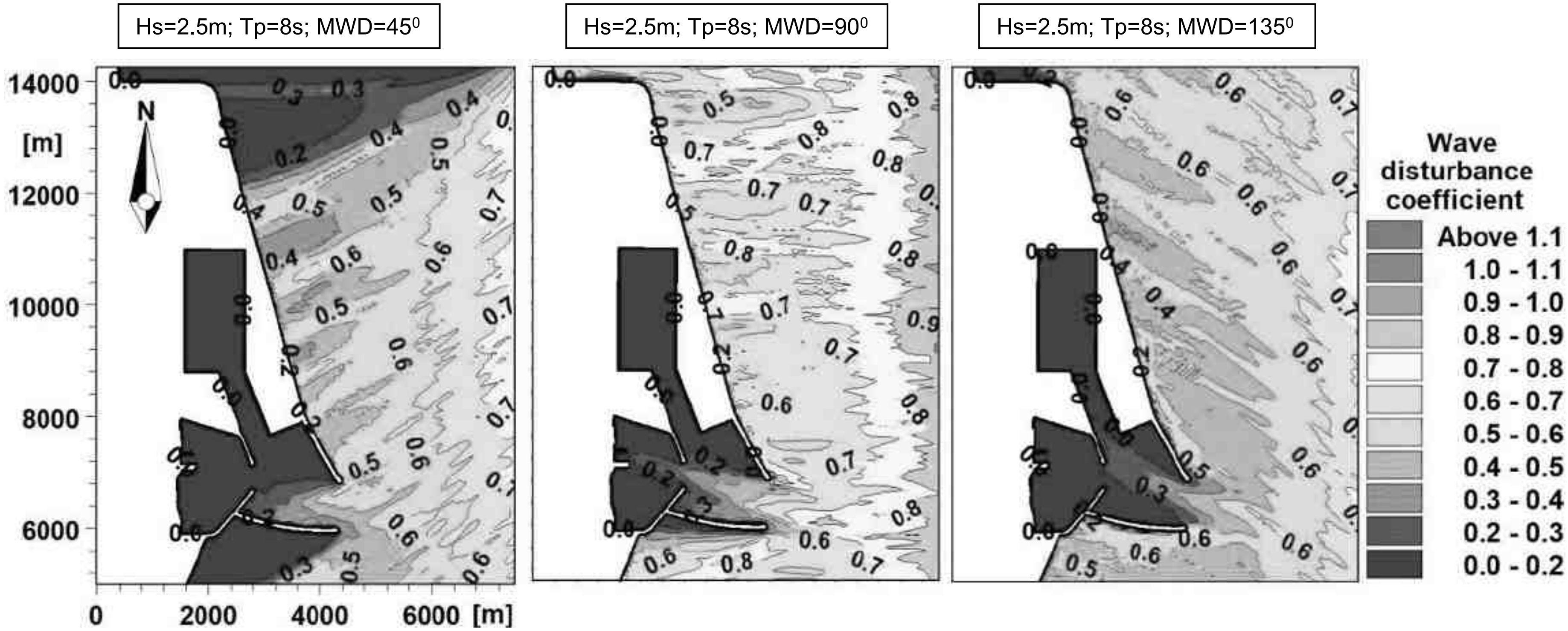


Figure 12-7 Contour plot of wave disturbance coefficient for operational condition (Case-2)

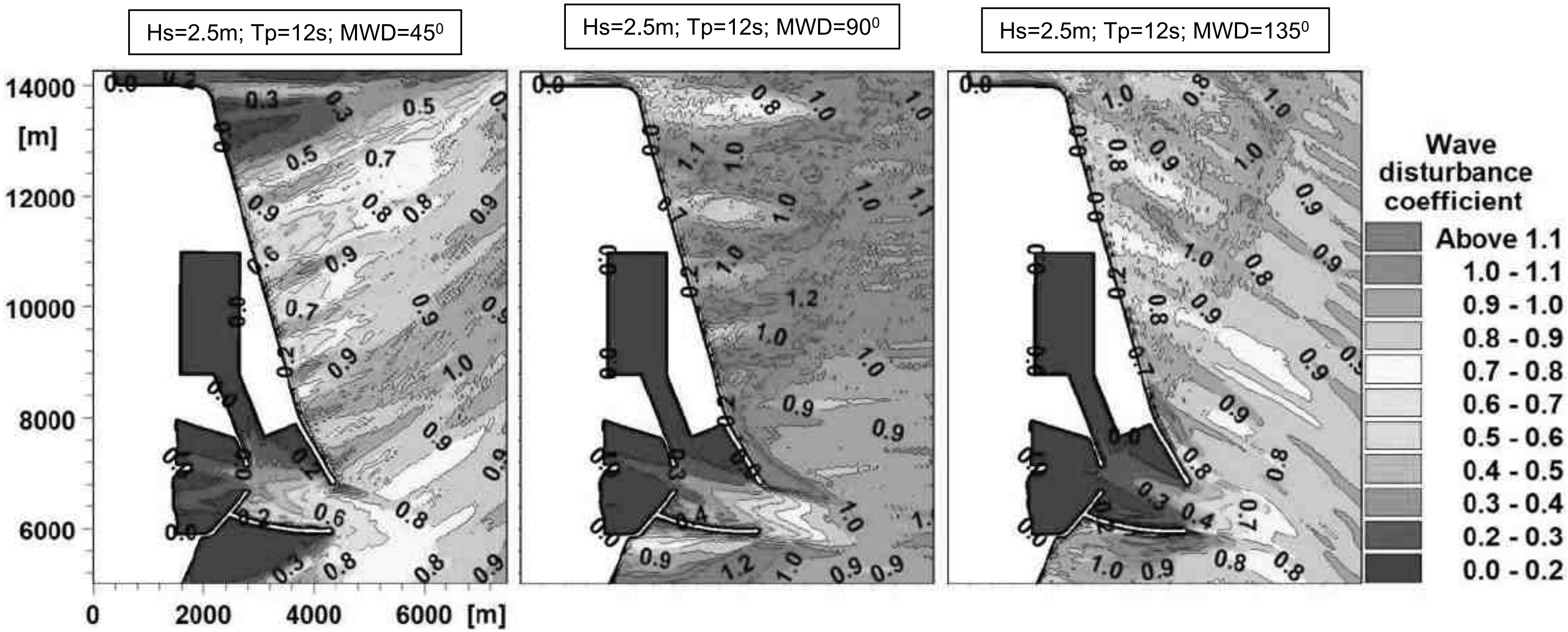


Figure 12-8 Contour plot of wave disturbance coefficient for operational condition (Case-2)

12.5.2 Water level

An example of a three-dimensional (3D) perspective view of the surface elevation is shown in Figure 12-9 and Figure 12-10. The wave crest pattern shows its direction of approach and the diffraction processes behind breakwaters at a different angle than the original wave train.

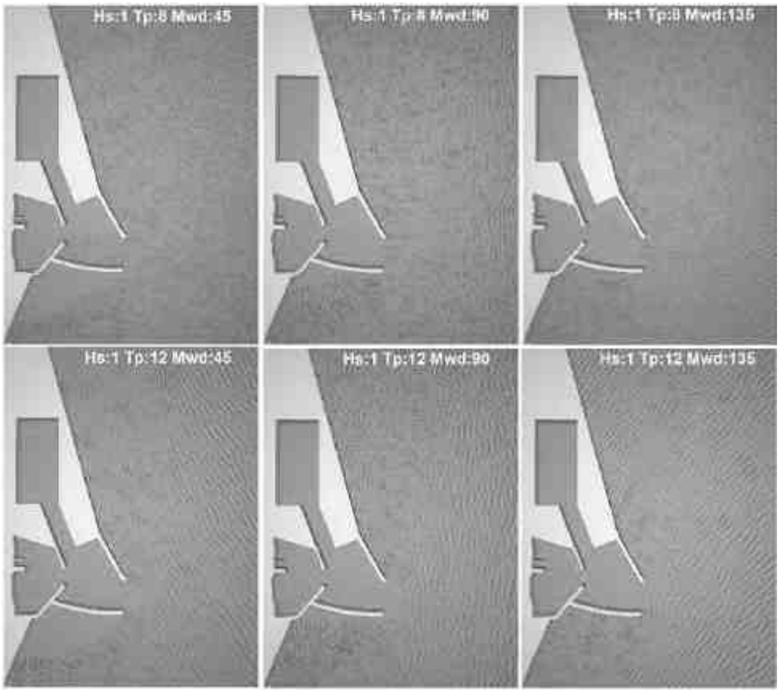


Figure 12-9 3D perspective view of instantaneous surface elevation for different peak wave period and mean wave directions (Case-1)

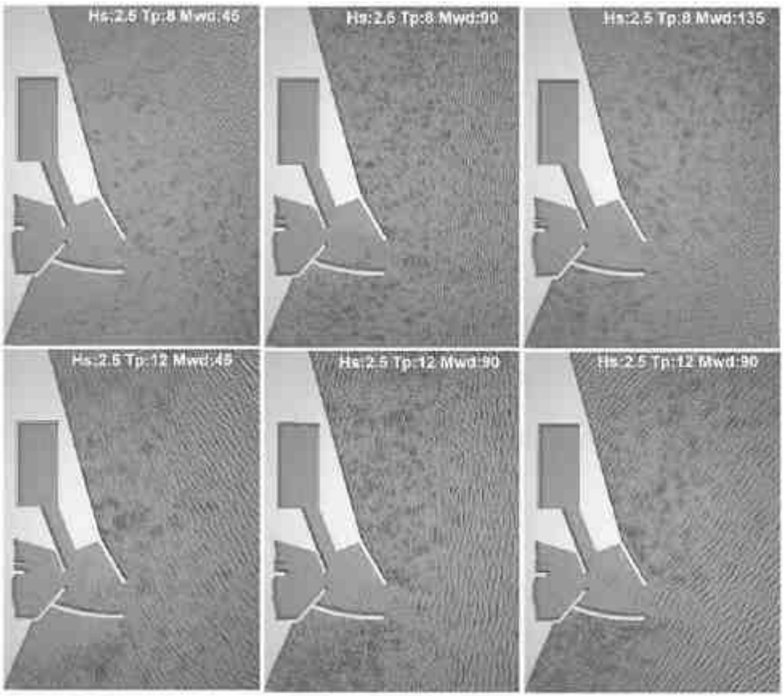


Figure 12-10 3D perspective view of instantaneous surface elevation for different peak wave period and mean wave directions (Case-2)

12.6 Conclusions

The key output from the wave tranquility modelling is the significant wave height in the basin area. As the incident wave height at the offshore boundary is 1m, the values can also be regarded as the wave disturbance coefficients, defined as the wave height relative to incident wave height.

The model output is presented as wave disturbance coefficient, which is defined as the ratio of wave height at given location to the incident wave height (or the wave height at the model boundary). Contour plots of the wave disturbance coefficients for all modelled wave conditions are presented.

The simulated results of the model have provided keen insight into the performance of the harbour layout in the wave agitation point of view. Although the tranquillity of a harbour cannot be completely characterized by means of wave height alone, this is an essence of harbour planning. From the results it could be seen that the tranquillity inside the harbour is very good.

Across all modelled scenarios the breakwater provides a large reduction of wave height for the modelled combination of wave periods and direction. Maximum wave disturbance coefficient from case-1 and case-2 are provided below.

No	Easting (m)	Northing (m)	Wave Disturbance Coefficients	
			Case-1	Case-2
1	434537	1469818	1.00	1.00
2	432214	1470434	0.70	0.67
3	431140	1471032	0.44	0.40
4	430049	1471384	0.18	0.15
5	429961	1473936	0.25	0.05

13 Sedimentation Study

The present chapter assess the annual maintenance dredging quantities with existing and proposed Mater Plan layout at Kattupalli Port. Since, sediment transport is dependent on hydrodynamic conditions, the calibrated hydrodynamic model is extended to sediment transport process calculations. The DHI's MIKE 21 Mud Transport (MT) model is used to assess the sedimentation in the approach channel, turning circle and berth pockets.

13.1 Model Setup

DHI's MIKE 21 Mud Transport (MT) module is a state-of-the-art cohesive sediment transport model that simulates the erosion, transport, and deposition of mud or sand/mud mixtures (< 63 µm) under the action of currents and waves in marine, brackish or freshwater environments. The model is capable of handling flocculation as well as hindered settling in the water column in addition to sliding and consolidation in the bed.

In the MIKE 21 model, the transport of fine-grained material (mud) has been included in the Mud Transport (MT), linked to the Hydrodynamic module (HD) and the Advection-Dispersion (AD) module. The primary input to sediment transport modelling is in the form of characteristics of the bed material as well as material in suspension in addition to the current and wave inputs which are directly embedded from the hydrodynamic simulation results. It considers the following sediment properties:

- Settling velocities
- Critical shear stresses for deposition and erosion
- Bed layer densities
- Sediment fractions (fine sand, silt, clay)
- Transport of suspended sediment concentrations

13.2 Model Bathymetry

The model extent and bathymetry considered for sedimentation study is shown in Figure 13-1 for baseline and layout conditions. Bathymetry data for the entire domain is provided by the client.

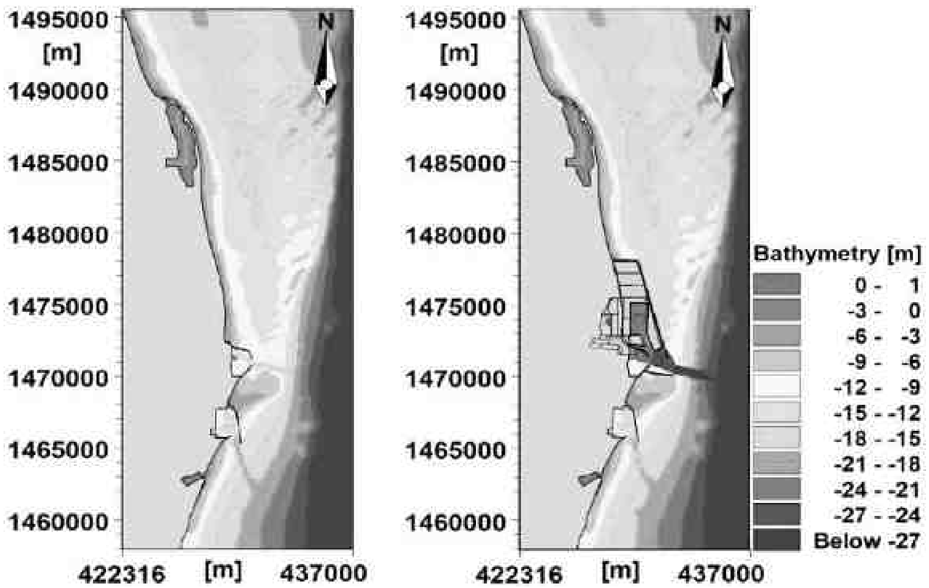


Figure 13-1 Bathymetry data: Baseline Conditions (Left), Master Plan Layout (Right)

13.3 Simulation Period

The simulation is carried out for a period of 15 days during pre-monsoon (2020) as part of model calibration. Followed by the calibration, the MT model is simulated for layout condition for pre monsoon, covers one spring and neap tidal cycle, in order to estimate the annual siltation quantity in the vicinity of the proposed development.
The production period of the mud transport model is given below.
For Calibration: Tide with pre-monsoon wind and wave: 18th February to 06th March 2020.

13.4 Model Parameters

The table below summarizes the sediment transport parameters applied during the simulation period.

Table 13-1 Mud Transport model parameters

Parameter	Value
No. of grain size fractions	2
No. of bed layers	2
Dispersion coefficient	1m^2/s
Boundary concentration	Zero gradient
Settling velocity	Varying for Silt & Clay
Critical shear stress for deposition	Varying [N/m^2]
Power of erosion	Soft Mud=8.1 and hard mud=1
Erosion coefficient	3e-05 [m^2/s]
Critical shear stress for erosion	Varying [N/m^2]
Density of bed layer	180 [kg/m^3] for layer 1 and 300 [kg/m^3] for layer 2
Bed roughness	0.005 [m]
Initial sediment concentration	0.005 kg/m^3

13.5 Water Column Parameters

Under the water column parameters, the following sections are included:

- Settling velocity
- Sand fractions
- Deposition

13.5.1 Settling Velocity and Erosion coefficient

The settling velocity of the fine sediment depends on the particle/floc size, temperature, concentration of suspended matter and content of organic material. Based on the grain size, the approximate settling velocities can be calculated using Stokes law. For sand fraction settling velocity is 0.24m/s and the settling velocity coefficient for the fine sediment is 50.

13.5.2 Critical Shear Stress for Erosion/Deposition

Selection of critical bed shear stress for deposition and bed erosion is important task in sediment transport and morphological modelling. The bed shear stress distribution and sedimentation condition in the study area is strongly related to hydrodynamic characteristics e.g., boundary conditions and characteristics of the tides (semidiurnal and diurnal).

The erosion of a bed layer is the transfer of sediment from bed layer to the water column. Erosion takes place from the active bed layer in areas where the bed shear stress is larger than the critical shear stress for erosion.

The deposition of suspended sediment is the transfer of sediment from the water column to the bed. Deposition takes place where the bed shear stress is smaller than the critical shear stress for deposition.

The critical shear stress of erosion and deposition determines the concentration profile of the water column. The criterion for erosion is that the shear stress exceeds the critical shear stress for erosion. Figure 13-2 shows the critical shear stress for erosion and deposition considered in the mud transport simulations.

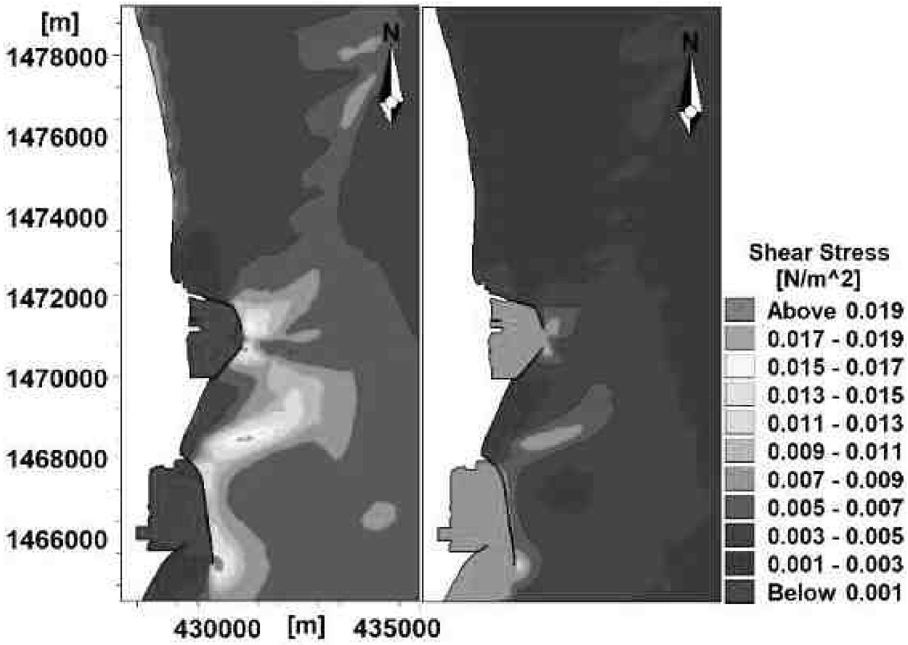


Figure 13-2 Critical shear stress: Erosion (Left), Deposition (Right)

13.5.3 Bed Parameters

The bed sediment is defined by the sediment mass contained in the layer and by the dry density and erosion properties of the layer. For Layer 1, the dry density is chosen as 180 kg/m^3 and for layer 2 the dry density is chosen as 300 kg/m^3 in the model. Bed roughness considered in mud transport model is 0.005m.

13.6 Initial Conditions

Values of bed composition and the suspended sediment are specified as initial conditions in the model calculations:

- Initial thickness of bed layers
- Initial concentration of suspended sediment
- Initial grain size distribution of the bed

The initial thickness of the specified bed layer defines the mass of sediment present in the bed at simulation start. The initial concentration defines the amount and distribution of sediment in the water column at the simulation start. The distribution of sediment fraction is specified as percentage of fraction.

13.7 Boundary Conditions

At each open boundary in the model, concentration of suspended sediment matter is specified. Zero sediment gradient is considered along the ocean boundaries.

13.8 Model Calibration

The calibration has been performed by comparing the modelled suspended sediment concentration (SSC) with the derived SSC from the measured water samples data. The water samples are collected by the survey consultant at various depths (surface, mid-depth and near-bottom) during spring tide at several geographic locations as shown in Figure 13-3.

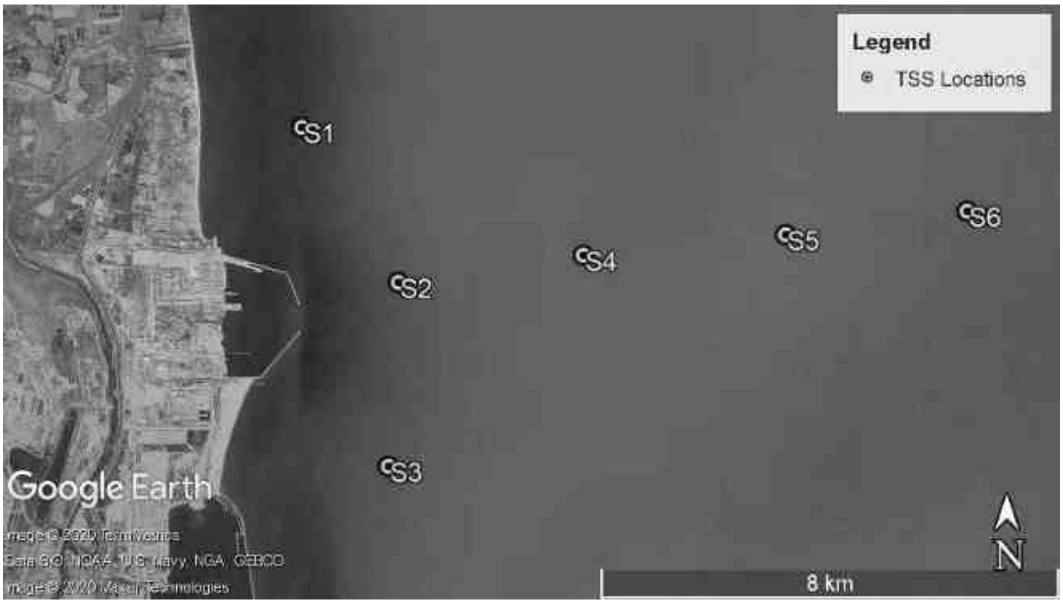


Figure 13-3 TSS sample collection locations during pre-monsoon

The periodically varying tidal currents, which increases linearly with tidal range, erode-resuspended material at a rate, which depends on the surface density of the sediment deposits and the bed shear stress. Sediment eroded from the seabed by the tidal currents is gradually dispersed throughout the depth by the process of vertical turbulent exchange.

A spring-neap tidal cycle has been simulated in order to predict the suspended sediment concentrations at the study area. The measured and simulated suspended sediment concentration during pre-monsoon season at three (3) locations is shown in Figure 13-4 to Figure 13-6.

The continuous lines in red colour represent the simulated suspended solids concertation and the fragmented lines in blue colour represents the measured suspended solids concentration. It should be noted that, measured water samples are not as continuous and hence the comparison is shown only for few hours. The maximum suspended solid concentration at location S1, S2 and S3 locations are ranging from 60 mg/l to 70 mg/l.

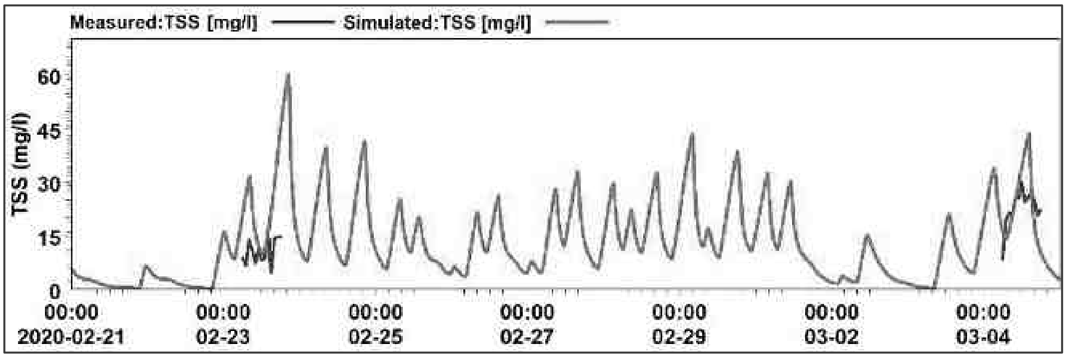


Figure 13-4 Comparison of measured and simulated suspended solid concentration at S1

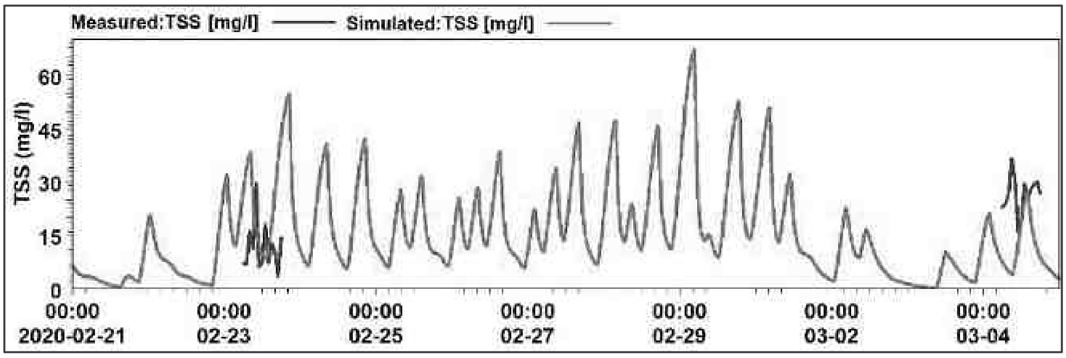


Figure 13-5 Comparison of measured and simulated suspended solid concentration at S2

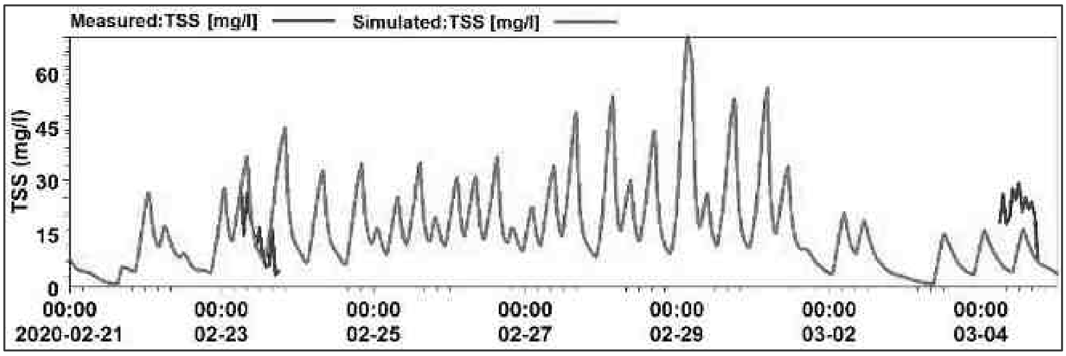


Figure 13-6 Comparison of measured and simulated suspended solid concentration at S3

Further, the model bed level changes in the approach channel are compared with actual dredging quantity information shared by MIDPL in existing approach channel. As per MIDPL records, the annual maintenance dredging quantity with the existing approach channel, turning circle and berthing area is around 450000 m^3. One-year average siltation quantity obtained from the mud transport model is around 455621 m^3. Table 13-2 lists the measured and modelled suspended solid concentration and siltation quantity, which indicates the model is replicating the bed level changes with a good agreement.

13.9 Model Results

The calibrated mud transport model presented in the previous section is further applied to predict the bed level changes in the approach channel, turning circle and basin area (Figure 1.7) with proposed Master Plan configuration.

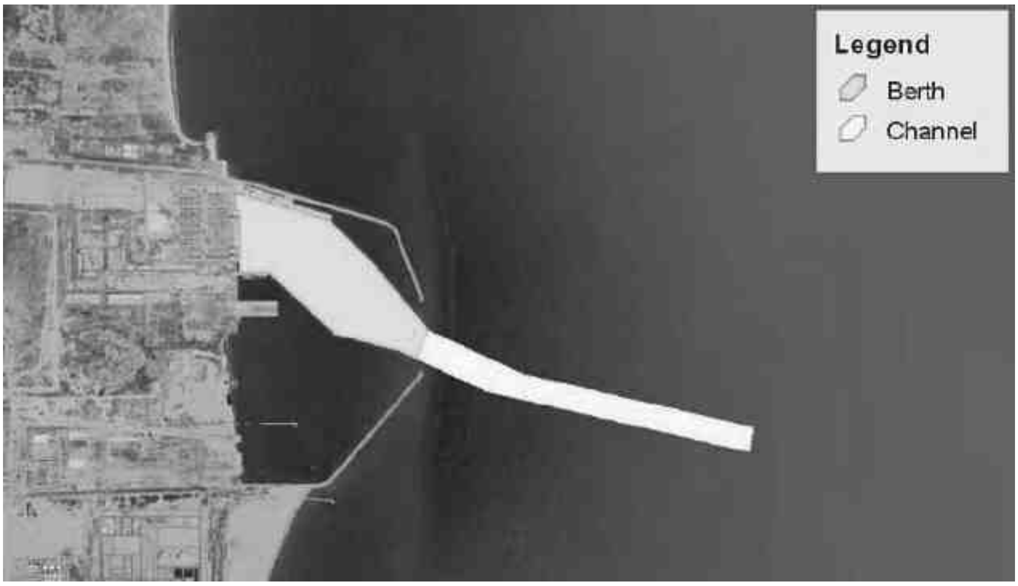


Figure 13-7 Existing dredging layout for in the Kattupalli port

Model results indicates that the maximum deposition of 0.055m is taking place during 15-day cycle (spring and neap) in the basin area with the baseline and proposed development.

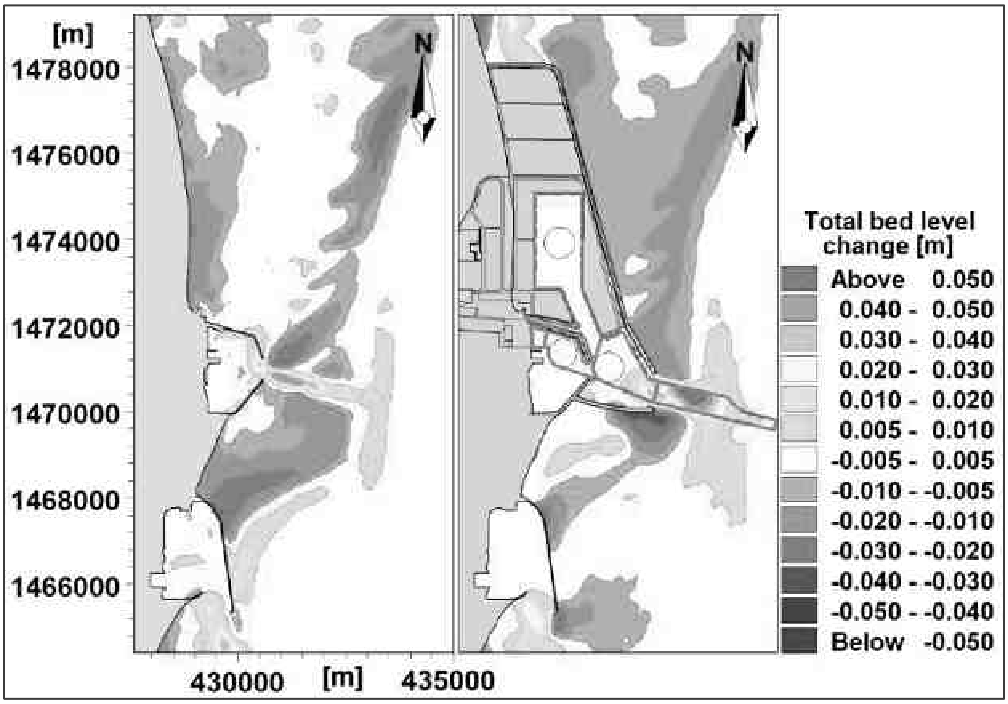


Figure 13-8 Bed level changes during pre-monsoon season with baseline & Master Plan layouts

Table 13-2 Annual siltation quantity with existing port facilities from model and dredging records

Section	Area (sq. m)	Annual Siltation (m^3) from MT Model		Annual Siltation (m^3) from dredging records
		Average	Maximum	
Turning circle & berth	718067	137869	689344	450000
Channel	440823	317393	528988	

13.10 Maintenance Dredging

Based on the siltation rates predicted using mud transport model, the annual maintenance dredging quantities are estimated at different sections of the proposed development (section-A, B, C and D) as shown in Figure 13-9. Table 13-3 lists the average/maximum bed level changes and siltation quantities in one-year (January to December 2020) at different sections (section-A, section-B, section-C and section-D) of proposed layout.

The analysis has set out that maximum sediment rates of between 0.91 and 1.85 m per year in the outer channel (Section A) and inner channel (Section B) respectively and up to 0.12m per year in the berthing area.

Further, the amount of dredging quantity per annum is estimated using the cross-sectional area of each section and listed below.

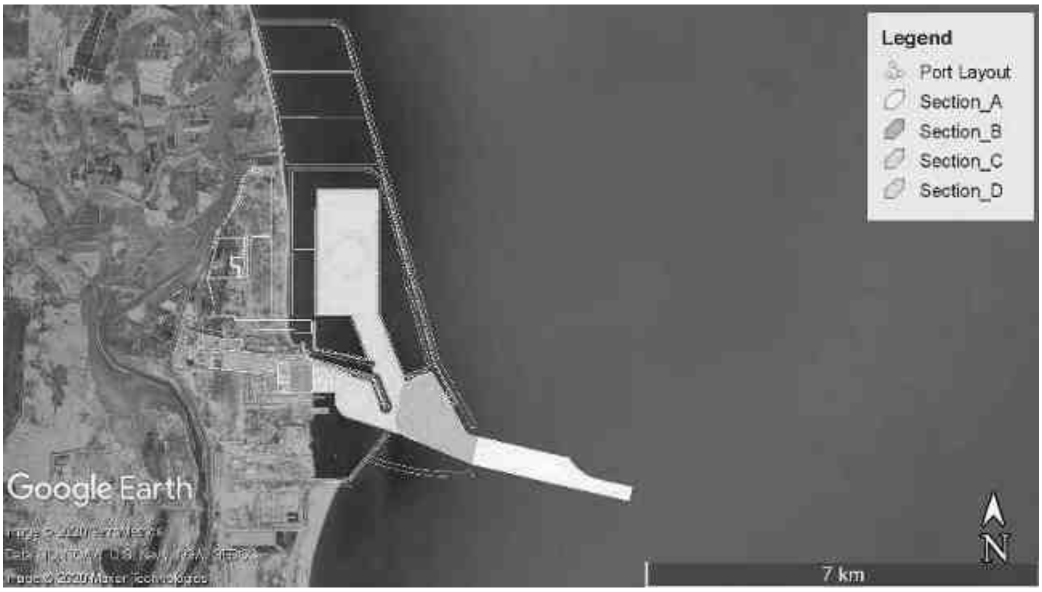


Figure 13-9 Proposed dredging layout plan cross-sections in the Kattupalli proposed layout

Table 13-3 Annual bed level change and siltation quantity with Kattupalli proposed layout

Section	Area (sq. m)	Annual Bed Level (m) Model: Layout		Annual Siltation (m^3) Model: Layout	
		Average	Maximum	Average	Maximum
Section-A	1186174	0.72	1.85	854045	1565750
Section-B	1329543	0.17	0.91	223363	1212543
Section-C	3757130	0.05	0.12	180342	450856
Section-D	129948	0.02	0.02	3119	3119

From the above information's the following inferences are made with regard to annual maintenance dredging quantities:

- To maintain a water depth of 27m w.r,t CD in the approach channel (Section-A) of the proposed Master Plan, the predicted average dredging quantity is 8,54,045 m^3/year and maximum dredging quantity is 1,56,5750 m^3/year.
- To maintain a water depth of 25m w.r,t CD in the basin area (Section-B) of the proposed Master Plan, the predicted average dredging quantity is 2,23,363 m^3/year and maximum dredging quantity is 1,21,2543 m^3/year.
- To maintain a water depth of 20.5m w.r,t CD in the basin area (Section-C) of the proposed Master Plan, the predicted average dredging quantity is 1,80,342 m^3/year and maximum dredging quantity is 4,50,856 m^3/year.
- To maintain a water depth of 16m w.r,t CD in the basin area (Section-D) of the proposed Master Plan, the predicted average dredging quantity is 3119 m^3/year and maximum dredging quantity is 3119 m^3/year.
- For the given Master Plan consisting of approach channel, turning circle and berthing area, the total predicted average dredging quantity is 12,60,869 m^3/year and maximum dredging quantity is 32,32,267 m^3/year.

The effects of deepening of the access channel have been analysed through certain hydraulic parameters. This provides an understanding of the flow at the channel, and effect of channel deepening. It is stressed that the changes in the hydraulic regime, from deepening the channel, relies entirely on the channel being dredged to a constant depth over the entire length and width to be maintained.

During the dredging period, it is observed that the high impact on marine water quality is mostly in the immediate vicinity of the port area. Also the turbidity level will reach the ambient level within a very short duration. Thus, it can be inferred that dredging would cause a short-term and localised impact on the marine water quality in the study area. Pulicat lake inlet/mouth is located approximately at 10 km north of proposed port masterplan boundary and the model results indicate that there is no sign of adverse impact to Pulicat lake due to the dredging activities involved during the maintenance dredging.

14 Non-Cohesive Sediment Transport Study

The present study portrayed the morphological change with its effect on bed level change for existing and proposed Mater Plan layout at Kattupalli Port under the combined action of waves and currents along Ennore to Pulicat Creek. It is specifically suited for application to coastal engineering problems for studying sediment transport studies of non-cohesive sediments. The DHI's MIKE 21 Sand Transport (ST) model is used to simulate morphological response to port structures and under natural conditions.

14.1 Model Setup

The non-cohesive sand transport model (MIKE 21 ST Model) is used for the calculation of sediment transport capacity and resulting bed level changes for non-cohesive sediment (sand) under the action of currents and waves or pure current. It calculates sand transport rates on a flexible mesh (unstructured grid) covering the area of interest based on the hydrodynamic data obtained from a simulation with the Hydrodynamic Module (HD) and possibly wave data (provided by MIKE 21 SW) together with information about the characteristics of the bed material.

The simulation is performed based on the hydrodynamic conditions that correspond to a given bathymetry. This model can be applied to quantify sand transport capacity in all areas where waves and/or currents are causing non-cohesive sediment movements. The ST module can be used on all scales from regional areas (10 kilometers) to local areas around coastal structures, where resolutions down to meters are needed. It is developed to span the gap from the river to the coastal zone.

The ST module covers accordingly many different application areas: The most typical ones are:

- Shoreline management
- Optimization of port layouts
- Shore protection works
- Stability of tidal inlets
- Sedimentation in dredged channels or port entrances
- Erosion over buried pipelines
- River morphology

14.2 Model Bathymetry

The model bathymetry considered for sedimentation study is shown in Figure 14-1 for baseline and Master plan layout conditions. Bathymetry data for the entire domain is obtained from the survey data provided by the client and from C-Map is used for the study.

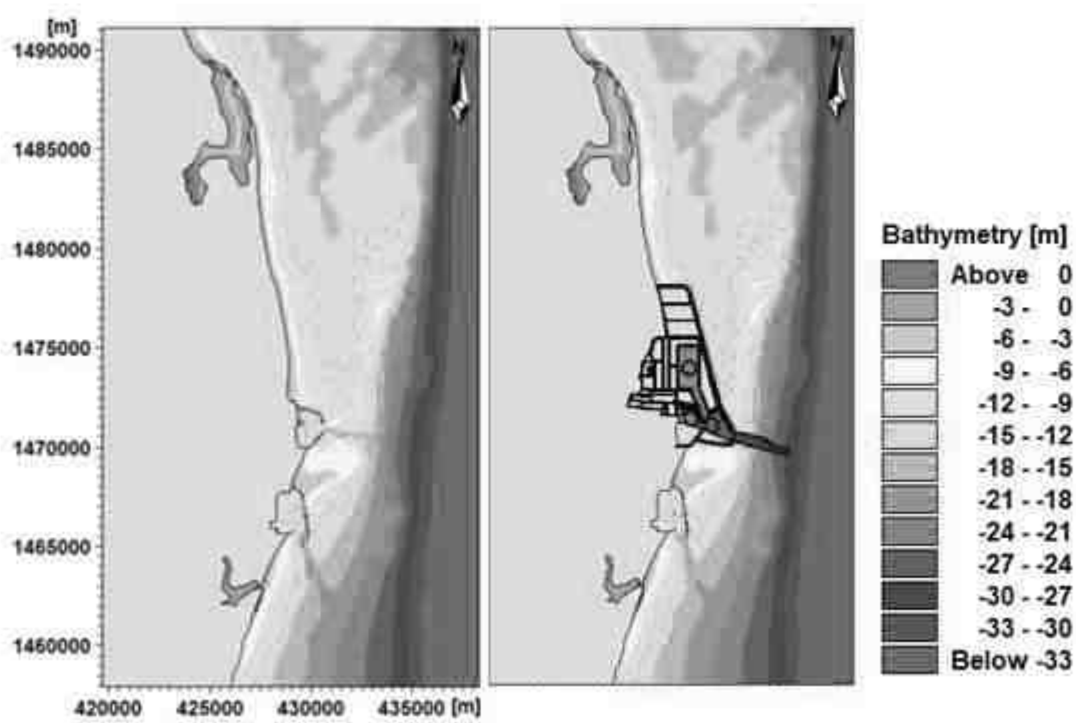


Figure 14-1 Bathymetry data: Baseline Conditions (Left), Master Plan Layout (Right)

14.3 Simulation Period

The simulation is carried out in coupled mode for a period of one year, from 1st January to 31st December 2020, for a typical monsoon and non-monsoon period, in order to estimate sediment transport capacity and resulting bed level changes in the vicinity of the existing and proposed layout development.

14.4 Model Parameters

The sediment transport is calculated in two modes: bed load and suspended load. For pure current model, the bed load and suspended load are calculated separately whereas for combined wave and current actions, the total load (bed + suspended) is calculated.

In combination with the hydrodynamic module, the sediment transport patterns for specified configurations are also simulated for the baseline conditions and for proposed Master plan layout conditions. For the model type with combined wave and current action, the model uses precalculated sediment transport rates for a set of specified parameters. For the simulation of sediment transport a table is generated beforehand using ‘MIKE21 Toolbox – Q3D Sediment transport table’ generator. The parameters used in the generation are specified in Table 14-1. These are then used in the calculations to find transport rates using linear interpolation.

Currently only one fraction of sediment input is allowed in both cases. There is also a provision for including the effects of morphological changes on the hydrodynamics of the area which in turn affect the sediment transport pattern. The model, in general, requires the following inputs and some bed characteristic information: Selection of model type, Sediment properties such as D_{50}, porosity, gradation, relative density. For model simulation, the characteristic of wave field is given as input in wave forcing which is obtained from results of the stand-alone SW model.

Table 14-1 Model parameters used in sand transport model set up

Model Parameter	Value
Model definition	Model type: Combined waves and current
Sediment properties	Porosity: 0.4 Grain diameter: 0.31 mm Grading coefficient: 1.10
Wave field	From Spectral wave model Results
Flow field	From Hydrodynamic model Results
Morphology	No slope failure Boundary conditions: Zero sediment flux gradient

The 'sediment transport table' is generated using a specified parameters as shown in Table 14-2.

Table 14-2 Parameter values for generating sediment transport table

Model Parameter	Value
General parameters Θ_c: S: N max N steps q_tole	 0.05 Critical Shields parameter) 2.65 (Relative density of sediment) 1000 (Max number of steps in concentration profile iteration) 140 (Number of steps during wave period) 0.1e-3 (Tolerance for suspended sediment transport)
Wave parameters Wave theory Wave breaking parameters	 Stokes's 5th order Υ_1= 1 and Υ_2 = 0.8
Calculation parameters Ripples Bed concentration formulation Boundary layer streaming Bed slope Cross current transport Centrifugal acceleration	 Included Deterministic (Engelund and Fredsøe, 1976) Included Included Included Excluded

The sediment transport table is then generated to cover the wave, current, sediment and bed slope parameters obtained from the hydrodynamic results, spectral results, and specified bathymetry. The combined waves and current model is then simulated by using characteristic wave field, which is generated from SW simulation for both baseline and Master port layout conditions. A condition of zero sediment flux gradient is applied at the boundaries. The sediment porosity and grading are considered as 0.4 and 1.10 respectively.

14.5 Model Processes and Physical Processes

The initial water level variation is kept constant throughout the simulation. The depth averaged current velocity is obtained from a flow simulation, due to wind force as temporally varying and spatially constant in the model domain and the resulting currents are feed into ST model simulation. Wave radiation stress is also considered as varying with model domain which is from the result of spectral wave model. Dissipation due to white capping, bottom friction and depth-induced wave breaking are considered in the model.

14.6 Boundary conditions

An important aspect in hydrodynamic modelling is the boundary conditions. For a proper simulation and reliable model outcomes it is evident to describe these boundary conditions accurately.

The boundary conditions in the HD-module are specified as constant levels based on the major diurnal (K1, O1, P1 and Q1) and semi-diurnal (M2, S2, N2 and K2) tidal constituents at a spatial resolution of 0.1250 X 0.1250.

The boundaries in the ST-module are specified as 'zero sediment flux gradient'. This way the inflow and the bottom of sediment into the model is kept at its place. This ensures a representative sediment flow into and out of the model domain.

14.7 Modelling Results

The numerical model of sand transport has been applied to simulate the bed level changes for existing condition and further applied to predict the bed level changes in the approach channel, turning circle and basin area with proposed Master Plan configuration under the action of prevailing wave and currents as shown in Figure 14-2.

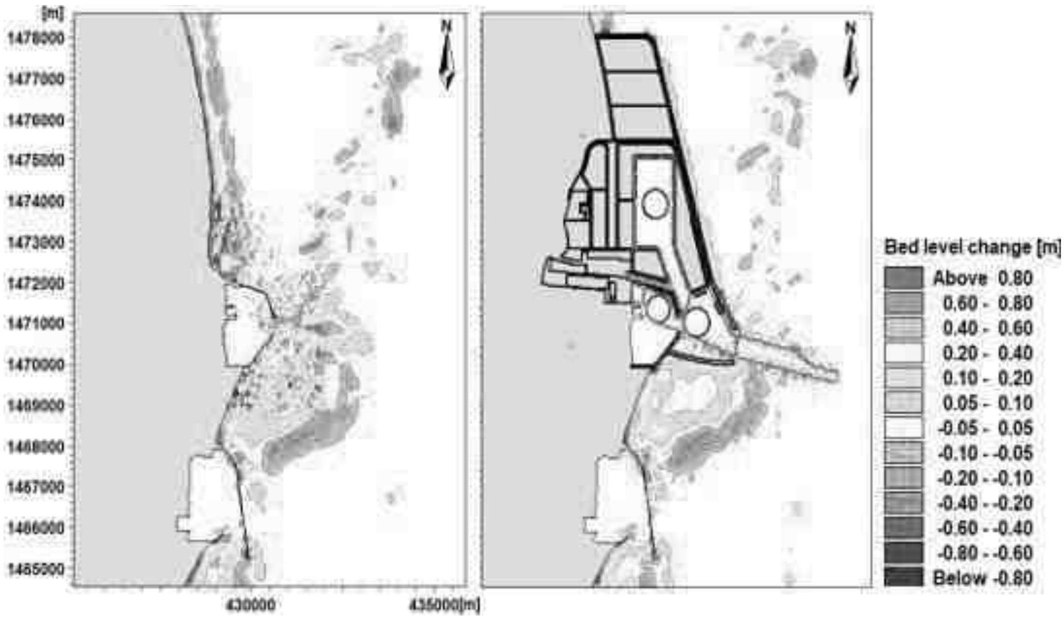


Figure 14-2 Bed level changes: baseline (Left), Master Plan layouts (Right)

It can be observed from Figure 14-2 that the resulting bed level changes are due to tidal currents which are of the order of -0.05 to 0.05 m can be considered as negligible. The bed level changes show the erosion/deposition where the wave induced currents are dominant over the region. The predicted values are not large, and this is mainly since the transport varies smoothly with no drastic changes.

The erosion is occurred at north side of Ennore port after the northern breakwater which is due to presence of shoals in that region and sediments get deposited towards the coast by reduced wave action. There is no bed level change inside Kattupalli port because of an effect of wave action is felt only at nearshore region. The deposition is noticed to be more at the entrance of Kattupalli port channel due to a variation of flow regime in deepening of channel approach. The erosion is occurred near to the surf or wave breaking zone at north of Kattupalli port and sediments get deposited along the coast.

14.8 Maintenance Dredging Quantities

14.8.1 Baseline Condition

The siltation capacity has been estimated using sand transport model from which the annual maintenance dredging quantities are quantified at different sections of existing port facilities as shown in Figure 14-3. Table 14-3 lists out the average and maximum bed level change and siltation quantities for the year of 2020 at two sections such as turning circle (berth) and channel.

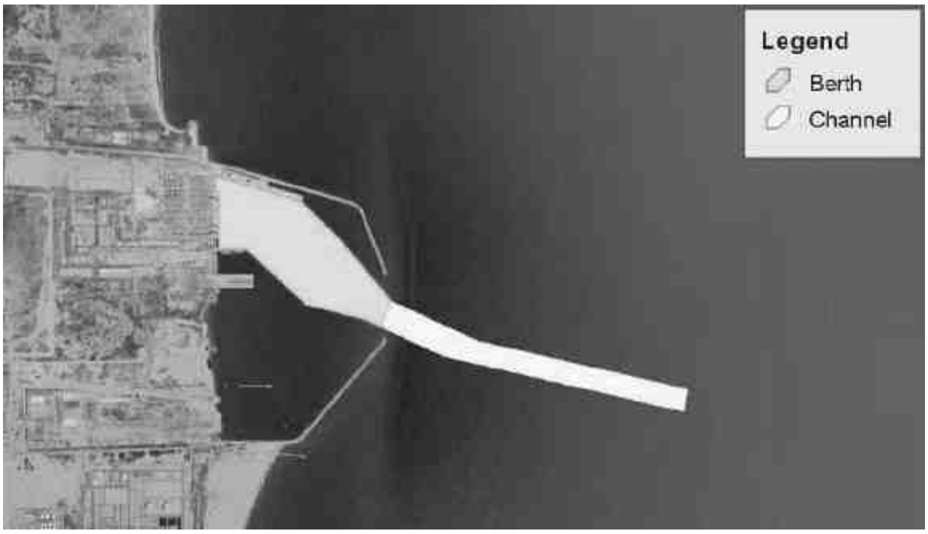


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Figure 14-3 Dredging layout of existing Kattupalli port

From the model results, it is examined that an average deposition of 0.7m is taking place in both sections for one year period in the existing port facilities.

Table 14-3 Annual bed level change and siltation quantity for existing port facilities

Section	Area (sq. m)	Annual Bed Level Change (m) Model: Existing Port		Annual Siltation (m^3) Model: Existing Port	
		Average	Maximum	Average	Maximum
Turning circle & berth	718067	0.21	1.15	152302	825777
Channel	440823	0.49	0.81	215078	357067

14.8.2 Master Plan Layout Condition

Based on the siltation rates, the annual maintenance dredging quantities are quantified at different sections of the proposed port development (section-A, B, C and D) as shown in Figure 14-4. Further, the amount of dredging quantity per annum is estimated using the cross-sectional area of each section and listed in below Table 14-4 which list out the average/maximum bed level changes and siltation quantities in one-year (January to December 2020) at different sections (section-A, section-B, section-C and section-D) of proposed layout.

The analysis has set out that maximum sediment rates are between 1.43 and 0.74m per year in the outer channel (Section A) and inner channel (Section B) respectively and up to 0.26m per year in the berthing area.

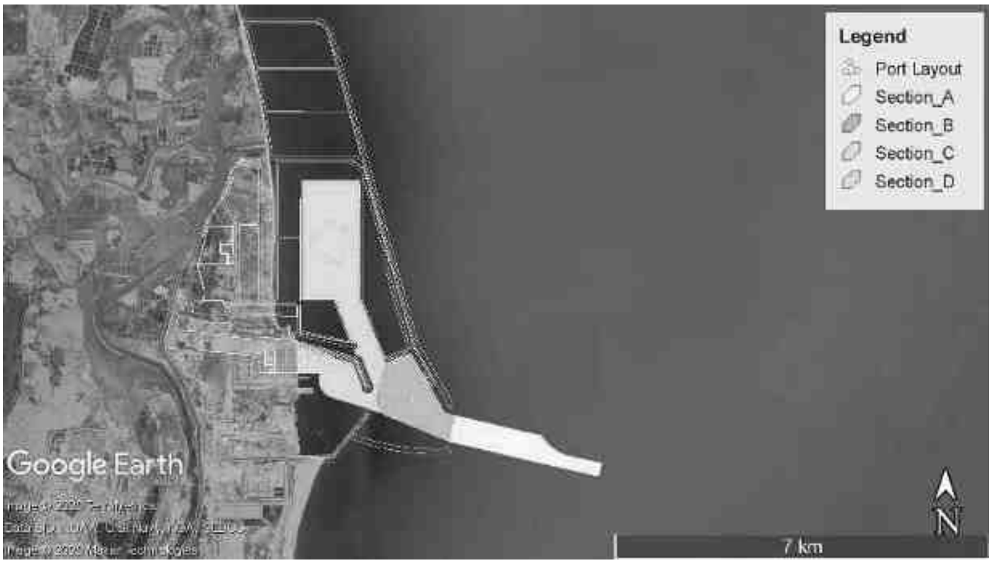

Figure 14-4 Proposed dredging layout plan proposed layout

Table 14-4 Annual bed level change and siltation quantity for proposed layout

Section	Area (sq. m)	Annual Bed Level Change (m) Model: Layout		Annual Siltation (m^3) Model: Layout	
		Average	Maximum	Average	Maximum
Section-A	1186174	0.28	1.43	332129	1696228
Section-B	1329543	0.04	0.74	53182	983862
Section-C	3757130	0.01	0.26	37571	976854
Section-D	129948	0.01	0.07	1300	9097

From the above table the following inferences are made with regard to annual maintenance dredging quantities:

- To maintain a water depth of 27m w.r,t CD in the approach channel (Section-A) of the proposed Master Plan, the predicted average dredging quantity is 3,32,129 m^3/year and maximum dredging quantity is 16,96,228 m3/year.
- To maintain a water depth of 25m w.r,t CD in the basin area (Section-B) of the proposed Master Plan, the predicted average dredging quantity is 53,182 m^3/year and maximum dredging quantity is 9,83,862 m^3/year.
- To maintain a water depth of 20.5m w.r,t CD in the basin area (Section-C) of the proposed Master Plan, the predicted average dredging quantity is 37,571m^3/year and maximum dredging quantity is 9,76,854 m^3/year.
- To maintain a water depth of 16m w.r,t CD in the basin area (Section-D) of the proposed Master Plan, the predicted average dredging quantity is 1,300 m^3/year and maximum dredging quantity is 9,097 m^3/year.
- For the given Master Plan consisting of approach channel, turning circle and berthing area, the total predicted average dredging quantity is 4,24,182 m^3/year and maximum dredging quantity is 36,66,041 m^3/year.

15 Dredge Soil Disposal and Dispersion

Dredge disposal sites should be selected on the basis of non-interference with navigation and also based on the nearshore circulation phenomena and hydrodynamic characteristics of the sea. Economic and environmental considerations should be covered before the selection of the dumping site. The selection of dumping ground for dredged material should be such that the dredged material disposed at the dumping ground should not come back into the port channel. Further, the material shall be disposed of evenly spread at the dumping ground to see that the depths should not get reduced unevenly.

Deepening the approach channel will most likely increase the amount of deposition in the channel there by increasing the needed maintenance dredging. The predicted quantities of maintenance dredging with the proposed Master Plan is around 1.2 Million cu.m/yr (Chapter-1), which is of predominantly fine material from approach channel, turning circle and berth area.

The fine material will be dredged using Trailer Suction Hooper Dredger and will be bottom disposed at the designated spoil ground of 2 sq. miles as shown in Figure 15-1.

In the present chapter the following two aspects are assessed with regard to dredge spoil disposal and dispersion:

- Stability of the spoil ground to make sure the disposed sediment stays at the spoil ground.
- In case the disposed sediment is not stable, in which quantities can be expected to leave the spoil ground and where does the sediment move. Does it return to approach channel where it will need to be removed again?

DHI proposed to base all these studies in detail consisting of hydrodynamic and spectral wave model which have been developed as part of the shoreline management plan. These models cover all the complete proposed development and are very well suited to the studies.

In the present study, two spoil grounds are considered, both the spoil ground is having an area of 1716264m^2 and approximatly.4.5km away from the proposed port location (Figure 15-1). The extent of spoil grounds is represented in the figure as rectangles with red (existing spoil ground) and yellow (proposed spoil ground). Spill rate and dredger trips details are provided in Table 15-1

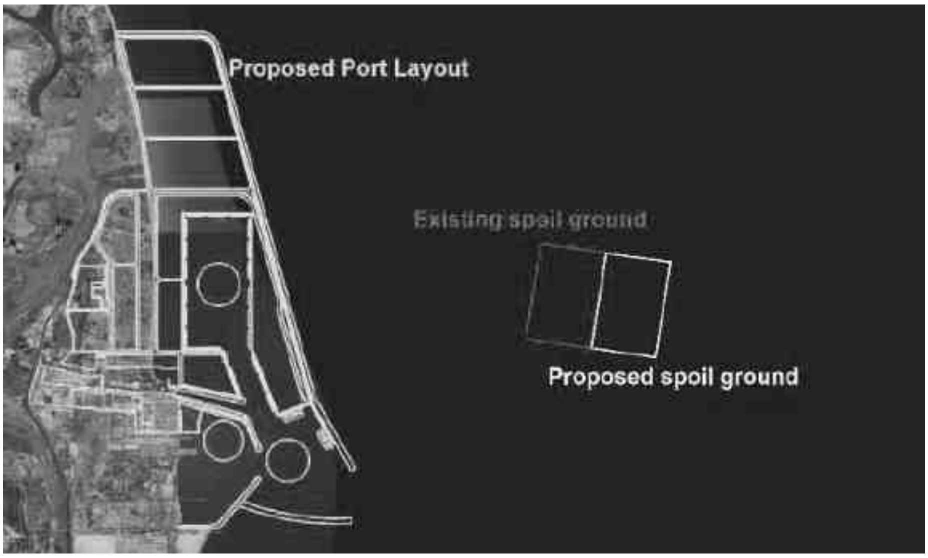

Figure 15-1 Dumping location of dredged materials

Table 15-1 Dredging and disposal details

Parameter	Unit	Value
Total Quantity	m^3	1260869
Total days for disposal	days	40
Cycles per day	trip	9
Time required per trip	Hours	2.6
Capacity of barge	m^3	3502
Spill rate	m^3/hour	1347

The selection of a disposal site in sea depends on several factors such as environmental considerations, characteristics of the material, short-term fate of the dredged material and the initial deposition pattern of the material in the sea bottom. These factors in turn determine the long-term movement of the disposed material from the disposal site. Generally, coarse material quickly settles to the bottom, while fine material is removed during its descent to the bottom and transported by currents to adjoining areas. In this case, the disposed material is mainly fine silty sand, which will be in suspension in the disposal area. Hence, the environmental conditions at the location of the disposal site should be such that, it is not subjected to high near-bottom current velocities, which may cause the disposed material to return to approach channel, etc. Moreover, the shuttle distance between the disposal site and the area of dredging should not be too long since the disposal quantity is 1.2M Cum, which is comparatively less.

The grain size of the surface sediment samples varies from fine sand to coarse sand hence useful for reclamation. The remaining quantity may be dumped into sea, at the appropriate site having favourable hydrodynamic conditions by arresting the movement of the disposed material. Keeping the above environmental and economic considerations in view, a suitable disposal area has been proposed at north-eastern side of the port limit at a water depth of 25-30 m adjacent to the existing disposal ground. The dredge spoils will be disposed through a hopper or suitable dredger at the dumping ground. The impacts due to disposal of dredged material are assessed through mathematical modelling. The spreading of turbidity at disposal location, suspension & resuspension of sediment in the bulk of water column

The hydrodynamic model is configured as a depth integrated 2D model which is coupled with MIKE 21 Mud Transport (MT) model. The dispersion of dredge material at the existing and proposed spoil ground is simulated for 60 days during the pre-monsoon period. A constant sediment disposal/spill rate of 1347m^3/hour is specified (assuming that the 1.2 million Cu. m of the annual maintenance dredged soil is to be disposed of within this time window). The maximum bed level change incurred due to dumping is around 0.28m at both the dumping grounds in 60 days simulation period. The spread of the disposed of sediment on the seabed is shown in Figure 15-2 to Figure 15-6. The model results show that the dumped materials not spreading beyond the port limit and also 1.2 million Cu. M of annual maintenance dredging will not make any adverse impact to the Pulicat lake.

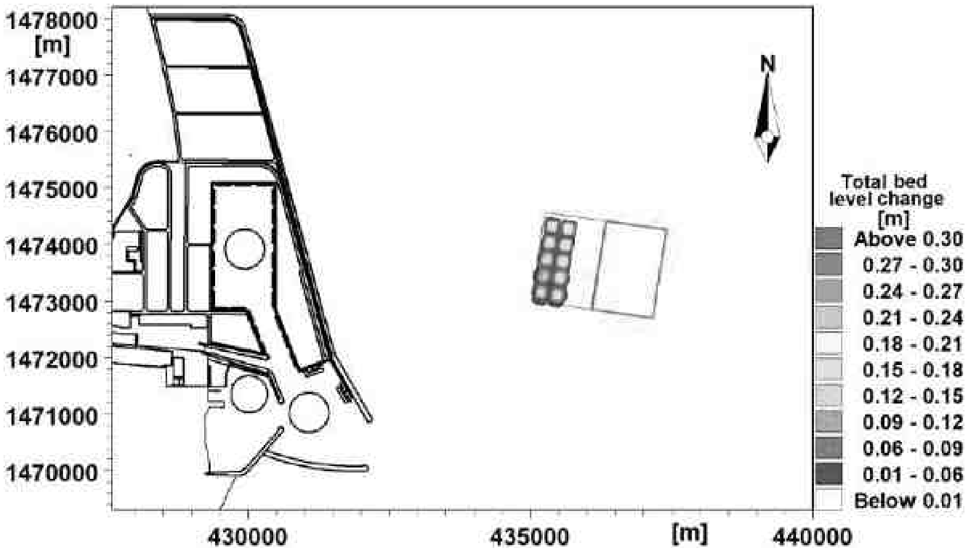

Figure 15-2 Total bed level change at spoil ground after 10 days of dumping

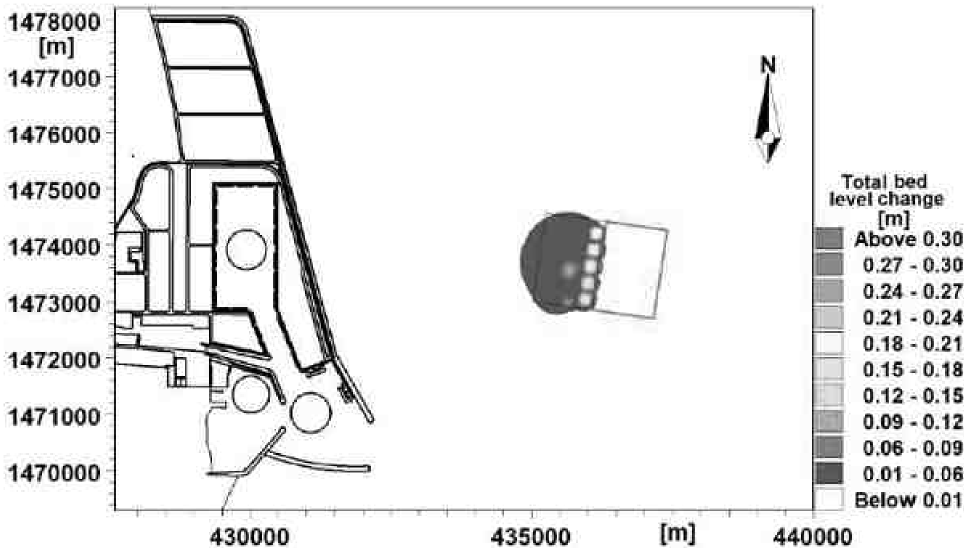

Figure 15-3 Total bed level change at spoil ground after 20 days of dumping

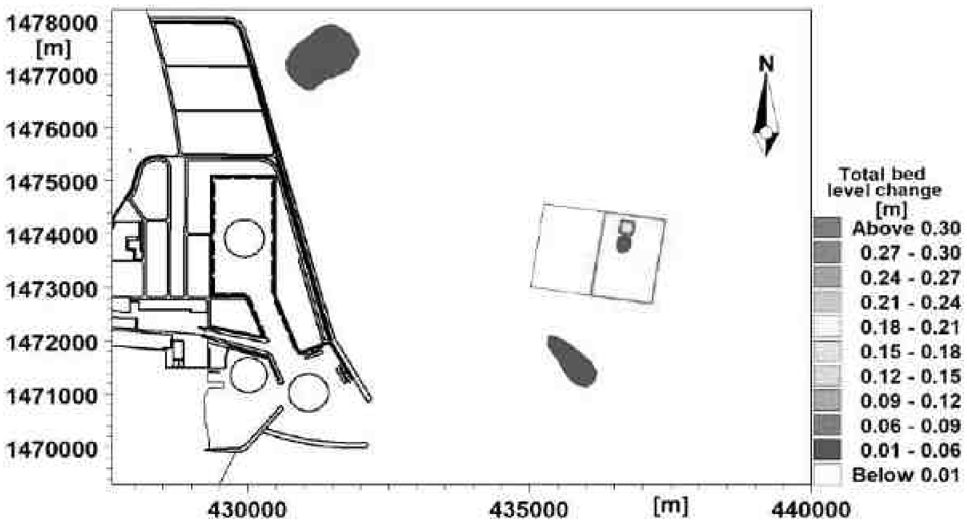

Figure 15-4 Total bed level change at spoil ground after 30 days of dumping

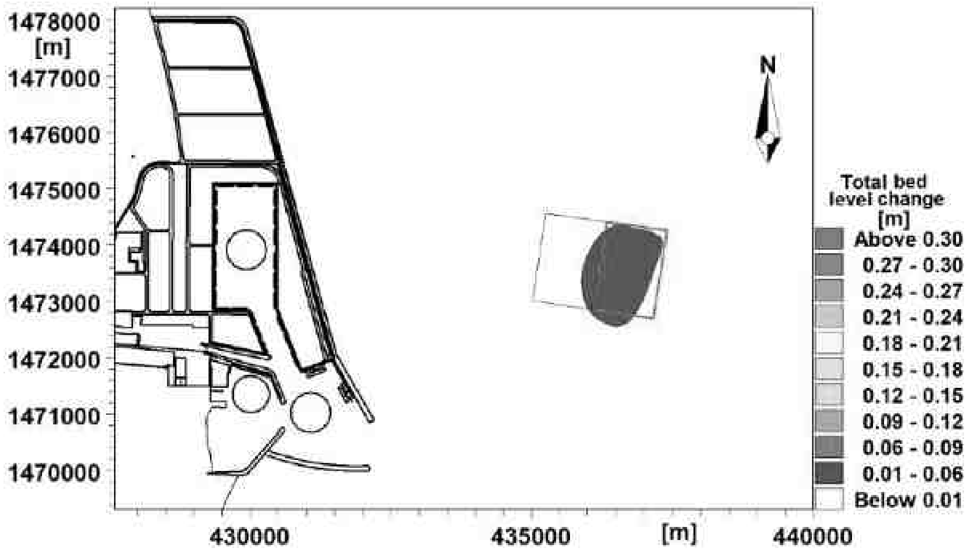

Figure 15-5 Total bed level change at spoil ground after 40 days of dumping

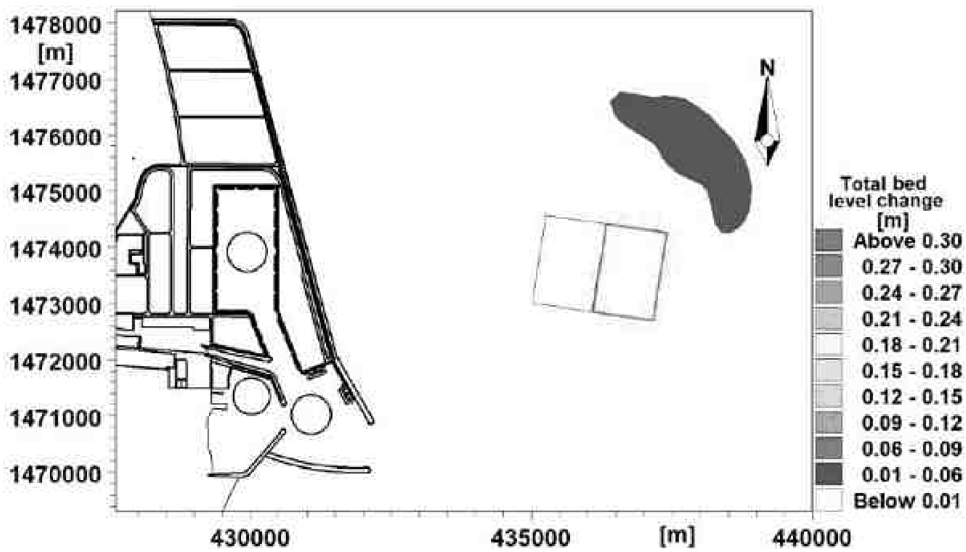

Figure 15-6 Total bed level change at spoil ground after 60 days of dumping

The area map of bed level change at different time periods shows that the bed level change after 20 days at the spoil area is less than 90mm. This is clearly seen that the sediment is not accumulating at the spoil ground. 60 days of model results shows that the spoil ground reaching its natural bed level

The maximum suspended solid concentration incurred due to dumping is around 4kg/m^3 while dumping at both the dumping grounds. The model result clearly shows that the total suspended sold concentration gradually changing from disposal ground to the nearby area. After 20 days of dumping the suspended solid concentration near the proposed breakwater is reaching up to 2kg/m^3 but the value is gradually reduced, and the value becomes 0.4kg/m^3 at the end of the simulation. The movement of the suspended solids mainly due to the action of tide induced current and the wave climate at the study area. The maximum TSS concentration is 0.4kg/m^3 at the spoil ground after 60 days and it clarifies that most of the dumped soil is in suspension and spreading to the port limit. The total suspended solid concentration at deferent time interval is represented in Figure 15-7 to Figure 15-11.

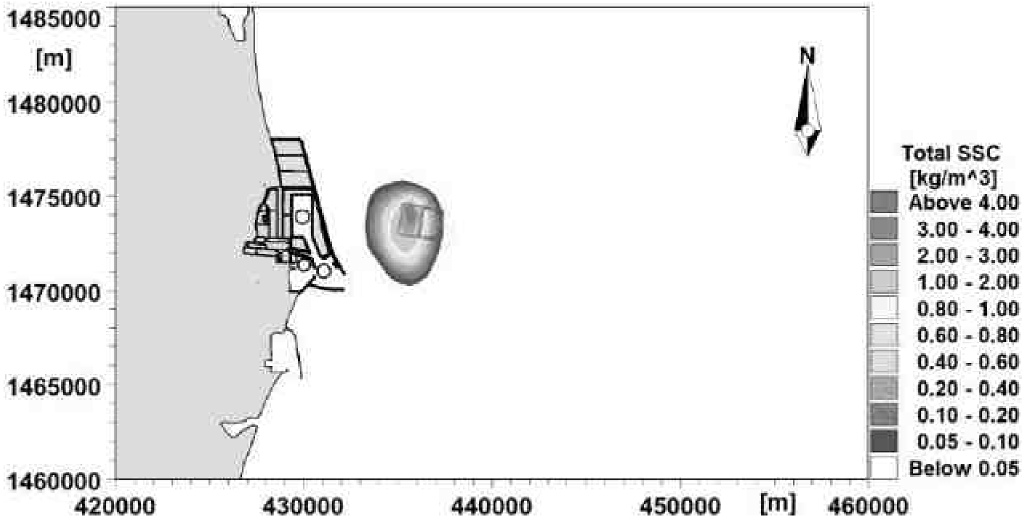

Figure 15-7 Total suspended solid concentration at spoil ground after 10 days of dumping

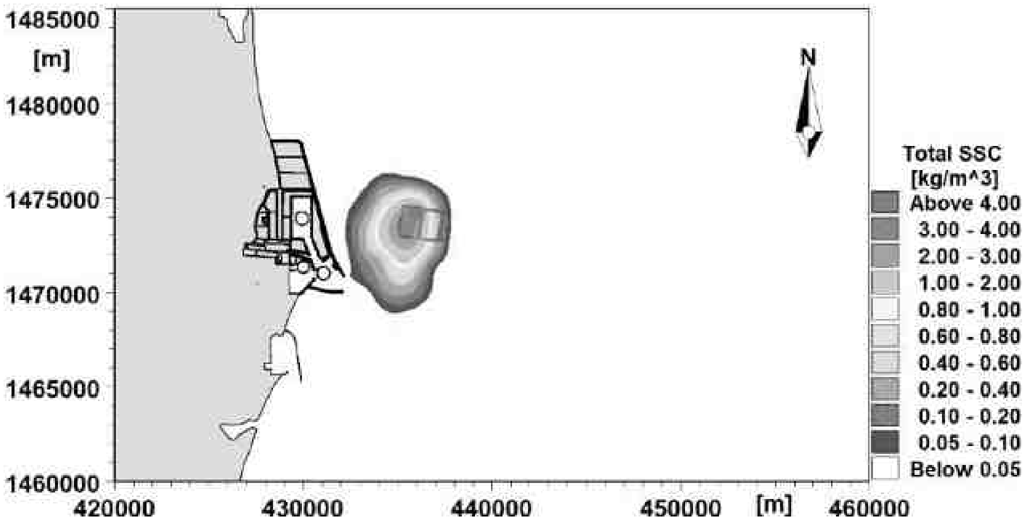

Figure 15-8 Total suspended solid concentration at spoil ground after 20 days of dumping

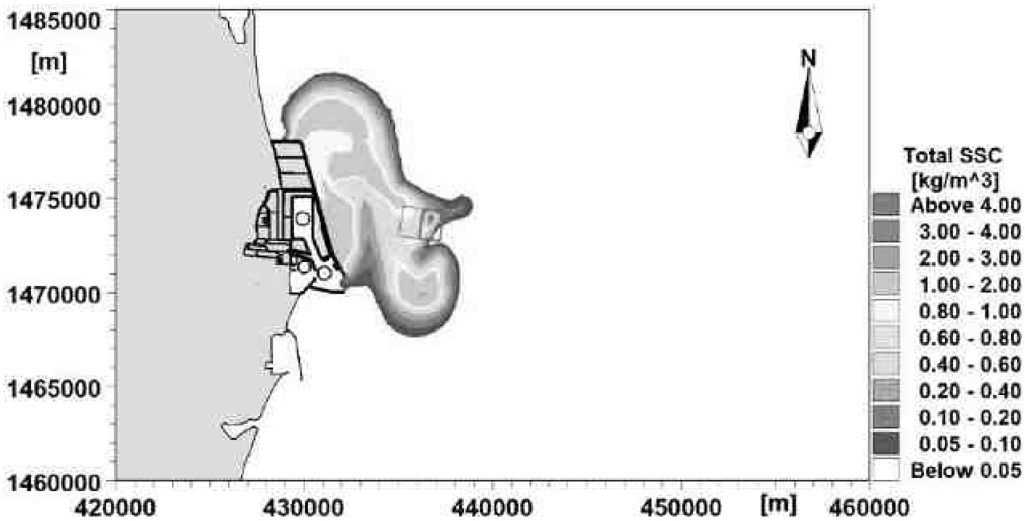

Figure 15-9 Total suspended solid concentration at spoil ground after 30 days of dumping

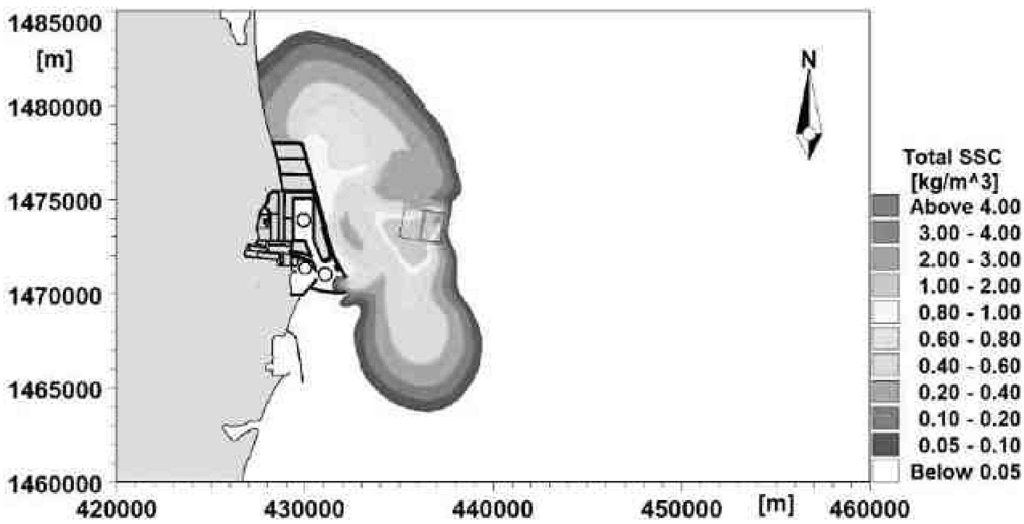

Figure 15-10 Total suspended solid concentration at spoil ground after 40 days of dumping

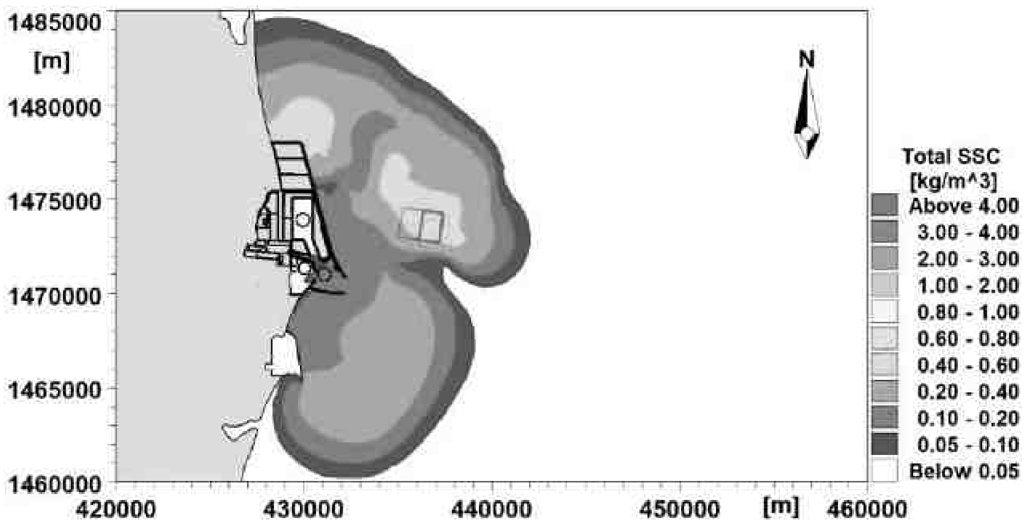

Figure 15-11 Total suspended solid concentration at spoil ground after 60 days of dumping

During the dredge disposal period, it is observed that the impact on marine water quality is observed mostly in the immediate vicinity of the disposal ground and the turbidity level will reach the ambient level within a short duration. Thus, it can be inferred that dredging would cause a short-term and localised impact on the marine water quality in the study area. Pulicat lake is located at 10 km north of the proposed port masterplan boundary and the model results indicates that there is no significant or adverse impact to Pulicat lake due to the activities involved during dredge disposal.

16 Recirculation Study

16.1 100 MLD and 30 MLD Seawater Desalination Plant

Govt. of Tamil Nadu and Chennai Metropolitan Water Supply & Sewerage Board (CMWSSB) has established a 100MLD sea water desalination plant at Kattupalli. The quantity of raw water drawn at intake is 235 MLD and quantity of product water produced is 100MLD.The process for the Desalination Plant at Kattupalli is Reverse Osmosis (RO) Membrane Conventional Method. The final product water is conveyed to the city distribution. The reject water from the RO is discharged into the sea with an outfall through 1600 mm diameter HDPE pipeline.

As a part of the proposed Master Plan development, a 30 MLD seawater desalination plant is proposed by MIDPL in addition to the existing CMWSSB 100 MLD plant. The quantity of the raw water drawn will be 75 MLD and quantity of product water produced will be 30 MLD. The final product water will be utilized for the drinking water purpose for MIDPL.

In this regard recirculation study for the existing 100 MLD and proposed 30 MLD as shown in Figure 16-1 is performed in this chapter. It is to be noted that from Figure 16-1, the Intake locations Intake-1, Intake-2 and Intake-3 are away from the entrance to the port also free from siltation (Refer Figure 13-8 and Figure 14-2).

The intake locations are selected mainly based on the aspects that it has to be free from siltation and availability of water through out. The Intake locations for 100 MLD and 30 MLD seawater treatment plants are outside the main breakwater. These locations are free from siltation (from Figure 14-2Bed level changes: baseline (Left), Master Plan layouts (Right)Figure 14-2).

The objective of the recirculation study is:

- Determine the dispersion of the brine discharge from the two units
- Determine the combined mixing zone of both outfalls for compliance with the environmental regulations

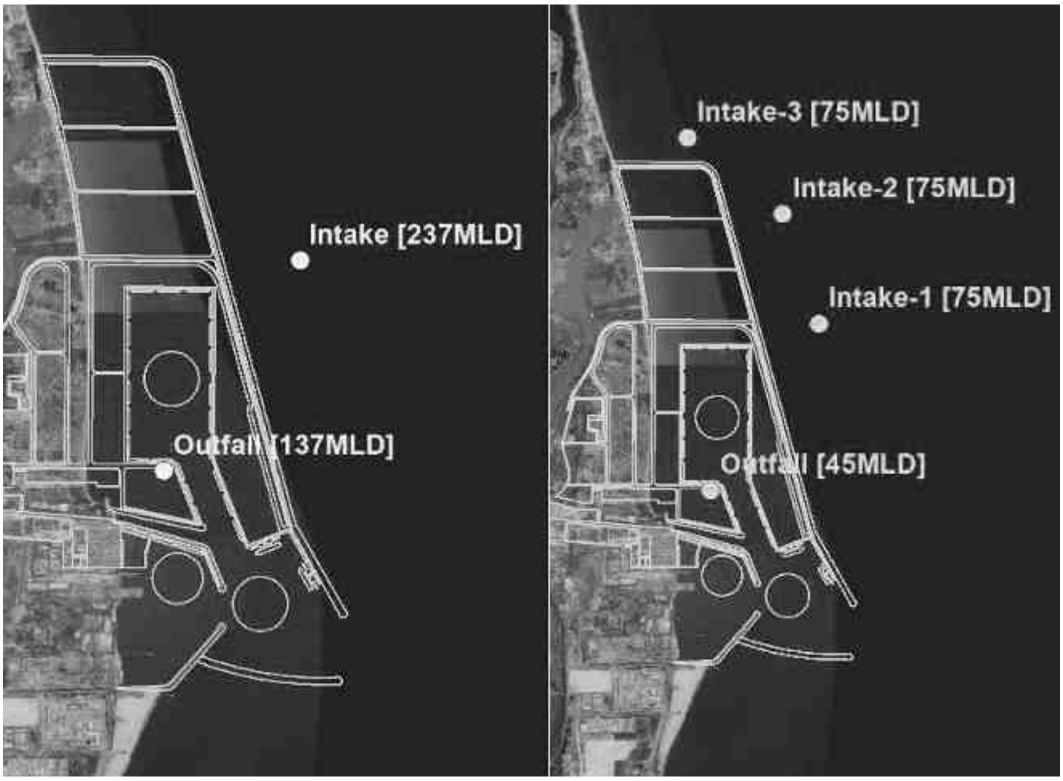

Figure 16-1 Intake and outfall locations: 100MLD (Left), 30MLD (Right)

Table 16-1 summarizes the intake and outfall details for both existing and proposed plants at the MIDPL layout. The geographical positions of the intakes and outfalls are chosen according to the information received from MIDPL. The intake and outfall locations are simulated using MIKE 21 FM Advection-Dispersion (AD).

The scenarios cover variations of the following variables that influence the current pattern in the vicinity of the Kattupalli port:

- Ambient current (tide conditions)
- Meteorological conditions (water temperature and wind)
- Seasonal conditions (winter, summer)

Table 16-1 Intake and outfall locations for 100 MLD and 30 MLD capacity desalination plants

Parameter	Intake	Outfall
CMWSSB Existing 100 MLD Plant		
Easting [m], UTM 44	431590	429843
Northing [m] UTM 44	1475433	1472733
Depth [m] w.r.t CD	13	9
Discharge rate [m^3/sec]	2.74	1.58
Excess temperature [^{o}C]	-	1
Excess Salinity [PSU]	-	35
MIDPL Proposed 30 MLD Plant (Option-1)		
Easting [m], UTM 44	431590	429843
Northing [m] UTM 44	1475433	1472733
Depth [m] w.r.t CD	13	9
Discharge rate [m^3/sec]	0.86	0.52
Excess temperature [^{o}C]	-	1
Excess Salinity [PSU]	-	35

MIDPL Proposed 30 MLD Plant (Option-2)		
Easting [m], UTM 44	431007	429843
Northing [m] UTM 44	1477212	1472733
Depth [m] w.r.t CD	13.4	9
Discharge rate [m^3/sec]	0.86	0.52
Excess temperature [°C]	-	1
Excess Salinity [PSU]	-	35
MIDPL Proposed 30 MLD Plant (Option-3)		
Easting [m], UTM 44	429466	429843
Northing [m] UTM 44	1478450	1472733
Depth [m] w.r.t CD	10.7	9
Discharge rate [m^3/sec]	0.86	0.52
Excess temperature [°C]	-	1
Excess Salinity [PSU]	-	35

A hydrodynamic model using DHI's 2D model system, MIKE 21 Flexible Mesh (FM) is set up and calibrated based on field data collected during pre-monsoon season. Water level and currents along the open boundaries of the model are taken from hydrodynamic model prepared as part of this study. High resolution model has been implemented in the outfall location.

16.1.1 Scenario Details

Each model simulation covers tidal variation of 15 days covering spring and neap conditions. The originally functioning CMWSSB intake is relocated to alternate location as this will be falling within the Master Plan area and cause water quality issues with the port operations.

- Scenario 1- CMWSSB outfall location with intake extended outside the proposed breakwater
- Scenario 2- MIDPL outfall location with three proposed intake options located outside the breakwater

16.1.2 Intake and Outfall

The intake and outfall of both the desalination plants are modelled so-called set of "connected sink and source". This means that the intake (sink) temperature and salinity is the actual absolute (and time varying) temperature/salinity at the location of the intake point. The temperature/salinity at the source point is the (time varying) intake temperature or salinity plus the specified excess temperature/salinity of the plant. From this it follows that any possible recirculation will increase not only the intake temperature/salinity but also the outfall temperature/salinity.

One assumption considered in the present assessment with the consent from MIDPL is, the outfall for the CMWSSB as well as for the MIDPL plant are similar to each other. They are modelled as several sources and prescribed excess temperature/salinity is added.

16.1.3 Results of Recirculation Modelling

The results are presented as excess salinities i.e. the salinity increase above the ambient salinity caused by the CMWSSB and MIDPL desalination plant outfalls. The model cannot reproduce in detail the flow around the intake and outfall. This would require an extremely detailed computational mesh and the simulation time would be excessive. Instead, the location of intake sinks, and outfall sources must be placed so they give a realistic representation of the effect of actual flow conditions near the structures on mixing and turbulence.

Model simulations are covering the spring and neap tide conditions. The maximum excess salinity calculated for every model point as a maximum value out of 15 days simulation.

Figure 16-2 and Figure 16-3, shows the mixing of the excess salinity and Figure 16-4 and Figure 16-5, shows the mixing of excess temperature released from CMWSSB outfall during the 15 days simulation with time varying tidal currents. The statistical average and maximum excess salinity indicate that maximum increase in salinity is 5 PSU close to the outfall location.

Figure 16-6 and Figure 16-7, shows the mixing of the excess salinity and Figure 16-8 and Figure 16-9, shows the mixing of excess temperature released from proposed MIDPL 30 MLD outfall during the 15 days simulation with time varying tidal currents. In all the simulations the excess salinity does not exceed 1.5 PSU at the outfalls, and this has further not reached to the intake locations considered outside the proposed Master Plan breakwater. Due to the excess salinity at the outfall, the dense plume is directed downwards to the bottom and maximum spreading can be occur at the bottom.

The model study results clearly indicates that the intake location is far from the contamination zone of the outfall water.

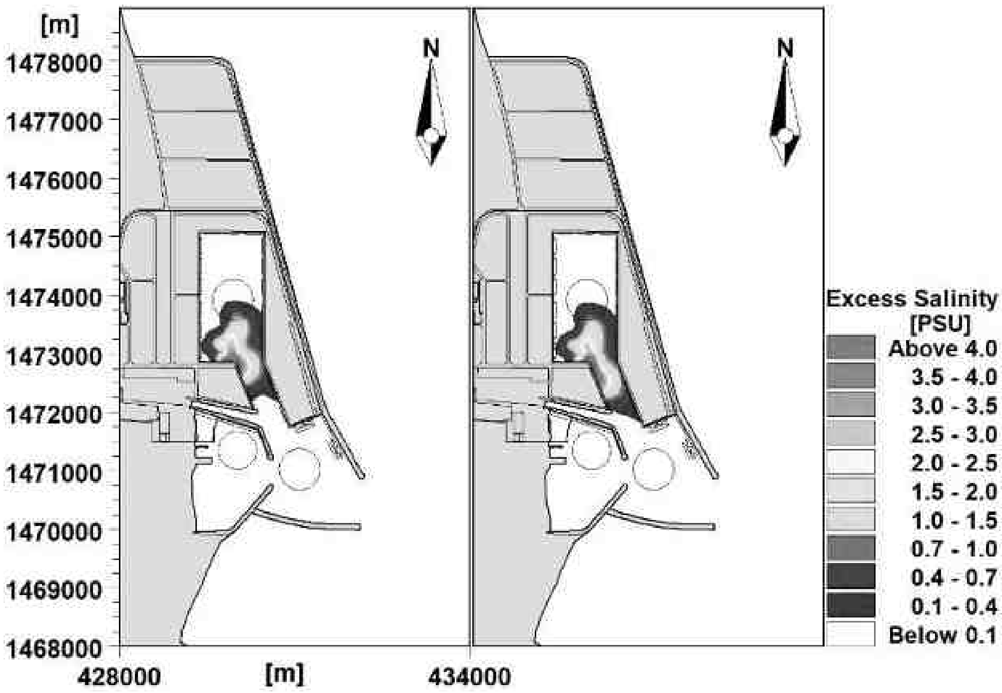

Figure 16-2 Excess salinity at CMWSSB outfall location - Spring flood (Left), Spring ebb (Right)

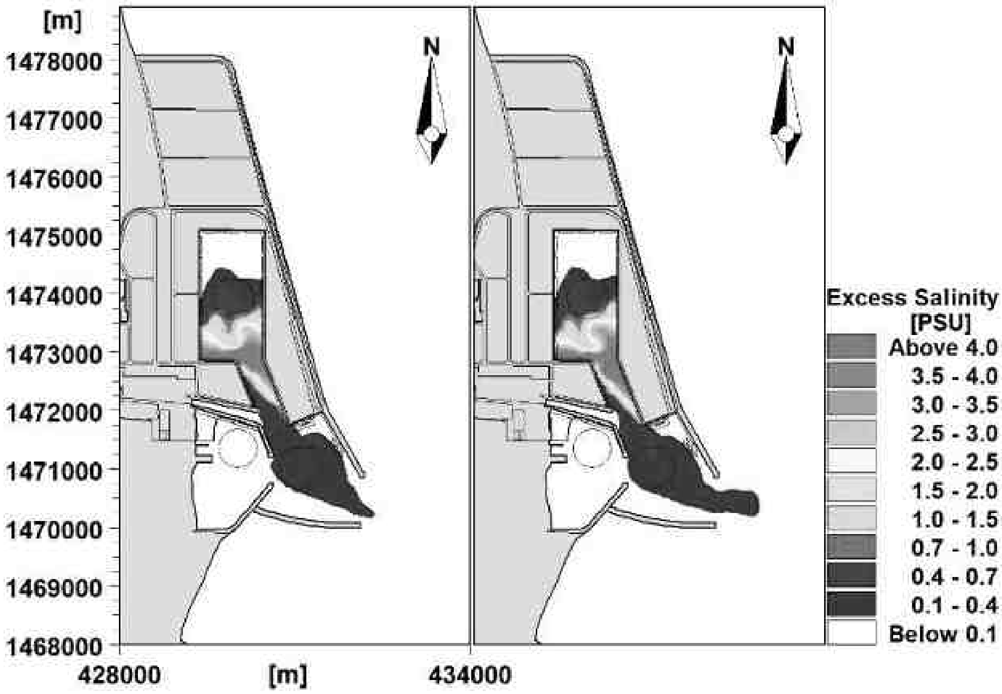

Figure 16-3 Excess salinity at CMWSSB outfall location - Spring flood (Left), Spring ebb (Right)

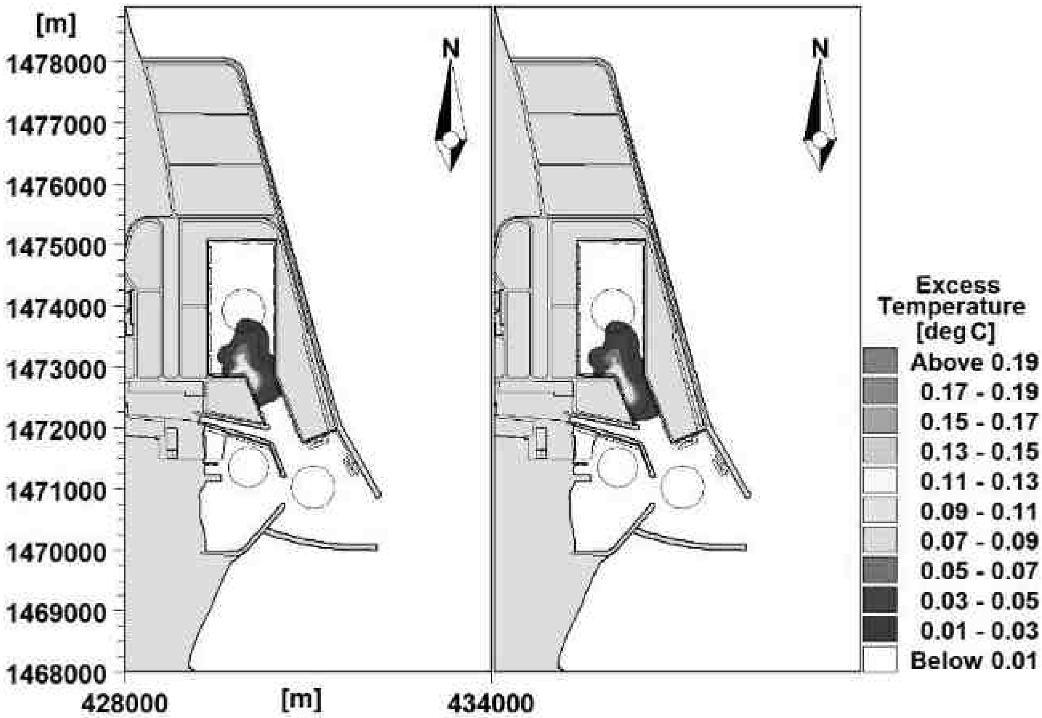

Figure 16-4 Excess Temperature at CMWSSB outfall location - Spring flood (Left), Spring ebb (Right)

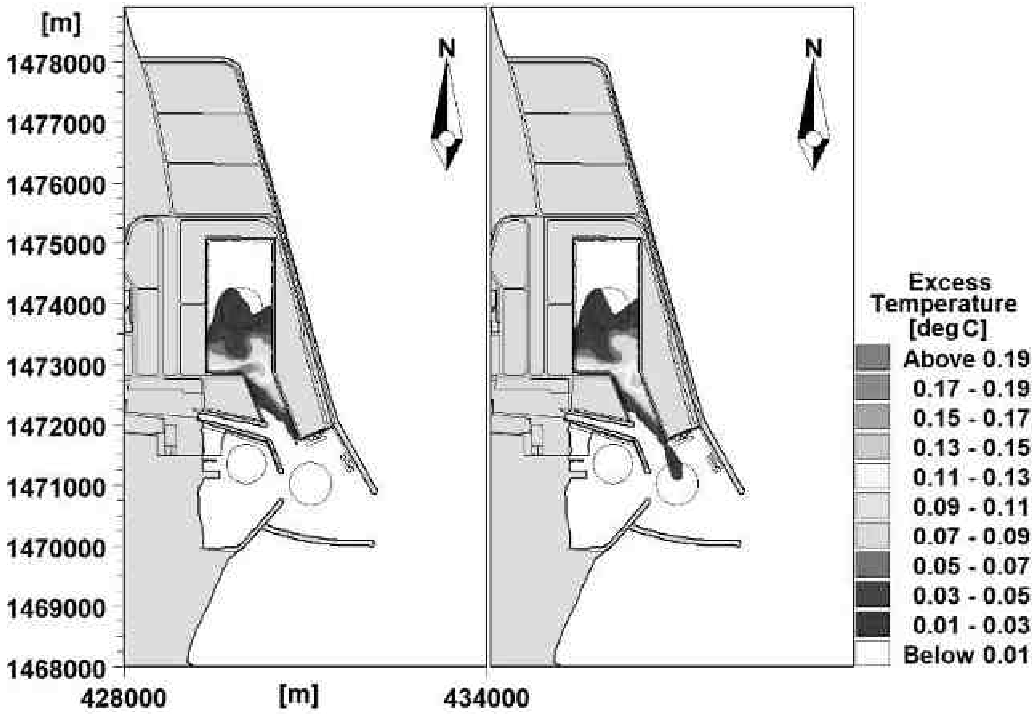

Figure 16-5 Excess Temperature at CMWSSB outfall location - Spring flood (Left), Spring ebb (Right)

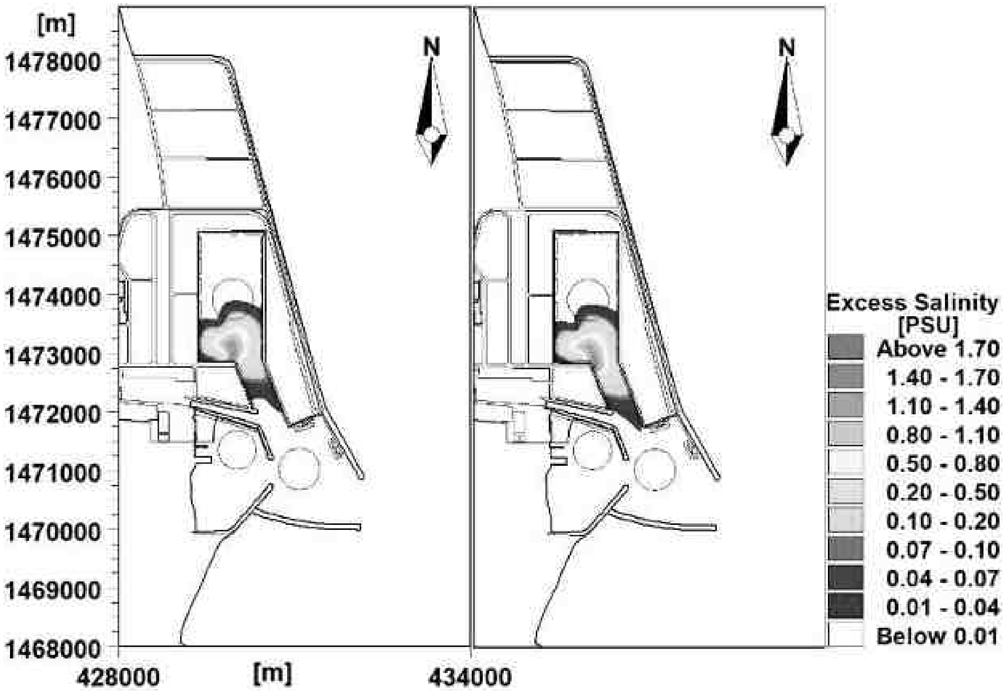

Figure 16-6 Excess salinity at MIDPL 30 MLD outfall location - Spring flood (Left), Spring ebb (Right)

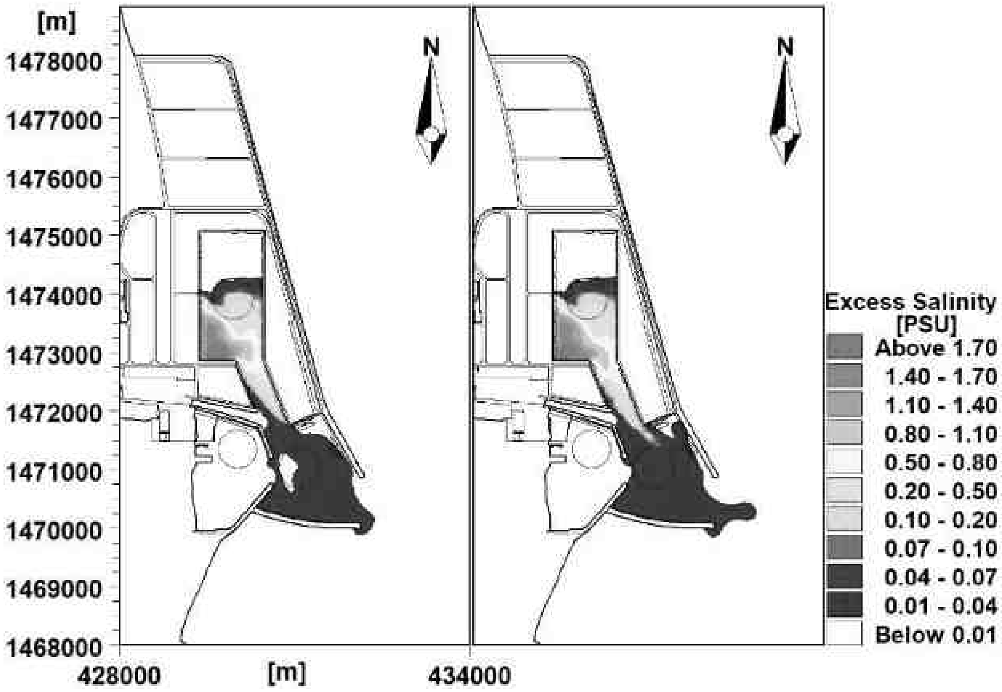

Figure 16-7 Excess salinity at MIDPL 30 MLD outfall location - Spring flood (Left), Spring ebb (Right)

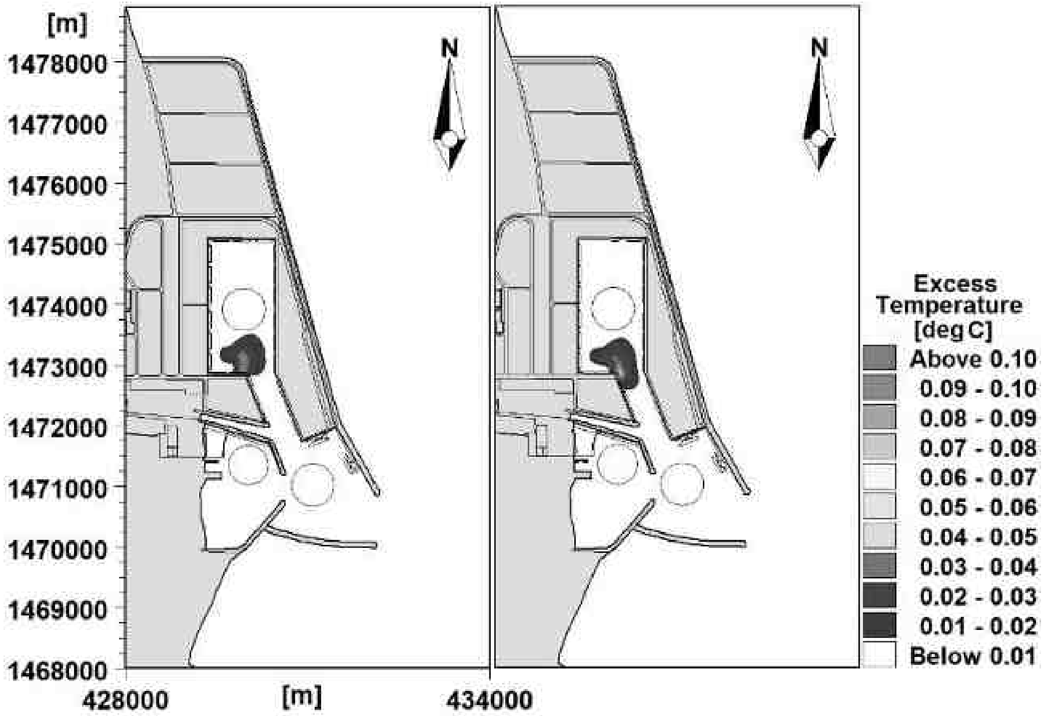

Figure 16-8 Excess Temperature at MIDPL 30 MLD outfall location - Spring flood (Left), Spring ebb (Right)

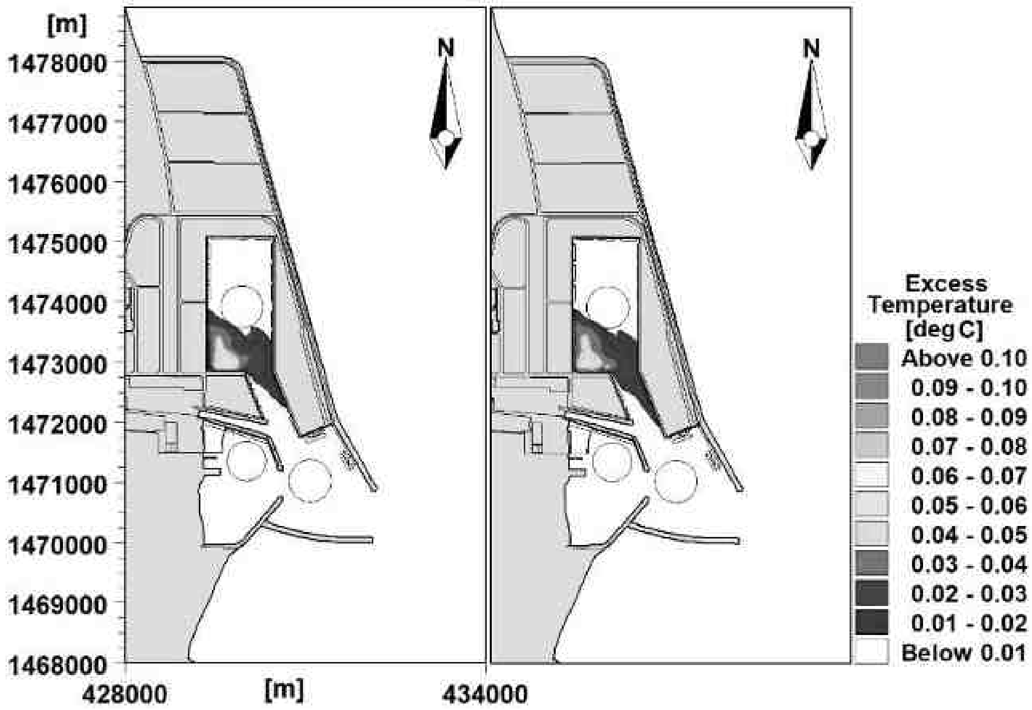

Figure 16-9 Excess Temperature at MIDPL 30 MLD outfall location - Spring flood (Left), Spring ebb (Right)

In all the simulations the excess salinity does not influence the intake locations. At outfall location the excess salinity does not exceed 5 PSU. The brine should result in a salinity increase of no more than 0.1 PSU at the edge of the zone where spreading extends.

Based on results, it is concluded that the 100 MLD and 30 MLD outlets result in excess salinity below 5 PSU and 1.5 PSU at the point of discharge and 0.1 PSU at the farthest point from the outlet. For 100MLD and 30MLD outlets the excess temperature is comparatively less, and the values are 0.18°C and 0.07°C respectively.

The simulated results for 100MLD and 30MLD desalination plants are therefore analyzed for temperature and salinity. The edge of the mixing zone is 3.5km from the discharge point of the outfall location (port entrance). The differences in temperature and salinity are observed to be less than 0.1°C and 0.04 PSU at the edge of mixing zone. The results of the model clearly illustrate that the discharge water from the outfall location does not mix with any intake location. The salinity dispersion from the outlet is not reaching the Intake locations hence water quality will not be altered (Figure 16-2 to Figure 16-9).

DHI suggests that Intake-1 will be the most appropriate intake water location for both 100MLD and 30MLD desalination plants.

16.2 20 MMTPA LNG/LPG Processing Facility

The intake and outfall discharge quantities from and into the Kattupalli port region pertaining to proposed 20 MMTPA LNG/LPG processing facility is approximately 1,20,000m^3/hr. The proposed facility will discharge processed water back into the open sea at the finalized disposal point (out of two optional locations) through a discharge outfall pipeline with decrease in temperature. The quantity of the discharge from the processing facility is around 1,20,000m^3/hr

16.2.1 Scenario Details

Each model simulation covers tidal variation of 15 days covering spring and neap conditions. The two intake options are considered outside the port area for functioning 20 MMTPA LNG/LPG processing facility.

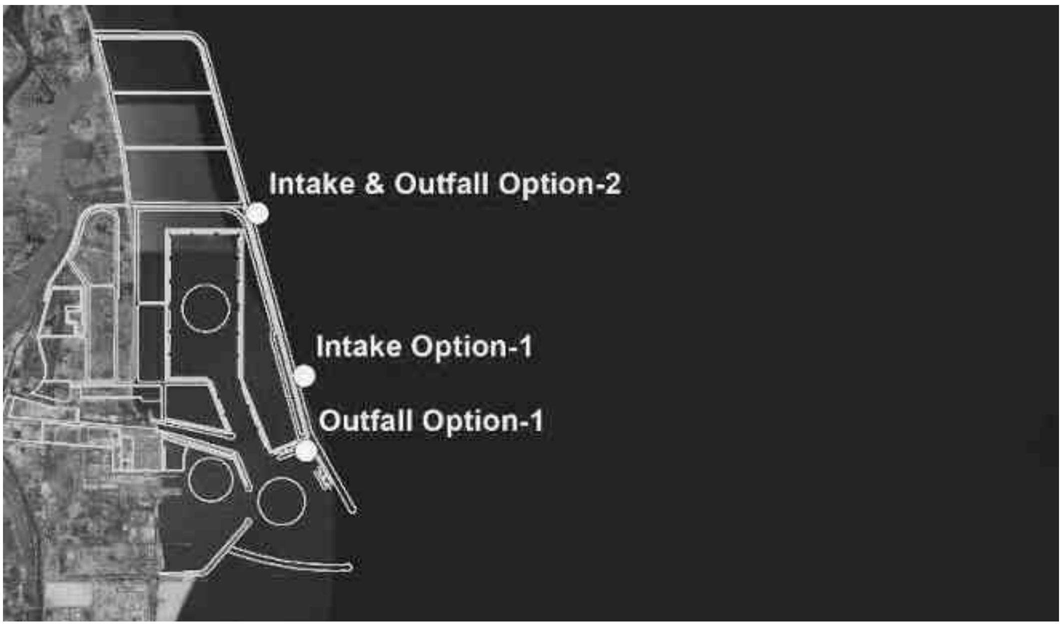

Figure 16-10 Intake and outfall location for 20 MMTPA LNG/LPG processing facility

- Option-1: Outfall location inside the port and intake extended outside the proposed breakwater
- Option-2: Intake and outfall location are provided outside the proposed breakwater

Table 16-2 Intake and outfall locations for 20 MMTPA LNG/LPG processing facility

Parameter	Intake	Outfall
20 MMTPA LNG/LPG processing facility (Option-1)		
Easting [m], UTM 44	431449.36	431417
Northing [m] UTM 44	1471780.45	1472902
Depth [m] w.r.t CD	25	11.5
Discharge rate [m^3/sec]	33.33	33.33
Excess temperature [^oC]	-	-7
Excess Salinity [PSU]	-	-
20 MMTPA LNG/LPG processing facility (Option-2)		
Easting [m], UTM 44	430716.31	430716.31
Northing [m] UTM 44	1475332.67	1475332.67
Depth [m] w.r.t CD	12.4	12.4
Discharge rate [m^3/sec]	33.33	33.33
Excess temperature [^oC]	-	-7
Excess Salinity [PSU]	-	-

A hydrodynamic model using DHI's 2D model system, MIKE 21 Flexible Mesh (FM) is set up and calibrated based on field data collected during pre-monsoon season. The water level and currents along the open boundaries of the model are taken from hydrodynamic model prepared as a part of this study. High resolution model has been implemented in the outfall location.

16.3 Results

The results pertaining to variation of temperature in the vicinity of discharge point for 15 days (one spring and neap period) is presented in the above sections (Figure 16-11 to Figure 16-14) and are discussed in detail below.

Coldwater from the LNG/LPG plant discharged at outfall option 1. The results (Figure 16-11 and Figure 16-12) shows the variation of temperature for flood and ebb tide during spring and neap phase of tide. The dispersion is taking place inside the port and around the proposed breakwater tip with less temperature difference in comparison to ambient temperature.

The Coldwater from the LNG/LPG plant discharged at outfall option-2 location, which is located outside the breakwater (Figure 16-10). The results (Figure 16-13 and Figure 16-14) shows the variation in temperature for flood and ebb tide during spring and neap phase of tide. It can be observed from the figure that the dispersion is taking place at outside of the breakwater. The difference in temperature is minimal in comparison to the ambient temperature, because of the prevailing environmental conditions outside of the breakwater. The dispersion is more and spreading to a larger patch area at the disposal location. Temperature values are lower during the spring and neap period for option 2.

Finally, it can be concluded that, in option-1, the cold-water discharge is not mixed with the intake and also no impact on water qualities at the intake as well as at the near shore since the proposed outfall location for option 1 is situated inside the basin.

The proposed intake and outfall location in Option-1 is the DHI's suggestion when compared to Option-2, based on a re-circulation study.

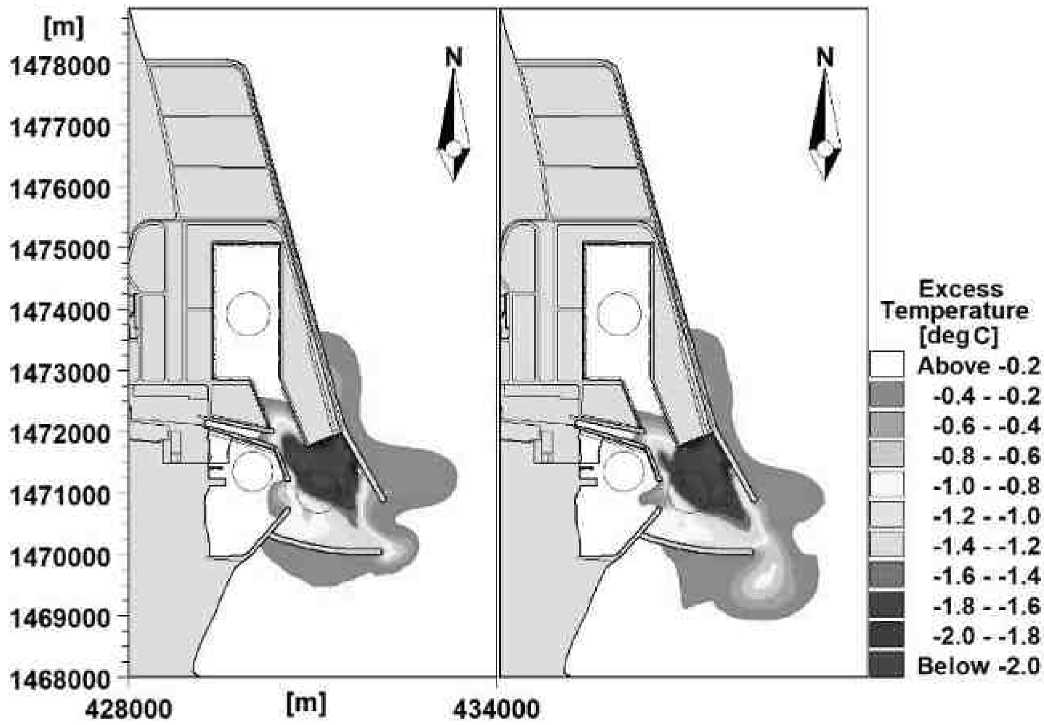

Figure 16-11 Temperature dispersion of cold water from LPG/LNG Plant during spring tide at outfall location option-1: Spring flood (Left), Spring ebb (Right)

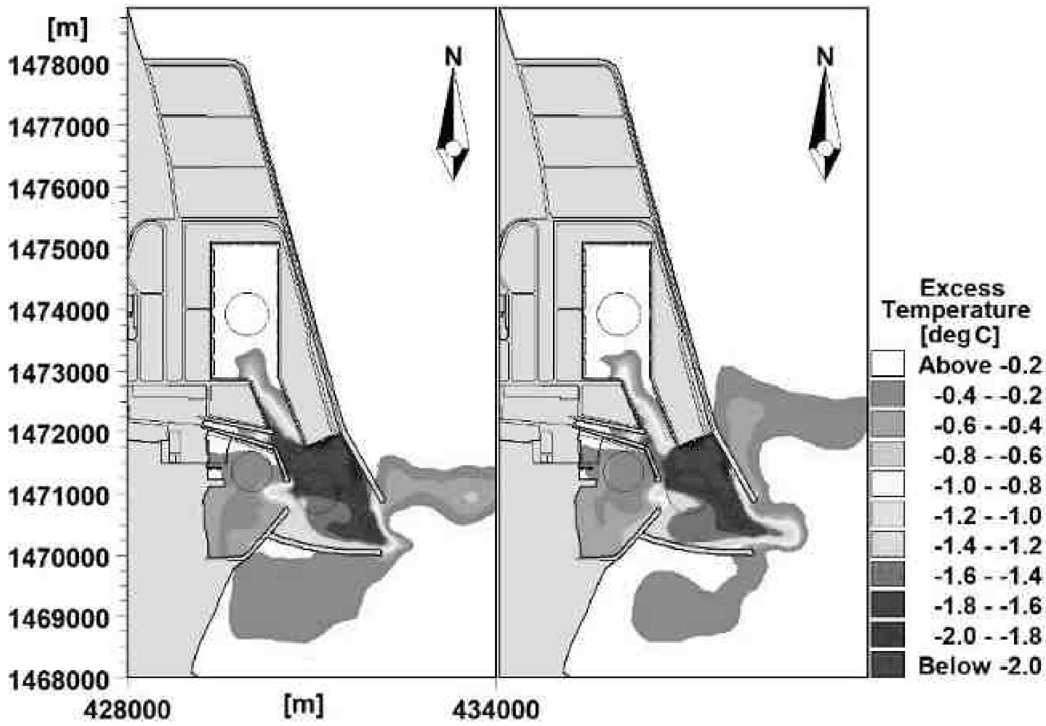

Figure 16-12 Temperature dispersion of cold water from LPG/LNG Plant during Neap tide at outfall location option-1: Spring flood (Left), Spring ebb (Right)

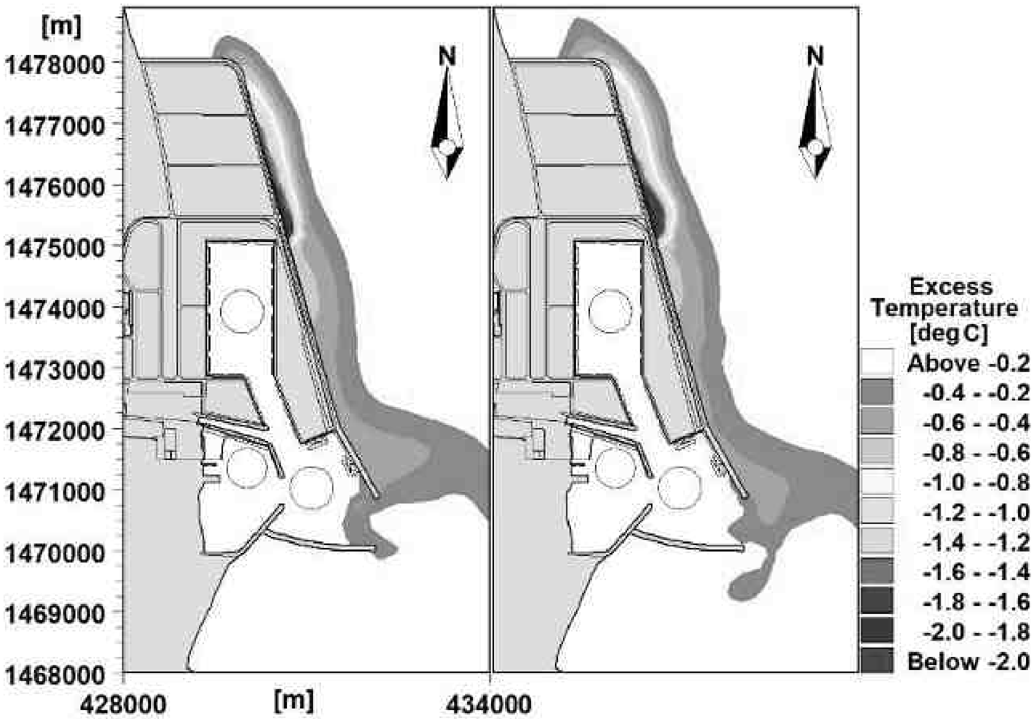

Figure 16-13 Temperature dispersion of cold water from LPG/LNG Plant during spring tide at outfall location option-2: Spring flood (Left), Spring ebb (Right)

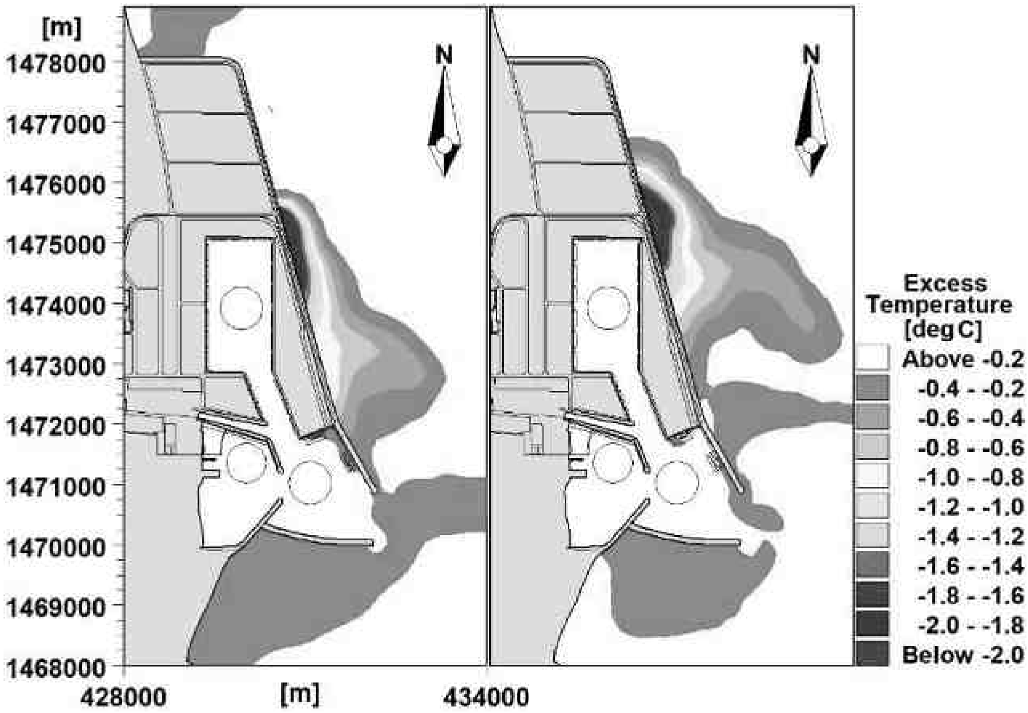

Figure 16-14 Temperature dispersion of cold water from LPG/LNG Plant during Neap tide at outfall location option-2: Spring flood (Left), Spring ebb (Right)

17 Oil Spill Risk Assessment

A stochastic oil spill assessment is undertaken to assist with oil spill contingency planning for the proposed Master Plan development at Kattupalli port. The spill events included 8 simulations (each four at turning circle and SPM location) to evaluate potential oil spill impact to the surrounding environmental resources under different weather and met-ocean conditions.

17.1 Overview

An oil slick on the surface will be subject to transport by predominant currents and winds. A good hydrodynamic model and good information on local winds at the spill site are therefore critical for predicting the movements of the oil. The HD modelling has been carried out using DHI MIKE21 modelling suite. The simulation of the hydrocarbon spills has been carried out using DHI's Oil Spill model MIKE 21 OS. In this model the oil is represented as (Lagrangian) particles being advected with the surrounding water body and exposed to weathering processes. The advection (drift) of the individual particles is determined by the combined effects of current, wind and bed drag. The model provides information on oil slick locations, the amount of oil left on the sea surface, the slick mobility, and the evolution of the physiochemical properties of the oil. The weathering processes included in the model are described below.

17.2 Oil Spill Processes

MIKE 21 OS model describes the spreading and weathering of oil spills in an aquatic environment under the influence of water movements and the associated dispersion processes. The oil itself is defined according to its distillation properties and chemical structure. The processes are considered in the models includes spreading, evaporation, emulsification, vertical dispersion, and dissolution (Figure 17-1).

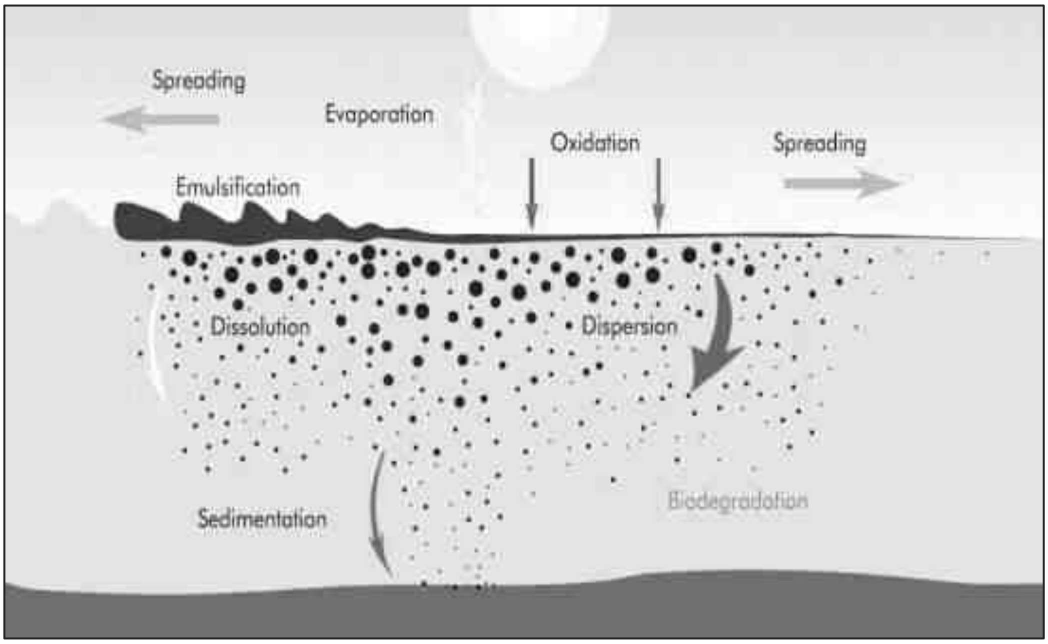

Figure 17-1 Processes acting on spilled oil

The physical and chemical changes that spilled oil undergoes are collectively known as weathering. Although the individual processes causing these changes may act simultaneously, their relative importance vary with time. Together they affect the behaviour of the oil and determine the fate. These processes are illustrated in Figure 17-2 for a spill of a typical medium crude oil under moderate sea conditions. Sedimentation only occurs for very heavy oils in connection with mineral particles (sand/clay). Biodegradation and photo-oxidation only affect oil spills in the longer term (i.e. weeks to months or years).

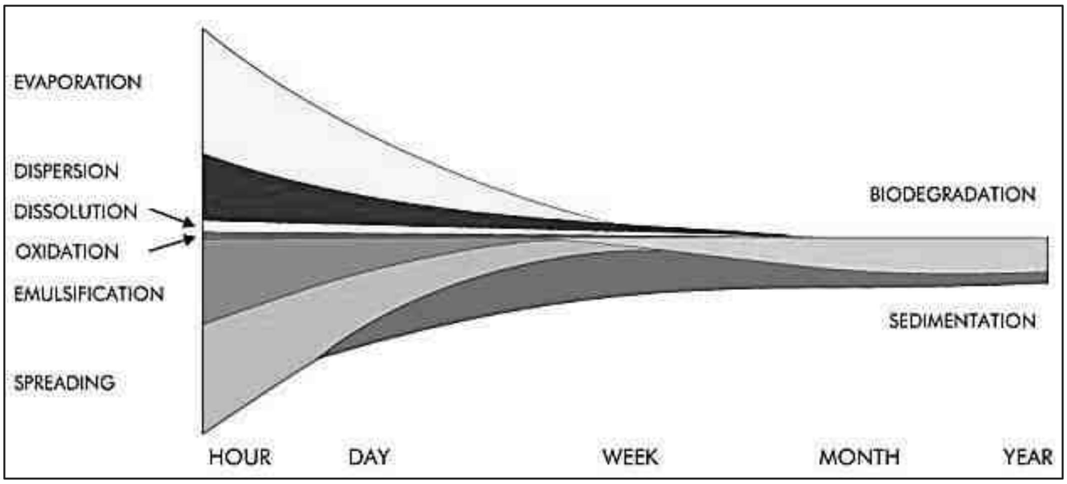

Figure 17-2 A schematic representation of the fate of a crude oil showing changes in the relative importance of weathering processes with time

17.3 Oil spill Process and Properties

The different parameters applied for the oil spill processes are listed below.

- Spreading: The currents define the water movement (advection) while the dispersion in the OS module is described using three dispersion coefficients that are proportional to the current in the longitudinal, transverse and vertical directions. Proportionality constants of 1.0 [m], 0.1 [m] and 0.01 [m] respectively are applied.
- Evaporation: Evaporation is given as a constant that is proportional to the amount of the evaporated oil. A default value of 0.0292 (dimensionless) has been applied.
- Emulsification: The emulsification process (water uptake) leads to a reduction in concentration, but also diminishes the evaporation of components from an emulsion. For the present study the emulsification is not included.
- Dispersion (called entrainment in MIKE 21 OS): The entrainment of oil (or vertical dispersion) into the water column is simulated using an interfacial tension parameter with a value of 20 dyne/cm valid for nonbreaking waves.
- Dissolution: The volume of oil leaving the slick due to dissolution is calculated via a mass transfer coefficient set to a default value of 2.36·10-6 (dimensionless).

Additionally, the heat transport is considered in MIKE 21 OS with the following parameters used in the balance calculation:

- Albedo value: 0.14
- Emissivity of oil: 0.8
- Emissivity of water: 0.95
- Emissivity of air: 0.82

Additionally, a viscosity of 3.24 and reference temperature of 22°C are included in the spill modelling set up.

17.4 Environmental Data

As outlined previously in the report, the hydrodynamic and wind conditions are key to drive the oil spill model.

17.4.1 Currents

The drift applied in the oil spill simulations is a combination of a traditional bed shear profile (logarithmic from the hydrodynamic model simulation and wind acceleration of particles directly exposed to the wind). The drift profile applied in the model is the sum of these two profiles.

17.4.2 Wind Data

Wind data obtained from the Kattupalli Port wind station is applied in the oil spill model to describe the surface drift.

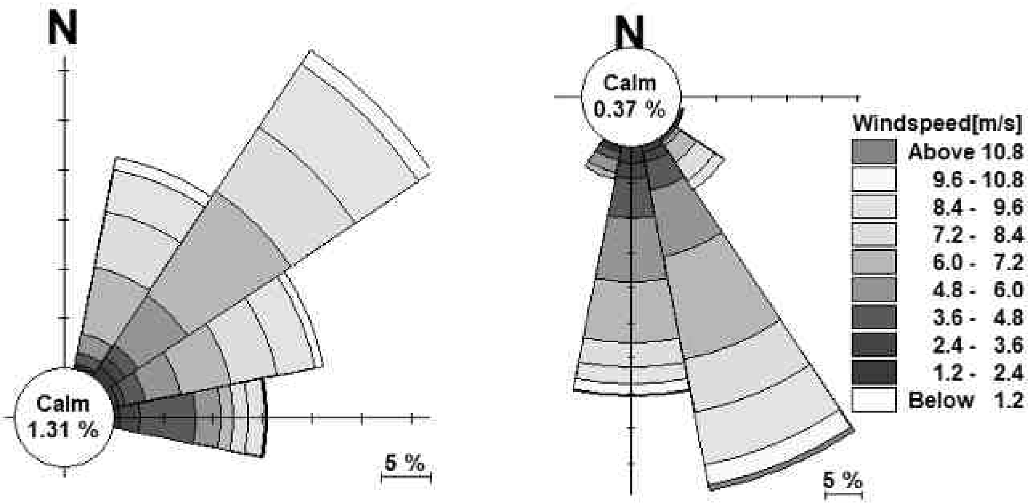

Figure 17-3 Northeast and Southwest monsoon wind used for the simulations

17.4.3 Oceanographic Data

A constant salinity of 33 PSU and a constant sea water temperature of 26°C has been considered.

17.5 Spill Scenarios

A single surface spill scenario is defined in terms of the spill location, oil properties, rate, duration, and temperature. The oil is divided into five fractions, each characterized by a vapour pressure, water solubility, viscosity, and density.

Eight oil spill scenarios have been modelled. Each spill event will involve simulation of 6000 (200 particles per 10 minutes for 5 hours) discrete oil spill particles whose advection, dispersion and weathering will be computed over a maximum two-week (14 days) period.

- Scenario 1 to 4: Collision at the turning circle with Gas oil and Heavy oil for NE and SW monsoon.
- Scenario 5 to 8: Collison at SPM location with possible rupture from hale.

Details of the individual oil spill scenarios are given in Table 17-1 and Table 17-2. Each spill simulates Gas oil and Heavy oil as a conservative approach.

Table 17-1 Spill parameter for scenarios 1-4

Scenario Number →	1	2	3	4
Location	Turning Circle	Turning Circle	Turning Circle	Turning Circle
Case	Collision	Collision	Collision	Collision
Type of oil	Gas Oil	Heavy Oil	Gas Oil	Heavy Oil
Total Spill [m^3]	15000	15000	15000	15000
Spill duration [hours]	5	5	5	5
Simulation duration [days]	15	15	15	15
Temperature [° C]	26	26	26	26
Water depth [m w.r.t CD]	25	25	25	25
Monsoon season	North East	North East	South West	South West

Table 17-2 Spill parameter for scenarios 5-8

Scenario Number→	5	6	7	8
Location	SPM	SPM	SPM	SPM
Case	Collision	Collision	Collision	Collision
Type of oil	Gas Oil	Heavy Oil	Gas Oil	Heavy Oil
Total Spill [m^3]	15000	15000	15000	15000
Spill duration [hours]	5	5	5	5
Simulation duration [days]	15	15	15	15
Temperature [° C]	26	26	26	26
Water depth [m w.r.t CD]	32	32	32	32
Monsoon season	North East	North East	South West	South West

17.6 Model Setup

Figure 17-4 shows the model bathymetry used for the oil spill simulations and the oil spill locations considered in the model. The overall flexible mesh set-up for the study area and zoom-in plot of the bathymetry at the area of interest can be seen in the figure. The computational triangular mesh of the model is made with sufficiently small cells to resolve the detailed conditions.

Bathymetry data from different sources were combined to produce a consistent bathymetry dataset covering the entire study area.

The boundaries of the model domain are selected to align with the tidal phase of the study area from hydrodynamic model studies. Tidal level and current predictions are imposed from the hydrodynamic model.

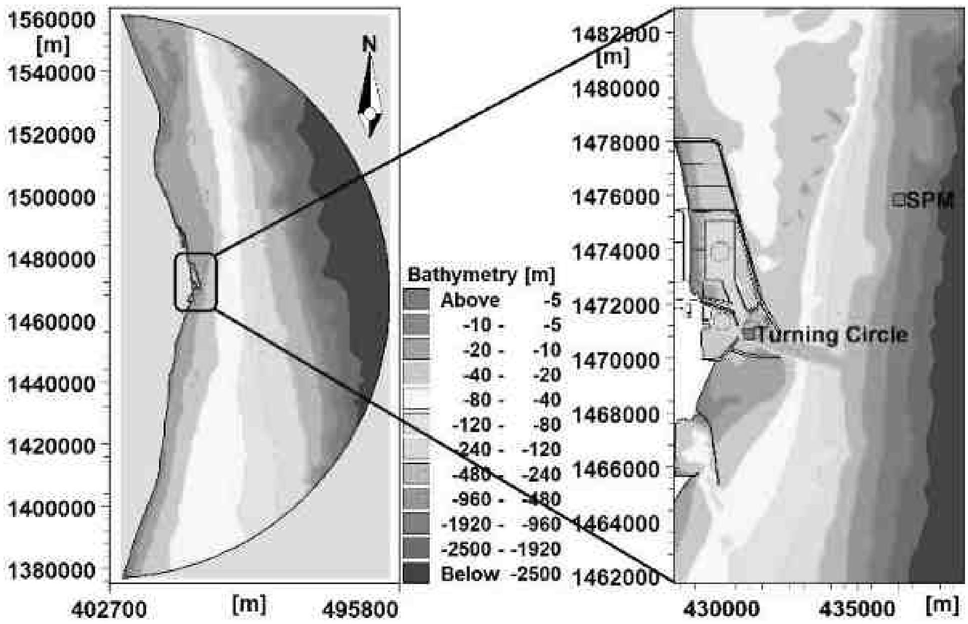

Figure 17-4 Left: Bathymetry used for oil spill model, Right: oil spill location considered in the simulations

17.7 Oil Spill Modelling Results

The simulated results from oil spill model are analysed for the following:

- Spreading of oil with respect to the spill location in the form of slick thickness
- Arrival time of spilled oil with respect to the sensitive environment in the vicinity

The weathering results from the combination of oil spill location, quantity, and environment for two monsoon seasons (SW and NE Monsoon) are analysed and presented in the following sections. The areas sensitive to the spill are identified based on utility, usage and ecological importance. The sensitive areas around the project stretch are identified as Pulicat, Ennore creek, and beaches. The analysis is carried out with respect to arrival time and the maximum thickness of oil spill reaching the sensitive areas. Simulations are carried out for available monsoon wind data from the site for all the spill locations considered in the model studies.

The results from the combination of 8 spill scenarios within the two monsoon seasons are presented in terms of arrival times (Shortest drift time) and oil slick thickness.

17.7.1 Oil Spill at Turning Circle

Oil spill simulation at turning circle is carried out for gas oil and heavy oil with 15000m^3 of spill quantities covering maximum perceived spill quantity. The analysis of trajectory and arrival time of spilled oil indicates the oil being confined to the port basin during both the monsoon period. Analysis of simulated result indicates the plume being confined to the port basin and not spreading to deeper water.

Figure 17-5 to Figure 17-8 show the maximum oil thickness with area of extent and minimum time to exposure at the end of 15-day simulation occurring during NE and SW monsoon for all scenarios at the turning circle.

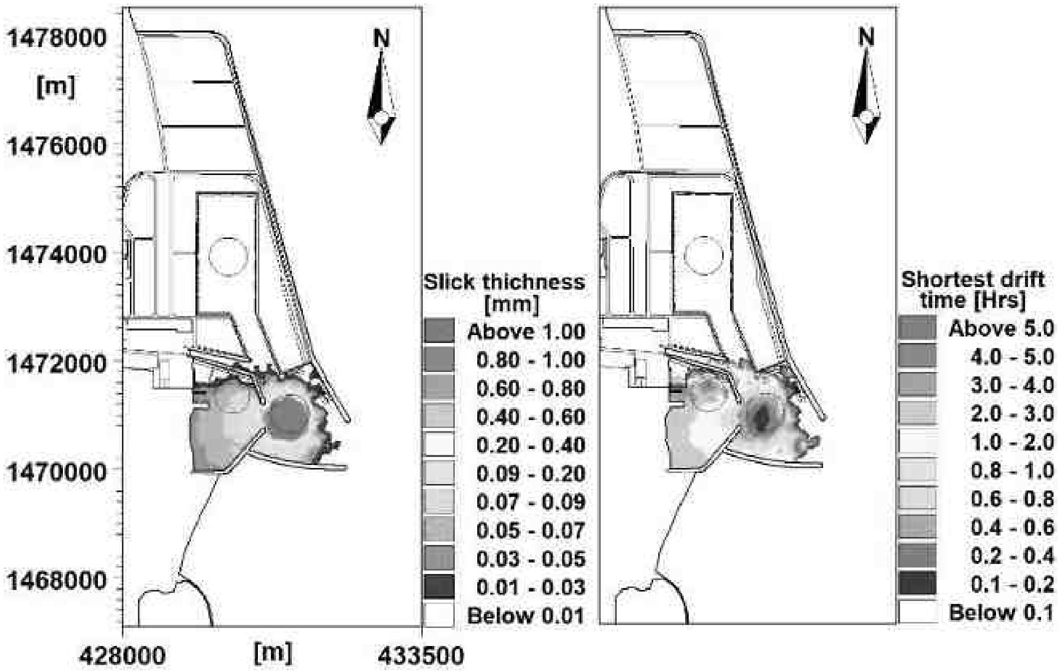

Figure 17-5 Scenario1- Maximum oil slick thickness and minimum time exposure to oil slick

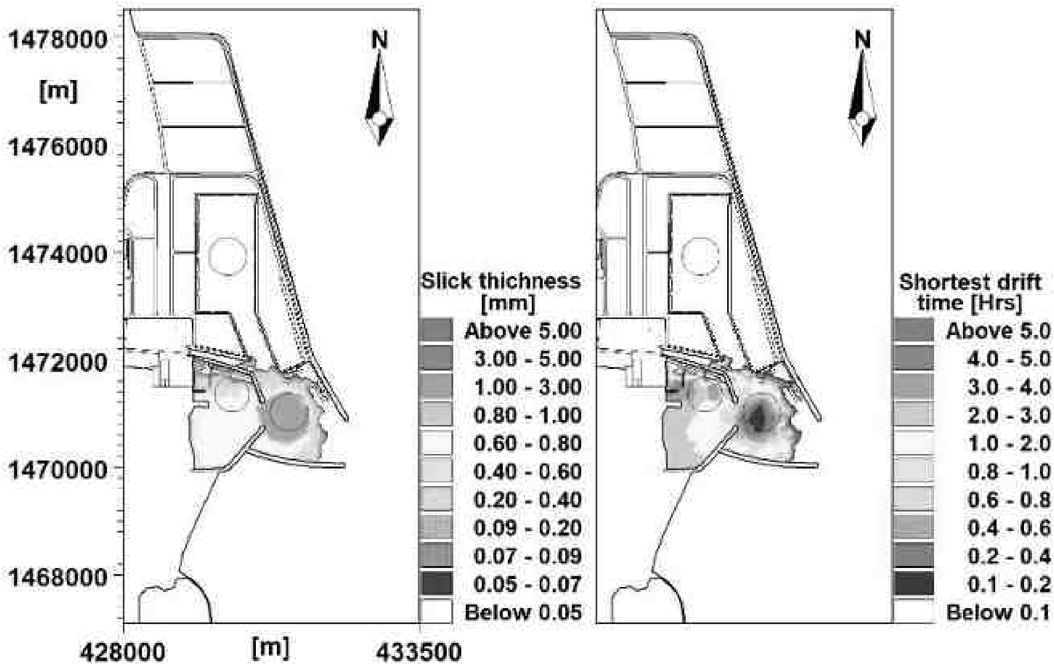

Figure 17-6 Scenario 2- Maximum oil slick thickness and minimum time exposure to oil slick

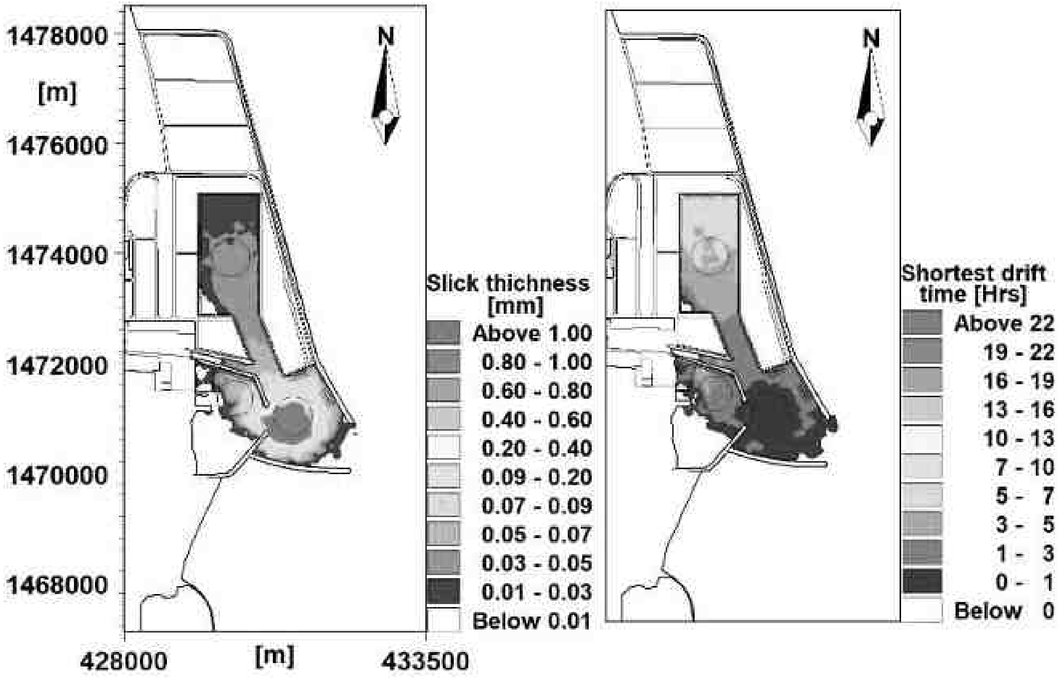

Figure 17-7 Scenario 3- Maximum oil slick thickness and minimum time exposure to oil slick

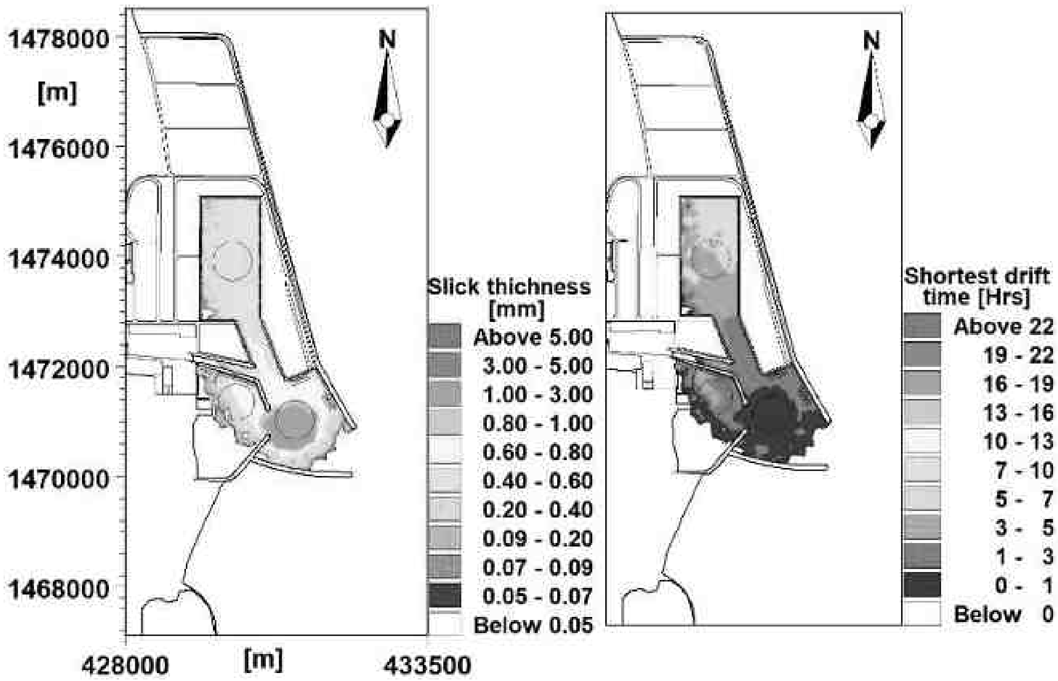

Figure 17-8 Scenario 4- Maximum oil slick thickness and minimum time exposure to oil slick

17.7.2 Oil Spill at SPM location

The spill at the SPM location is carried out for gas oil and heavy oil with 15000 m^3 of spill quantity covering the maximum quantity of spill perceived. The analysis of the simulated scenarios indicates the spill plume is mainly confined from deeper water to the east side of the breakwater and is less likely to spread in the beach immediately north of the port mainly in southwest monsoon season and this has been observed for scenario 5, scenario 6 and scenario 7. The spill plume mainly confined to the deeper water in scenario 8.

Figure 17-9 to Figure 17-12 shows the maximum oil thickness with area of extent and minimum time to exposure at the end of 15 day simulation occurring during NE and SW monsoon for all scenarios at SPM location.

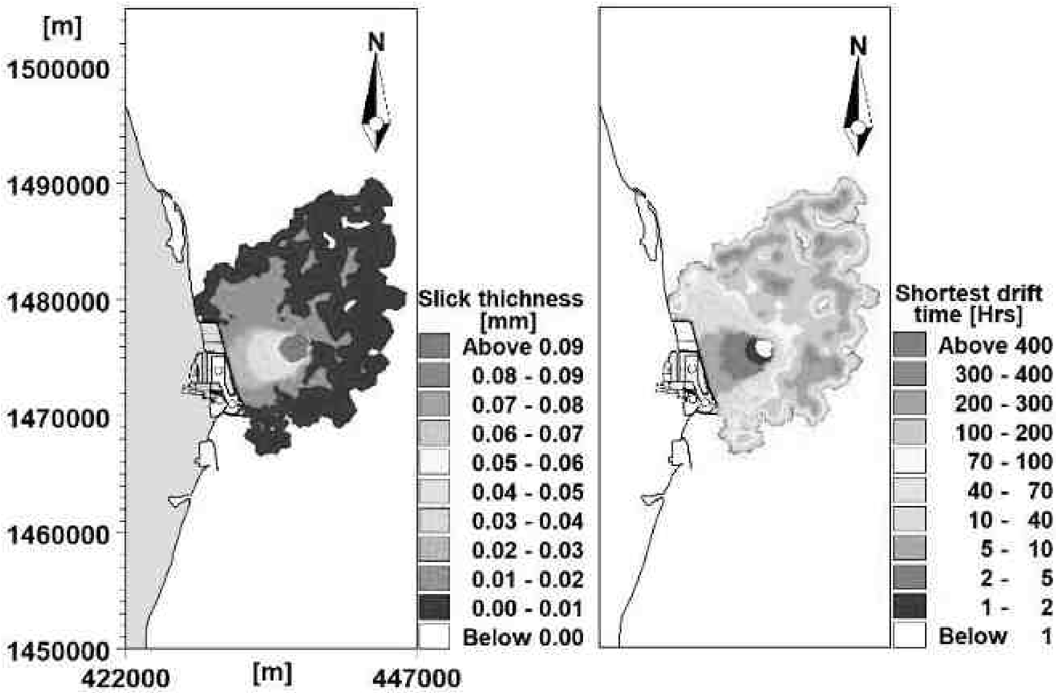

Figure 17-9 Scenario 5- Maximum oil slick thickness and minimum time exposure to oil slick

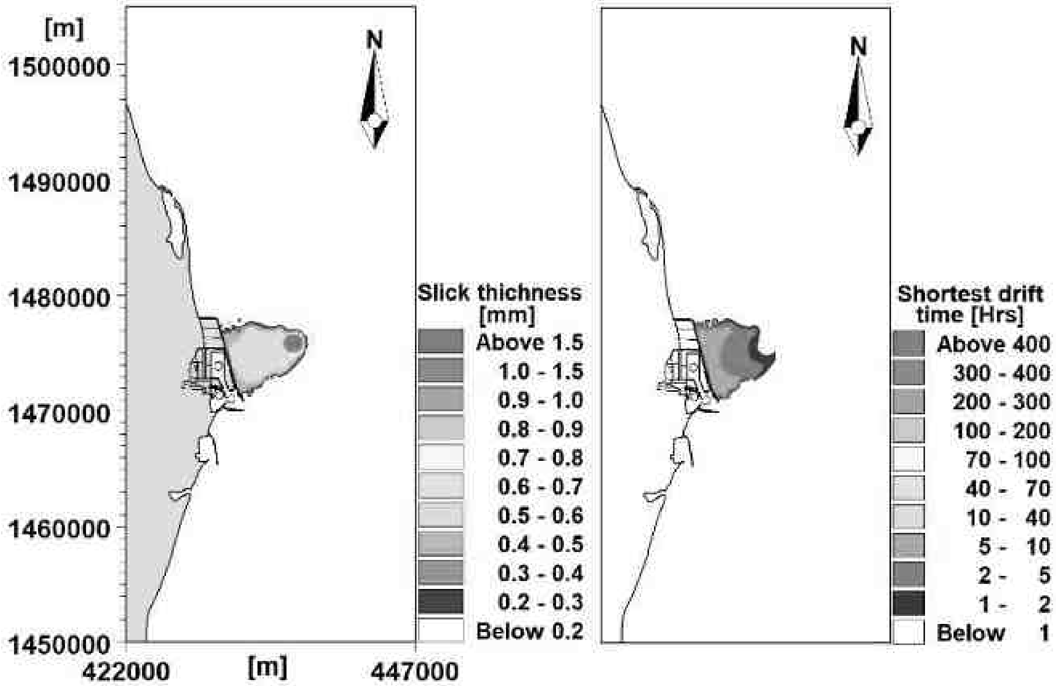

Figure 17-10 Scenario 6- Maximum oil slick thickness and minimum time exposure to oil slick

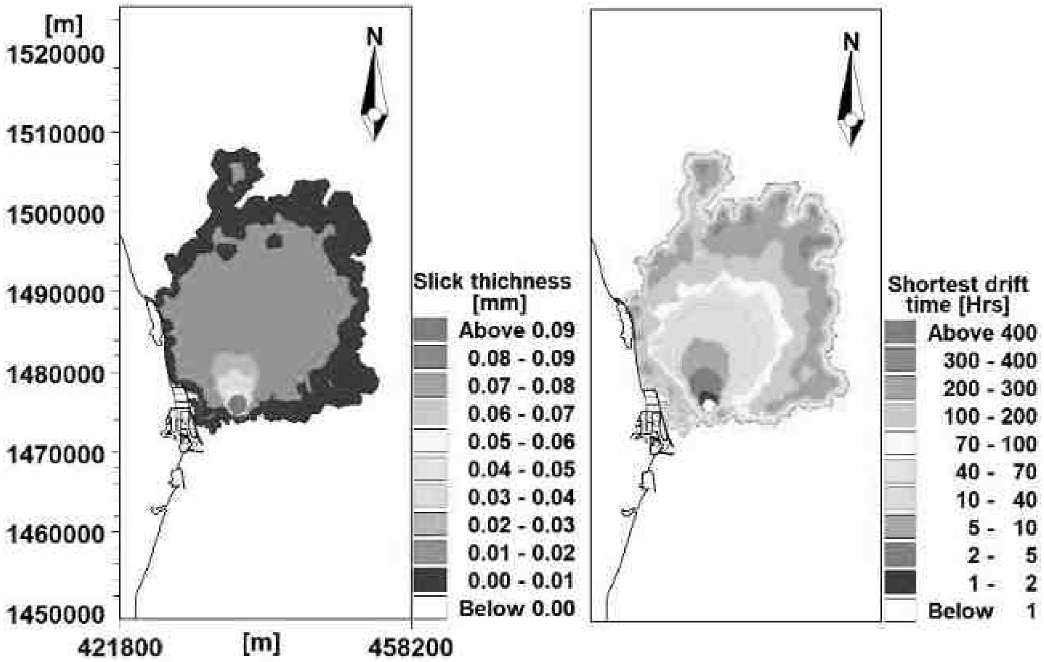

Figure 17-11 Scenario 7- Maximum oil slick thickness and minimum time exposure to oil slick

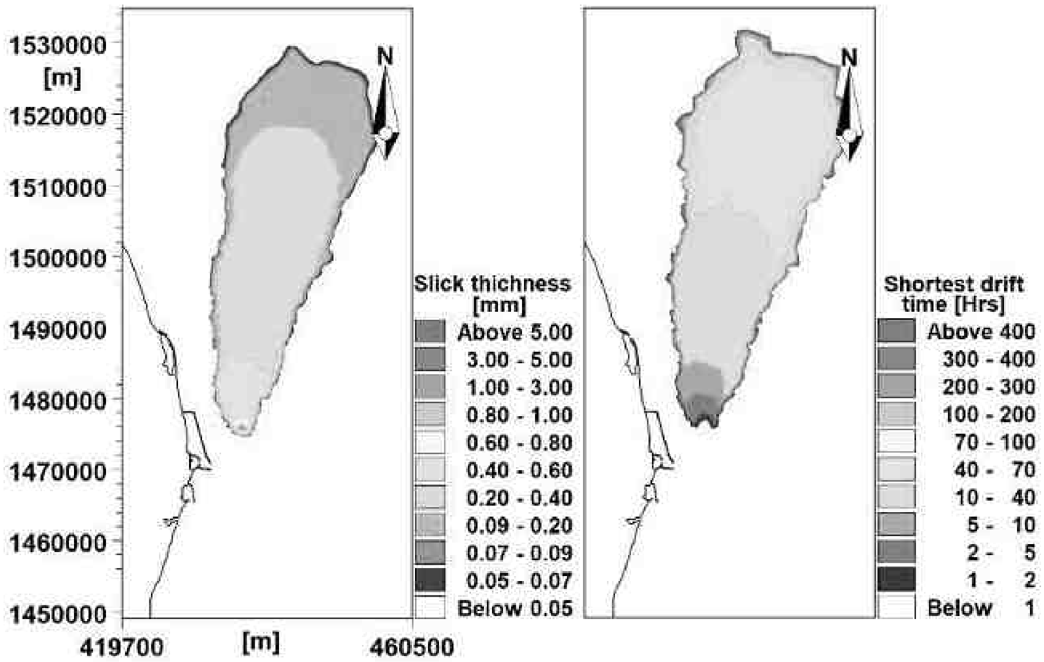

Figure 17-12 Scenario 8- Maximum oil slick thickness and minimum time exposure to oil slick

Some key observations include:

Spillage occurrence at turning circle wis not having any shoreline impact. This is due to the shelter effect of the proposed breakwater and predominant wind direction is from South East direction. The oil slick is concentrated within the berth area and does not travel far away. For some combination of tide and wind conditions, the oil slick tends to get trapped within the port. It is to be noted that the oil spill from the Turning circle is not reaching to the Intake locations.

Spillage occurrence at SPM location is having shoreline impact on the northern side of the proposed development. During the southwest monsoon (June to August), winds from southeasterly is able to move oil very far to the east. The spill at the SPM location, during the NE monsoon the intake locations (Intake-1, Intake-2 and Intake-3) are being contaminated by the spill, during the SW moon the oil spill from SPM location has no impacts on the intake locations.

18 Summary and Discussion

The present report summarises the data analysis and model studies pertaining to the preparation of Shoreline Management Plan and environmental models for the development of Katupalli Port Master Plan.

Coastal processes responsible for shoreline changes are reviewed for three phases (Phase-I: February-March 2020, Phase-II: September-October 2020 and Phase-III: January-February 2021). Filed measurements on tides, currents, waves, bathymetry, sediment characteristics etc., are analysed at selected locations between Pulicat and Ennore creek. During phase-I, the maximum tidal range at W1P and W3K are 0.44m and 0.94m respectively. Maximum current speed at C1, C2, and C3 is 0.17m/s, 0.25m/s, and 0.27m/s respectively. Similarly, the maximum current speed at W1P and W3K are 0.24m/s and 0.91m/s respectively. For Phase-II maximum tidal range at P1, P2 and K1 are 0.43m, 0.45m and 1.3m and the maximum current speed at C1, C2, and C3, are 0.24m/s, 0.28m/s, 0.35m/s respectively. For Phase-III maximum tidal range at P1, P2 and K1 are 0.59m, 0.41m and 0.41m and the maximum current speed at C1, C2, and C3, are 0.42m/s, 0.47m/s, 0.47m/ respectively.

Keeping in view of processes identified from field investigations, model investigations on hydrodynamical aspects, nearshore wave transformation processes, sediment transport pattern and shoreline changes have been carried out. The models are calibrated with the field data collected during the pre-monsoon season. By integrating the results of field and model investigations, the sediment budget for Ennore-Pulicat creek is estimated. The existing sediment transport rates are determined. The proposed Master Plan layout of Kattupalli Port is investigated to assess the sediment transport and shoreline changes. The areas prone to erosion and deposition have been identified.

The following models are being used to generate impact model

- Hydrodynamic model to simulate flow pattern
- Spectral wave models for deriving the wave climate
- LITPACK model for prediction of shoreline changes.

Hydrodynamic Study

2-dimensional hydrodynamic model (MIKE 21 HD FM) has been set-up and calibrated for the baseline conditions in order to simulate the water levels and current pattern from Ennore to Pulicat creek. The model account for bottom friction, wind effect, wave radiation stresses. The simulation is carried out with tide and wind conditions for a period of 15 days, which covers spring and neap tidal cycles. The simulated water levels and currents are having a good agreement with the measured water level and current data. The two major forcing functions, i.e., tide and wind, influence the circulation pattern, latter being a dominant forcing function, which controls the direction of current. The flow field south of Kattupalli Port is complex and circulation north of port is influenced by the presence of shoals. Hydrodynamic model study with proposed masterplan shows that there is no change in the circulation pattern at Pulicat lake and Ennore shoal area.

Wave Transformation Study

Third generation wave model is applied to predict the annual wave climate for Ennore-Pulicat coast. The maximum percentage of waves occur in the height range of 1.0 to 1.5 m and with peak wave period of 4-10 sec. The coast north of Kattupalli experiences concentrations of wave energy at some places due to convergence of waves resulting from complex bathymetry (shoals). The only change predicted with the Master Plan layout is formation of shadow zone, with less energy waves around immediate north of the breakwater when waves are coming from southwest direction. Otherwise, the wave transformation study indicates that similar results for baseline and layout conditions. The Pulicat Lake inlet/mouth is located approximately at 10 km from the proposed master plan boundary, and the model results show that there is no change in wave pattern at Pulicat lake with the proposed Katupalli port master plan.

Historical Shoreline Changes
GIS techniques and satellite images are used to estimate the historical shoreline changes from 2000-2020. The coastline of the study area is divided in to Six zones (Zone-A to Zone-F). The north of Kattupalli Port (Zone-C), where erosion is more predominant, and it is active after the construction of Kattupalli Port. These changes started during the construction stages of the port, affecting the area within the port as well as on the south and north sides of the port.

Shoreline change prediction
The annual distribution of wave data indicates that during November-December, the waves are coming mostly from 60^0-70^0 and in other months from 120^0-140^0. Thus, the annual wave climate along Kattupalli Port leads to a net northward littoral sediment transport pattern over a year.

The following results have noticed from the shoreline change prediction:

- Northward movement of sand in the order of 458329 m^3 and southward movement of sand in the order of 66043 m^3 is noticed with the baseline conditions for 1 year.
- Northward movement of sand in the order of 367070 m^3 and southward movement of sand in the order of 69830 m^3 is noticed with proposed port facilities for 1 year.
- Northward movement of sand in the order of 1764412m^3 and southward movement of sand in the order of 237554 m^3 is noticed with proposed port facilities for 5 years.
- Northward movement of sand in the order of 3477689 m^3 and southward movement of sand in the order of 365349 m^3 is noticed with proposed port facilities for 10 years.
- Northward movement of sand in the order of 5139085 m^3 and southward movement of sand in the order of 448683 m^3 is noticed with proposed port facilities for 15 years.

Shoreline Management Plan
In order to prevent the erosion along north coast, two types of interventions, soft measures (sand bypassing) and hard measures (groynes) are modelled and their consequent impacts on shoreline along the coast is studied.

Soft measure: One km of the coastline immediate north of the proposed master plan is nourished with dredged material from the channel, berthing area. This nourished material helps the shoreline stability up to 12 years and started eroding thereafter.

Hard measure: One km of the coastline immediate north of the port is nourished with dredged material and protected by groin field after 3 km from proposed breakwater. The results indicate that the shoreline is protected in the nourished area and behind the groin field. The erosion is further shifting to north of the groin field.

Soft and Hard measures: Along with beach nourishment, implementation of three groynes having (length 100 m and 150 m and distance of 1 km) will help to keep the nourished material on the beach during extreme weather conditions such as cyclones.

The model analysis clearly shows that the Pulicat lake inlet/mouth is further 7km from the erosion stretch and the mouth will not have any impact due to the proposed development and protection measures considered.

Tsunami Modelling
The maximum water level predicted at Kattupalli Port entrance is about 2.18m due to 2004 Sumatra tsunami. The corresponding current speed at Kattupalli Port entrance is estimated about 2.8m/s.

Cyclone modelling
December 2016 Vardah cyclone made severe impact to the study area with a maximum surge height of 0.78m and a maximum current speed of 2.74 m/s. The maximum significant wave height at Kattupalli port due to 2016 Vardah cyclone is 5.15m.

Maintenance Dredging Estimation

- To maintain a water depth of 27m w.r,t CD in the approach channel (Section-A) of the proposed Master Plan, the predicted average and maximum dredging quantities are 0.85M m^3/year and 1.56M m^3/year respectively.
- To maintain a water depth of 25m w.r,t CD in the basin area (Section-B) of the proposed Master Plan, the predicted average and maximum dredging quantities are 0.22M m^3/year and 1.21M m^3/year respectively.
- To maintain a water depth of 20.5m w.r,t CD in the basin area (Section-C) of the proposed Master Plan, the predicted average and maximum dredging quantities are 0.18M m^3/year and 0.45M m^3/year respectively.

For the given Master Plan consisting of approach channel, turning circle and berthing area, the total predicted average and maximum dredging quantities are 1.26M m^3/year and 3.23M m^3/year respectively.

The predicted quantities of maintenance dredging with the proposed Master Plan is around 1.2 million cu.m/yr of predominantly fine material from the approach channel, turning circle and berth area. In the present study, two spoil grounds are considered, having an area of 1.71M m^2 and approx.4.5 km away from the proposed port location.

The spread of the disposed sediment on the seabed is presented in the form of bed level change and total suspended solid concentration. The maximum bed level change is around 0.28m in both the dumping grounds, after 60 days simulation period. The model results show that the dumped materials are not spreading beyond the port limit and 1.2 million Cu. m of annual maintenance dredging will not have any impact to the Pulicat lake.

Recirculation study

The recirculation study of 100 MLD and 30 MLD Seawater Desalination Plant shows that, in all the simulations the excess salinity does not influence at the intake locations. It is concluded that the 100 MLD and 30 MLD outlets result in excess salinity below 5 PSU and 1.5 PSU at the point of discharge and 0.1 PSU at the farthest point from the outlet. For 100MLD and 30MLD outlets the excess temperature is comparatively less, and the values are 0.18°C and 0.07°C respectively.

Two intake and outfall options are considered for 20 MMTPA LNG/LPG processing facility. The results indicates that, there will not be any recirculation and there will be no impact on water quality at the intake as well as at the shore due to the disposal from the proposed outfall discharge option-1, as well as free from siltation.

Oil Spill Risk Assessment

Eight oil spill scenarios have been modelled, each spill event involve simulation of 6000 (200 particles per 10 minutes for 5 hours) discrete oil spill particles whose advection, dispersion and weathering are computed over two-week (14 days) period.

Some key observations include:

Spillage occurrence at turning circle is not having any shoreline impact. This is due to the shelter effect of the proposed breakwater and predominant wind direction is from southeast direction. The oil slick is concentrated within the berth area and does not travel far away. For some combination of tide and wind conditions, the oil slick tends to get trapped within the port.

Spillage occurrence at SPM location is having shoreline impact on the northern side of the proposed development. During the southwest monsoon (June to August), winds from south-easterly is making oil slick moving very far to the east.

As far as the intake structures are concerned, if the spill occurs at the turning circle and at basin, there is no risk of an oil spill at the intake locations. If the spill were to occur at the SPM location, there would be moderate to high risk at the intake location.

19 References

[1] Pre-Monsoon (phase 1) Data Collection Report Physical Oceanographic, Bathymetry, Topographic Observations for MIDPL, prepared by National Institute of Ocean Technology

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[3] Post-Monsoon (phase 3) Data Collection Report Physical Oceanographic, Bathymetry, Topographic Observations for MIDPL, prepared by National Institute of Ocean Technology

[4] Emile A and Costas E. (2003), "A Theoretical Comparison of Tsunamis from Dislocations and Landslides", *Pure and applied Geophysics*, 160, 2177-2188.

[5] Stephen et. al., (2007) "Source Constraints and Model Simulation of the December 26, 2004, Indian Ocean Tsunami", *The Journal of Waterway, Port, Coastal, and Ocean Engineering*, November/December, 414-428.

[6] Usha T. et. al., (2011), "Tsunami vulnerability assessment in urban areas using numerical model and GIS", *Natural Hazards*, DOI 10.1007/s11069-011-9957-7.

Annexure-1

Measured TSS data for Phase-3

Table -1 Total Suspended Solid Concentration: Pre monsoon period (06 January 2021)

TSS1			TSS2			TSS3			TSS4			TSS5		
Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom
4.0	9.3	4.2	9.2	6.6	8.1	6.7	9.8	6.3	11.5	4.6	5.4	28.5	6.9	4.3
3.3	4.0	5.0	2.8	4.3	10.1	6.2	8.8	13.9	11.3	2.4	4.7	3.8	6.2	4.6
5.4	4.1	4.7	1.8	4.0	3.3	5.1	13.3	6.5	8.6	14.8	14.7	5.3	4.6	2.5
2.7	2.3	3.1	5.5	3.9	21.5	9.0	8.7	8.5	5.8	8.6	6.8	2.6	4.8	3.8
5.0	4.4	5.2	4.2	4.8	3.3	4.8	7.1	5.5	4.5	3.8	5.6	3.6	4.4	4.5
3.0	1.6	8.0	8.1	3.9	6.6	3.3	7.3	10.4	5.6	4.4	8.5	5.8	7.4	18.8
4.5	9.6	3.6	3.9	2.7	4.6	11.2	6.6	8.2	2.9	3.2	5.3	3.1	14.6	13.8
3.5	4.4	3.5	2.3	3.7	6.3	6.8	6.4	8.6	7.0	12.0	8.3	7.3	6.2	5.0
1.1	2.5	6.3	8.0	7.6	9.8	5.1	7.2	7.3	2.3	6.2	6.3	8.3	4.3	6.4
4.4	8.3	3.4	6.1	8.6	8.0	10.8	7.7	11.7	7.5	6.4	10.5	3.2	2.5	3.0
4.0	5.8	4.3	2.3	2.6	1.9	2.3	6.5	11.1	2.6	6.3	6.3	7.3	9.9	5.6
2.9	3.2	4.7	7.2	6.9	4.4	11.5	9.6	8.0	3.5	4.4	7.0	5.8	1.9	3.2
3.7	4.9	4.7	2.5	4.1	6.5	3.8	5.8	9.5	4.1	6.8	7.3	21.4	6.6	4.9

Table -2 Total Suspended Solid Concentration: Pre monsoon period (07 January 2021)

TSS1			TSS2			TSS3			TSS4			TSS5		
Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom
5.4	7.9	4.4	7.4	4.9	3.0	17.5	5.4	6.1	6.8	3.6	6.3	3.3	2.6	4.1
5.8	4.3	5.1	15.8	12.0	13.4	10.6	16.6	13.7	14.7	11.1	11.3	13.3	13.2	13.0
5.1	21.1	9.6	3.0	5.5	9.1	5.9	8.5	7.8	3.4	3.0	3.7	8.5	5.8	5.2
9.0	5.8	4.3	1.2	2.5	2.8	8.7	6.3	7.2	2.8	5.3	3.1	7.6	8.0	5.9
2.2	5.8	4.2	3.6	4.9	5.5	5.0	-2.6	12.7	5.0	2.9	5.9	7.5	4.6	5.8
4.1	7.7	8.7	3.5	3.9	2.1	6.2	4.1	7.0	3.1	5.7	3.6	4.8	6.1	3.4
2.6	5.1	3.5	8.6	19.8	21.3	3.2	5.4	24.5	4.7	4.1	4.9	3.5	4.5	6.1
2.5	4.8	7.2	5.9	5.3	5.0	4.0	3.3	5.6	4.0	3.3	9.9	3.1	2.9	2.3
6.8	3.5	8.3	5.2	4.5	10.8	12.0	11.7	14.7	3.0	2.4	7.2	10.2	21.8	11.2
6.3	6.3	4.7	3.0	2.7	5.9	10.8	10.8	12.3	11.1	10.4	12.3	13.0	12.3	13.5
3.7	6.3	4.2	6.9	4.6	4.1	13.6	11.8	17.2	1.2	3.1	4.5	6.4	6.7	8.3
7.2	5.5	8.7	2.2	14.8	5.5	5.7	5.3	4.9	2.5	2.9	2.5	16.6	44.4	6.1
3.5	2.6	5.1	3.6	5.8	6.4	4.6	9.1	15.1	9.2	11.7	11.7	11.5	13.2	12.8

Table -3 Total Suspended Solid Concentration: Pre monsoon period (13 January 2021)

TSS1			TSS2			TSS3			TSS4			TSS5		
Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom
10.5	5.1	6.7	20.1	9.7	5.1	7.4	6.7	8.7	6.6	3.9	6.3	2.7	4.5	3.9
14.4	13.1	30.3	3.2	5.4	6.7	10.9	12.9	10.6	25.3	10.7	7.9	13.9	12.5	12
22	8.4	4.3	4.3	3.4	3.9	6.6	6.7	16.8	11.4	11.9	12.3	12.5	15.1	14.1
14.1	27.1	13.1	3.1	3.4	4	5.3	4.4	3.9	4.4	4.7	7.2	13.6	27.3	13.3
14.7	18.8	13.5	4	4.7	5.8	6.2	4.4	9.7	4.3	7.4	6.9	11.3	12.6	15.6
10.1	8.1	8.2	11.8	10.8	11.8	4.335	6.6	22.3	6	40.1	10.8	3.2	2	5
3.7	4.3	5.5	4.7	3.6	1.4	12.6	4.3	0.5	17.8	12.9	10.7	10.4	13	14.1
4	3.3	5.6	4	4.1	5.9	4.8	14.8	11	5.5	6.3	3.9	12.3	13.1	13.6
12	11.7	14.7	12	9.1	11.3	3.9	5.2	13.2	5.7	6.3	2.8	3.1	3	2.8
10.8	10.8	12.3	3	3.1	3.7	1.9	3.9	18.7	7.6	37.1	16.3	5.6	7	6.2
13.6	11.8	17.2	12.1	11.6	11.9	9.6	11.8	15.5	6.5	29	6.9	3.5	2.6	5.6
5.7	5.3	4.9	11.4	12.5	12.1	3.2	3.6	19.6	11.2	5.4	8.1	2.4	3.7	5.2
4.6	9.1	15.1	4.7	4.5	2.5	5.5	3.4	6.2	15.5	12.6	12.9	14.7	14.2	14.4

Table -4 Total Suspended Solid Concentration: Pre monsoon period (14 January 2021)

TSS1			TSS2			TSS3			TSS4			TSS5		
Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom
13.3	3.2	5.7	6.9	8.9	8.9	8.1	3.9	10.7	17.5	15	14.5	6.1	5.9	5
8	5.4	9.9	3.9	6.7	7	16.9	13.8	8.8	4.1	10	11.8	3.2	8.9	8.3
4.5	6.4	3.8	3.7	4.5	4.4	19.4	9.7	11.8	13.4	17.1	16.3	4.6	9.9	5.2
4.7	10.1	9.8	5.3	8.4	10.8		3.7	3.3	15.7	17.2	14.4	5.7	7.5	5.5
7	6.9	7.8	4.2	3.5	5.4	7.2	10	15.4	3.4	45.3	6	6.6	11.1	5.2
5.7	6.5	4.1	0.7	5.2	7.8	7.3	4.4	8.8	14.4	15.6	12.1	5.9	7.4	7.8
6.7	8.9	11.5	9.8	9.9	6	10.5	7.3	9.3	18.2	17.8	15.8	7.9	6	7.3
5.5	4.1	6	8.2	5.5	7.1	31.8	10.4	6.7	5.8	13	13.5	9.7	28.6	7.9
6.3	4.8	10.5	9	4.1	5.5	4.8	5.7	7.6	11.7	10	15.2	5.3	7.5	5.4
8.1	5.6	12.5	2.2	7.6	13.7	8.5	10.1	7	2.5	2.9	3.4	12.9	12.5	14.1
2.9	5.9	6.4	2.9	5	7.3	13.6	7.8	19.3	11.9	12.9	12.9	6.8	5.6	5.2
7.2	55.6	3.7	5.7	5.2	8.2	3.4	6.3	8.4	18.5	15.1	14.3	6.1	40.5	5.2
3.8	6	6	4	5.2	5.5	8.4	8.4	8.7	15.1	2.1	12.1	5.7	9.1	15

Marine Biodiversity Plan

Comprehensive assessment on the Biodiversity, Impact Assessment and Management Plan on Marine, Brackish Water and Fresh Water Ecosystems in and around Kattupalli Port, Chennai, Tamil Nadu

Final Report

Submitted to

Marine Infrastructure Developer Private Limited
Kattupalli Village, Ponneri Thaluk
Chennai – 600 120, Tamil Nadu

By

By

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17.11.2022

Contents

PART - I:

Comprehensive assessment on the Biodiversity of Marine, Brackish Water and Fresh Water Ecosystems

i. Executive Summary

The present study on the biological resources of the proposed project area is a comprehensive investigation that provides to update the benchmark / baseline information of the available resources which was carried out during November 2019 to January 2020. The study is helpful in the preparation and implementation of conservation strategy to minimize or nullify the impacts of any coastal development project in the area. The present assessment on landward and seaward was carried out in the same 10 km radius of baseline survey, and the alignment was derived from the existing baseline survey map, present assessment was carried out during August 2022 to November 2022. The assessment covered the coastal area between Ennore and Pulicat, which includes coastal wetlands, inland region, Ennore Creek, Pulicat Lake, Kosasthalaiyar River and Buckingham Canal. Because of the availability of marine, brackish and freshwater ecosystems next to each other, associated biodiversity is considerably high in the study area. There are many species of fishes, molluscs, crustaceans and polychaetes within the study area. Totally 225 sampling locations were fixed within the study area for collection of water and sediment samples and for assessment of biological resources including underwater resources.

Underwater assessment of the study area reveals that the seascape is dominated by sandy and clayey bottom. Because of the bottom topography and prevailing strong currents, benthic communities are very less in amount. Dynamic and ecologically sensitive marine habitats such as coral reefs and seagrasses are not observed in any of the assessed grids due to the unsupportive environmental parameters. Because of the absence of critical habitats, density and diversity of fish and other biodiversity are comparatively low. In total, 56 fish species were recorded in the study area. Fish density and diversity vary between zones and the density ranges between 15.93 (no/250 m^2) and 41.86 (no/250 m^2) in the sea. *Rastrelliger kanagurta, Sardinella* sp., *Sphyraena jello,* and *Selaroides leptolepis* are the most abundant fishes in the study area. Among the benthic macrofauna, molluscs, sponges and soft corals are the dominant groups. In the study area, aquatic mammals were not sighted during the study period. Sea snakes and sea turtles were also not sighted.

The study area has a reasonable amount of mangrove habitat as freshwater supply is available. Due to the availability of mangroves, the mangrove associated biodiversity also occurs within the study area. Mangroves are seen along the Ennore Creek, Kosasthalaiyar River (at connection points between Ennore Creek and Pulicat Lake), at the mouth of the Buckingham Canal and in Pulicat Lake. Mangroves are seen in patches and lines along with mangrove associated halophytic plants. Total area cover of mangroves in the study area is 61.2 ha. The south side of the existing port has 21.4 ha, the area parallel to the port has 36.7 ha while the northern region has only 3.1 ha. Totally three mangrove species are seen namely *Avicennia marina, Avicennia* sp. and *Rhizophora mucronata*, of which *Avicennia marina* is the dominant species. Five types of halophytic plants occur in the mangrove areas namely *Sesuvium portulacastrum, Suaeda monoica, Suaeda* sp.*, Suadea nudifolra Moq.* and *Salicornia brachiate Roxb*. The study area encompasses a fair extent of coastal vegetation apart from the mangroves. The study area has a total of 41 species of plants. Of which 5 are herbs dominated by *Cyperus conglomeratus*, 20 shrubs dominated by *Ipomoea pes-caprae* and 16 are trees dominated by *Eucalyptus globulus*. The total area cover of coastal vegetation is 282 ha, in which *Eucalyptus globulus* is the dominant plant covering an area cover of 94 ha.

Molluscs are represented by 37 species in the study area and the density ranges between 5.29±0.20 and 14.27±0.32 (no/5 m^2). *Babylonia spirata*, *Agaronia gibbosa*, *Cerithium columna*, *Turritella attenuata* and *Donax scortum* are the most abundant molluscan species. Marine sponges are represented by 12 species, of which *Clathria* sp., *Spirastrella* sp. and *Cliona* sp. are the most common. Density of sponges ranges between 0.67±0.28 (no/5 m^2) and 5.53±0.67 (no/5 m^2). Soft corals present in the study areas are represented by 5 species, of which *Virgularia* sp., *Cavernulina* sp. and *Carijoa* sp. are common. Soft coral density in the study area ranges between 0.2±0.14 (no/5 m^2) and 2.8±0.25 (no/5 m^2). Apart from molluscs, sponges and soft corals, there are other benthic macrofauna such as sea anemones and echinoderms though with poor representation. Sea cucumbers and one species of sea anemone were sighted during the present assessment.

Sediment samples were collected from all the zones to assess the density and diversity of macro- and meiofaunal communities. Density and diversity of both macro- and meiofaunal communities are reasonably good in the study area. A total of six groups namely polychaetes, gastropods, bivalves, amphipods, isopods and others were categorized from the samples collected. Among them, polychaetes are the most dominant group followed by gastropods. The meiofauna found in the study area include six major groups namely nematodes, Foraminifera, cumaceans, Harpacticoids, Ostrocods, and others. A total of 40 macrofaunal species and 75 species of meiofauna were observed in the mangrove waters. In Kosasthalaiyar River, a total of 34 macrofaunal species and 66 meiofaunal species were recorded. In the canal samples, 27 species of macrofauna and 58 species of meiofauna were identified. Samples from Pulicat Lake and Ennore Creek reveal 43 macrofaunal species and 59 meiofaunal species. From the marine samples, a total of 110 species of macrofauna and 102 species of meiofauna were identified.

Density and diversity of phyto- and zooplankton has a fair proportion in the study area. From the samples collected from the study area phytoplankton species belonging to three groups namely diatoms, dinoflagellates and cyanophyceae were observed. Phytoplankton density in the study area ranges between 100 and 42,500 cells/l whereas zooplankton density ranges between 100 and 5,200 no/m^3. Chlorophyll 'a' ranges between 0.33 and 18.49 mg/m^3 and chlorophyll 'b' ranges between 0.11 and 10.86 mg/m^3 while primary productivity ranges between 60.01 and 530.94 $mgCm^{-3}d^{-1}$ in the study area. Microbial parameters such as total viable count show significant variation in Ennore Creek. *E. coli* shows variation in Pulicat Lake, mangrove area, and Kosasthalaiyar River. Faecal coliform exhibit significant variation in Buckingham Canal. In the water samples collected from the study area total viable count ranges from 2.32 $x10^4$ to8.10$x10^4$ CFU/ml and total coliform ranges from 0.65 $x10^4$ to 2.19$x10^4$ CFU/ml. In the case of sediment samples total viable count ranges from 1.72 $x10^5$ to 8.78$x10^5$ CFU/g and total coliform count ranges between 0.72$x10^5$ and 2.41$x10^5$ CFU/g.

Terrestrial mammals recorded within the study area include cows, buffaloes, squirrel, field mouse, bat, house rat, hare, dog, snake and tree lizard. Water snakes were found entangled in the fishing nets laid in the Buckingham Canal and Kosasthalaiyar River. The landforms observed in the study area include river, intertidal region, waterlogged area, canal, creek, lake, cultivable land, non-cultivable land, coastal track and coastal track and hence the density and diversity of birds are considerably high. Totally 37 species of migratory and resident birds were sighted during the study period dominated by *Ardea intermedia, Sterna albifrons, Mycteriya leucocephala, Pelecanus philippensis*, *Tringa glareola* and *Himantopus himantopus*.

There are five fishing villages in the study area namely Vairavankuppam, Koraikuppam, Kadalkannikuppam, Kattupalli and Karungali, where the fishery survey was conducted. Fishing is the primary occupation of the residents of these villages. There is significantly high exploitation of the fishery resources in the marine and brackish water zones by the fishermen. Some of the fishing related activities of the villagers include fishing in sea and brackish waters, hand picking of prawns, shell collection, polychaetes collection and working as coolies in aqua forms and other agencies. There are about 1,534 fishermen living in the study area. The fishermen employ mostly FRP (Fibre Reinforced Plastic) boats fixed with outboard engine. There are about 229 motorized FRP boats being operated from the study area. Fish catch is higher in Koraikuppam, followed by Vairavankuppam and Kattupalli with 1,990 kg/day, 1,350 kg/day and 1,100 kg/day respectively during the study period. *Rastrelliger kanagurta* is the abundantly caught fish followed by *Alepes djedaba* and *Sphyraena* sp. As for shell fish, *Metapenaeus* sp. and *Penaeus monodon* are the abundantly landed species. The land cover in the study area is occupied by vegetation, agriculture, mangroves, (CRZ-1A), intertidal zone (CRZ-1B), coastal sand (CRZ-III), tidal influence water bodies (CRZ-IVB), aqua farms, habitation, salt pans and industries. The landward side of the study area is found dominated by agriculture land with an area cover of 4,700 ha, where paddy is the dominant crop cultivated. Industries and ports cover an approximate area of 2,571 ha.

Based on the data collected during 2020 and 2022, it may be concluded that the biological parameters within the study area did not show significant changes except minor variations which may be due to seasonal changes.

1. Introduction

Marine Infrastructure Developer Private Limited (MIDPL) has proposed Revised Master Plan for development of Kattupalli port, which is located in the Tamil Nadu State on the Southeast coast of India. The total proposed quantity of Capital Dredging is 85 Mm^3 and the dredged material used for reclamation of 1145 Ha area (that includes level raising). The total proposed reclamation including land fill quantity estimated is ~138 Mm^3. In addition, apart from existing Breakwater, two new Breakwater of about total 12.10 km length is proposed, out of which new Northern Breakwaters about 9.02 & 1.22 km and new Southern Breakwater about 1.86 km. Pulicat Lake is located on the northern side of the project site (about 12 km distance from the existing Kattupalli port) and the existing Ennore Port is located on the southern side. Considering the said project activities, the present marine biodiversity study is carried out (by fixing appropriate number of locations for sample collection and underwater surveys) for subsequent development of Marine Biodiversity Management Plan in line to ToR conditions specified by MoEF&CC.

The previous baseline assessment was carried out from November 2019 to January 2020 and the present study was conducted from August 2022 to November 2022.

The main objective of the present study is to update the comprehensive Baseline Data (2020) of ecological important habitats include Marine zone, brackish and freshwater zone adjacent to the project site. The findings of the present study would help to protect and manage the biodiversity and associated livelihood of the marine, brackish and fresh water ecosystems through effective action plan and monitoring.

1.1 ToR conditions specified by MoEF&CC for Marine Biodiversity Management plan

- To suggest measures for protection of general ecosystem of Kosasthalaiyar estuary including mangroves.
- To study the Biodiversity of the proposed project area, viz, estuary and coastal region,
- To study the impact of dredging and dumping on marine ecology and draw up a management plan,
- To prepare a detailed biodiversity impact assessment report and management plan on marine, brackish water and freshwater ecology and biodiversity. The report shall study the impact on the rivers, estuary and the sea and include the intertidal biotopes, corals and coral communities, molluscs, sea grasses, sea weeds, subtidal habitats, fishes, other marine and aquatic micro, macro and mega flora and fauna including benthos, plankton, turtles, birds, etc. as also the productivity. The data collection and impact assessment shall be as per standard survey methods.

- A detailed marine biodiversity management plan shall be prepared and submitted to and implemented to the satisfaction of the State Biodiversity Board and the CRZ authority. The report shall be based on a study of the impact of the project activities on the intertidal biotopes, corals and coral communities, molluscs, sea grasses, sea weeds, sub-tidal habitats, fishes, other marine and aquatic micro, macro and mega flora and fauna including benthos, plankton, turtles, birds etc. as also the productivity. The data collection and impact assessment shall be as per standards survey methods and include underwater photography.

Major study Zones

1. Marine Zone
2. Brackish and Fresh water

Study Locations

1. Inter tidal and sub tidal in the marine zone
2. Kosasthalaiyar River (including two mouths) - For Brackish and Fresh water
3. Buckingham canal - For Brackish and Fresh water

1.2. Study area description

Taking the Kattupalli Port as the centre point, assessment was carried out in 10 km radius towards the land and towards the sea (Fig. 1.1). The coastal area between Ennore and Pulicat has been covered in the assessment which includes coastal wetlands, inland region, Ennore creek, Pulicat Lake, Kosasthalaiyar River and Buckingham Canal. Survey locations used for the present study were from baseline study in 2020.

Pulicat Lake

Lakes are ideal grounds from unravelling a number of hydrogeochemical processes like evaporation, mixing, dissolution, precipitation of minerals and chemicals, and isotopic exchange between water, sediments and the atmosphere (Kharaka et al. 1984). Pulicat Lake (Fig. 1.2), also called as Lake of Palar river basin, is the second largest lagoon on the east coast of India, located 40 km north of Chennai city (Raj, 1995) and is about 12 km north of existing Kattupalli Port. The lake has a narrow pass into the Bay of Bengal near the Pulicat town and it is one of good productive ecosystems in India (Raj, 2006). The fauna and flora in the lake system are unique.

The main source of fresh water is land run-off and three small seasonal rivers open into the lake, namely the Arani river discharging at the southern end of the lake in Tamil Nadu; the Kalangi River towards the mid-western region of the lake in Andhra Pradesh; and the Swarnamukhi river at the northern end of the lake in Andhra Pradesh. Water flows in the rivers during northwest monsoon (October to December). Small non perennial streams enter the lake at various points for flushing the storm water during the rainy season. All resources from plankton to mammals directly or indirectly depend on the benthic resources in the Pulicat lake ecosystem.

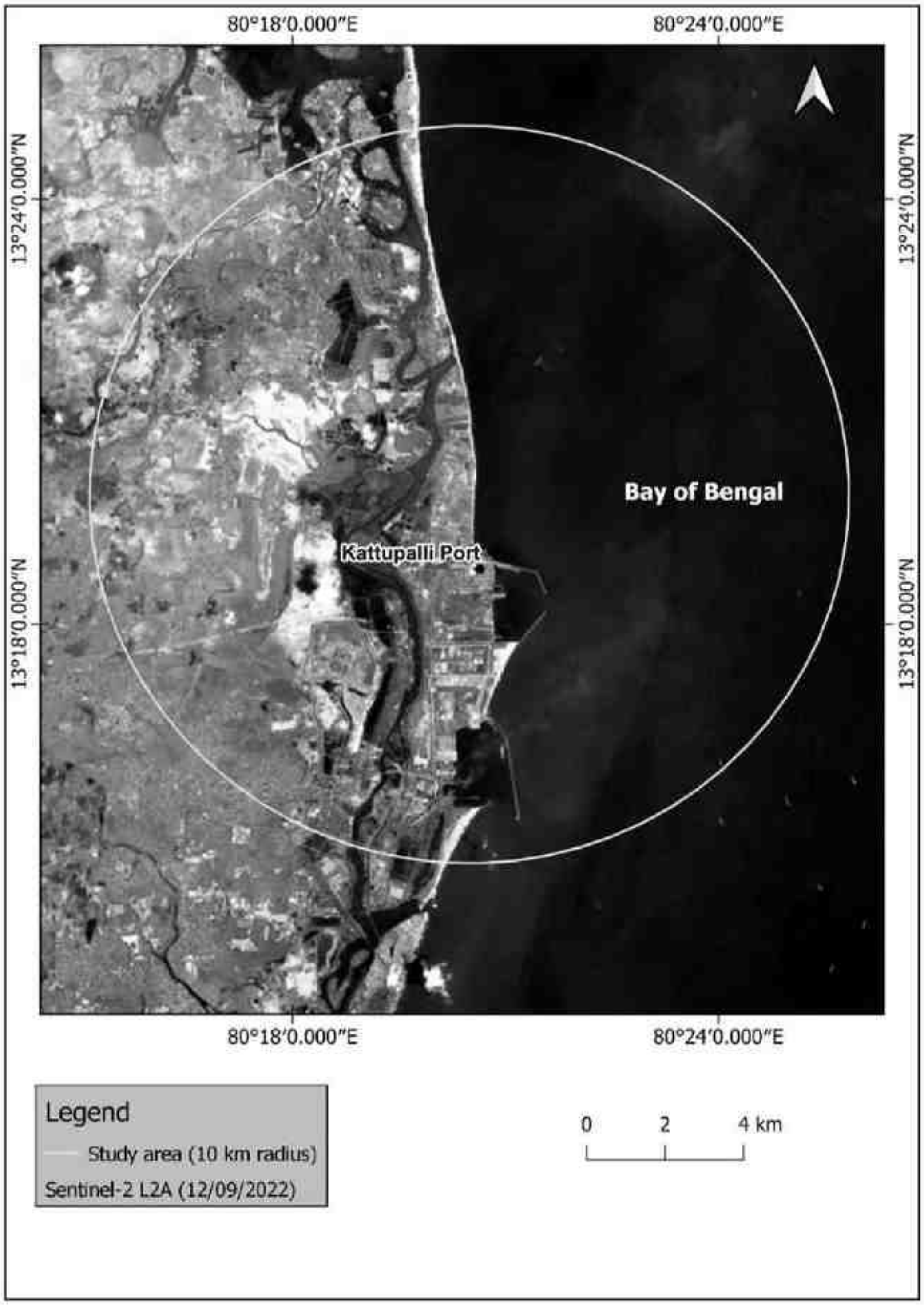


Fig. 1.1: Satellite image showing the 10 km radius of the study area

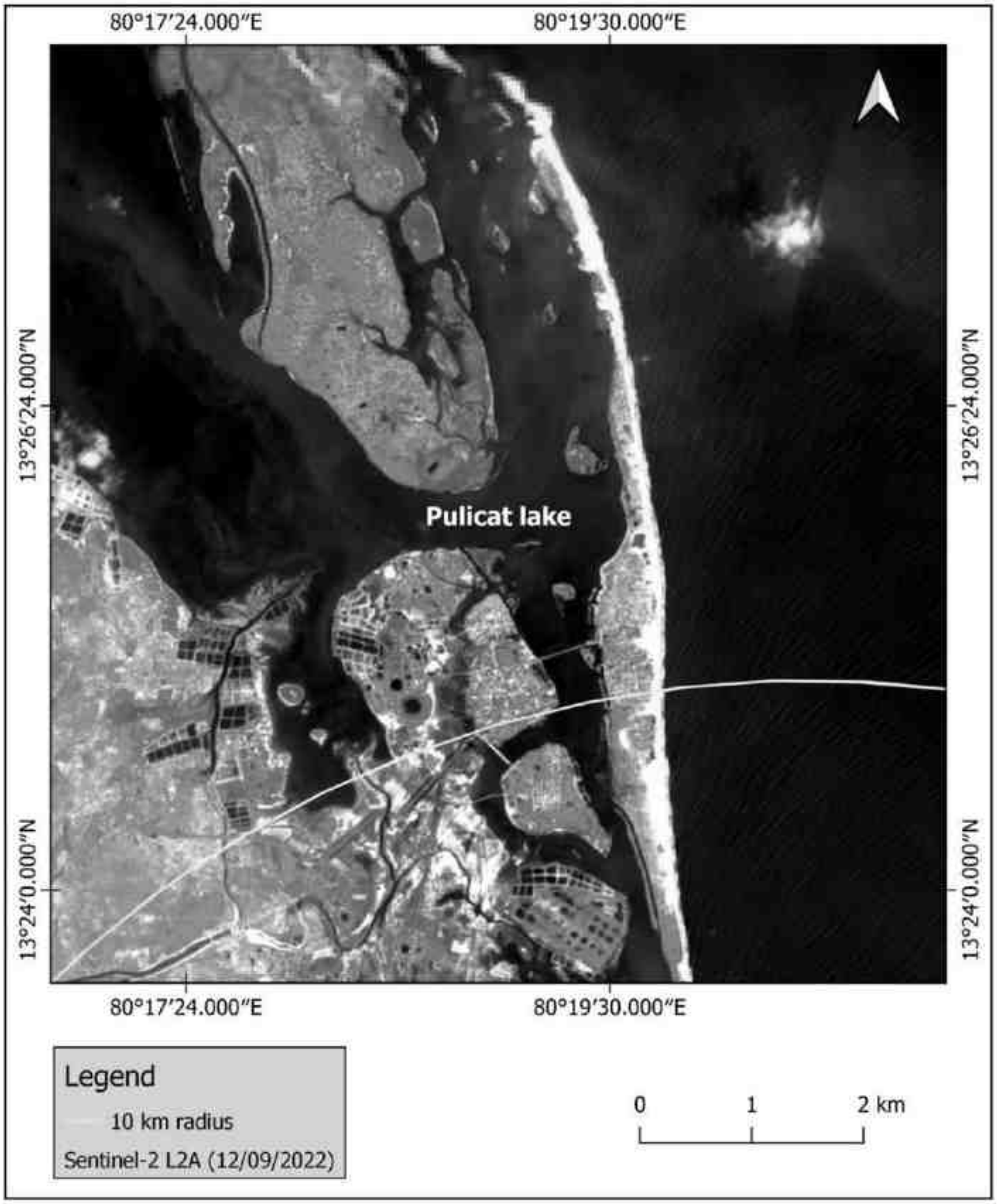


Fig. 1.2: Satellite image showing part of Pulicat Lake of the study area

Ennore creek

Ennore creek is a complex brackish water system situated in Ennore. It is the estuary or the mouth of the river Kosasthalaiyar, which drains into Bay of Bengal through a small opening (Fig. 1.3). The unique physical landscape and marshes of Ennore creek are covered by fresh water and saline water which provides a rich supply of food that supports a large variety of animal and plant life (Moorthy and Habibullah, 2001). It supports the livelihood of thousands of fishing families in the nearby villages (Jayaprakash, 2003; Jayaprakash et al., 2005). The north-south trending channel of Kosasthalaiyar River links the Ennore creek with the Pulicat Lake.

Fig. 1.3: Satellite image showing Ennore creek of the study area

Kosasthalaiyar River

Kosasthalaiyar River originates near Pallipattu in Thiruvallur district and drains into Bay of Bengal at Ennore creek (Fig. 1.4). A tidal influence channel (CRZ-IVB) of Kosasthalaiyar River which runs from the north of Ennore creek connect the Pulicat Lake with the Ennore creek is endowed with large cover of flat intertidal zone (CRZ-1B). These intertidal zones are usually flooded with water during monsoon seasons. Mangrove (CRZ-1A) and hypersaline plants are seen in the intertidal zone all along from Ennore creek to Pulicat Lake. This environment supports a unique intertidal fauna and flora, which supports livelihood of local fishing communities (Jayaprakash et al., 2005).

Fig. 1.4: Satellite image showing Kosasthalaiyar River and Buckingham canal of the study area

Buckingham Canal

The Buckingham canal is a brackish water canal, which was excavated for inland transportation during the British period (Fig. 1.4). The canal consists of a total length of 796 km largely joining backwater and depressions running from Kakinada in East Godavari district of Andhra Pradesh to Marakkanam in Viluppuram district of Taml Nadu. It runs almost parallel to Coromandel Coast and cuts Pulicat Lake and Ennore creek. It also meets Kosasthalaiyar River at number of locations. It is flooded by freshwater during monsoon season. Aquafarms situated in the banks of the canal, draw waters from the adjacent canal and discharge nutrient water back into the river.

Details of sampling locations used baseline study (2020)

As the present study is to update the baseline information of 2019/2020, all sampling locations were selected exactly from previous survey sites to determine the changes in environmental, biological, and fisheries status in 2022.

Study Locations

Underwater Assessment	- 92 locations within 10 km radius in Bay of Bengal (marine zone)
Marine Water	- 86 Locations within 10 km radius towards marine zone
Marine Sediment	- 86 Locations within 10 km radius towards marine zone
Benthic Assemblages	- within 10 km radius towards marine zone
Fishery and Fish landing	- within 10 km radius towards marine zone & landing site
Mangroves	- Locations fixed based on its presence
Others	- within 10 km radius towards marine zone

Study Locations (including the river mouths)

Water & Sediment	- 13 Locations in Kosasthalaiyar River within 10 km radius
Water & sediment	- 12 Locations in Buckingham canal within 10 km radius
Water & sediment	- 11 Locations in Kosasthalaiyar River Mouths, outside 10 km radius (6 near Pulicat lake & 5 near Ennore)
Fishery and Fish landing	- Within 10 km radius
Mangroves	- 11 Locations are fixed
Others	- Within 10 km radius

The underwater assessment was conducted within the 10 km radius to assess the benthic biota in Bay of Bengal adjacent to the proposed project site. The survey area was divided into 8 major zones, starting from the shore with an approximate interval of 1 km from the shore; within each perpendicular zone, further division was done as 1 sq.km grids parallel to the shore. Totally 92 locations were constituted to perform the underwater biodiversity assessment (Fig. 1.5, Table 1).

Sampling was done in both marine zone and brackish & fresh water zones. Among the divided zones in Bay of Bengal, 86 water and sediment samples were collected. Samples were collected with an interval of 0.5 km near the centre of the study area (existing Kattupalli Port), whereas samples away from the centre were collected at distances of 1 and 2 km interval (Fig. 1.6, Table 2). In the brackish and freshwater zone, totally 47 samples were collected from mangrove ecosystem, Kosasthalaiyar River, Buckingham canal, Pulicat lake and Ennore creek (Fig. 1.7, Table 3). In mangrove ecosystem, totally 11 locations were selected randomly for sample collection and mangrove studies. In the river, totally 13 sampling locations were selected covering the entire river from south to north side of the study area. In Buckingham canal, totally 12 sample locations were selected covering the entire area from south to north side within 10 km radius. Sampling was also done outside the 10 km radius at Pulicat Lake and Ennore creek. Totally 6 sampling locations were selected from Pulicat Lake 5 were inside the lake. Among the 5 locations in Ennore creek, 2 were inside the sea along the mouth. The sampling location in marine, brackish water and freshwater are shown in the map (Fig. 1.7) and their coordinates are given in the table 1.

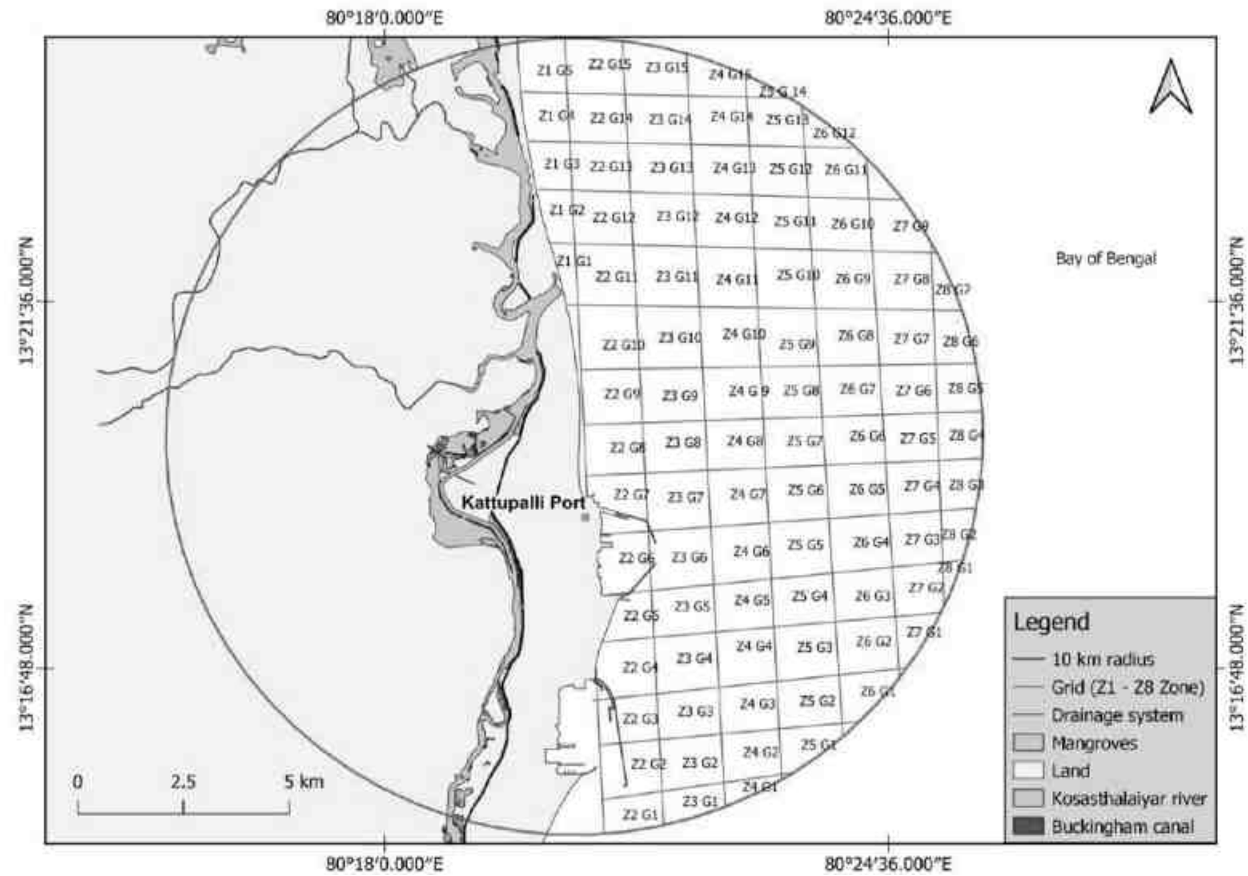


Fig. 1.5: Map showing the underwater assessment locations in the 10 km radius of the Kattupalli study area

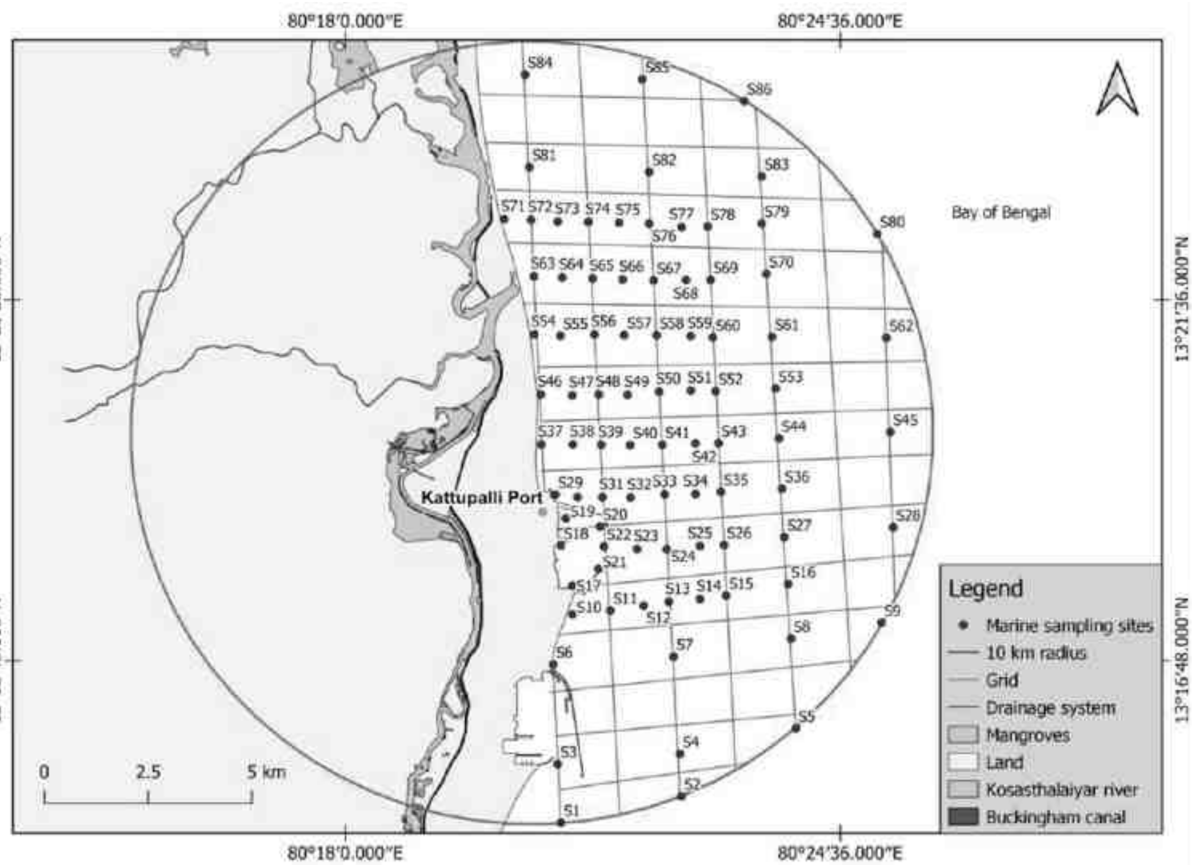


Fig. 1.6: Map showing the biological parameters assessment locations in the 10 km radius of Bay of Bengal region of the Kattupalli study area

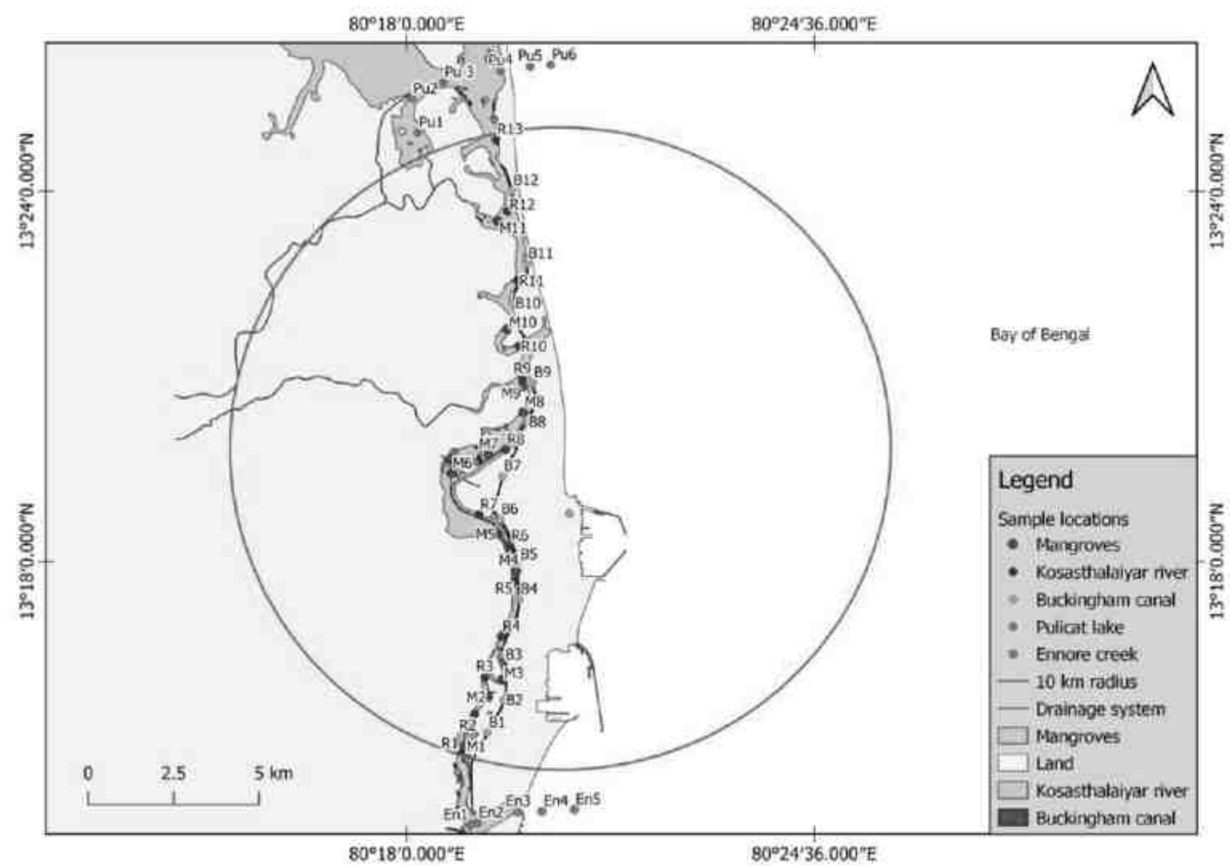


Fig. 1.7: Map showing the biological parameters assessment locations along the coastal area between Ennore creek and Pulicat lake

Table 1: shows the underwater assessment locations and coordinates in 10 km radius of the Kattupalli Port in the marine zone

Sl.No.	Zone	Grid	Depth (m)	Sediment type	Latitude	Longitude
1	Z1	Z1 G1	5	Sand	N 13^o 22' 8.046"	E 80^o 20' 22.506"
2		Z1 G2	5	Sand	N 13^o 22' 48.209"	E 80^o 20' 16.7"
3		Z1 G3	7	Sand	N 13^o 23' 24.5"	E 80^o 20' 12.829"
4		Z1 G4	6	Sand	N 13^o 24' 2.243"	E 80^o 20' 8.716"
5		Z1 G5	8	Sand	N 13^o 24' 37.809"	E 80^o 20' 7.022"
6	Z2	Z2 G1	12	Sandy shale	N 13^o 14' 53.8"	E 80^o 21' 14.605"
7		Z2 G2	11	Sand	N 13^o 15' 33.64"	E 80^o 21' 21.057"
8		Z2 G3	8	Sand	N 13^o 16' 9.125"	E 80^o 21' 14.605"
9		Z2 G4	4	Sand	N 13^o 16' 49.449"	E 80^o 21' 14.605"
10		Z2 G5	7	Sand	N 13^o 17' 30.095"	E 80^o 21' 15.25"
11		Z2 G6	17	Clay	N 13^o 18' 15.257"	E 80^o 21' 11.379"
12		Z2 G7	8	Sand	N 13^o 19' 5.259"	E 80^o 21' 7.508"
13		Z2 G8	8	Sand	N 13^o 19' 42.034"	E 80^o 21' 4.604"
14		Z2 G9	9	Sand	N 13^o 20' 23.971"	E 80^o 21' 0.088"
15		Z2 G10	7	Sand	N 13^o 21' 2.359"	E 80^o 20' 58.475"
16		Z2 G11	11	Sand	N 13^o 21' 55.909"	E 80^o 20' 53.314"
17		Z2 G12	12	Sand	N 13^o 22' 42.362"	E 80^o 20' 50.733"
18		Z2 G13	13	Sandy shale	N 13^o 23' 22.363"	E 80^o 20' 48.798"
19		Z2 G14	13	Sandy shale	N 13^o 24' 0.429"	E 80^o 20' 48.798"
20		Z2 G15	12	Sandy shale	N 13^o 24' 42.688"	E 80^o 20' 47.507"
21	Z3	Z3 G1	15	Sandy shale	N 13^o 15' 4.284"	E 80^o 22' 1.703"
22		Z3 G2	14	Sandy shale	N 13^o 15' 34.608"	E 80^o 22' 1.38"
23		Z3 G3	12	Sand	N 13^o 16' 14.931"	E 80^o 21' 57.832"
24		Z3 G4	5	Sand	N 13^o 16' 56.546"	E 80^o 21' 56.864"
25		Z3 G5	9	Sand	N 13^o 17' 37.353"	E 80^o 21' 55.251"
26		Z3 G6	18	Sandy shale	N 13^o 18' 15.903"	E 80^o 21' 52.832"
27		Z3 G7	12	Sandy shale	N 13^o 19' 3.001"	E 80^o 21' 49.928"
28		Z3 G8	13	Sandy shale	N 13^o 19' 45.905"	E 80^o 21' 47.993"
29		Z3 G9	12	Sandy shale	N 13^o 20' 22.519"	E 80^o 21' 45.735"
30		Z3 G10	13	Sandy shale	N 13^o 21' 8.004"	E 80^o 21' 42.831"
31		Z3 G11	12	Sandy shale	N 13^o 21' 56.07"	E 80^o 21' 40.573"
32		Z3 G12	14	Sandy shale	N 13^o 22' 43.33"	E 80^o 21' 41.057"
33		Z3 G13	12	Sandy shale	N 13^o 23' 21.556"	E 80^o 21' 36.38"
34		Z3 G14	12	Sandy shale	N 13^o 23' 59.299"	E 80^o 21' 35.089"
35		Z3 G15	13	Sand	N 13^o 24' 40.268"	E 80^o 21' 32.508"
36	Z4	Z4 G1	17	Sandy shale	N 13^o 15' 15.736"	E 80^o 22' 48.64"
37		Z4 G2	18	Sandy shale	N 13^o 15' 42.834"	E 80^o 22' 49.285"

38		Z4 G3	16	Sandy shale	N 13° 16' 20.899"	E 80° 22' 46.704"
39		Z4 G4	12	Sand	N 13° 17' 6.062"	E 80° 22' 43.801"
40		Z4 G5	11	Sand	N 13° 17' 42.192"	E 80° 22' 42.188"
41		Z4 G6	13	Sandy shale	N 13° 18' 20.58"	E 80° 22' 41.543"
42		Z4 G7	11	Sand	N 13° 19' 5.42"	E 80° 22' 38.962"
43		Z4 G8	8	Sand	N 13° 19' 47.034"	E 80° 22' 36.704"
44		Z4 G 9	9	Sand	N 13° 20' 26.068"	E 80° 22' 37.994"
45		Z4 G10	8	Sand	N 13° 21' 10.908"	E 80° 22' 33.155"
46		Z4 G11	12	Sand	N 13° 21' 53.812"	E 80° 22' 27.994"
47		Z4 G12	13	Sand	N 13° 22' 42.201"	E 80° 22' 27.349"
48		Z4 G13	11	Sand	N 13° 23' 21.234"	E 80° 22' 25.736"
49		Z4 G14	12	Sandy shale	N 13° 24' 1.558"	E 80° 22' 23.478"
50		Z4 G15	11	Sand	N 13° 24' 34.623"	E 80° 22' 22.187"
51	Z5	Z5 G1	25	Clay	N 13° 15' 48.802"	E 80° 23' 34.851"
52		Z5 G2	23	Clay	N 13° 16' 23.158"	E 80° 23' 33.641"
53		Z5 G3	22	Clay	N 13° 17' 5.255"	E 80° 23' 31.705"
54		Z5 G4	24	Clay	N 13° 17' 45.418"	E 80° 23' 27.592"
55		Z5 G5	20	Clay	N 13° 18' 25.58"	E 80° 23' 24.205"
56		Z5 G6	19	Sand	N 13° 19' 8.646"	E 80° 23' 24.447"
57		Z5 G7	18	Sand	N 13° 19' 47.115"	E 80° 23' 23.479"
58		Z5 G8	14	Sand	N 13° 20' 26.551"	E 80° 23' 20.818"
59		Z5 G9	9	Sand	N 13° 21' 2.843"	E 80° 23' 17.431"
60		Z5 G10	11	Sand	N 13° 21' 57.28"	E 80° 23' 15.737"
61		Z5 G11	7	Sand	N 13° 22' 39.378"	E 80° 23' 13.56"
62		Z5 G12	10	Sand	N 13° 23' 20.508"	E 80° 23' 9.931"
63		Z5 G13	12	Sand	N 13° 23' 58.977"	E 80° 23' 7.269"
64		Z5 G 14	11	Sand	N 13° 24' 21.236"	E 80° 23' 1.705"
65	Z6	Z6 G1	30	Clay	N 13° 16' 30.658"	E 80° 24' 21.304"
66		Z6 G2	28	Clay	N 13° 17' 9.852"	E 80° 24' 17.916"
67		Z6 G3	27	Clay	N 13° 17' 45.66"	E 80° 24' 17.191"
68		Z6 G4	28	Clay	N 13° 18' 27.758"	E 80° 24' 15.981"
69		Z6 G5	26	Clay	N 13° 19' 9.372"	E 80° 24' 12.594"
70		Z6 G6	27	Clay	N 13° 19' 50.986"	E 80° 24' 13.078"
71		Z6 G7	23	Clay	N 13° 20' 27.761"	E 80° 24' 5.335"
72		Z6 G8	23	Sand	N 13° 21' 9.859"	E 80° 24' 3.884"
73		Z6 G9	21	Sand	N 13° 21' 54.377"	E 80° 24' 1.464"
74		Z6 G10	20	Sand	N 13° 22' 37.321"	E 80° 23' 58.682"
75		Z6 G11	7	Sand	N 13° 23' 19.903"	E 80° 23' 53.48"
76		Z6 G12	8	Sand	N 13° 23' 48.694"	E 80° 23' 44.044"
77	Z7	Z7 G1	38	Clay	N 13° 17' 17.232"	E 80° 24' 57.837"
78		Z7 G2	36	Clay	N 13° 17' 52.071"	E 80° 24' 59.289"

79		Z7 G3	36	Clay	N 13^o 18' 29.814"	E 80^o 24' 56.385"
80		Z7 G4	38	Clay	N 13^o 19' 11.912"	E 80^o 24' 55.901"
81		Z7 G5	33	Clay	N 13^o 19' 49.171"	E 80^o 24' 52.514"
82		Z7 G6	31	Clay	N 13^o 20' 26.431"	E 80^o 24' 49.127"
83		Z7 G7	30	Clay	N 13^o 21' 7.077"	E 80^o 24' 47.675"
84		Z7 G8	28	Clay	N 13^o 21' 54.014"	E 80^o 24' 47.675"
85		Z7 G9	28	Clay	N 13^o 22' 35.628"	E 80^o 24' 47.191"
86	Z8	Z8 G1	41	Clay	N 13^o 18' 2.233"	E 80^o 25' 24.934"
87		Z8 G2	41	Clay	N 13^o 18' 33.945"	E 80^o 25' 24.49"
88		Z8 G3	39	Clay	N 13^o 19' 12.88"	E 80^o 25' 30.741"
89		Z8 G4	40	Clay	N 13^o 19' 51.591"	E 80^o 25' 31.225"
90		Z8 G5	40	Clay	N 13^o 20' 28.366"	E 80^o 25' 30.257"
91		Z8 G6	38	Clay	N 13^o 21' 5.141"	E 80^o 25' 26.386"
92		Z8 G7	36	Clay	N 13^o 21' 45.788"	E 80^o 25' 20.096"

Note: ‘Z’ denotes zone and G denotes grid

Table 2: shows the biological parameters assessment locations and coordinates in 10 km radius of the Kattupalli Port in the marine zone

Sample No.	Latitude	Longitude
S1	N 13^o 14' 38.645"	E 80^o 20' 52.545"
S2	N 13^o 14' 59.581"	E 80^o 22' 28.846"
S3	N 13^o 15' 25.411"	E 80^o 20' 50.005"
S4	N 13^o 15' 33.487"	E 80^o 22' 27.664"
S5	N 13^o 15' 53.838"	E 80^o 24' 0.445"
S6	N 13^o 16' 44.965"	E 80^o 20' 46.456"
S7	N 13^o 16' 51.167"	E 80^o 22' 22.621"
S8	N 13^o 17' 5.442"	E 80^o 23' 56.584"
S9	N 13^o 17' 18.137"	E 80^o 25' 9.072"
S10	N 13^o 17' 24.952"	E 80^o 21' 1.86"
S11	N 13^o 17' 27.958"	E 80^o 21' 31.866"
S12	N 13^o 17' 31.802"	E 80^o 21' 58.586"
S13	N 13^o 17' 34.89"	E 80^o 22' 18.646"
S14	N 13^o 17' 37.127"	E 80^o 22' 43.69"
S15	N 13^o 17' 39.843"	E 80^o 23' 4.573"
S16	N 13^o 17' 48.983"	E 80^o 23' 54.351"
S17	N 13^o 17' 47.724"	E 80^o 21' 1.613"
S18	N 13^o 18' 19.793"	E 80^o 20' 52.525"
S19	N 13^o 18' 41.531"	E 80^o 20' 56.63"
S20	N 13^o 18' 34.932"	E 80^o 21' 23.465"
S21	N 13^o 18' 1.242"	E 80^o 21' 22.399"

S22	N 13^{o} 18' 19.074"	E 80^{o} 21' 26.746"
S23	N 13^{o} 18' 17.066"	E 80^{o} 21' 53.299"
S24	N 13^{o} 18' 16.878"	E 80^{o} 22' 17.14"
S25	N 13^{o} 18' 19.366"	E 80^{o} 22' 43.74"
S26	N 13^{o} 18' 20.284"	E 80^{o} 23' 3.065"
S27	N 13^{o} 18' 26.436"	E 80^{o} 23' 51.171"
S28	N 13^{o} 18' 34.311"	E 80^{o} 25' 18.491"
S29	N 13^{o} 19' 0.48"	E 80^{o} 20' 48.056"
S30	N 13^{o} 18' 58.484"	E 80^{o} 21' 5.913"
S31	N 13^{o} 18' 58.329"	E 80^{o} 21' 25.558"
S32	N 13^{o} 18' 58.152"	E 80^{o} 21' 47.942"
S33	N 13^{o} 19' 0.717"	E 80^{o} 22' 15.383"
S34	N 13^{o} 19' 0.986"	E 80^{o} 22' 40.086"
S35	N 13^{o} 19' 2.569"	E 80^{o} 23' 0.477"
S36	N 13^{o} 19' 5.049"	E 80^{o} 23' 49.436"
S37	N 13^{o} 19' 40.531"	E 80^{o} 20' 36.885"
S38	N 13^{o} 19' 40.554"	E 80^{o} 21' 2.146"
S39	N 13^{o} 19' 40.196"	E 80^{o} 21' 24.786"
S40	N 13^{o} 19' 39.989"	E 80^{o} 21' 47.655"
S41	N 13^{o} 19' 40.22"	E 80^{o} 22' 13.58"
S42	N 13^{o} 19' 41.32"	E 80^{o} 22' 39.97"
S43	N 13^{o} 19' 41.41"	E 80^{o} 22' 58.569"
S44	N 13^{o} 19' 45.342"	E 80^{o} 23' 46.929"
S45	N 13^{o} 19' 50.432"	E 80^{o} 25' 16.201"
S46	N 13^{o} 20' 20.343"	E 80^{o} 20' 36.414"
S47	N 13^{o} 20' 19.693"	E 80^{o} 21' 1.626"
S48	N 13^{o} 20' 20.411"	E 80^{o} 21' 22.619"
S49	N 13^{o} 20' 20.223"	E 80^{o} 21' 45.739"
S50	N 13^{o} 20' 22.605"	E 80^{o} 22' 11.054"
S51	N 13^{o} 20' 23.525"	E 80^{o} 22' 36.377"
S52	N 13^{o} 20' 23.083"	E 80^{o} 22' 56.152"
S53	N 13^{o} 20' 25.04"	E 80^{o} 23' 44.21"
S54	N 13^{o} 21' 8.279"	E 80^{o} 20' 31.181"
S55	N 13^{o} 21' 7.225"	E 80^{o} 20' 52.163"
S56	N 13^{o} 21' 8.335"	E 80^{o} 21' 19.15"
S57	N 13^{o} 21' 7.842"	E 80^{o} 21' 43.076"
S58	N 13^{o} 21' 7.604"	E 80^{o} 22' 8.983"
S59	N 13^{o} 21' 7.042"	E 80^{o} 22' 36.236"
S60	N 13^{o} 21' 5.859"	E 80^{o} 22' 53.937"
S61	N 13^{o} 21' 6.39"	E 80^{o} 23' 41.325"
S62	N 13^{o} 21' 5.567"	E 80^{o} 25' 12.958"

S63	N 13° 21' 54.553"	E 80° 20' 30.957"
S64	N 13° 21' 53.782"	E 80° 20' 53.629"
S65	N 13° 21' 52.901"	E 80° 21' 17.771"
S66	N 13° 21' 52.154"	E 80° 21' 41.753"
S67	N 13° 21' 51.398"	E 80° 22' 6.689"
S68	N 13° 21' 51.754"	E 80° 22' 32.571"
S69	N 13° 21' 51.81"	E 80° 22' 52.082"
S70	N 13° 21' 56.622"	E 80° 23' 36.926"
S71	N 13° 22' 40.339"	E 80° 20' 7.175"
S72	N 13° 22' 39.736"	E 80° 20' 28.706"
S73	N 13° 22' 38.35"	E 80° 20' 50.182"
S74	N 13° 22' 38.113"	E 80° 21' 14.542"
S75	N 13° 22' 37.438"	E 80° 21' 38.806"
S76	N 13° 22' 36.694"	E 80° 22' 2.873"
S77	N 13° 22' 33.892"	E 80° 22' 29.034"
S78	N 13° 22' 34.36"	E 80° 22' 49.811"
S79	N 13° 22' 36.801"	E 80° 23' 33.137"
S80	N 13° 22' 28.519"	E 80° 25' 5.683"
S81	N 13° 23' 21.949"	E 80° 20' 27.223"
S82	N 13° 23' 17.978"	E 80° 22' 2.905"
S83	N 13° 23' 14.361"	E 80° 23' 33.112"
S84	N 13° 24' 35.65"	E 80° 20' 23.827"
S85	N 13° 24' 31.952"	E 80° 21' 57.378"
S86	N 13° 24' 14.511"	E 80° 23' 19.172"

Note: ‘S’ denotes sampling location in Bay of Bengal

Table 3: shows the brackish and freshwater zone sampling locations and coordinates in 10 km radius of the Kattupalli Port

Sample No.	Location	Latitude	Longitude
M1	**Mangrove**	N 13° 15' 0.379"	E 80° 18' 56.009"
M2		N 13° 15' 48.34"	E 80° 19' 18.94"
M3		N 13° 16' 5.27"	E 80° 19' 32.78"
M4		N 13° 17' 50.38"	E 80° 19' 46.16"
M5		N 13° 18' 26.75"	E 80° 19' 28.2"
M6		N 13° 19' 25.81"	E 80° 18' 43.37"
M7		N 13° 19' 43.99"	E 80° 19' 19.65"
M8		N 13° 20' 25.26"	E 80° 19' 53.23"
M9		N 13° 20' 50.61"	E 80° 19' 52.86"
M10		N 13° 21' 46.17"	E 80° 19' 37.374"
M11		N 13° 23' 31.21"	E 80° 19' 28.09"

R1	**Kosasthalaiyar river**	N 13° 14' 57.034"	E 80° 18' 52.67"
R2		N 13° 15' 31.927"	E 80° 19' 5.781"
R3		N 13° 16' 7.623"	E 80° 19' 15.994"
R4		N 13° 16' 47.382"	E 80° 19' 31.891"
R5		N 13° 17' 40.801"	E 80° 19' 45.004"
R6		N 13° 18' 15.262"	E 80° 19' 40.152"
R7		N 13° 18' 45.637"	E 80° 19' 9.929"
R8		N 13° 19' 49.01"	E 80° 19' 36.107"
R9		N 13° 20' 57.306"	E 80° 19' 52.383"
R10		N 13° 21' 29.502"	E 80° 19' 49.013"
R11		N 13° 22' 32.987"	E 80° 19' 47.069"
R12		N 13° 23' 40.547"	E 80° 19' 37.914"
R13		N 13° 24' 50.319"	E 80° 19' 26.547"
B1	**Buckingham canal**	N 13° 15' 13.791"	E 80° 19' 18.286"
B2		N 13° 15' 45.539"	E 80° 19' 34.426"
B3		N 13° 16' 29.815"	E 80° 19' 33.612"
B4		N 13° 17' 23.658"	E 80° 19' 49.243"
B5		N 13° 18' 0.708"	E 80° 19' 48.402"
B6		N 13° 18' 41.14"	E 80° 19' 30.396"
B7		N 13° 19' 23.125"	E 80° 19' 33.031"
B8		N 13° 20' 15.822"	E 80° 19' 56.617"
B9		N 13° 20' 54.128"	E 80° 20' 2.394"
B10		N 13° 22' 11.529"	E 80° 19' 43.588"
B11		N 13° 22' 49.742"	E 80° 19' 56.743"
B12		N 13° 24' 0.777"	E 80° 19' 42.107"
Pu1	**Pulicat lake**	N 13° 24' 57.236"	E 80° 18' 10.552"
Pu2		N 13° 25' 29.989"	E 80° 18' 4.848"
Pu3		N 13° 25' 45.969"	E 80° 18' 35.523"
Pu4		N 13° 25' 56.982"	E 80° 19' 31.205"
Pu5		N 13° 26' 1.469"	E 80° 19' 59.949"
Pu6		N 13° 26' 3.25"	E 80° 20' 19.796"
En1	**Ennore creek**	N 13° 13' 44.012"	E 80° 19' 1.357"
En2		N 13° 13' 45.901"	E 80° 19' 8.483"
En3		N 13° 13' 56.52"	E 80° 19' 48.309"
En4		N 13° 13' 57.135"	E 80° 20' 11.308"
En5		N 13° 13' 58.998"	E 80° 20' 42.875"

Note: 'M' denotes Mangrove sites; 'R' denotes Kosasthalaiyar River sites; 'B' denotes Buckingham canal sites; 'Pu' denotes Pulicat Lake sites; 'En' denotes Ennore creek sites

2. Methodology

Over view of parameters studied

Marine Zone

Marine Water

Bacteriological Parameters: Total Viable Count (TVC),Total Coliform (TC), Faecal Coliform (FC), E.coli, *Shigella* sp., *Salmonella* sp., *Steptococcus faecalis*, *Pseudomonas aeruginosa*, *Vibrio parahaemolyticus* and *Vibrio cholera*.

Marine Biology: Phytoplankton, Zooplankton, Chlorophyll ‘a’ and ‘b’, and primary productivity and Fish Eggs & Larvae

Marine Sediment

Bacteriological parameters: Total Viable Count (TVC),Total Coliform (TC), Faecal Coliform (FC), E.coli, *Shigella* sp., *Salmonella* sp., *Steptococcus faecalis*, *Pseudomonas aeruginosa*, *Vibrio parahaemolyticus* and *Vibrio cholera*.

Marine Biology: Micro, macro and mega flora and fauna including benthos

Benthic assemblages in inter tidal and sub tidal areas
<u>*Seaweed area (if any)*</u>

- Species composition and size structure of seaweed communities.
- Assessment of associated fauna and flora on seaweed community.
- Numbers, species composition, size and structure of fish populations.
- Juvenile fishes, especially target species.
- Threats

Mangroves (if any)

- Species composition and vegetation structure
- Density, height, growth and canopy
- Associated fauna and flora.
- Numbers, species composition, size and structure of fish populations.
- Juvenile fishes, especially target species.
- Threats.

Fishery and fish landing details

- Fishing type
- Fishing ground

- Commonly landed fish species
- Fish landing details

Others

- Coastal vegetation, Avifauna, Turtles, Mammals etc. in the study area (within 10 Km radius)

<u>Brackish and Fresh Water Zone</u>

Water

Bacteriological Parameters: Total Viable Count (TVC),Total Coliform (TC), Faecal Coliform (FC), E.coli, *Shigella* sp., *Salmonella* sp., *Steptococcus faecalis*, *Pseudomonas aeruginosa*, *Vibrio parahaemolyticus* and *Vibrio cholera*.
Biology: Phytoplankton, Zooplankton, Chlorophyll 'a' and 'b', and primary productivity and Fish Eggs & Larvae

Sediment

Bacteriological parameters: Total Viable Count (TVC),Total Coliform (TC), Faecal Coliform (FC), E.coli, *Shigella* sp., *Salmonella* sp., *Steptococcus faecalis*, *Pseudomonas aeruginosa*, *Vibrio parahaemolyticus* and *Vibrio cholera*.
Biology: Micro, macro and mega flora and fauna including benthos.

Mangroves (if any)

- Species composition and vegetation structure
- Density, height, growth and canopy
- Associated fauna and flora.
- Numbers, species composition, size and structure of fish populations.
- Juvenile fishes, especially target species.
- Threats.

Fishery and fish landing details

- Fishing type
- Fishing ground
- Commonly landed fish species
- Fish landing details

Others

- Vegetation, Avifauna, Turtles, Mammals etc. in the study area (within 10 Km radius)

i. Marine zone underwater assessment

The underwater assessment was conducted within the 10 km radius to assess the benthic biota in the marine zone. Totally 92 locations were constituted to perform the underwater assessment. The bottom topographical structure of the seascape is dominated by sandy or silt clay. All sites were marked with GPS and all underwater monitorings was executed involving SCUBA diving upto 30 m and the grids with more than 30 m depth were assessed by using remotely operated vehicle (ROV). Since there was no notable benthic resource in the area, there was no need for specific underwater protocols such as Line Intercept transect (LIT) and Belt transect methods.

Macrofauna and fish community assessment

Macrofaunal density was assessed in the sandy and clay sites separately using haphazardly placed quadrats (1 X 1m) divided in to 25 grids. In each grid 20 to 30 quadrats were deployed. Major macrofaunal categories occur inside the quadrats were counted separately. Available benthic macrofaunal were classified into four major taxonomical group namely molluscs, sponges, soft corals and others (echinoderms, sea anemones etc.)

Fish community was estimated separately in sandy and clay sea floors using belt transect method (50 X 5 m) by following English *et al.* (1997). All transects were laid haphazardly to assess the fishes. Fish counts were performed using visual census technique. Each census area covered 250 m^2 extending 2.5 m to the right and left sides of 50 m transect line. All the fishes were counted and categorized using underwater fish ID cards, then the details were written on the underwater slates.

GIS Mapping

Base map for the current study was prepared with the help of Google image and GPS data collected during the survey using (ArcGIS). To this base map, collected GPS coordinates from sampling sites were transferred to the GIS software. Attribute tables were created for each site and all the data collected were added. Sampling location maps were created. (Horvat, 2013).

Diversity indices

Diversity community indices was performed to measure ecosystem health (Pillans *et al.*, 2007), macrofaunal and fish communities were calculated using the Shannon diversity index (H') in natural log. Coral and fish species richness (S) was counting the number of species from the quadrat.

All undwater assessment parameters were compared with baseline study during 2020.

ii. Mangrove habitat assessment

GIS Mapping

Rapid assessment was conducted by moving through the study area to collect water and sediment samples and to record data about mangrove ecosystem. During the field survey, mangrove species, distribution, density, growth, associated fauna and flora and avifauna are assessed. Handheld GPS Garmin etrex was used to record the coordinate during field survey. Mangrove distribution was recorded during fieldwork with the help of GPS and recent imageries. This was then transferred into GIS system (ArcGIS) for preparing mangrove cover mapping with the help of recent imageries (Horvart, 2013; Dowling & Stephens, 2001) for the study area.

At each site, quantitative observations were made with respect to mangrove density, height, health, seed and sapling density. Using this method, 11 sites were examined in Kosasthalaiyar river of the study area. Line transect plot method (English *et al.,* 1994) was used to assess mangroves quantitatively. Along transects across vegetation types, 5m x 5m plots were examined. In each plot mangroves were identified to species level and counted (Wagner et al., 2004). The height of growth of mangroves and their steam diameter were also measured. Similarly the length and width of their leaves were measure and the health conditions of the leaves were also recorded. Mangrove associated flora were also recorded in their respective sites.

Assessment of Mangrove associated biota

Benthic epi-macrofaunas were assessed by placing a quadrat (1 x 1 m) in 3 random locations at each site on the substratum and counting fauna by species. Mangrove associated fish were identified through visual observation along the mangrove habitat area. Detailed checklist was prepared from local fishing area.

Transect survey was done to record and photo document the avifauna (SNH, 2005) at the study site. The distributions of different avifauna in different landforms were recorded. Photo documentation was also done. Similarly, mammals were recoded and photo documented. Mangrove study parameters were compared with baseline study during 2020.

iii. Coastal floral assessment

Random survey was conducted, inorder to identify the plant species available in the coastal vegetation (Gillison and Brewer, 1985). The region that lies between Kosasthalaiyar River and coast were considered as coastal vegetation. Google earth image was used to get preliminary information about the distribution of coastal vegetation. During field survey google earth image was used to mark the coastal plantation. With the help of collected data from the field, geo-referred google earth image and sentinel images were used to prepare coastal plantation map and to calculate area cover in ArcGIS software (Horvat, 2013). Species observed during field visit were recorded and photo documented. The region that lies after the Kosasthalaiyar River was also surveyed for the vegetation cover during the fieldwork. Coastal vegetation study were compared with baseline study during 2020.

iv. Macro, meio and micro faunal assessment

The macro, meio and micro faunal assemblages were assessed in four different locations including kosasthalaiyar River, Buckingham canal, Mangrove waters, river mouth of Pulicat and Ennore creek (these sampling locations lie between Ennore creek and Pulicat lake).

Monitoring protocol

The macrobenthic sediment samples were collected by using Peterson grab having the bite of area 0.0256 m^2. The benthic sediment samples were collected at each station and samples were sieved gently through 0.5mm nylon mesh. The sieved samples were transferred into plastic containers and preserved using 7% (neutral) formaldehyde and brought to the laboratory. In the laboratory, each samples were transferred into sieve containers with 0.5mm mesh size, removing other adhering sediment particles using running tap water system. Separated benthic animals were stored in the plastic containers and samples were stained by using Rose Bengal solution (1%). All separated macrobenthic organisms were categories into five major groups which are polychaetes, gastropods, bivalves, amphipods, isopods and other organisms. The Macrobenthic community was identified up to species level using standard keys.

The meiobenthic sediment samples were collected from the five different locations between Ennore creek and Pulicat. Immediately after grab hauling and ascertaining that the sediment was undisturbed and the sub-samples were collected using the hand corer (2.5 cm inner diameter 15 cm length) from the middle of each grab sample (Platt and Warwick, 1983). The core samples were fixed in 5% formalin and then the samples were sieved using a combination of sieves with varying mesh size (upper sieve- 0.5mm mesh and lower sieve - 0.063mm mesh). The animals retained on the finer mesh (0.063mm) were considered as meiofauna (Coull, 1970). The identification was done with the help of Olympus (Phase contrast fluorescent microscope) and confirmations of the species was done using standard identification keys (Day 1967; Gosner, 1971).Specimens were photographed

Diversity community indices was performed to measure ecosystem health (Pillans *et al*., 2007), benthic sediment communities were calculated using the Shannon diversity index (H') in natural log. Species richness (s) of corals and fishes was calculated. Macro and meio faunal community in terms of species richness and abundance were performed through mul- tivariate tools such as Bray–Curtis similarity after suitable transformation of sample abundance data, classification (hierarchical agglom-erative clustering using group-average linking) and ordination [multidimensional scaling (MDS)] were used for treating the data. Macro and meio faunal assessmblages were compared with baseline study during 2020.

v. Phytoplankton and zooplankton communities

Phytoplankton and zooplanton communities were studied from the four different locations including Kosasthalaiyar River, Buckingham canal, Mangrove waters, river mouth of Pulicat and Ennore creek (these sampling locations lie between Ennore creek and Pulicat Lake.

Sampling techniques

Plankton net: The plankton net is a field-equipment used to collect plankton. It has a polyethylene filter of a defined mesh size and a measuring jar attached to the other end. A handle holds the net. The mesh size of the net determines the size range of the plankton trapped.

Sampling Procedure: Plankton net number 25 of mesh size 60 µm was used for collecting samples. 1000 litres of water was filtered through the net by towing the net for a set distance and time and the samples collected and concentrated in a 120 ml bottle preserved for further analysis.

Labelling: The samples are labelled with the date, time of sampling, sampling site name and pasted on the containers.

Preservation of the sample: Between the time that a sample is collected in the field and until its analysis in the laboratory, physical, chemical and biochemical characteristics may change altering the intrinsic quality of the sample. It is therefore necessary to preserve the samples before shipping, to prevent or minimise changes. For phytoplankton samples, the samples collected for this study were preserved by adding suitable amounts of 1 ml chloroform to act as the narcotising agent and 2ml of 4% formalin for preservation and analyses.

Mounting the slides: Preserved samples which are stored in bottles are mixed uniformly by a gentle inversion. One drop of the sample is pipetted out onto the glass slide for analysis. A cover slip is carefully placed ensuring no air bubbles remain and the cover slip is ringed with a transparent nail enamel to prevent evaporation during the counting process.

Microscope: A compound microscope is used in the counting of plankton with different eyepieces such as 10X and 40X.

Counting method: In this method one drop of the sample is pipetted out onto a glass slide such as the Sedwick Rafter counting chamber. The sample is spread evenly on the slide and the planktonic organisms are counted in the grids. This volume expanded to an appropriate factor yields the organisms per litre of water for particular sampling site.

a. Phytoplankton

The phytoplankton sample in the Sedwick rafter chamber was photographed under the microscope under 10x and 40x magnification for further identification. Identification of the organisms to species level was done by following morphological identification keys (Tomas 1997, Sahu 2013) and identification guide by University of California, Santa Cruz.

Determination of chlorophyll

The chlorophyll determination was done by concentrating the sample by filtering through a membrane filter coated with Magnesium carbonate solution. (Whatman, Glass fibre filter GF/F of 47 mm, 0.7 µm pore size). The pigments are obtained from the sample solution kept in 90% acetone for 24 hrs. The contents were centrifuged at room temperature for 10 minutes at 3000 to 4000 rpm. The supernatant is decanted into a 10 cm path length spectrophotometer cuvette without delay. The chlorophyll a and b concentration is determined spectrophotometrically by measuring the absorbance of the extract at 750, 664, 647 and 630nm (Strictland and Parsons, 1972). The amount of pigment in the original seawater sample is calculated using the equation given below:

(Ca) Chlorophyll *a* = 11.85 E664 – 1.54 E647 – 0.08 E630
(Cb) Chlorophyll *b* = 21.03 E647 – 5.43 E664 – 2.66 E630

Where E stands for the absorbance at different wavelengths (corrected by the 750 nm reading) and Ca and Cb are the amounts of chlorophyll (in Kg/mL if a 1 cm light path cuvette), then
mg chlorophyll/m^3 = C × v / V × 10

Where,
*v*is the volume of acetone in mL (15 mL)
V is the volume of the seawater in liters
Ca and Cb are the two chlorophylls which are substituted for C in the above equation, respectively.

Primary productivity

Primary productivity was estimated by adopting the light and dark bottle technique. The samples were incubated in situin places from where they were collected for period of 12 hrs. The Winkler's method of determining dissolved oxygen as described by Strickland and Parsons (1972) was used for the estimation of production rate. Oxygen values observed were converted to the organic carbon per unit volume of water 'm^3' in time t' and the productivity has been expressed as mg/day^{-1}. Both Gross Primary Productivity and Net Primary Productivity were calculated. GPP or NPP value of oxygen (ml O2/l/D) multiplied by 0.429 would give the Primary (Photsynthetic) productivity value in $mgCm^{-3}d^{-1}$.

b. Zooplankton

Zooplankton analysis was done via qualitative estimation. Like the phytoplankton collection, specific plankton nets with a mesh size of 0.2mm which is usually used to collect zooplankton samples was carried out. The samples collected were then labelled with the date, time of sampling, study area, sampling site name and pasted on the containers. The total volume of water sampled was 1000 liters. The concentrated samples were of 120ml which then 1ml was taken and the presence of zooplankton organisms was counted using a Sedwick rafter chamber under a microscope under 10X and 40X which was raised to the total volume. The biomass of the zooplankton was calculated and represented in nos/m^3 (Varghese 2015). Plankton community structure were compared with baseline study during 2020.

vi. Microbial community estimation

Surface water samples

Surface water samples were collected in 30ml sterile screw capped bottles for bacteriological assessment. Enough air space was left in the bottles to allow thorough mixing. Precautionary measures were taken to avoid contamination through handling. Immediately after collection, the samples were labelled and transported to the laboratory in an ice box for analysis.

Sediment samples

For microbial assessment in sediment samples, a known quantity of samples was collected from the grab samples using sterilised spatula. The central portion of the collected sediment was aseptically transferred into sterile sample bottle. The samples was labelled and brought to the laboratory in portable icebox for analysis.

Preparation of Samples

The presence of various microorganisms in the water samples were processed by 1 ml each of the water samples was separately added to 9 ml of 0.1% peptone water diluents. After thorough shaking further serial dilutions were made by transferring 1 ml of the original solution to freshly prepared 9 ml peptone water diluents to a range of 10^{-5} dilutions. Aliquots (0.1 ml) of various dilutions were transferred to agar plates in triplicate and inoculated by spreading with flamed glass spreaders and incubated.

Sediment samples were processed by dispense ten grams of the sample to 90ml of sterile distilled water to get an aliquot. One milliliter of the aliquots, were then serially diluted to a range of 10^{-6} dilutions. Aliquots (0.1 ml) of various dilutions were transferred to agar plates in triplicate and inoculated by spreading with flamed glass spreaders as described by Prescott et al., (2005).

Total Viable Counts

TVC was enumerated by adopting the spread plate method using Plate Count Agar (PCA) medium (M091S; Hi-Media, Mumbai). Here 0.1ml of the serially diluted samples (water and sediment) was inoculated onto sterile Plate count agar plates in triplicates and it was spread using a 'L' shaped glass spreader. The plates after inoculation were incubated for 24 hours at 37^{o}C. After incubation, colonies that appeared on the plates were counted and the mean expressed as CFU/ml for surface water and CFU/g for sediment samples.

Total coliform

The method of Prescott et al., (2005) was adopted, where 0.1 ml of the serially diluted samples were inoculated onto different sterile MacConkey Agar (MH081; Hi-Media, Mumbai) plates in triplicates, the inoculums were then spread evenly on the surface of the media using a sterile spreader. This was followed by incubation at 37ºC for 24 hours, after which the colonies were counted and the mean total coliform count expressed as CFU/ml and CFU/g.

E.coli

MacConkey Agar (MH081; Hi-Media, Mumbai) was used to discriminate *E.coli* from other non-lactose fermenting coliforms from water and sediment samples. Sample suspension was inoculated onto MacConkey agar followed by 18-24 h incubation at 37ºC. Pink, round medium sized colonies were counted as *E.coli* colonies.

Faecal coliform

M-FC Agar (M1124; Hi-Media, Mumbai) is employed for detection and enumeration faecal coliforms at higher temperature (44.5°C). The agar weighing 52 g was suspended in 1000 ml of distilled water and heated up to the boiling point to dissolve the medium completely, 10ml of Rosolic acid (dissolved in 0.2 N NaOH) was added, heated with frequent agitation and boiled for 1 min. Then the medium was cooled to 50°C. One milliliter of the serially diluted samples was inoculated onto sterile agar plates in triplicates. The inoculum were then spread evenly on the surface of the media using a sterile spreader. The plates were then incubated at 48 hours. All blue or partially blue colonies were counted as faecal coliforms.

Streptococcus faecalis

KF Streptococcal Agar (M248; Hi-Media, Mumbai) is used for selective isolation and enumeration of *Streptococcus faecalis* in water and sediment by direct plating method. The agar weighing 76.4 g in 1000 ml distilled water heated up to the boiling point to dissolve the medium completely. Add rehydrated contents of 1 vial of Bromo Cresol Purple, heated with frequent agitation and boiled for 1 min. Then the medium was cooled to 50°C and aseptically add 10 ml of 1% 2, 3, 5-Triphenyl Tetrazolium Chloride (TTC). Finally the medium was poured into sterile Petri plates and incubated at 35-37°C for 24-48 hours. After incubation, the colonies of *Streptococcus faecalis* appeared with pink to red colonies were counted.

***Salmonella* and *Shigella* sp.**

Xylose Lysine Deoxycolate (XLD) Agar (M031; Hi-Media, Mumbai) is employed for detection and enumeration of entric pathogens, especially *Salmonella* and *Shigella* species. The media formulation does not allow the overgrowth of other organisms over *Salmonella* and *Shigella*. The agar weighing 56.68 g in 1000 ml distilled water was heated with frequent agitation until the medium boils. Transfer immediately to a water bath at 50°C. After cooling, pour into sterile Petri plates and incubated at 35-37ºC for 18-24 hours. Lactose, Sucrose, and Xylose are the fermentable carbohydrates present in the medium and phenol red is used as the pH indicator. Bacteria that ferment none of these sugars, e.g., *Shigella*, appear as red and translucent colonies. Salmonella form red colonies with black center in 24 hours by Lysine decarboxylation under alkaline conditions. *Salmonella-Shigella* counts recorded accordingly *Salmonella* sp.appear as red colonies with black centers while *Shigella* sp. appeared with red colour.

Pseudomonas aeruginosa

To determine fluorescent *Pseudomonas aeruginosa* levels in water and sediment, appropriate dilutions were spread-plated in triplicate on to Cetrimide Agar (M024B; Hi-Media, Mumbai). Plates were incubated at 37°C for 18-24 h, then exposed to fluorescent light for 18 to 24 h to enhance pigmentation. Colony counts were made under long-wave ultraviolet.

Vibrio parahaemolyticus

Vibrio parahaemolyticus Sucrose (VPSA) Agar (M1153; Hi-Media, Mumbai) is recommended by (APHA, 2001) for isolating and enumerating *V. parahaemolyticus*. The agar weighing 73.52 grams in 1000 ml distilled water was heated up to the boiling point to dissolve the medium completely. Mix well and pour into sterile Petri plates. One milliliter of the serially diluted samples were inoculated onto sterile pre-dried VPSA agar plates in triplicates and then spread evenly with a sterile bent glass rod. The plates were incubated at 18-20 hours at 42°C. *V. parahaemolyticus* does not ferment sucrose and forms green to blue colonies which differentiates it from other sucrose fermenting *Vibrio* species.

Vibrio cholera

Thiosulfate Citrate Bile Salts Sucrose **(**TCBS) Agar (M870S; Hi-Media, Mumbai) is used for the selective isolation of *Vibrio cholerae* and other enteropathogenic Vibrios. The agar weighing 88.1 g in 1000 ml of distilled was heated up to boiling, stirring with constant agitation until complete dissolution. Cool to 50°C and pour into sterile Petri plates. One milliliter of the serially diluted samples were inoculated onto sterile TCBS agar plates in triplicates and then spread evenly with a sterile bent glass rod. The plates were incubated at 37ºC for 24 hours. After incubation, the colonies of *Vibrio cholera* appeared withyellow colonies. After the incubation period, mean of the colonies for the triplicate plates were calculated and recorded accordingly.
Microbial parameters were compared with baseline study during 2020.

vii. Brackish and freshwater associated resources

Benthic epi-macrofaunas were assessed by placing a quadrat (1 x 1 m) in 3 random locations at each site on the substratum and counting fauna by species. Mangrove associated fish were identified through visual observation along the mangrove habitat area. Detailed checklist was prepared from local fishing area. Brackish water epi-macrofaunal community parameters were compared with baseline study during 2020.

viii. Assessment of Avifauna and Mammals

Transect survey was done to record and photo document the avifauna (SNH, 2005) at the study site. The distributions of different avifauna in different landforms were recorded. Photo documented were done during field visit. Similarly, mammals were recorded and photo documented were done during field visit. Avifaunal and mamal survey were compared with baseline study during 2020.

ix. Fishery status

Five fishing villages (Vairavankuppam, Koraikuppam, Kadalkannikuppam, Karungali and Kattupalli) were selected to study the fishery resources from the study area and fish landing data was collected during study period. Fish landing data was collected by following the method of Srinath *et al*., (2005). The following are the steps:

i. Enquiring of the total number of fishing days in the particular village (Sampling was done normally for 16-18 days per month in each selected village).

ii. Enquiring of the total number of fishing crafts on the particular fishing day.

iii. 1: 6 boats were surveyed in case of large numbers of boats (Random). A minimum total of 15 boats at least surveyed in which 100% of the catch has to be checked.

iv. The different fishing gears were surveyed. Fish catch by different gears was noted down if necessary.

v. Species composition of the fish landed has been checked out.

vi. Weight of a group (eg: carangids, groupers) / genus (*Scomberoides, Tylosurus* etc.) / species (*Sardinella longiceps, Rastrelliger kanagurta*) per the fishing crafts surveyed to be calculated. For this the weight of a standard basket was enquired and the total number of standard baskets in that boat has to be enquired (Eg:- Weight of one standard basket of Groupers in the landing center = 10 kg. Total number of standard baskets in the boat 'A' = 5. Groupers landed in boat 'A' = 10 x 5 = 50).

vii. Similarly the weight of groupers in all the boats surveyed is calculated. The resultant data gives the total groupers landed in the given day in the surveyed boats. This data is then made up to the total number of boats gone for fishing in the particular fishing day. The resultant data is further calculated up to one month by multiplying the total number of fishing days during that month.

Fishery status were compared with baseline study during 2020.

x. Land use and land cover mapping

For the extraction of various feature of land use and land cover in the study area, Google earth image was used to get preliminary information about the various features. During field survey google earth image was used to mark the various land use and land cover features. With the help of collected data from the field, geo-referred google earth image was used to prepare Land use and Land cover map for the study area and their area cover was calculated in ArcGIS software (Horvat, 2013). Changes of land use and land cover were compared with baseline study during 2020 and with CRZ maps.

3. Results

i. Marine zone underwater assessment

I. Macro faunal community structure

a. Molluscan diversity and abundance

Fair distribution has been observed which comprised 37 species in the study area. Species richness was varied from 22 to 37 among the zones. *Babylonia zeylanica, Babylonia spirata, Cerithium columna* and *Ficus gracilis* were the most sighted species accounted during the survey. Mean density was 9.66±0.99 (no/5 m^2), it was ranged between 5.29±0.20 and 14.27±0.32 (no/5 m^2) among the stations (Fig. 3.1.1 & Table 3.1.1). The Shannon diversity index value was ranged from 3.3 to 3.6, whereas evenness exhibited lesser variation their values between 0.95 and 0.98.

In Zone-1, poor assemblages pattern of molluscs were accounted in this zone. Totally 33 species was recorded, of these, *Babylonia spirata, Cerithium columna, Sunetta meroe* and *Phalium glaucum* were the dominant species. Mean density was 10.60±0.16 (no/5 m^2), whereas within the zone, highest density had 15(no/5 m^2) at G5 followed by G4 with 14(no/5 m^2) and lowest exhibited in G1 with 7 (no/5 m^2).

In Zone-2, relatively lesser molluscs were accounted in this zone. Totally 37 species was recorded, of these, *Ficus gracilis, Babylonia zeylanica, Babylonia spirata* and *Bullia tranquebarica* were the dominant species. Mean density was 9.67±0.25 (no/5 m^2), whereas within the zone, highest density had 20(no/5 m^2) at G14 followed by G8 with 19(no/5 m^2) and lowest exhibited in G15 with 5 (no/5 m^2).

In Zone-3, relatively higher abundance of molluscs was accounted in this zone. Totally 38 species was recorded, of these, *Bullia tranquebarica*, *Babylonia spirata*, *Macalia bruguieri*, *Tibia curta* and *Phalium glaucum* were the dominant species. Mean density was 14.27±0.32 (no/5 m^2), whereas within the zone, highest density had 22(no/5 m^2) at G13 followed by G2 & G5 with 21(no/5 m^2) and lowest exhibited in G9 with 6 (no/5 m^2).

In Zone-4, fair occurrence of mollucs was observed in this zone. Totally 37 species was recorded, of these, *Macalia bruguieri, Agaronia gibbosa, Cerithium columna* and *Babylonia spirata* were the dominant species. Mean density was 12.20±0.36 (no/5 m^2), whereas within the zone, highest density had 24(no/5 m^2) at G13 followed by G12 with 22(no/5 m^2) and lowest exhibited in G4 with 5 (no/5 m^2).

In Zone-5, a reasonable amount of molluscsn density was found in this zone. Totally 37 species was recorded, of these, *Pirenella cingulate, Turritella attenuate, Babylonia spirata* , *Donax scortum* and *Turritella attenuate* were the dominant species. Mean density was 11.00±0.34 (no/5 m^2), whereas within the zone, highest density had 17(no/5 m^2) at G11 followed by G12 & G13 with 15(no/5 m^2) and lowest exhibited in G2 with 5 (no/5 m^2).

In Zone-6, relatively lesser molluscs were accounted in this zone. Totally 37 species was recorded, of these, *Babylonia spirata, Bullia tranquebarica, Turritella attenuate, Natica vitellus* and *Clypeomorus bifasciata* were the dominant species. Mean density was 7.33±0.20 (no/5 m^2), whereas within the zone, highest density had 15(no/5 m^2) at G10 followed by G5 and 10 with 9(no/5 m^2) and lowest exhibited in G11 with 3 (no/5 m^2).

In Zone-7, relatively lesser molluscs were accounted in this zone. Totally 33 species was recorded, of these, *Agaronia gibbosa, Vepricardium asiaticum, Natica vitellus* and *Semicassis canaliculata* were the dominant species. Mean density was 6.89±0.23 (no/5 m^2), whereas within the zone, highest density had 9(no/5 m^2) at G3 followed by G1 and G6 with 8(no/5 m^2) and lowest exhibited in G4 and G9 with 5 (no/5 m^2).

In Zone-8, relatively lesser molluscs were accounted in this zone. Totally 20 species was recorded, of these, *Babylonia spirata, Babylonia zeylanica, Vepricardium asiaticum* and *Volegalea cochlidium* the dominant species. Mean density was 5.29±0.20 (no/5 m^2), whereas within the zone, highest density had 8(no/5 m^2) at G6 followed by G1 with 7(no/5 m^2) and lowest exhibited in G5 with 3 (no/5 m^2). Details are given in the (Fig. 3.1.1 & Table 3.1.1)

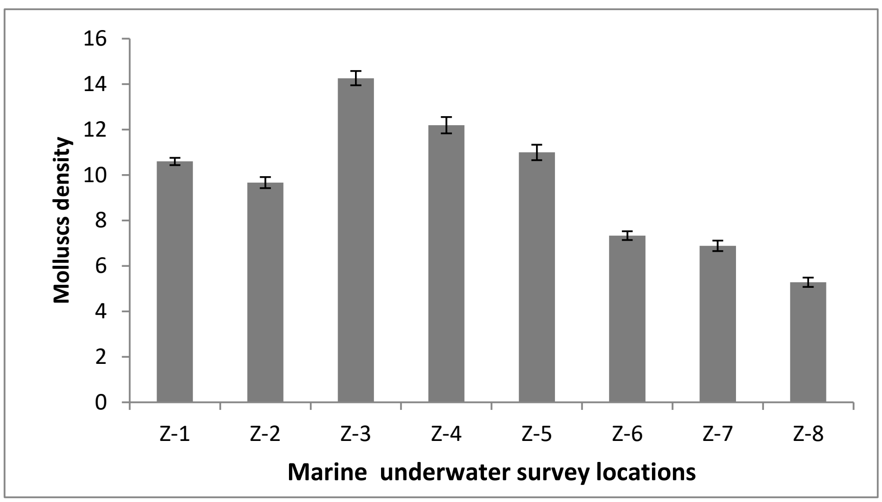


Fig. 3.1.1: Molluscs density observed in zone 1 to 8 within the 10 km radius of Bay of Bengal

Table 3.1.1: Molluscs macrofaunal density in zones

	Underwater assessment zones in Bay of Bengal							
Species	**Z-1**	**Z-2**	**Z-3**	**Z-4**	**Z-5**	**Z-6**	**Z-7**	**Z-8**
Agaronia gibbosa	2	5	6	9	7	3	7	3
Anadara gubernaculum	1	3	4	2	5	5	1	1
Anadara inaequivalvis	0	4	7	2	4	1	0	1

Babylonia spirata	5	6	7	7	7	5	2	3
Babylonia zeylanica	3	6	8	6	2	2	1	1
Bufonaria crumena	2	3	8	2	5	3	3	0
Bullia tranquebarica	0	6	3	3	4	4	1	1
Calliostoma tranquebaricum	2	3	2	2	6	2	2	3
Cerithium columna	3	8	9	9	4	3	1	0
Clypeomorus bifasciata	1	5	6	5	5	4	1	2
Conus sp	1	4	6	5	0	2	1	1
Donax scortum	2	4	3	8	9	2	3	1
Ficus ficus	2	3	6	6	5	1	1	1
Ficus gracilis	0	7	6	3	2	3	2	0
Ficus variegata	1	4	4	3	5	4	1	2
Harpa davidis	1	3	8	3	5	3	1	0
Macalia bruguieri	1	3	8	9	4	1	1	4
Mactra antiquata	1	2	7	4	3	3	4	0
Mactra sp	2	4	4	4	6	1	2	3
Murex carbonnieri	1	4	3	8	2	3	2	0
Nassaria coromandelica	1	3	8	6	4	1	2	0
Natica cincta	1	4	6	6	5	2	1	3
Natica vitellus	0	5	7	6	3	4	4	0
Oliva oliva	2	6	2	3	5	1	1	1
Oliva vidua	1	3	5	7	2	2	2	0
Phalium areola	2	1	4	4	3	1	1	2
Phalium glaucum	2	2	7	2	2	2	2	0
Pirenella cingulata	2	4	4	6	9	2	1	0
Placuna placenta	1	3	8	2	1	2	2	4
Semicassis canaliculata	1	2	5	6	5	3	3	0
Sunetta meroe	3	2	5	2	3	1	2	1
Tibia curta	0	5	8	5	1	3	2	1
Turbinella pyrum	1	3	4	5	4	1	2	1
Turritella attenuata	1	5	8	8	8	4	1	2
Vasticardium elongatum	1	3	4	6	3	2	0	0
Vepricardium asiaticum	2	3	7	5	3	1	5	0
Volegalea cochlidium	1	4	7	4	3	1	0	0

b. Marine sponges diversity and abundance

The low population of Marine sponges has been reported in the study area. Only 12 species were observed, of these, *Clathria microciona*, *Cliona* sp. and *Clathria* sp. were the common species. The species richness varied among the zones it was ranged between 5 and 12.

Zone 4 had the highest species richness with 10 followed by Zone 3 with 9 no. Diversity index value had ranged between 1.49 and 2.49, while evenness value exhibited that between 0.92 and 0.98 in the study area. Mean density was 2.35±0.39 (no/5 m^2), highest density was in Zone 4 with 5.53±0.67 (no/5 m^2) and lowest had found at Zone 6 with 0.67±0.28 (no/5 m^2) respectively (Fig. 3.1.2 & Table 3.1.2).

In zone 1, dominant species are *Spirastrella* sp. and *Cliona* sp.; in zone 2, dominant species are *Cliona* sp. , *Chondrilla* sp., and *Clathria* sp.; in zone 3, dominant species are *Chondrilla* sp., *Clathria microciona, Chalinula* sp. and *Clathria* sp.; in zone 4, dominant species are *Chalinula* sp., *Oceanopia sp.* and *Clathria microciona*; in zone 5, dominant species are *Xestospongia* sp., *Clathria microciona, and Echinodyctium* sp.; in zone 6, dominant species are *Clathria* sp., *Chondrilla* sp. and Cliona sp.; in zone 7, dominant species are *Chalinula* sp., *Spirastrella* sp., and *Xenospongia* sp.; in zone 8, dominant species are *Spirastrella* sp. and Axinella sp. Details are given in the (Fig. 3.1.2 & Table 3.1.2)

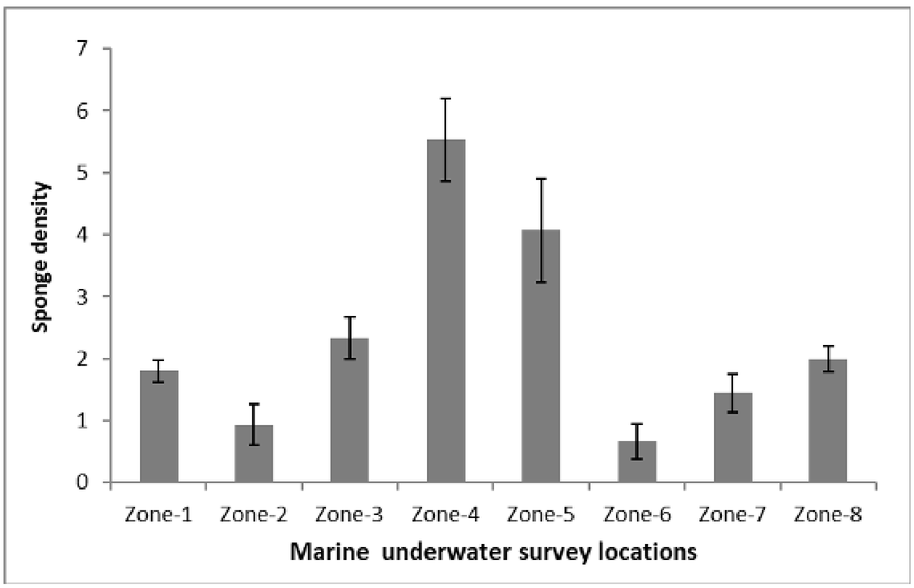


Fig. 3.1.2: Sponge density in zone 1 to 8 within the 10 km radius of Bay of Bengal

Table 3.1.2: Sponge faunal density in zones

	Underwater assessment zones in Bay of Bengal							
Species	**Zone-1**	**Zone-2**	**Zone-3**	**Zone-4**	**Zone-5**	**Zone-6**	**Zone-7**	**Zone-8**
Chalinula sp.	0	1	4	10	2	0	3	1
Echinodyctium sp.	1	1	2	7	7	1	0	1
Spirastrella sp.	2	1	3	9	4	0	2	2
Chondrilla sp.	1	2	5	7	4	2	0	1
Clathria microciona	1	0	4	7	8	0	2	2

Clathria sp.	1	1	2	8	7	3	2	2
Oceanopia sp.	0	0	2	10	3	0	1	1
Xestospongia sp.	0	1	2	6	10	0	0	2
Axinella sp.	0	0	3	4	6	1	0	1
Xenospongia sp.	1	1	1	2	0	0	0	0
Cliona sp.	1	4	4	7	4	1	1	0
Hyatella sp.	1	2	3	6	2	0	2	1

c. Soft corals diversity and abundance

The sparse occurrence of soft coral communities had found in the study area. Only 5 species were observed, of theses, *Virgularia sp. Cavernulina sp.* and *Carijoa sp.* were the common species. The species richness varied among the zones it was ranged between 1 and 5. Zone 2, 3 and 4 had the highest species richness with 5 followed by Zone 5 and 6 with3 no. Diversity index value had ranged between 0.69 and 2.12, while evenness value exhibited that between 0.90 and 1.0 in the study area. Mean density was 1.28±0.33 (no/5 m^2), highest density was in Zone 3 with 2.8±0.25 (no/5 m^2) and lowest had found at Zone 7 with 0.20±0.14 (no/5 m^2) respectively.

In zone 1, dominant species are *Carijoa* sp. and *Virgularia* sp.; in zone 2, dominant species are *Carijoa* sp., *Virgularia* sp. and *Cavernulina* sp. ; in zone 3, dominant species are Carijoa sp., *Cavernulina* sp., *Virgularia* sp. and *Virgularia* sp.; in zone 4, dominant species are *Cavernulina* sp., *Virgularia* sp. and *Carijoa* sp. .; in zone 5, dominant species are *Subergorgia* sp., and *Virgularia* sp. ; in zone 6, dominant species are *Virgularia* sp. and *Cavernulina* sp. ; in zone 7, dominant species is *Virgularia* sp., and *Cavernulina* sp. ; in zone 8, dominant species is *Carijoa* sp. Details are given in the (Fig. 3.1.3 & Table 3.1.3)

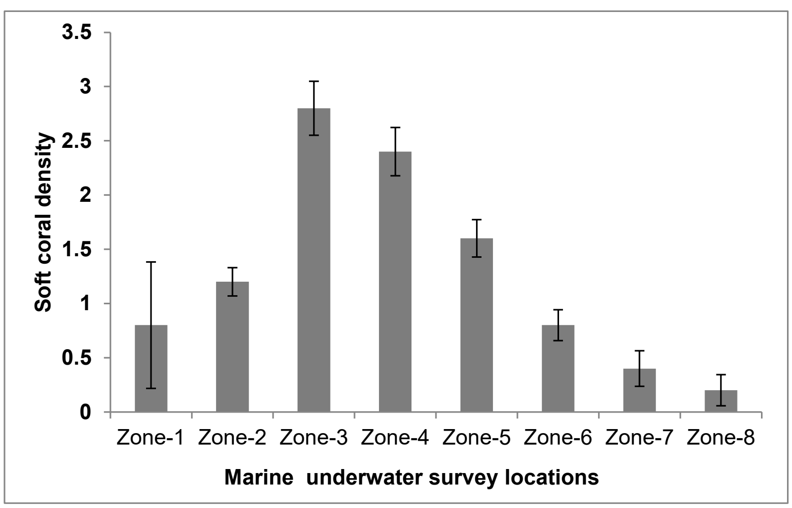


Fig. 3.1.3: Soft coral density in zone 1 to 8 within the 10 km radius of Bay of Bengal

Table 3.1.3: Soft coral faunal density in zones

	Underwater assessment zones in Bay of Bengal							
Species	**Zone-1**	**Zone-2**	**Zone-3**	**Zone-4**	**Zone-5**	**Zone-6**	**Zone-7**	**Zone-8**
Carijoa sp.	1	1	3	1	1	1	0	1
Subergorgia sp.	0	0	0	2	2	0	0	0
Junceella sp.	0	1	2	1	0	0	1	0
Cavernulina sp.	0	0	2	2	3	1	0	0
Virgularia sp.	1	1	2	2	3	0	0	0

Others distribution

A relatively poor occurrence of other fauna was observed in the marine zone. Totally 11 species were recorded, *Astropecten indicus* was the dominant species. Sand dollars comprised three species: *Clypeaster* sp., *Clypeaster* sp1. and *Echinodiscus auritus*. Two species of sea urchin include *Salmacis bicolor* and *Salmacis* sp., and two species from starfish are *Astropecten indicus* and *Astropecten* sp. Sea cucumber, one species of Holothuria sp., was observed. Anemone species are *Paracondylactis sinensis, Stichodactyla* sp. and *Paracondylactis* sp. were recorded during the assessment. Mammals have not been observed during the survey periods. Sea snakes and sea turtles were not sighted.

2. Fish community structure

In total, 56 fish species were recorded in the study area. Fish communities in terms of diversity and abundance were comparatively low. Species richness varied from 11 to 50, while total fish individuals counted between 92 and 586. In fish density, significantly varied among the zones it was varied between 15.93no/250 m^2) and 41.86 (no/250 m^2) Details are given in the (Fig. 3.1.4 & Table 3.1.4). *Rastrelliger kanagurta, Sardinella* sp., *Sphyraena jello,* and *Selaroides leptolepis* were the most abundant fishes in the study area. Reef fishes are poorly occurs in the marine zone.

In zone-1, fish communities in terms of species richness and abundance relatively low in this zone. Totally 27 species was observed, among them *Dussumieria acuta, Tenualosa ilisha, Escualosa thoracata, Arius jella* and *Rastrelliger kanagurta* were the most sighted fishes. Mean fish density was 18.40±0.37 (no/250 m^2). Within the zone, highest abundance was reported in G4 with 27 (no/250 m^2) followed by G3 with 25 (no/250 m^2), while low were accounted in G1 with 11 (no/250 m^2).

In zone-2, fish communities in terms of species richness and abundance relatively low in this zone. Totally 35 species was observed, among them *Sardinella* sp., *Rastrelliger kanagurta, Platax orbicularis, Penaeus japonicus* and *Selaroides leptolepis* were the most sighted fishes. Mean fish density was 15.93±1.39 (no/250 m^2). Within the zone, highest abundance was reported in G5 with 30 (no/250 m^2) followed by G1 with 27 (no/250 m^2), while low were accounted in G7 with 3 (no/250 m^2).

In zone-3, fish communities in terms of species richness and abundance relatively low in this zone. Totally 43 species was observed, among them *Rastrelliger kanagurta, Sardinella* sp.*, Alepes melanoptera., Euthynnus affinis* and *Scarus ghobban* were the most sighted fishes. Mean fish density was 23.73±1.94 (no/250 m^2). Within the zone, highest abundance was reported in G10 with 47 (no/250 m^2) followed by G2 and G12 with 36 (no/250 m^2), while low were accounted in G7 with 7(no/250 m^2).

In zone-4, fish communities in terms of species richness and abundance relatively fair in this zone. Totally 42 species was observed, among them *Rastrelliger kanagurta, Sphyraena jello, Megalaspis cordyla, Sardinella* sp.and *Lutjanus rivulatus, Leiognathus dussumieri* were the most sighted fishes. Mean fish density was 32±1.85 (no/250 m^2). Within the zone, highest abundance was reported in G1 with 94 no/250 m^2) followed by G3 with 57 (no/250 m^2), while low were accounted in G12 with 9 (no/250 m^2).

In zone-5, comparatively higher fish abudnace was presented in this zone. Totally 49 species was observed, among them *Rastrelliger kanagurta, Sphyraena jello, Sardinella* sp., *Scomberoides commersonianus, Carangoides armatus* and *Gerres limbatus* were the most sighted fishes. Mean fish density was 41.86±2.02 (no/250 m^2). Within the zone, highest abundance was reported in G9 with 94 (no/250 m^2) followed by G12 with 73 (no/250 m^2), while low were accounted in G6 with 13 (no/250 m^2).

In zone-6, fish communities in terms of species richness and abundance relatively low in this zone. Totally 43 species was observed, among them *Rastrelliger kanagurta, Selaroides leptolepis, Scomberoides commersonianus, Carangoides armatus, Megalaspis cordyla, Scatophagus argus* were the most sighted fishes. Mean fish density was 27.92±1.15 (no/250 m^2). Within the zone, highest abundance was reported in G7 with 51 (no/250 m^2) followed by G6 with 40 (no/250 m^2), while low were accounted in G5 with 14 (no/250 m^2).

In zone-7, fish communities in terms of species richness and abundance relatively low in this zone. Totally 50 species was observed, among them *Penaeus japonicas,Penaeus monodon, Euthynnus affinis, Rastrelliger kanagurta,Parapenaeopsis uncta, Alepes djedaba, Lutjanus fulviflamma, Pelates quadrilineatus, Selaroides leptolepis* were the most sighted fishes. Mean fish density was 25.70±0.58 (no/250 m^2). Within the zone, highest abundance was reported in G10 with 47 (no/250 m^2) followed by G2with 46 (no/250 m^2), while low were accounted in G3 and G5 with 12 (no/250 m^2).

In zone-8, fish communities in terms of species richness and abundance were least in this zone. Totally 44 species was observed, among them *Lutjanus rivulatus*,*Rastrelliger kanagurta, Trachinocephalus myops, Alepes melanoptera,Pelates quadrilineatus, Alepes djedaba, Dussumieria acuta, Scomberoides commersonianus, Tenualosa ilisha, Hemiramphus far*.were the most sighted fishes. Mean fish density was 26.62 ±0.52 (no/250 m^2). Within the zone, highest abundance was reported in G3 with 46 (no/250 m^2) followed by G8 with 43 (no/250 m^2), while low were accounted in G7 with 12 (no/250 m^2). Details are given in the (Fig. 3.1.4 & Table 3.1.4)

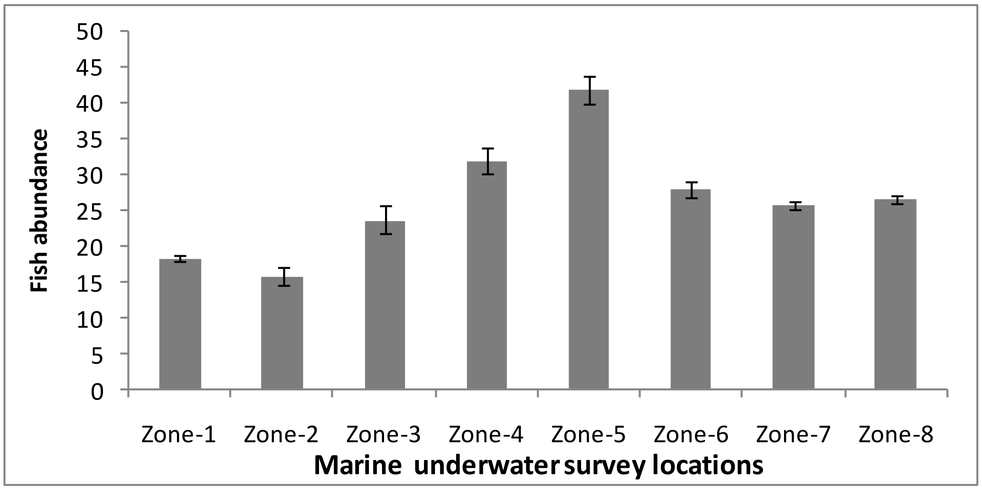


Fig. 3.1.4: Fish abundance in zone 1 to 8 within the 10 km radius of Bay of Bengal

Table 3.1.4: Fish community structure

	Zone-1	Zone-2	Zone-3	Zone-4	Zone-5	Zone-6	Zone-7	Zone-8
Epinephelus malabaricus	0	0	0	3	5	0	3	1
Cephalopholis formosa	2	1	0	4	4	9	2	15
Epinephelus merra	2	2	2	5	9	6	4	3
Carangoides armatus	0	1	1	11	21	13	2	4
Dussumieria acuta	12	1	2	0	17	5	7	8
Tenualosa ilisha	9	3	2	13	10	7	4	6
Escualosa thoracata	8	3	12	10	7	2	6	11
Thryssa malabarica	4	2	0	14	17	7	3	1
Chirocentrus dorab	1	0	4	0	4	3	4	2
Trachinocephalus myops	5	3	3	9	5	2	6	8
Hemiramphus far	2	9	6	10	13	10	5	5
Pelates quadrilineatus	0	3	1	9	8	4	7	7
Sillago sihama	1	2	4	5	16	0	2	1
Alepes melanoptera	3	2	33	4	11	3	4	8
Alepes djedaba	0	2	3	15	10	8	12	7
Megalaspis cordyla	0	2	3	18	9	12	5	2
Selaroides leptolepis	3	9	10	5	13	33	8	1
Leiognathus dussumieri	0	0	4	16	12	6	1	5
Lutjanus rivulatus	1	5	2	16	8	5	5	12
Lutjanus fulviflamma	3	0	8	13	3	7	11	6
Gerres limbatus	2	2	9	9	19	4	3	0
Platax orbicularis	0	18	3	11	8	7	6	2
Scatophagus argus	0	0	2	1	9	12	3	5
Chaetodon decussatus	0	9	12	5	4	8	0	0

Heniochus acuminatus	2	0	4	13	4	3	0	0
Liza parsia	0	0	0	4	4	0	1	2
Liza vaigiensis	2	5	4	4	7	9	4	0
Scarus ghobban	0	0	15	13	7	0	4	2
Siganus lineatus	2	0	2	6	9	5	3	3
Sphyraena jello	1	2	0	38	40	4	2	0
Rastrelliger kanagurta	6	44	81	87	92	42	11	11
Scomberoides commersonianus	0	6	7	0	29	31	2	6
Euthynnus affinis	0	0	30	5	17	10	14	4
Zebrias synaptuoides	1	4	2	4	4	1	0	0
Synaptura commersonnii	0	3	2	13	10	7	1	2
Triacanthus biaculeatus	2	3	2	17	5	4	3	7
Portunus pelagicus	0	0	3	0	5	1	4	0
Portunus sanguinolentus	2	3	6	5	6	8	2	0
Charybdis natator	3	7	2	6	13	4	2	1
Parapenaeopsis uncta	0	3	4	0	13	5	11	0
Penaeus monodon	3	4	3	0	8	5	14	8
Penaeus japonicus	0	10	3	8	8	6	21	4
Carcharhinus limbatus	0	2	4	6	2	2	0	5
Narcine brunnea	0	0	5	4	9	6	4	2
Chirocentrus dorab	0	7	2	0	2	0	3	0
Arius jella	7	3	1	8	5	1	3	3
Trachinocephalus myops	3	0	2	5	3	3	0	0
Trichonotus sp.	0	0	0	9	2	5	5	0
Sardinella sp.	0	54	46	17	40	0	0	8
Rhabdosargus sarba	0	0	0	0	0	0	5	3
Terapon sp.	0	0	0	0	0	0	3	4
Rachycentron canadum	0	0	0	0	0	0	5	5
Gnathanodon speciosus	0	0	0	0	0	0	5	3
Siganus sp.	0	0	0	0	0	0	6	5
Platax sp.	0	0	0	0	0	0	2	2
Monodactylus sp.	0	0	0	0	0	0	4	3

* Z - Zone

Summary results and remarks

Underwater assessment carried in the study area revealed that the seascape is dominated by sandy and clayey bottom. Because of the bottom topography and prevailing strong currents, benthic communities were very less in amount. Dynamic and ecologically sensitive marine habitats such as coral reefs and seagrasses were not observed in any of the assessed grids. Because of the absence of critical habitats, density and diversity of fish and other biodiversity were comparatively low. In total, 56 fish species were recorded in the study area. Fish communities in terms of diversity and abundance were comparatively low. Species richness varied from 11 to 50, while total fish individuals counted deviated between 92 and 586. Fish density and diversity varied between zones as the density ranged between 15.93 (no/250 m^2) and 41.86 (no/250 m^2). *Rastrelliger kanagurta, Sardinella* sp., *Sphyraena jello,* and *Selaroides leptolepis* were the most abundant fishes in the study area. Among the benthic macrofauna, fair distribution of molluscs was observed which comprised of 37 species in the study area. *Babylonia zeylanica, Babylonia spirata, Cerithium columna* and *Ficus gracilis* were the most sighted species. Density of molluscs ranged between between 5.29±0.20 and 14.27±0.32 (no/5 m^2). Other category, marine sponges was represented by 12 species and of these, *Clathria microciona*, *Cliona* sp. and *Clathria* sp. were the common species. Density of sponges ranged between 0.67±0.28 (no/5 m^2) and 5.534±0.67 (no/5 m^2). Soft corals were also observed in the study areas that are represented by 5 species. *Virgularia sp. Cavernulina sp. and Carijoa sp.* were the common soft coral species observed. Soft coral density in the study area ranged between 0.20±0.14 (no/5 m^2) and 2.8±0.25 (no/5 m^2). Apart from molluscs, sponges and soft corals, other benthic macrofauna such as sea anemones and echinoderms were also sighted with poor representation. In the study area, Mammals have not been observed during the survey periods. Sea snakes and sea turtles were not sighted.

Mollusc species recorded in Marine zone (2020)

Bufonaria albovaricosa

Ficus variegata

Oliva vidua

Sunetta donacina

Turritella acutangula

Ficus variegata

Mollusc species recorded in Marine zone (2022)

Nassaria sp.

Conus sp.

Turbinella pyrum

Babylonia zeylanica

Mactra sp.

Mactra antiquata

Sunetta donacina

Ficus variegata

Chicoreus virgineus

Bufonaria albovaricosa

Armina sp.

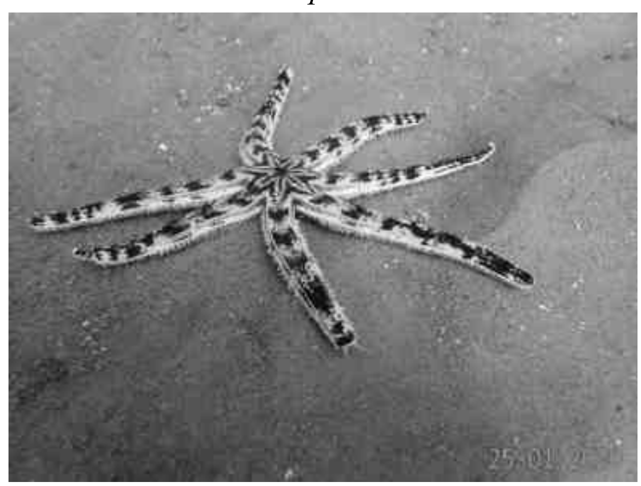
Phalium areola

Other faunal community recorded in Marine zone –Echinoderms (2020)

Luidia hardwicki

Astropecten indicus

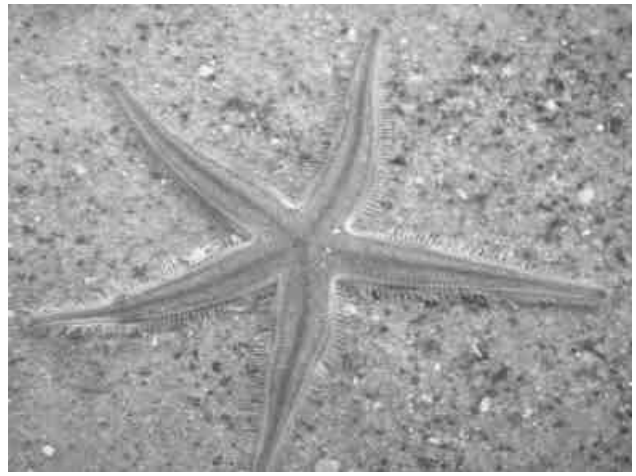
Astropecten indicus



Luidia maculata var. ceylonica

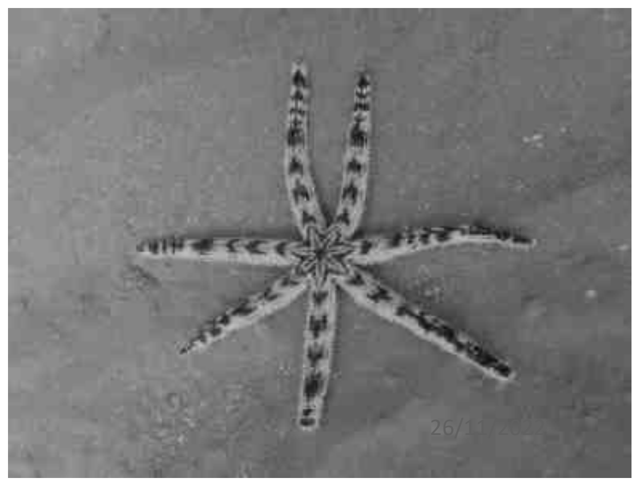
Other faunal community recorded in Marine zone –Echinoderms (2022)

Salmacis bicolor



Luidia hardwicki

Pentaceraster sp



Luidia maculate

Holothuria sp.

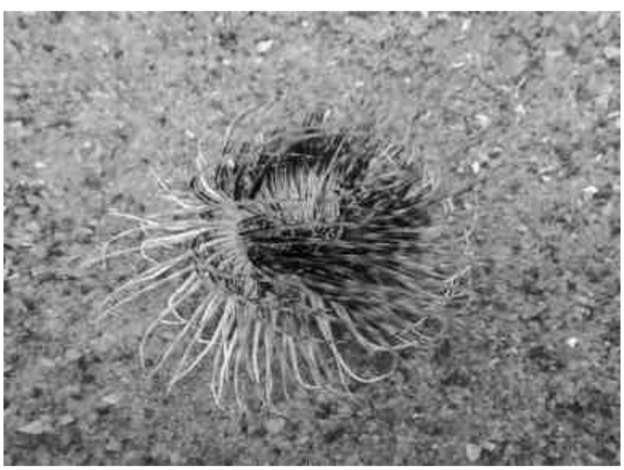
Pentaceraster sp

Sea anemone recorded in Marine zone 2020

Sea anemone recorded in Marine zone 2022








Soft coral community recorded in Marine zone (2020)

Cavernularia sp

Cavernularia sp

Retracted *Cavernularia* sp.

Virgularia sp 1.

Virgularia sp 2.

Virgularia sp 3

Soft coral community recorded in Marine zone (2022)

Cavernularia sp.

Cavernularia sp.

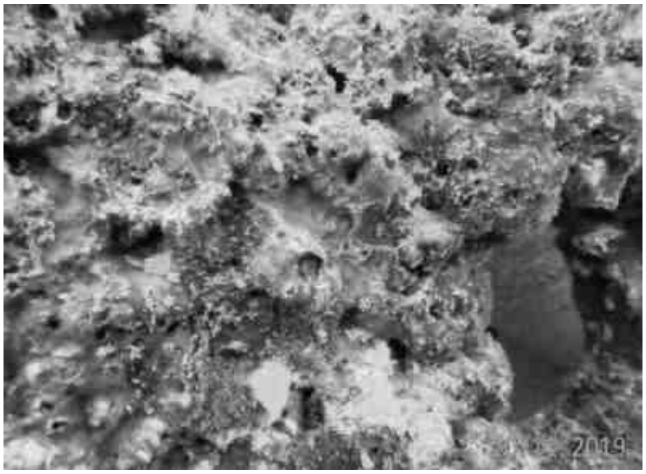
Virgularia

Virgularia

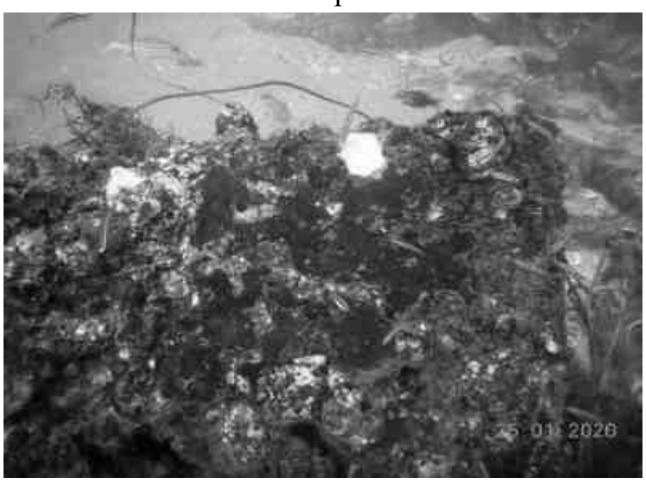
Cavernularia sp.

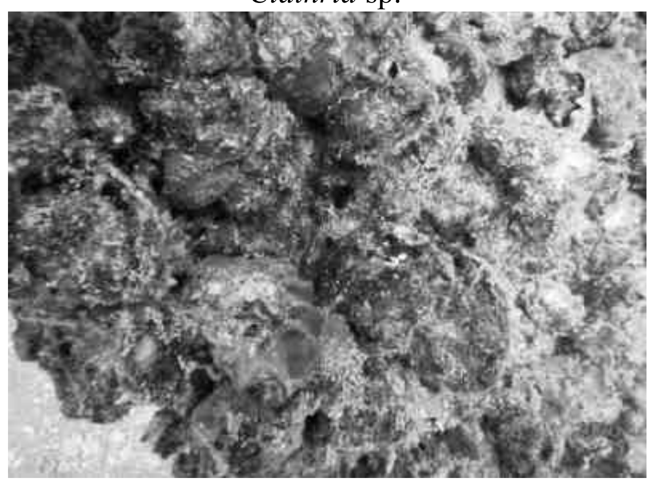
Cavernularia sp.

Sponge community recorded in Marine zone 2020



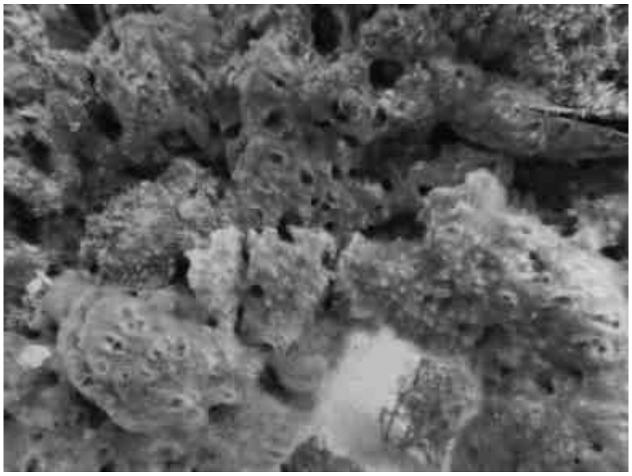
Chondrilla sp. *Clathria* sp.



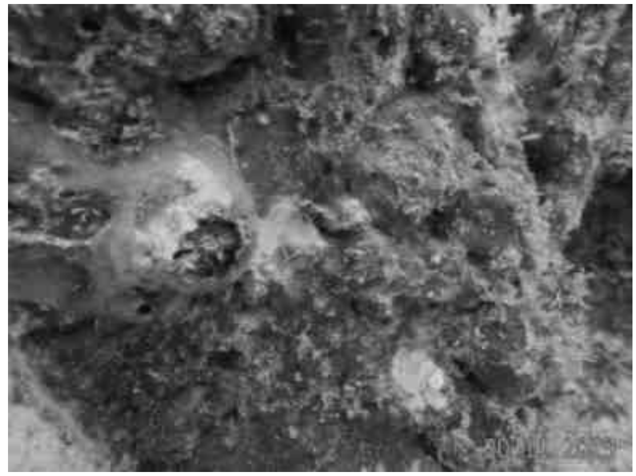


Chalinula sp. *Chondrilla* sp.

Sponge community recorded in Marine zone 2022

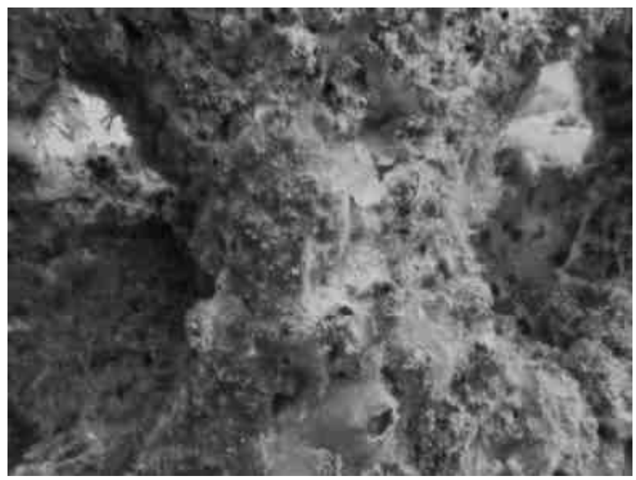


Cliona sp

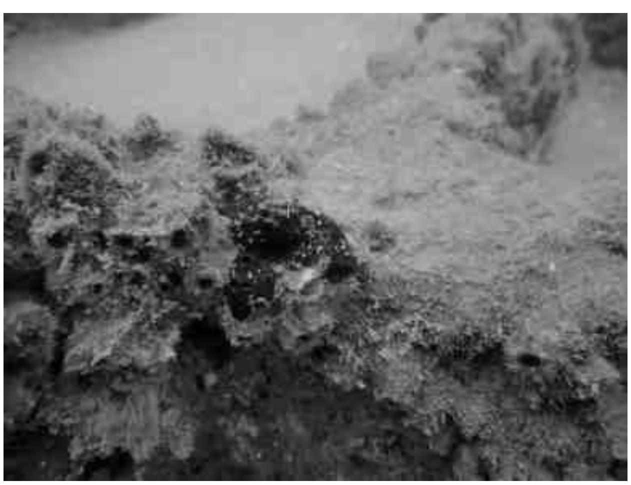


Cliona sp.

Clathria sp.



Spirastrella sp.



Dysidea sp

Clathria sp

Fish community recorded in Marine zone (2020)

.

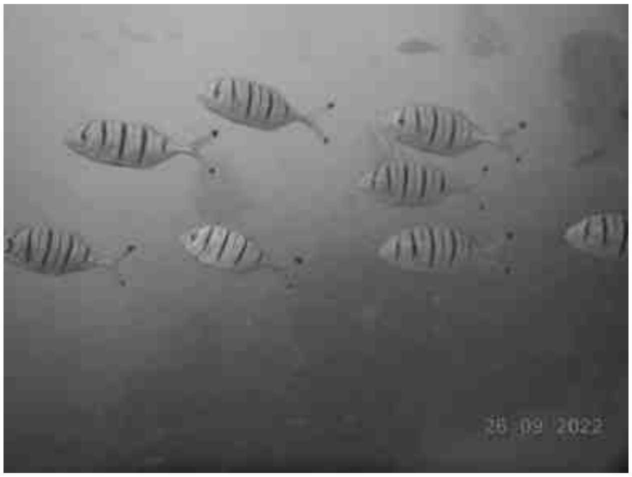
Rhabdosargus sarba

Sphyraena jello

Rastrelliger kanagurta

Scarus ghobban

Fish community recorded in Marine zone (2022)



Gnathanodon speciosus

***Platax* sp.**

Epinephelus malabaricus

***Caranx* sp.**

***Lutjanus* sp.**

***Sphyraena* sp.**

Rastrelliger kanagurta

Rhabdosargus sarba

Lutjanus fulviflamma

Siganus

***Monodactylus* sp**

***Siganus and Lutjanus* sp.**

ii. Mangrove habitat assessment

Distribution of Mangroves

Mangroves are seen in Ennore creek, Kosasthalaiyar river (connecting Ennore creek and Pulicat lake), mouth of the Buckingham canal and Pulicat lake region of the study area (Fig. 3.2.1). Mangroves are seen as patches and lines. Small to larger patches of mangroves are seen on the intertidal zone present inside and on the banks of the river. Similarly, sparely distributions of mangroves are also noticed along the banks of the river at many locations. Mangroves are also seen at few locations along the mouth of Buckingham canal, where it meets the Kosasthalaiyar river.

Total area cover of mangroves in the study area was 62.8 ha (10km radius). Mostly mangroves are seen as small and large patches, totally fourteen large patches were observed in the study area, which are seen in the intertidal zone on the river banks and few inside the Kosasthalaiyar river. Well grown healthy mangrove vegetation is seen in most of the patches, whereas stunted and degraded mangroves are also seen in few patches particularly were flushing of water is absent. Similarly well grown healthy mangrove vegetation is also distributed along the banks of the rivers, whereas at few locations, stunted mangroves are also seen. Out of total 61.2 ha mangrove area, 21.4 ha occurs south of the Kattupalli Port while 36.7 ha occurs parallel to the port and only 3.1 ha occurs north of the port.

Well grown mangroves

Stunted and degraded mangroves

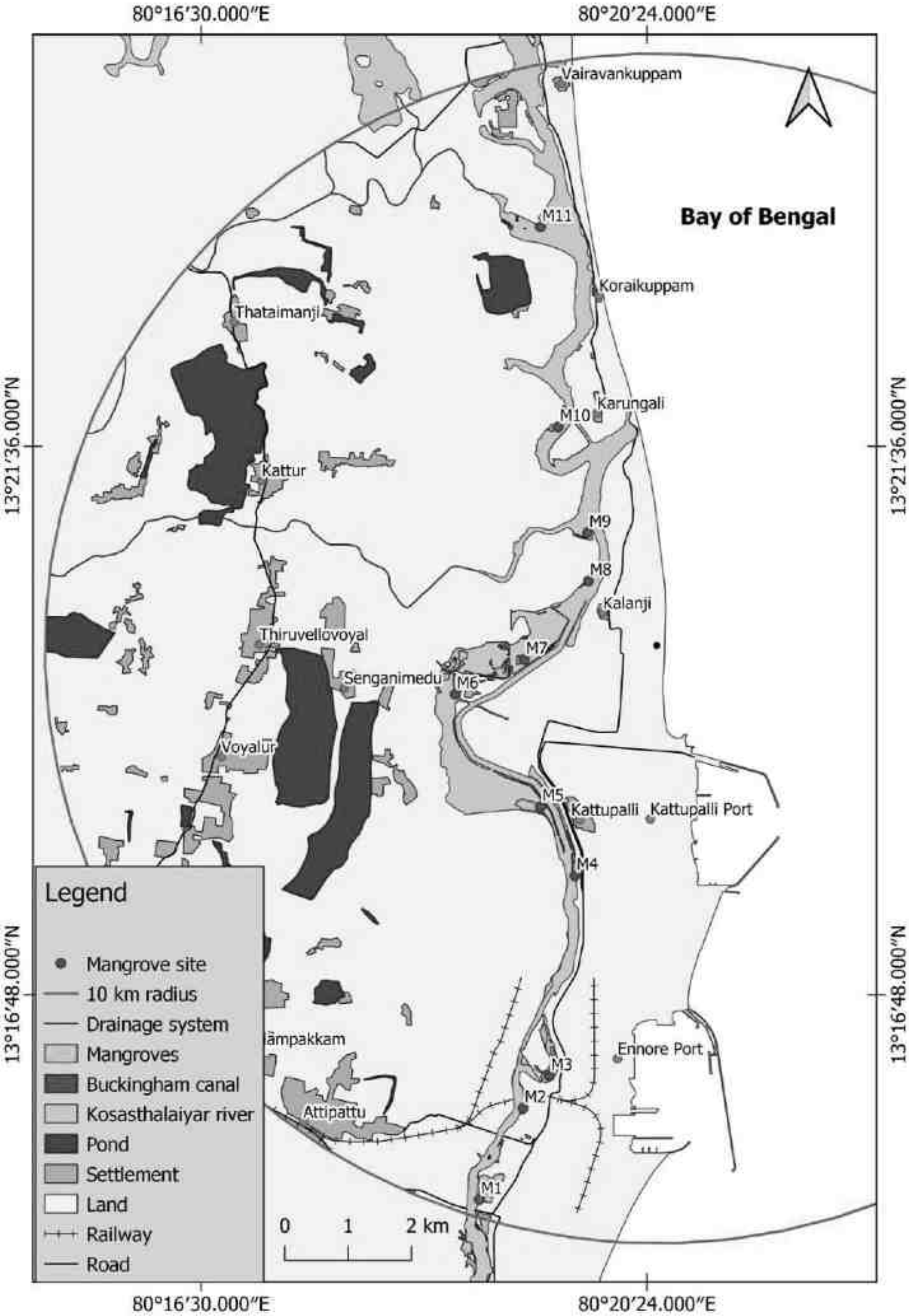


Fig. 3.2.1: Map showing the distribution of mangroves with study sites in the study area

Mangrove diversity

Three species of mangroves are observed in the study area. *Avicennia marina, Avicennia* sp. and *Rhizophora mucronata* belonging to two family Avicenniaceae and Rhizophoraceae. The study area is dominated by well grown *Avicennia marina*, whereas *Avicennia* sp. and *Rhizophora mucronata* are very fewer in number and limited to the northern side of the study area near Pulicat (Fig. 3.2.2 & Fig. 3.2.3). *Avicennia* sp. dominates at M 10 with few stunted growth of *Avicennia marina* and very few *Rhizophora mucronata*, whereas at M 11, both well grown *Avicennia* sp. and *Rhizophora mucronata* are seen, with very few stunted growth of *Avicennia marina.*

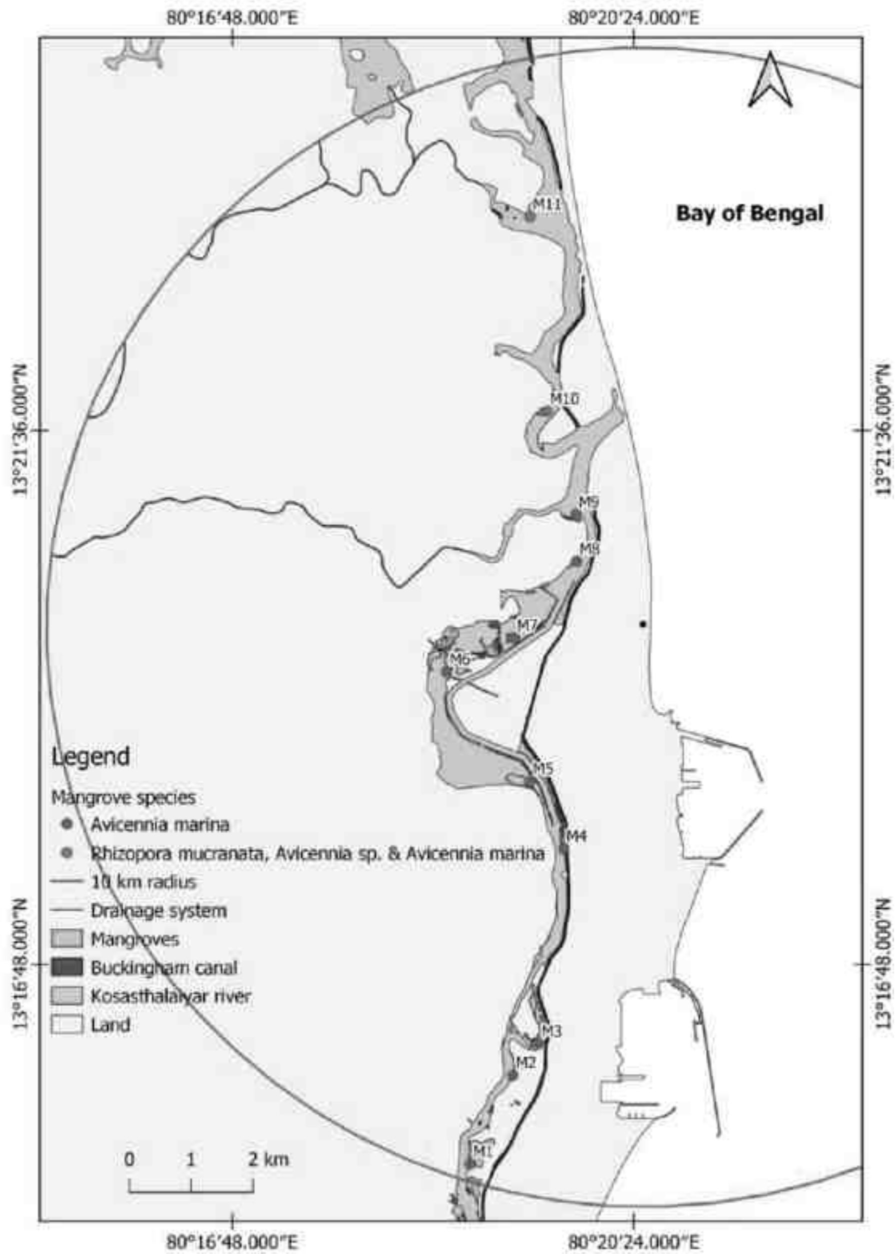


Fig. 3.2.2: Map showing the number of mangrove species at different sites in the study area

Avicennia marina

Avicennia marina

***Avicennia* sp.**


***Avicennia* sp.**


Rhizophora mucronata


Rhizophora mucronata

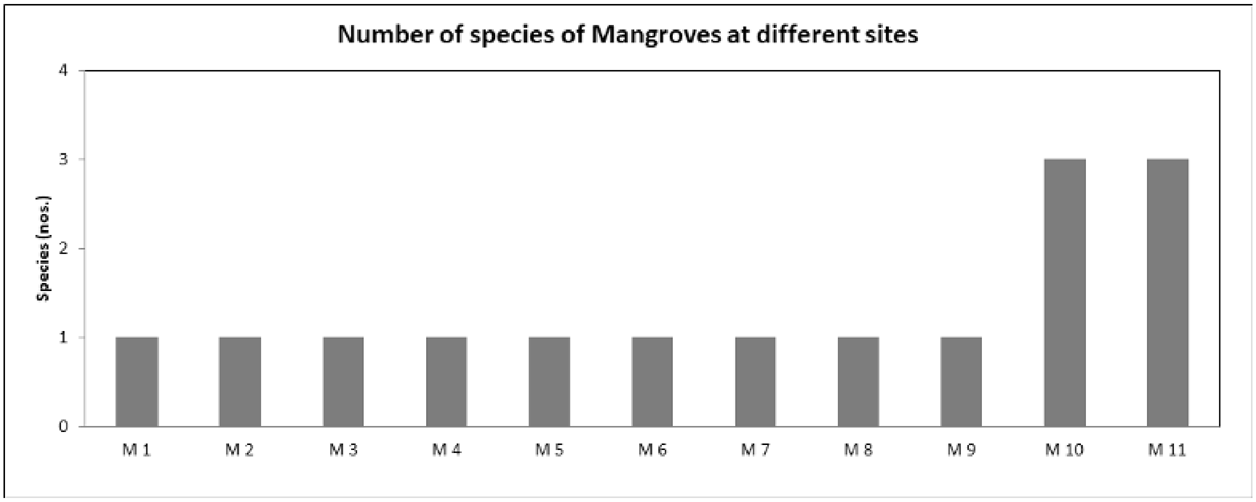


Fig. 3.2.3: Mangrove species recorded in the Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

Mangrove density, growth and height canopy

The mangrove vegetation density in the study area varied between 1.5 and 12 plants per 5 square meters (Fig. 3.2.4 & Fig. 3.2.5). For *Avicennia marina,* it varied between 4 and 12 plants per 5 square meters, for *Avincennia* sp. it varied between 1.5 and 4 plants per 5 square meters. *Rhizophora mucronata*, it varied between 1.5 and 3 plants per 5 square meters. High density of mangroves are recorded at M8 and M9 followed by M4, while low density was recorded at M1, M10 and M11. Generally nangrove seen as huge patch or larger in size exhibits less density, while mangrove seen as small patch along the river banks exhibits higher density. The less mangrove density observed at M 10 and M 11 is due to the plantation of mangrove at these sites.

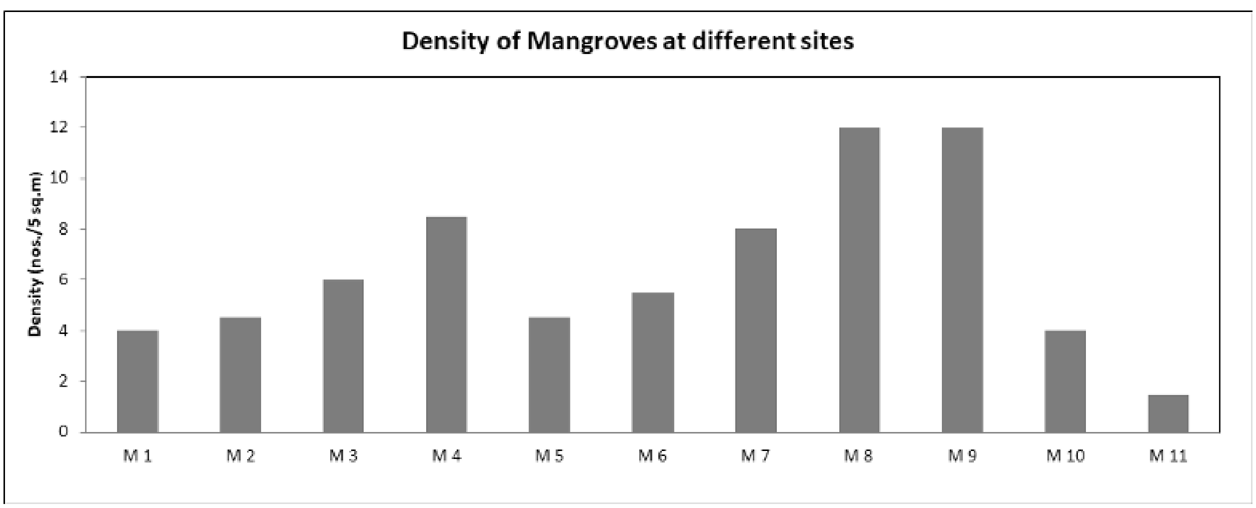


Fig. 3.2.4: Mangrove plant density in the Kosasthalaiyar River within 10 km radius of onshore region (M – Mangrove sampling site)

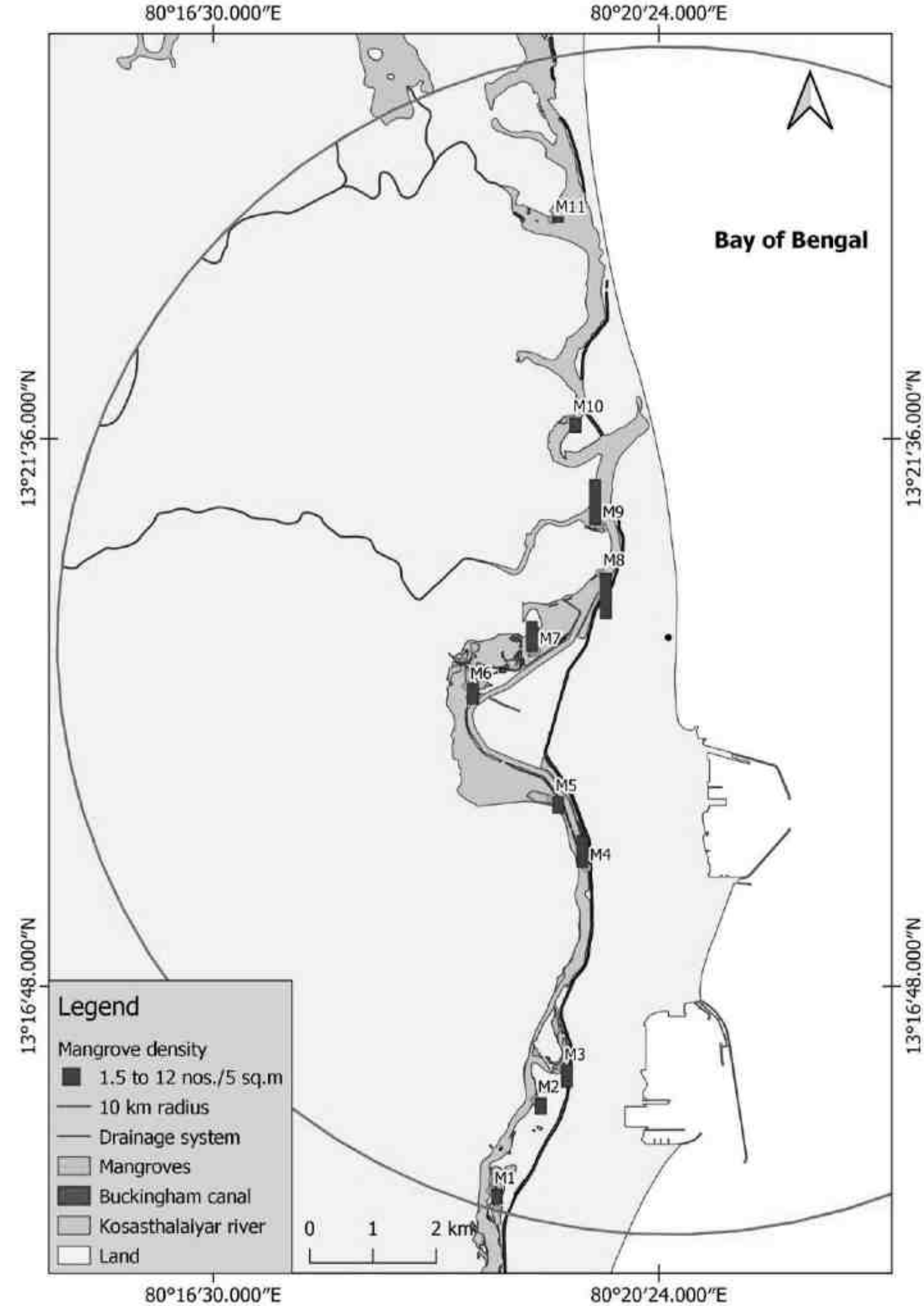


Fig. 3.2.5: Map showing the mangrove density at different sites in the study area

Mangrove density

Mangrove density

The mangrove tree stem circumference ranged between 4 and 72 cm in the study area (Fig. 3.2.6 & Fig. 3.2.7). For *Avicennia marina*, it ranged between 4 and 56 cm, for *Avicennia* sp., it varied between 30 and 72 cm and for *Rhizophora mucronata*, it varied between 10 and 32 cm. Both *Avincennia marina* and *Avincennia* sp. exhibits larger circumference than the *Rhizophora mucronata* and the stem thickness of *Avicennia* sp. is higher than other species of mangroves in the study site.

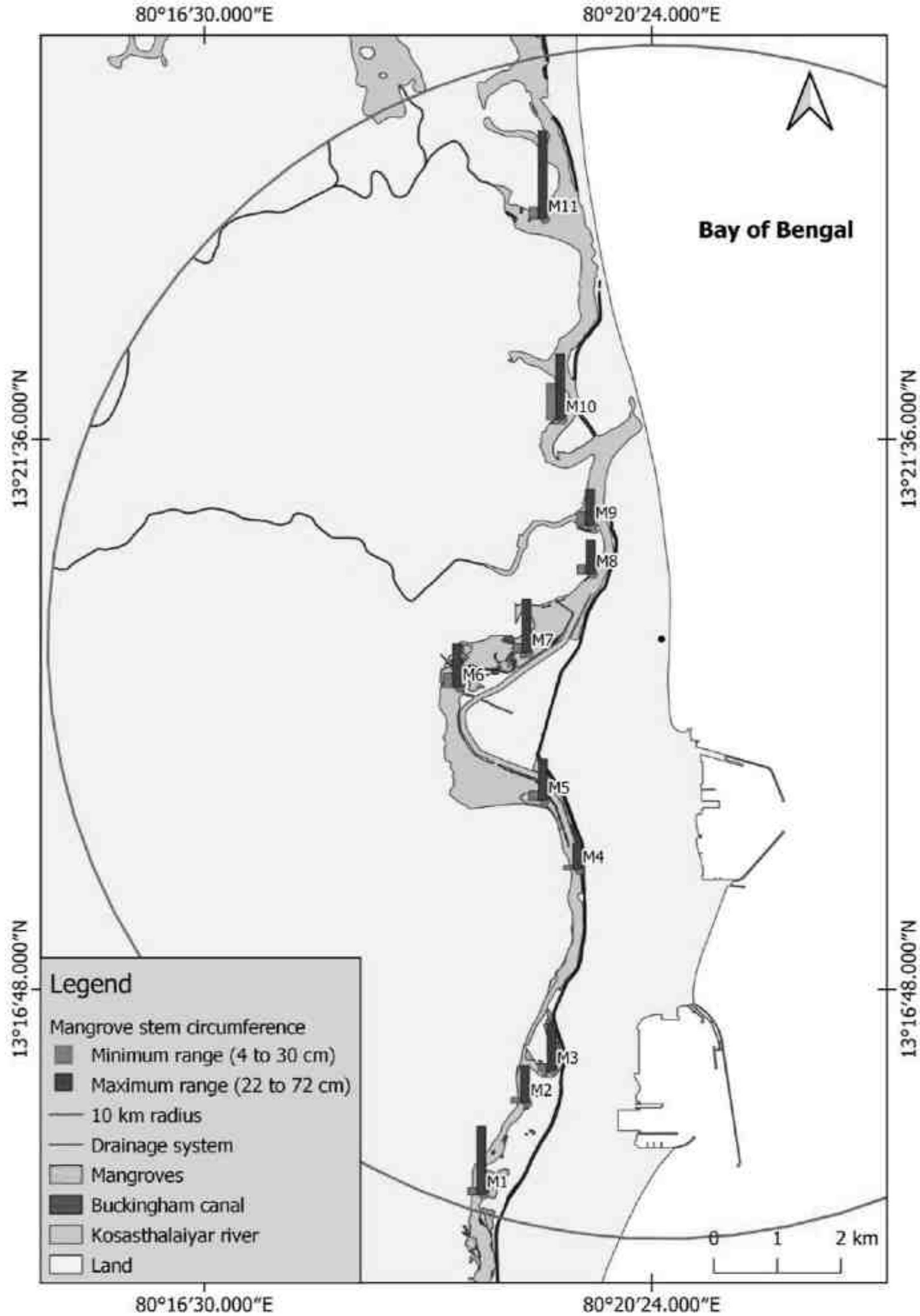


Fig. 3.2.6: Map showing the mangrove stem circumference at different sites in the study area

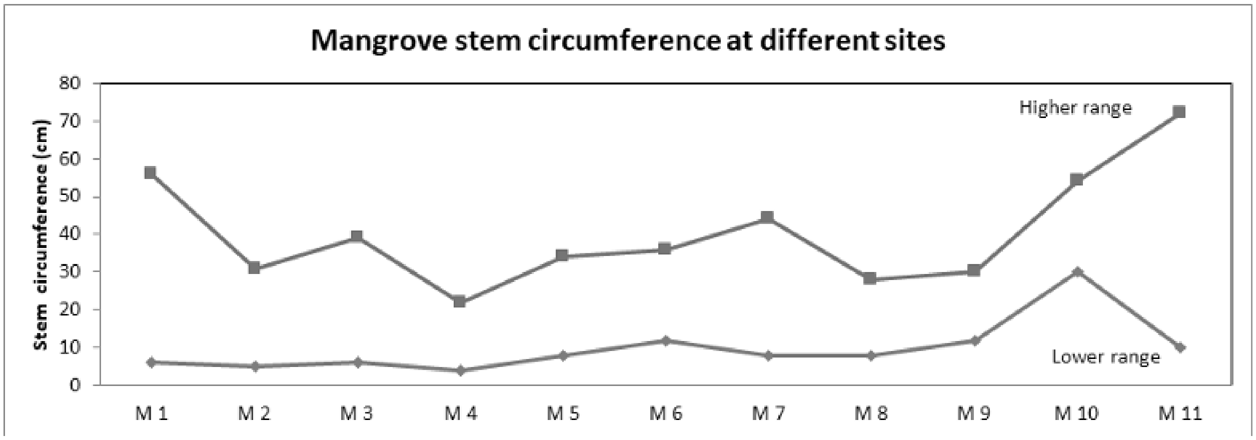


Fig. 3.2.7: Plot showing the mangrove stem circumference at different sites in the Kosasthalaiyar river within 10 km radius of onshore region

Mangrove stem circumference

Mangrove stem circumference

Usually the mangrove propogules develops during the rainy season that is from October to December. During the present survey, propogules are observed in the most of the location. But there are in primitive to developing stage in the plant itself. The propogules are observed in *Avicennia marina* and *Avicennia* sp. and *Rhizophora mucronata*. At M1, M3, M10 and M11 comparitively larger number of mangroves has propogule than other locations (Fig. 3.2.8). Stunted mangroves propogules are smaller in sizes when comparing with the well grown mangrove of *Avicennia marina* and *Avicennia* sp.

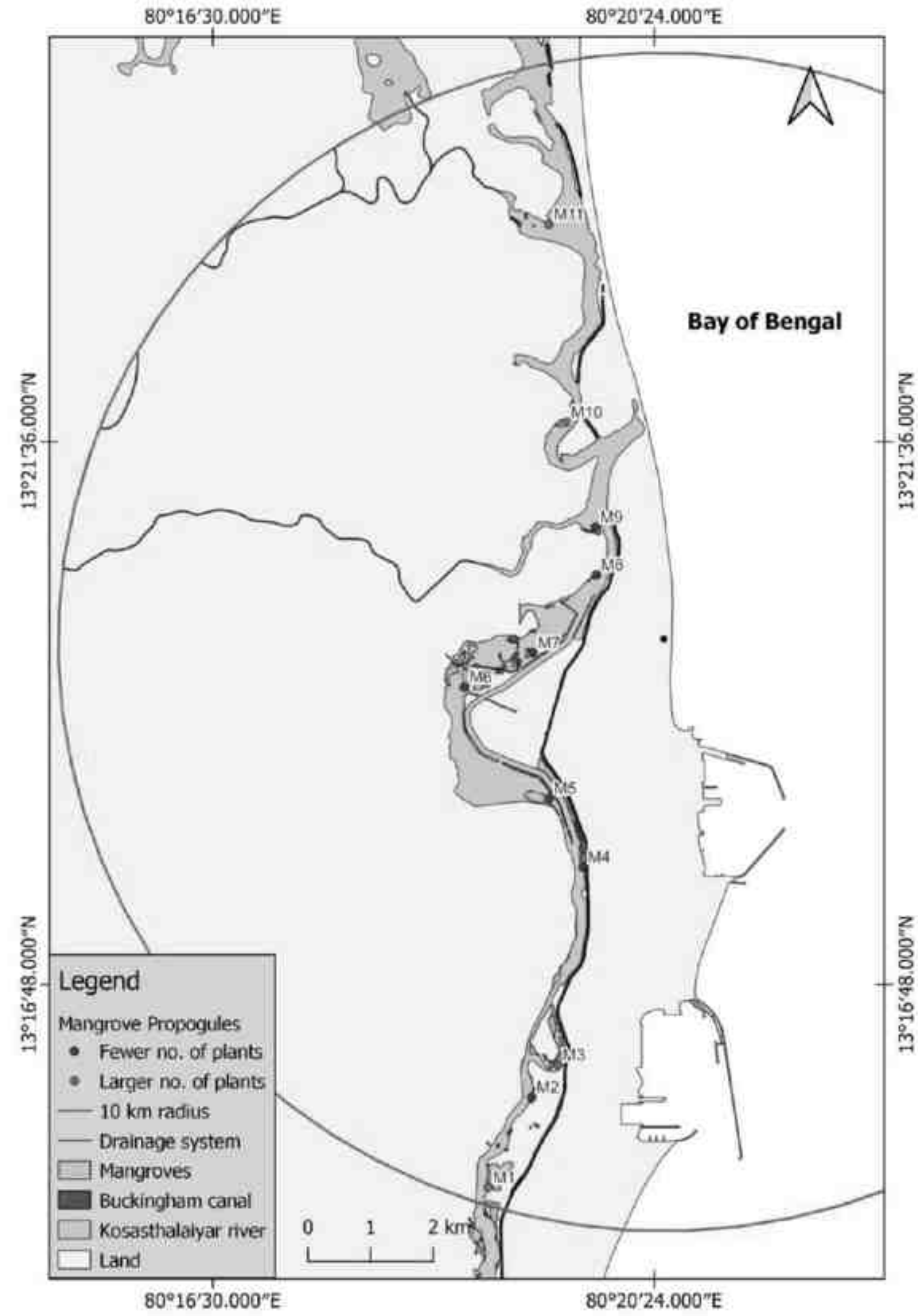


Fig. 3.2.8: Map showing the mangrove seed abundance at different sites in the study area

The width and length of the propogules of *Avicennia marina, Avicennia* sp. are less than 1.5 and 1.8 cm respectively, where as for *Rhizophora mucronata* it was 1.5 and 35 cm respectively. Well developed propogules *Avicennia marina* and *Avicennia* sp. are not observed in the ground surface or water coloum, whereas at M11 3 to 5 propogules of *Rhizophora mucronata* are seen in the ground around few plants of *Rhizophora mucronata* that is also in the starting stage of growth.

Mangrove seedling

Mangrove seedling

As far the leaves dimension is concerned, the average length in the different sites ranged from 4 to 9 cm for *Avicennia marina,* ranged from 5.5 to 10 cm for *Avicennia* sp. and ranged from 8.5 to 13 cm for *Rhizophora mucronata* (Fig. 3.2.9). Similarly, the average width for each species was 2.5 to 4.5 cm for *Avicennia marina,* 2.5 to 5 cm for *Avicennia* sp. and 4 to 6 cm for *Rhizopora mucronata*. The length and width of *Rhizopora mucronata* leaves is larger than *Avicennia marina* and *Avicennia* sp.

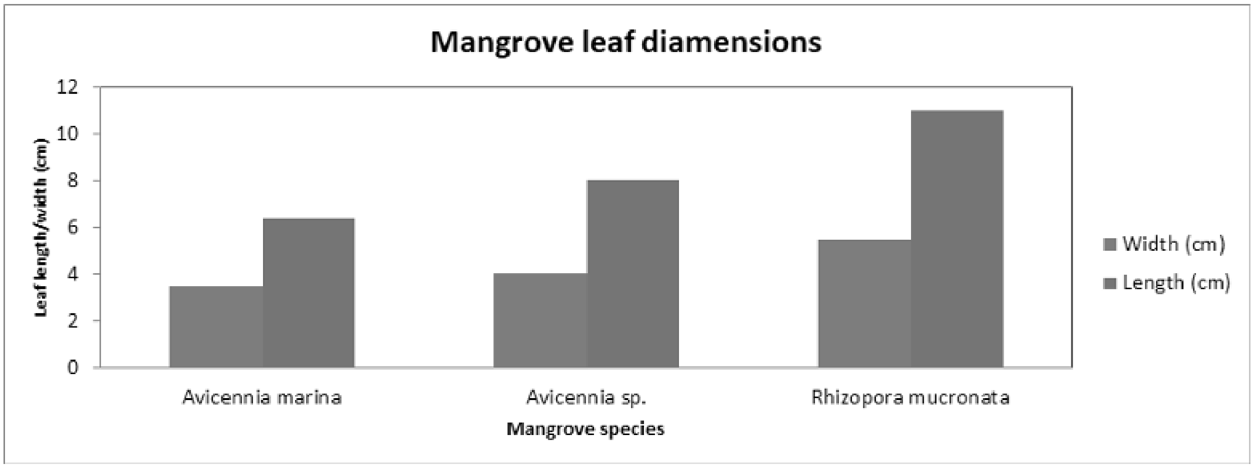


Fig. 3.2.9: Plot showing the mangrove leaf dimensions in the Kosasthalaiyar river within 10 km radius of onshore region


Mangrove leaves


Mangrove leaves

As far as the mangrove height canopy is concerned, the height of different species of mangroves in the study area ranged from 0.6 to 5 m for *Avicennia marina,* 2.2 to 5.1 m for *Avicennia* sp. and 3 to 3.4 m for *Rhizophora mucronata (*Fig. 3.2.10 & Fig. 3.2.11). Well grown mangroves are observed in the larger patches (M1, M3, M6, M7, M10 and M11) and few places along the banks of the river. Stunted grown *Avicennia marina* were observed in the places were flushing of water is poor or absent.

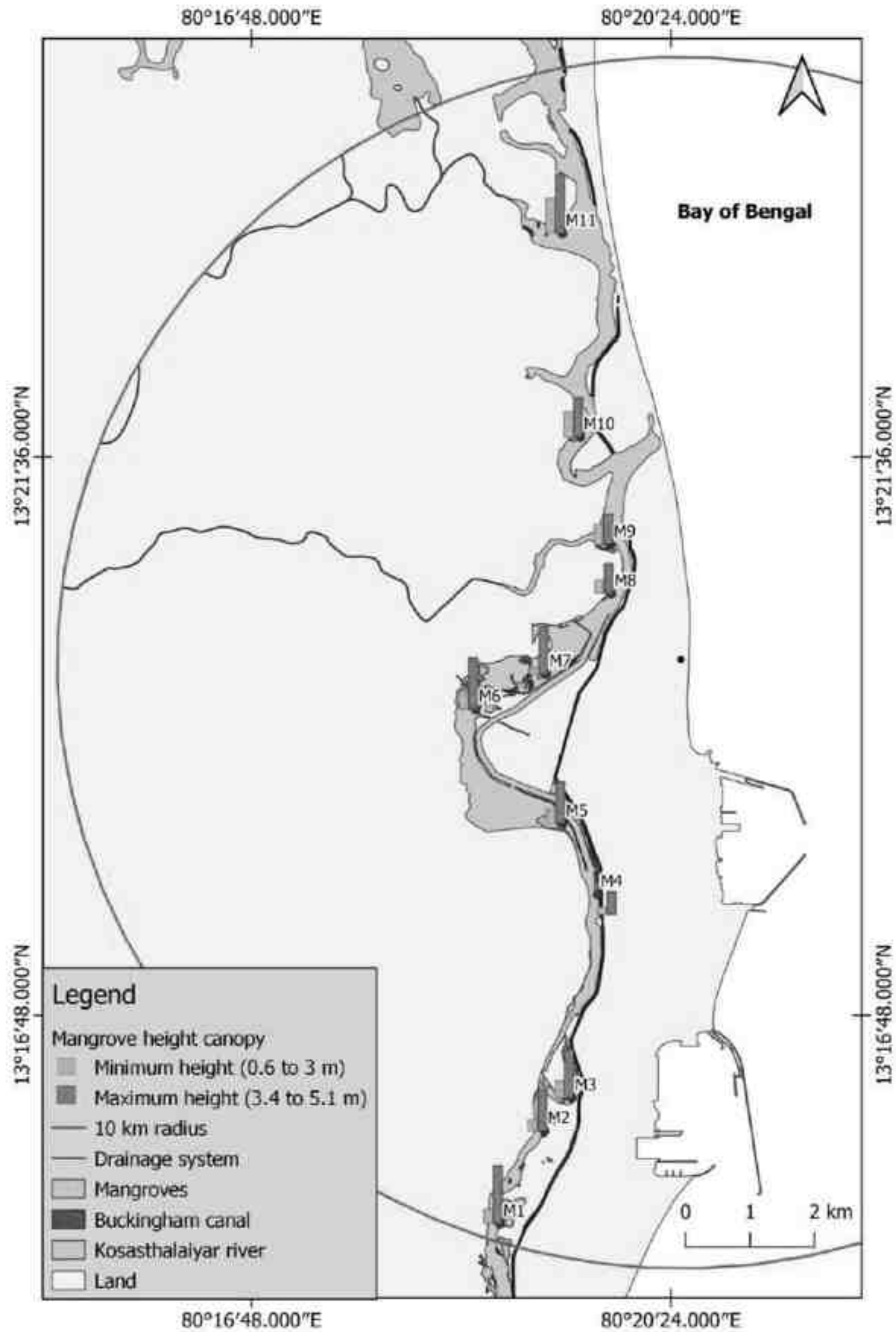


Fig. 3.2.10: Map showing the mangrove height canopy at different sites in the study area

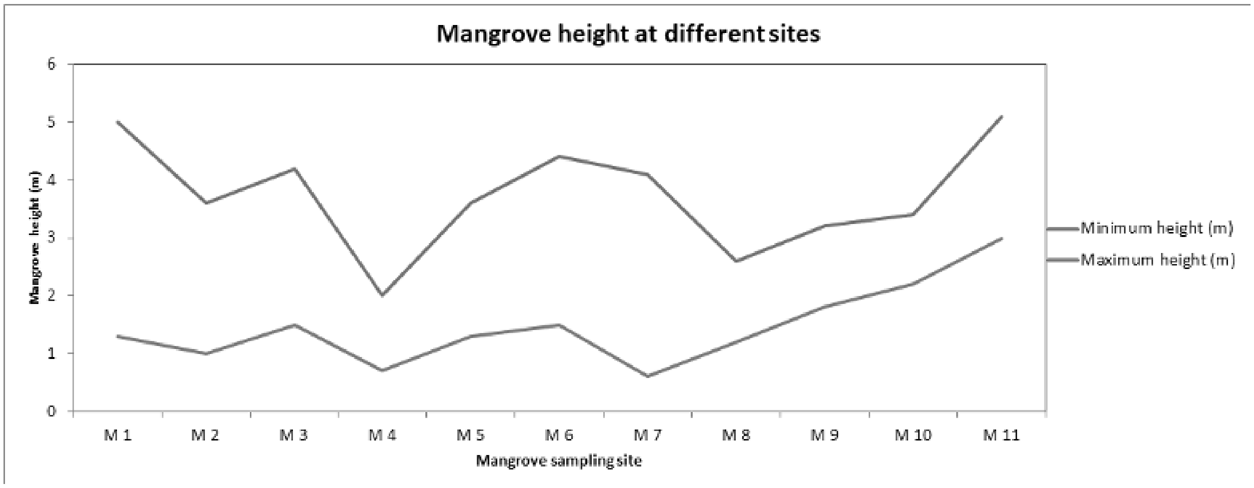


Fig. 3.2.11: Plot showing the mangrove height canopy at different sites in the Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

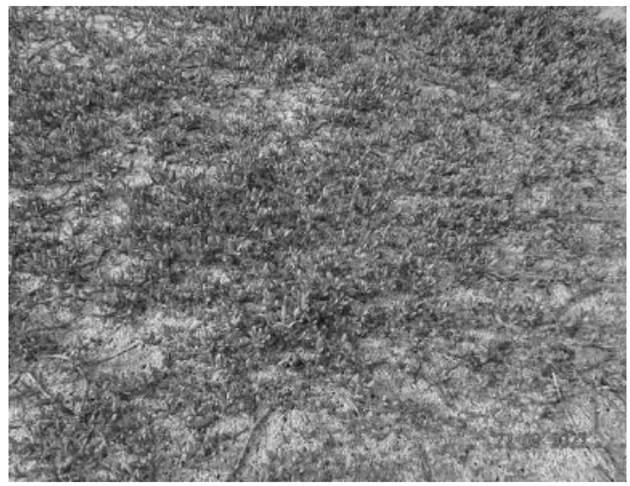
Mangrove height

Mangrove height

Mangrove associated vegetation

Mangroves ecosystem is a reservoir of salt tolerant halophytic plants. They are also called as associate mangroves (Selvam et al., 2004). The terrestrial species that found associate with mangroves are unable to tolerate high salts and therefore do not penetrate deep into the mangrove wetlands. They normally found in elevated lands present within mangrove ecosystem. Five types of halophytic plants were observed in the study area (Table 3.2.1). They are *Sesuvium portulacastrum, Suaeda monoica, Suaeda* sp.*, Suadea nudifolra Moq.* and *Salicornia brachiate Roxb.* They are seen in the periphery of mangrove patches and also with mangrove along the banks of the river. On the other hand halophytic plants are also seen as mono-specific in the intertidal zone, were mangroves are absent and regions of no flushing of water where hypersaline condition exists. *Suaeda monoica* and *Sesuvium portulacastrum* were dominant halophytic plants in the study area.

Suadea nudiflora Moq.



Sesuvium portulacastrum

Salicornia brachiate

Suaeda monoica

Table 3.2.1: List of halophytic plants observed in the study area

Sl. No.	Scientific name
1	*Sesuvium portulacastrum*
2	*Suaeda monoica*
3	*Suaeda* sp.
4	*Suaeda nudiflora Moq.*
5	*Salicornia brachiata Roxb.*

Algal flora in mangrove

Algal vegetation is common in mangroves and two types of algal thrive in the study area. The first type attaches itself to the trunk or roots of mangrove and is exposed during low tide. The second type is spongy mass floating in the water in the mangrove area. The first type alga was seen in some places in the central region of the study area at M5, M6, M7 and M10; whereas the second type is limited to northern region particularly Site M11.

Algal flora

Summary results and remarks

The study area has a reasonable amount of mangrove habitat as freshwater supply is available. Due to the availability of mangrove, mangrove associated biodiversity also occurs within the study area. Mangroves are seen along the Ennore creek, Kosasthalaiyar River (at connection points between Ennore creek and Pulicat Lake), mouth of the Buckingham canal and small patch in Pulicat lake. Mangroves are seen as patches and lines along with mangrove associated halophytic plants. Total area cover of mangroves in the study area was 62.8 ha. Three species of mangrove plants were observed in the study area that are *Avicennia marina, Avicennia* sp. and *Rhizophora mucronata* in which *Avicennia marina* was the dominant species. Mangrove vegetation density in the study area varied between 1.5 and 12 plants per 5 square meters while mangrove tree stem circumference ranged between 4 and 72 cm in the study area. Seed are present *Avincennia marina* and *Avicennia* sp.plants in primitive to developing stage and they are absent in the ground surface or in water coloumn whereas for *Rhizophora mucronata* seed are seen in plant in developed form. Few propogules of *Rhizophora mucronata* are seen in ground near the plant and they are in the starting stage of growth. The average length of mangrove leaves ranged from 4 to 9 cm for *Avicennia marina, 5.5* to 10 cm for *Avicennai* sp. and 8.5 to 13 cm for *Rhizophora mucronata*. Leaf width ranged between 2.5 to 4.5 cm for *Avicennia marina, 2.5* to 5 cm for *Avicennia* sp. and 4 to 6 cm for *Rhizophora mucronata*. Height canopy of mangrove plants ranged from 0.8 to 5 m for *Avicennia marina,* 2.6 to 5.2 m for *Avicennia* sp. and 3 to 3.3 m for *Rhizophora mucronata*. Five types of halophytic plants were observed in the mangrove areas that are *Sesuvium portulacastrum, Suaeda monoica, Suaeda* sp.*, Suadea nudifolra Moq.* and *Salicornia brachiate Roxb*; among them *Suaeda monoica* and *Sesuvium portulacastrum* were dominant. Two type of algal vegetation were observed in study are they were restricted to the central and north part of the region.

iii. Coastal floral assessment

Vegetation refers to the great diversity of plant species which occur in repeating assemblages over a place. The primary objective of this study is to record the coastal plantation and to produce coastal plantation map for the study area. These resources can be used in coastal resource assessment, management and conservation.

As far as coastal vegetation is concerned, totally 41 species of plants were observed from the coastal region (Table 3.3.1). In which 5 were herbs, dominated by *Cyperus conglomeratus*, 20 were shrubs dominated by *Ipomoea pes-caprae* followed by *Lantana camara* and 16 were trees, dominated by *Eucalyptus globulus* followed by *Anacardium occidentale* and *Borassus flabellifer* (Fig. 3.3.1& Fig. 3.3.2). The total area cover of coastal plantation was 282 ha, in which the dominant plantation cover was *Eucalyptus globulus* covering an area cover of 94 ha, followed by *Borassus flabellifer* covering an area cover of 8.6 ha, whereas mixed vegetation covers an area of 110.6 ha, which is dominated by *Casuarina littorea* and *Anacardium occidentale.* Old agriculture field covering an area of 54.8 ha and shrubs with other vegetation covers an area of 14.5 ha which is dominated by *Prosopis chilensis.*

The dune vegetation in coastal region is characteristically governed by proximity to sea resulting in zones of different vegetation types that run parallel to the coastline, seaward embryo/mobile and fore dune with sand binders, particularly by *Spinifix littoreus* and *Ipomoea pes-caprae*. Whereas the inner sandy plains in mostly covered with shrubs and trees, where *Prosopis juliflora* dominates with other such as *Azadirachta indica*. Apart from the natural vegetation, numbers of manmade coastal plant farms are observed from central to north-central region. Availability of shallow groundwater supplies water for the coastal plantation. Numbers of small manmade ponds are observed in the farms, which are filled with water. Similarly low lying areas in the coastal track are also filled with water and plants, such as *Salvinia molesta*. The plant species observed in the farm includes, *Eucalyptus globulus*, *Casuarina littorea* and *Anacardium occidentale*, in which *Eucalyptus globulus* farm dominates. Increase in plant diversity was observed as moving from the coastal track to Kosasthalaiyar river and Buckingham canal. Similarly on the river and canal side, *Sporobolus virginicus* dominates the bank of the Kosasthalaiyar River and Buckingham canal.

Table 3.3.1: List of halophytic plants observed in the study area

Sl. No.	Scientific name
	Trees
1	*Anacardium occidentale*
2	*Azadirachta indica*
3	*Borassus flabellifer*
4	*Casuarina littorea*
5	*Catunaregam spinosa*
6	*Cocos nucifera*

7	*Eucalyptus globulus*
8	*Excoecaria agallocha*
9	*Ficus benghalensis*
10	*Ficus religiosa*
11	*Lannea coromandelica*
12	*Phoenix pusilla*
13	*Prosopis chilensis*
14	*Syzygium cumini*
15	*Thespesia populnea*
16	*Ziziphus nummularia*
	Shrubs
17	*Acalypha ciliata*
18	*Achyranthes aspera*
19	*Calotropis gigantea*
20	*Cassia occidentalis*
21	*Crotalaria retusa*
22	*Datura stramonium*
23	*Dodonaea viscosa*
24	*Ipomoea pes-caprae*
25	*Jatropha gossypifolia L.*
26	*Lantana camara*
27	*Nerium oleander*
28	*Opuntia dillenii*
29	*Pentatropis capensis*
30	*Pergularia daemia*
31	*Physalis angulata*
32	*Pupalia lappacea*
33	*Ricinus communis*
34	*Senna alata*
35	*Solanum trilobatum*
36	*Vernonia cinerea (L.) Less.*
	Herbs
37	*Cyperus conglomeratus*
38	*Fimbristylis ferunginea*
39	*sporobolus virginicus*
40	*Typha sp.*
41	*Salvinia molesta* (Water plant)

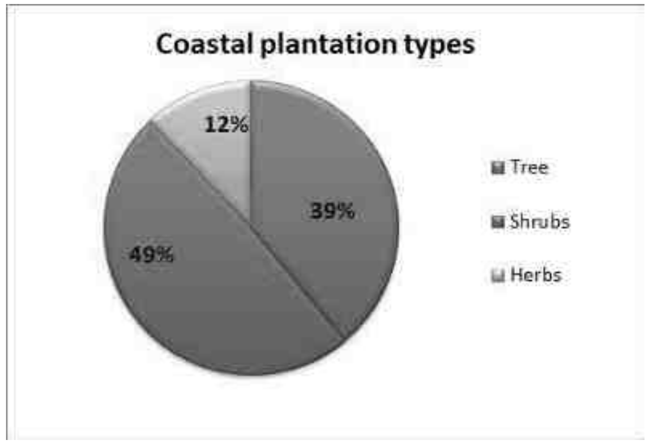


Fig. 3.3.1: Pi-diagram showing the coastal plantation types for the study area

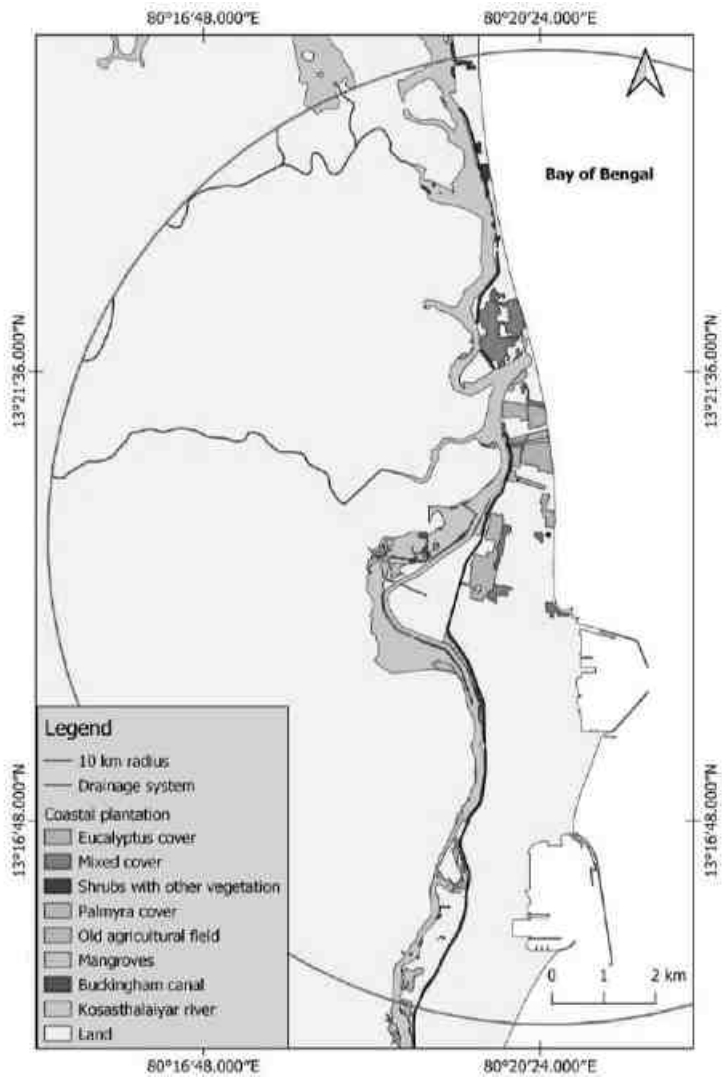


Fig. 3.3.2: Map showing the various types of coastal plantation cover in the Kattupalli study area

Eucalyptus globulus

Azadirachta indica

Anacardium occidentale

Ricinus communis

Borassus flabellifer

Phoenix pusilla


Cocos nucifera ***Calotropis gigantea***


Nerium oleander ***Jatropha gossypifolia***


Lannea coromandelica ***Physalis peruviana***

Datura ferox

Ziziphus nummularia

Dodonaea viscosa

Typha sp.

Lantana camara

Prosopis chilensis

Excoecaria agallocha ***Datura stramonium***

Summary results and remarks

The study area encompasses a good amount of coastal vegetation apart from the mangrove vegetation. A total of 41 species of plants were observed from the study area. Among them, 5 were herbs dominated by *Cyperus conglomeratus*, 20 were shrubs dominated by *Ipomoea pes-caprae* and 15 were trees dominated by *Eucalyptus globulus*. The total area cover of coastal vegetation was 282 ha, in which *Eucalyptus globulus* was the dominant plant covering an area cover of 94 ha. The dune vegetation in the coastal region is influenced by proximity to sea. Different zones of vegetation run parallel to the coastline. Fore dunes are dominated by sand binders such as *Ipomoea pes-caprae* and *Spinifix littoreus*, whereas the inner sandy plains are covered with shrubs and trees dominated by *Prosopis juliflora.* Apart from the natural vegetation, manmade planation is also observed from central to north-central region along the coast. Availability of shallow groundwater is good enough for the coastal vegetation.

iv. MACRO, MEIO AND MICRO FAUNAL ASSESSMENT

1. Mangrove waters

a. Macrofaunal community

The macrobenthic faunas were collected in the mangrove waters which were covered between Ennore Greek and Pulicat area with a total of 11 stations. The macrobenthic organisms were represented by six groups *viz*., Polychaetes, Gastropods, Bivalves, Amphipods, Isopods and others. A total of 40 species from 29 genera comprised with 24 families was found in the mangrove waters. Totally 461 macrobenthic faunal individuals was recorded in the study area. Among the groups, Polychaetes was predominantly occurs in the mangrove sediments with 229 individuals followed by Gastropods with 79 individuals while low abundance was exhibited for the Isopod and Others with 23 and 20 individuals (Table 3.4.1). The analysis of diversity indices showed that Shannon diversity (H') value ranged between 2.81 and 3.18 and Evenness (J) was ranged between 0.92 and 0.98. Highest value was found at M3 and M2, lowest at M9 (Fig. 3.4.6,7,8). Spatial variation of macrofaunal assesmblage pattern was represented in plot and community similarity was indicated in Bray–Curtis similarity matrix (Fig. 3.4.4 & 5).

Polychaetes

The Polycheates community relatively greater abundance was found in the all Stations. *Spionidae* (73 nos.) and Capitellidae (37 nos.) were the most common families which represented as greater density. Nereis sp. *Scololepis squamata*, *Prionospio pinnata, Capitella capitata*, Glycera sp. and *Lumbrineris aberans* were the dominant species found in the study area. Highest abundance was recorded in station M10 with 59 nos./0.0256m^2 followed by M3 with 22 nos./0.0256m^2 whilst poor occurrence had reported in M4 with 11 nos./0.0256m^2 respectively.

Gastropods

Five species belonging to 3 families of gastropods was represented in the study area. Of which, *Umbonium* sp*., Cerithedia cingulata* and *Umbonium vestiarium* was the most common species recorded. Highest abundance was recorded in station M10 with 12 nos./0.0256m^2 followed by M7 and M11 with 11 nos./0.0256m^2. Low abundance was marked in M1 and M9 with 3 nos./0.0256m^2

Bivalves

In Bivalves, least species richness was represented in this group with 3 species. Of these, *Meretrix* sp. and *Andadara* sp. was dominated species in the sediments. Maximum density was found to be in M5 with 6 nos./0.0256m^2 followed by M2, M8 andM10 with 5 nos./0.0256m^2 and low density recorded in M9 with 1 nos./0.0256m^2.

Amphipods

Low occurrence of Amphipods in terms of diversity and abundance were represented in the sediments. Five species from four families have been sighted, of these, *Amphithoe* sp. and *Gammarus* sp. being the predominant organisms witnessed in across all stations. Highest was counted in M7 with 11 nos./0.0256m^2 and low numbers were obtained for the stations M6 and M10 with 4 nos./0.0256m^2.

Isopods

The isopods are sparse density was found to be in the Mangrove waters. Only three species from two families are represented, among them, *Eurydice* sp. and *Asellota* sp. were the common beings in this region. Poor occurrence was sighted in all stations.

Others

Only one species is accounted in this group and poor occurrence was found in the study area. Details of diversity and abundance are represented in Table 3.4.1 and Fig. 3.4.1,2&3.

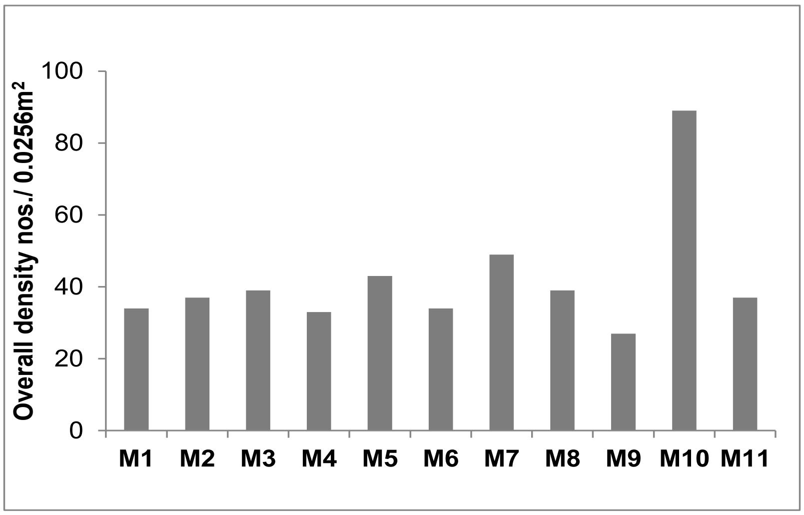


Fig. 3.4.1: Macro benthic faunal density in the mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

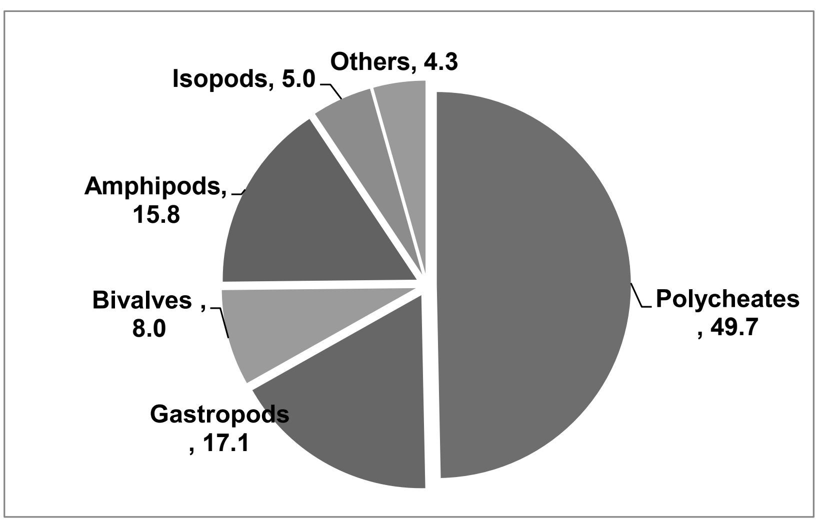


Fig. 3.4.2: Macro benthic community percentage composition in the mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region

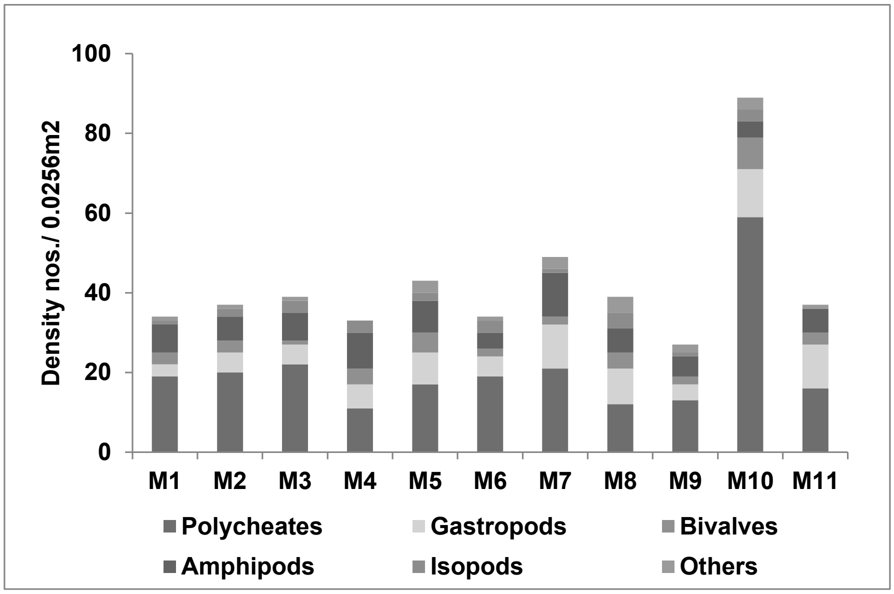


Fig. 3.4.3: Macro benthic community density in the mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region

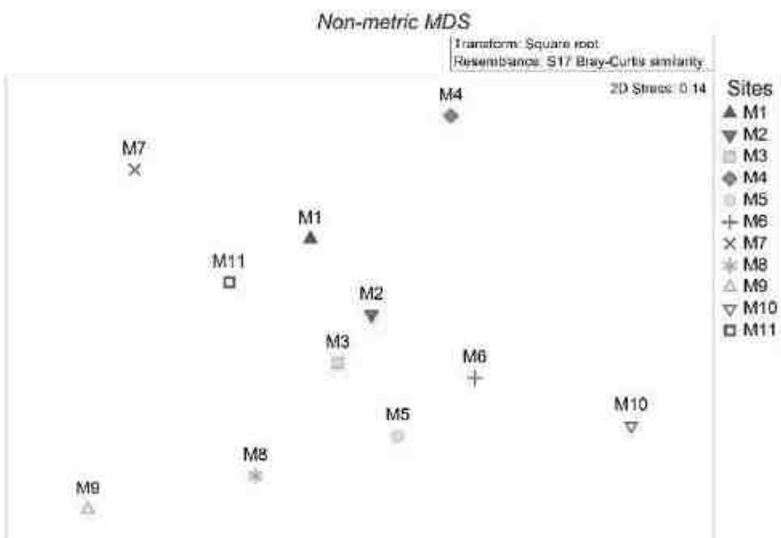


Fig. 3.4.4: MDS plot indicating macro benthic communities in the mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

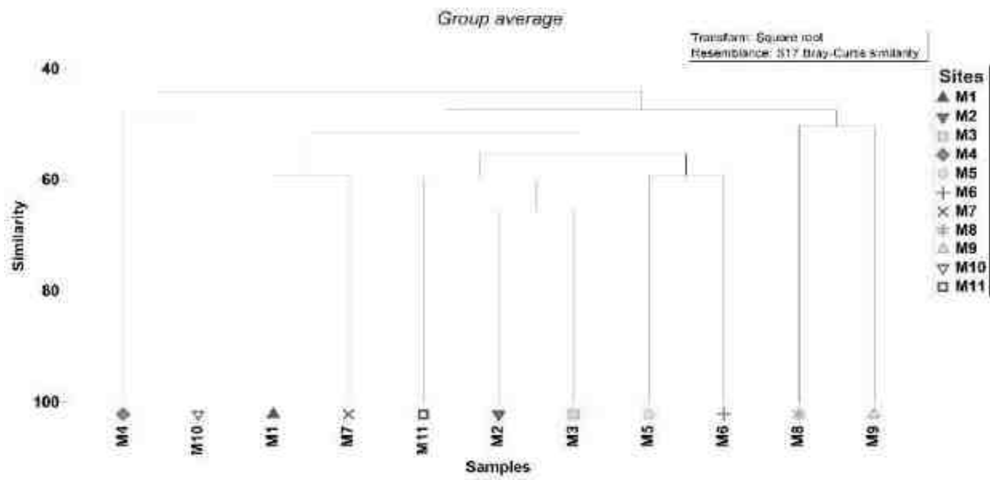


Fig. 3.4.5: Dendrogram of hierarchical cluster analysis showed the similarity of community structure among sampling sites in the mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

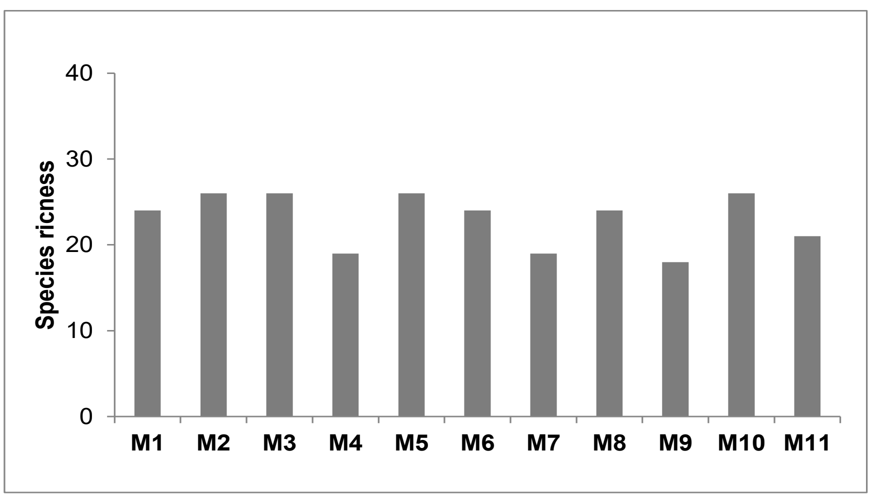


Fig. 3.4.6: Macro faunal species richness in mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

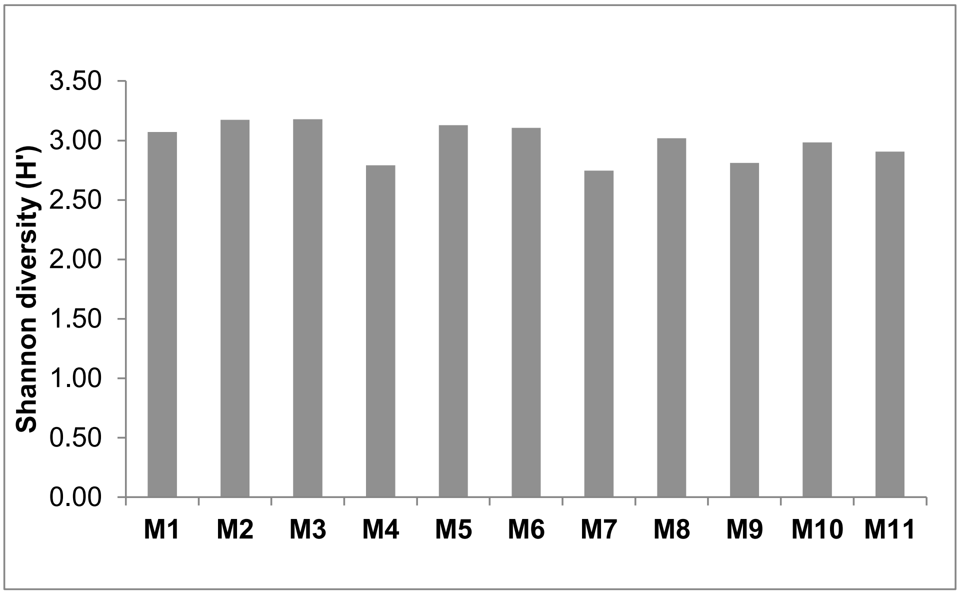


Fig. 3.4.7: Macro faunal Diversity (H') in mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

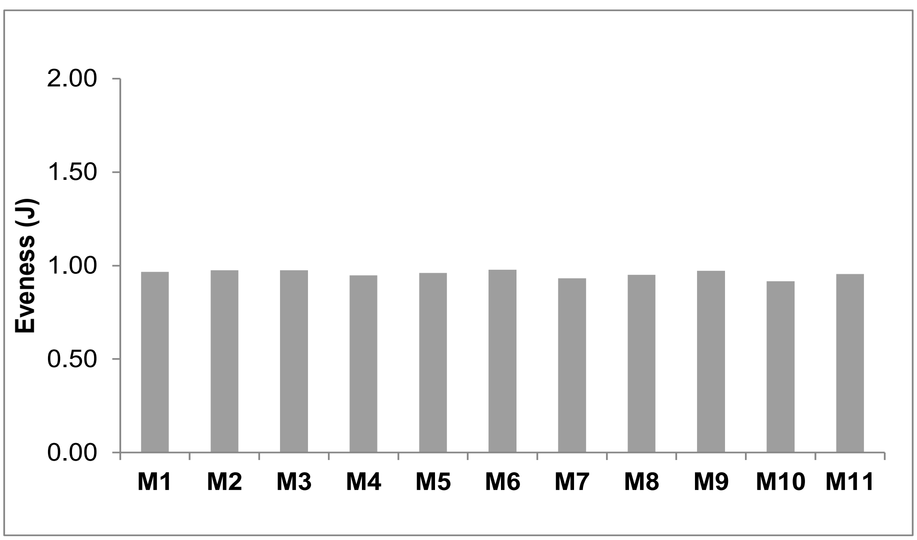


Fig. 3.4.8: Macro faunal evenness in mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

Table 3.4.1: Macro benthic faunal density in the mangrove habitat of Kosasthalaiyar river (M – Mangrove sampling site)

S. No.	Family	Genus	Species	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
	Polycheates													
1	Capitellidae	*Capitella*	*capitata*	1	2	0	1	0	2	1	0	0	5	2
2	Capitellidae	*Capitella*	sp.	0	0	2	0	0	0	0	1	0	0	0
3	Capitellidae	*Notomastus*	*aberrans*	1	1	1	2	1	1	0	0	0	4	0
4	Capitellidae	*Notomastus*	sp.	0	2	0	0	0	2	2	1	1	0	1
5	Cirratulidae	*Cirratulus*	sp.	2	0	0	1	2	0	0	1	0	2	0
6	Cossuridae	*Cossura*	sp.	1	2	2	0	0	0	0	1	1	0	2
7	Glyceridae	*Glycera*	sp.	0	1	1	1	1	1	0	0	1	8	1
8	Lumbrineridae	*Lumbreneris*	sp.	0	0	0	0	0	0	3	1	2	0	0
9	Lumbrineridae	*Lumbrineris*	*aberans*	3	0	1	0	0	2	2	0	0	2	2
10	Nereididae	*Nereis*	*capensis*	0	1	2	0	0	0	0	0	0	1	2
11	Nereididae	*Nereis*	sp.	1	2	1	0	1	1	0	0	0	12	0
12	Orbiniidae	*Orbinia*	sp.	0	0	2	0	2	0	2	0	1	0	1
13	Orbiniidae	*Orbinia*	*angrapequensis*	1	1	0	1	0	0	0	1	1	5	0
14	Phyllodocidae	*Phyllodace*	sp.	0	2	1	0	1	1	0	1	0	6	0
15	Pilargidae	*Ancistrosylls*	sp.	1	0	0	0	2	0	3	0	0	1	0
16	Spionidae	*Prionospio*	*pinnata*	3	1	1	2	0	1	3	1	2	1	1
17	Spionidae	*Prionospio*	sp.	0	0	0	1	2	2	0	0	2	4	0
18	Spionidae	*Scololepis*	sp.	2	1	2	0	1	0	1	0	0	0	2
19	Spionidae	*Scololepis*	*squamata*	1	2	3	0	2	1	4	1	1	0	1
20	Spionidae	*Spiophanes*	*bombyx*	0	0	2	1	0	0	0	1	0	4	0
21	Spionidae	*Spiophanes*	sp.	0	1	0	0	1	2	0	0	0	1	0
22	Spionidae	*Spionida*	sp.	1	0	0	1	0	1	0	2	0	3	0
23	Syllidae	*Syllis*	sp.	1	1	1	0	1	2	0	0	1	0	1

	Gastropods Groups													
24	Epitoniidae	*Epitonium*	sp.	0	1	1	1	1	0	0	1	2	0	0
25	Potamididae	*Cerithum*	sp.	1	2	0	2	0	1	6	0	0	1	2
26	Potamididae	*Cerithedia*	*cingulata*	1	0	0	0	4	2	1	5	1	0	5
27	Trochidae	*Umbonium*	sp.	0	1	2	1	3	1	0	3	0	5	4
28	Trochidae	*Umbonium*	*vestiarium*	1	1	2	2	0	1	4	0	1	6	0
	Bivalves Groups													
29	Arcidae	*Anadara*	sp.	1	1	1	1	4	0	1	2	0	1	2
30	Veneridae	*Meretrix*	*meretrix*	0	1	1	0	1	3	3	0	1	0	1
31	Veneridae	*Meretrix*	sp.	1	3	0	2	1	1	0	3	0	4	0
	Amphipods Groups													
32	Ampeliscidae	*Ampelisca*	sp.	1	2	1	1	2	0	2	1	0	0	1
33	Gammaridae	*Gammarus*	sp.	0	0	2	0	3	2	0	1	3	3	0
34	Noctuoidae	*Amphithoe*	sp.	3	1	1	5	0	0	8	2	2	0	2
35	Noctuoidae	*Ampithoe*	*ramondi*	1	0	0	0	1	2	1	2	0	1	2
36	Urothoidae	*Urothoe*	sp.	2	3	3	3	2	0	0	0	0	0	1
	Isopods Groups													
37	Apoidae	*Eurydice*	sp.	1	2	1	0	1	2	1	3	1	2	0
38	Asellidae	*Asellota*	sp.	0	0	2	3	1	1	0	1	0	1	0
	Others													
39	Cumacea	*Cumacea*	sp.	1	0	1	0	1	1	3	1	0	1	1
40	-	Unknown	Unknown sp.	0	1	0	0	2	0	0	3	2	2	0

b. Meio Faunal community

The benthic meiofauna community in terms of diversity and density showed to be fair in the shallow water intertidal mangrove habitats. Totally six major groups were represented which are Nematodes, Foraminifera, Cumaceans, Harpacticoids, Ostrocods, and Others groups. It comprised 75 species from 58 genera belonging to 45 families (Table 3.4.2). Of the group, Foraminifera, Nematodes were the most dominant in the mangrove region while least population density has been found for the Harpacticoids and Cumaceans. The Shannon diversity (H') value ranged between 3.0 and 3.43 and Evenness (J) was ranged between 0.89 and 0.97. Highest value was found at M4 and M8, lowest at M7 (Fig. 3.4.14, 15, 16).

Nematodes

In the nematodes, moderate species richness and density were accounted in the study area. Mesacanthion sp. *Jenneri* sp., Paragastrophora sp. and *Theristus sp.* were the most sighted species with greater abundance. Among the stations, highest density was exhibited in M6 with 61 nos./10cm^2 followed by M10 with 56 nos./10cm^2 whilst poor assemblages was found in M4 and M2 with 14 and 16 nos./10cm^2 respectively.

Foraminifera

In the Foraminifera, relatively reasonable amount of population density were accounted in the study area. *Ammonia* sp., Spiroloculina sp., *Eliphidium* sp. *Rotalia* sp. and *Eliphidium sp.* represented as dominant species with greater abundance. Across the stations, greatest density was observed in M 5 with 161 nos./10cm^2 followed by M10 with 82 nos./10cm^2 whilst poor assemblages was found in M1 with 19 nos.10cm^2.

Cumaceans

In the Cumaceans, relatively reasonable amount of population density were accounted in the study area. *Gynodiasytlis* sp. represented dominant species with greater abundance. Across the stations, greatest density was observed in M 9 with 5 nos./10cm^2 followed by M1, M3, M4, M8, M10 and M11 with 2 nos./10cm^2 whilst Cumaceans assemblages was absent in M6 and M7.

Harpacticoids

In the Harpacticoids, relatively reasonable amount of population density were accounted in the study area. *Euterpina* sp., *Macrosetella* sp., and *Canuella* sp. represented dominant species with greater abundance. Across the stations, maximum density was observed in M1 with 10 nos./10cm^2 followed by M4 with 8 nos./10cm^2 whilst totally absent in M2 and M7.

Ostrocods

In the Ostrocods, relatively reasonable amount of population density were accounted in the study area. *Basslerites Liebaui, Conchoecia elegans,* and *Cypridina* sp. represented dominant species with greater abundance. Across the stations, greatest density was observed in M5 with 9 nos./10cm^2 followed by M3, M8 and M9 with 6 nos./10cm^2 whilst poor assemblages was found in M1 with 1 ind./10cm^2.

Others

In the others, relatively sparse amount of population density were accounted in the study area. *Turbellarians* sp., spinarus, Unknown sp. and Polychaete larvae were the most represented species. Among the stations, greatest density was observed in M6 with 18 nos./10cm^2 followed by M7 with 14 nos./10cm^2 whereas poor assemblages was found in M8 with 4 nos./10cm^2 followed by M3 with 6 nos./10cm^2 Details of diversity and abundance are represented in Table 3.4.2.

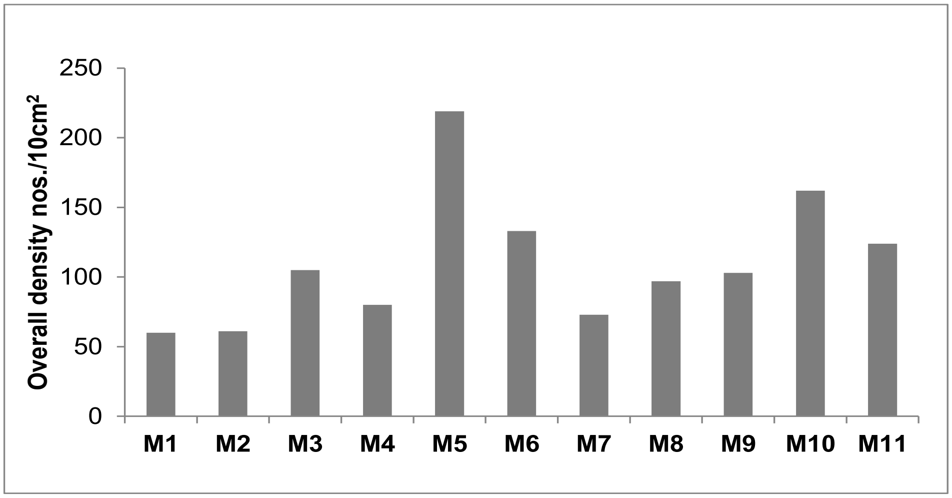


Fig. 3.4.9: Meio benthic faunal density in the mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

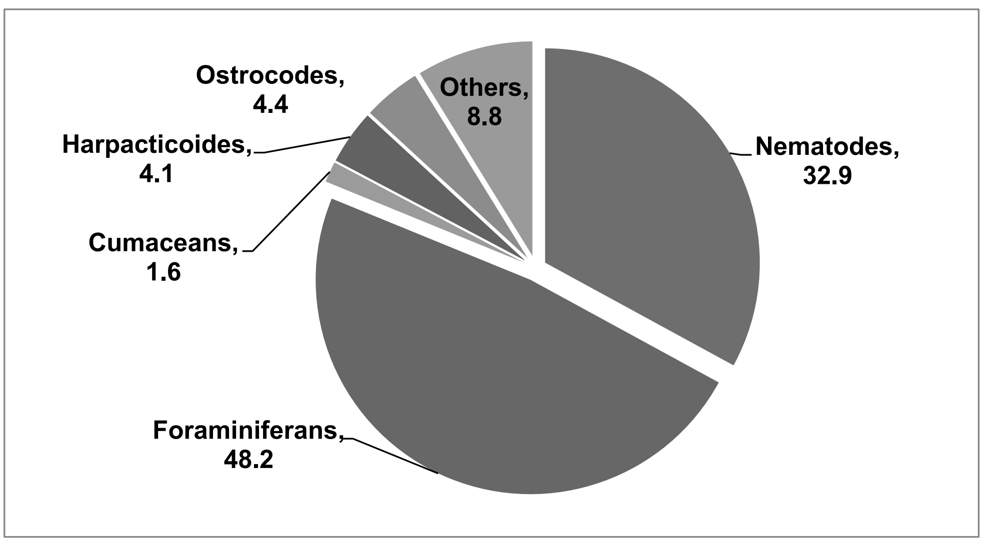


Fig. 3.4.10: Meio benthic community percentage composition in the mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region

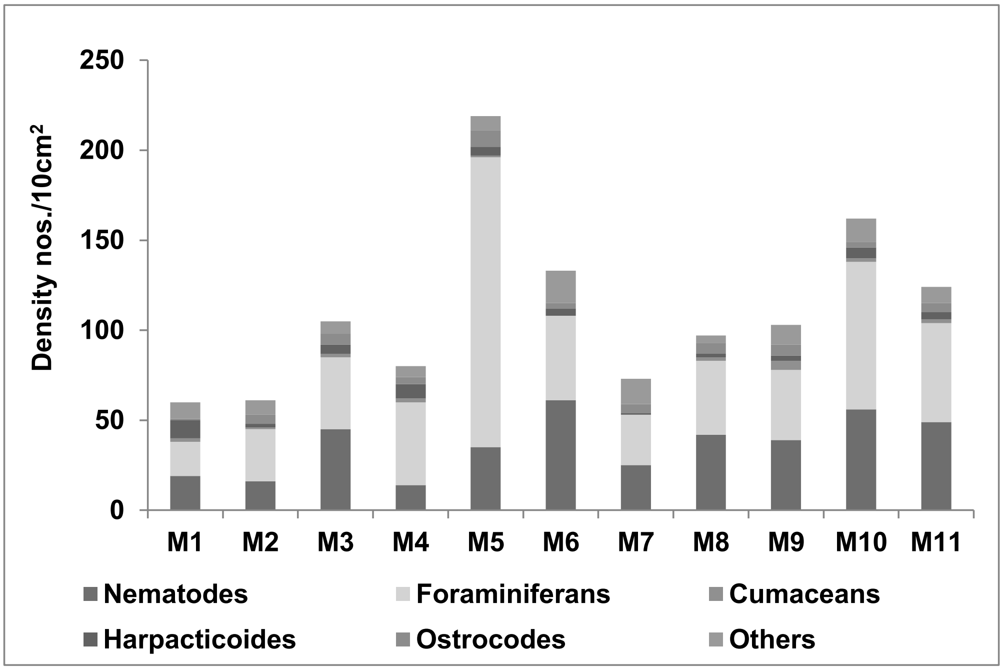


Fig. 3.4.11: Meio benthic community density in the mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

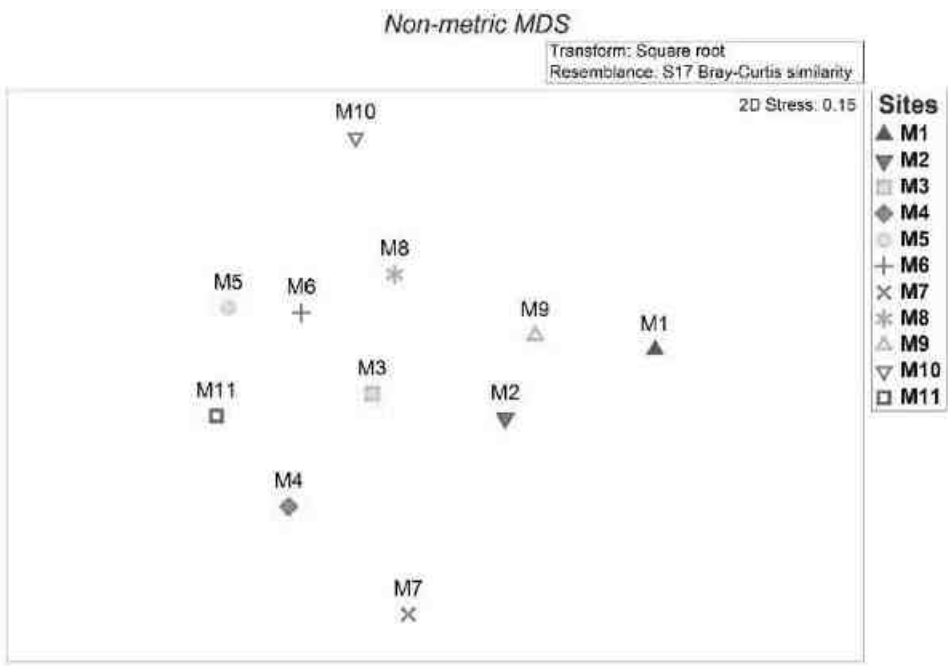


Fig. 3.4.12: MDS plot indicating meio benthic communities in the mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

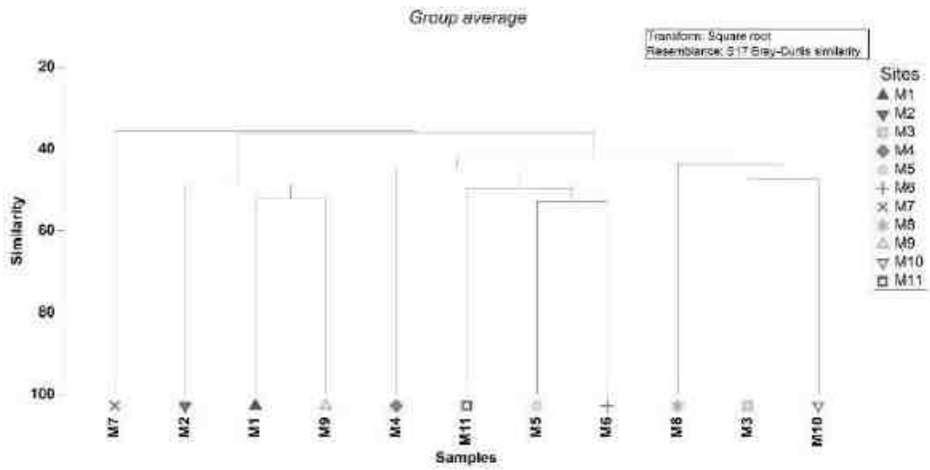


Fig. 3.4.13: Dendrogram of hierarchical cluster analysis showed the similarity of community structure among sampling sites in the mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

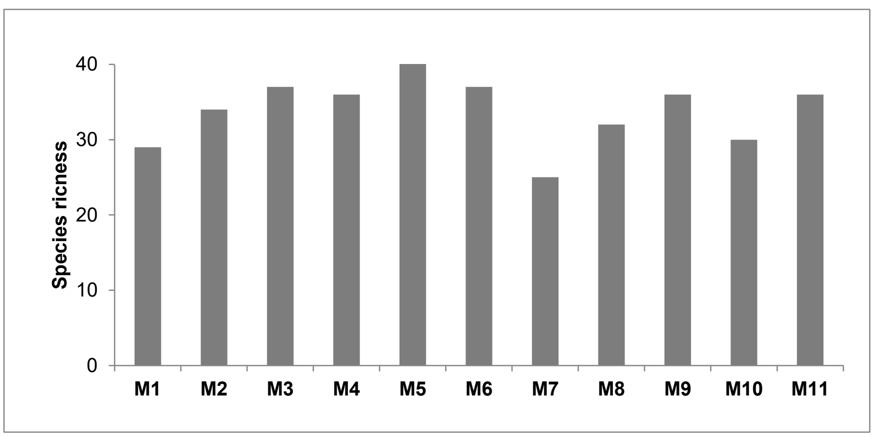


Fig. 3.4.14: Meio faunal species richness in mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

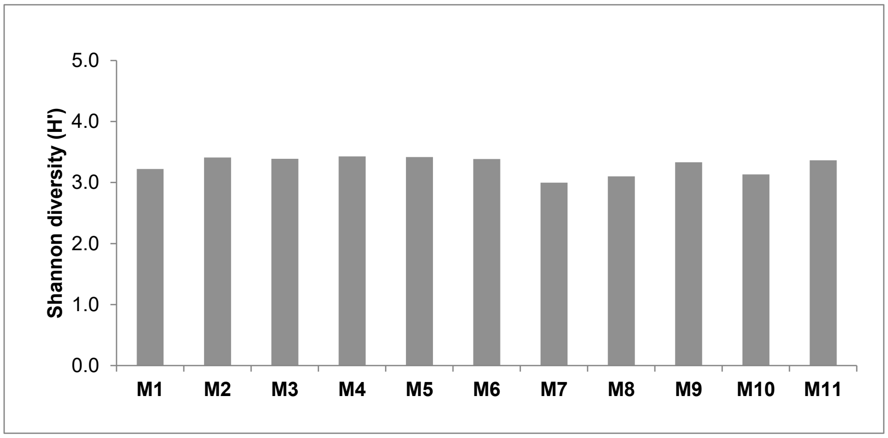


Fig. 3.4.15: Meio faunal Diversity (H') in mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

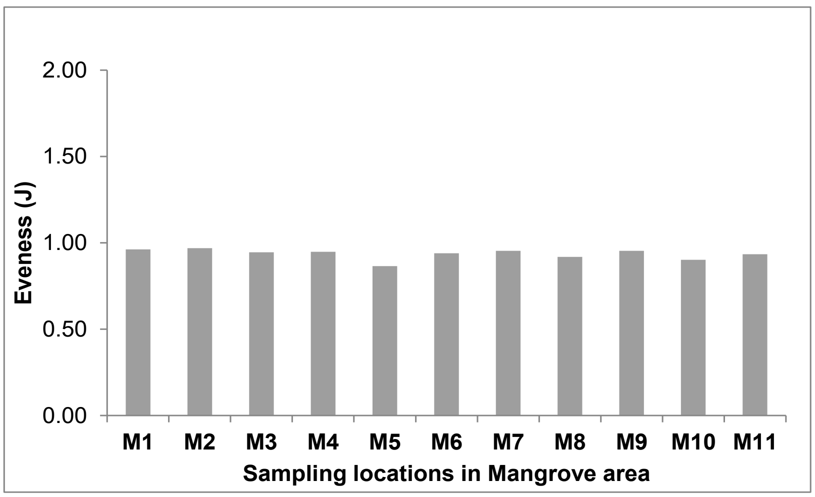


Fig. 3.4.16: Meio faunal evenness in mangrove habitat of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

Table 3.4.2: Meio benthic faunal density in the mangrove habitat of of Kosasthalaiyar river within 10 km radius of onshore region (M – Mangrove sampling site)

Sl.No.	Family	Genus	Species	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
	Nematodes													
1	Axonolaimidae	*Ascolaimus*	*elongates*	1	0	5	0	1	6	0	0	2	8	1
2	Axonolaimidae	*Ascolaimus*	sp.	1	1	0	0	0	0	1	1	0	5	0
3	Axonolaimidae	*Odontophora*	*longisetosa*	2	0	6	0	2	1	0	0	1	0	0
4	Axonolaimidae	*Odontophora*	sp.	0	0	0	1	0	5	2	2	0	0	5
5	Comesomatidae	*Sabatieria*	sp.	0	1	4	0	4	0	0	1	1	7	0
6	Comesomatidae	*Sabatieria*	*paracupida*	0	0	0	1	2	8	1	0	0	0	2
7	Desmodoridae	*Desmodora*	sp.	0	2	1	0	0	0	2	1	1	0	3
8	Desmoscolecidae	*Haplaomus*	sp.	0	1	2	0	2	2	0	2	0	4	7
9	Draconematidae	*Desmoscolex*	sp.	2	0	0	2	0	0	1	1	1	0	0
10	Enchelidiidae	*Paragastrophora*	sp.	0	0	7	0	2	5	2	5	0	3	3
11	Microlaimidae	*Trochamus*	sp.	0	1	0	1	0	2	0	4	1	0	0
12	Microlaimidae	*Microlaimus*	*conothelis*	2	2	0	0	1	0	1	0	2	0	2
13	Microlaimidae	*Microlaimus*	sp.	0	0	2	0	0	2	2	2	0	0	1
14	Oncholaminidae	*Viscosia*	sp.	1	1	3	0	1	1	0	1	1	6	8
15	Oxystominidae	*Oxystomina*	sp.	0	0	0	1	2	0	5	8	4	0	3
16	Oxystominidae	*Halalaimus*	*filum*	0	1	1	0	0	3	0	0	0	3	1
17	Siphonolaimidae	*Astomonema*	*jenneri*	1	0	0	2	5	7	0	5	0	12	0
18	Thoracostomopsidae	*Enoploides*	sp.	0	2	0	0	0	0	1	3	2	4	3
19	Thoracostomopsidae	*Epsilonema*	sp.	1	0	0	0	4	0	0	1	0	0	0
20	Thoracostomopsidae	*Mesacanthion*	sp.	0	0	10	2	7	6	3	0	8	0	4
21	Trefusiidae	*Halanonchus*	sp.	3	1	1	0	0	0	0	0	5	1	0

22	Xyalidae	*Daptonema*	*conicum*	1	0	0	2	2	4	0	4	3	0	3
23	Xyalidae	*Daptonema*	sp.	0	1	1	2	0	0	2	1	2	0	3
24	Xyalidae	*Theristus*	sp.	4	2	2	0	0	9	2	0	5	3	0
	Foraminiferans													
25	Anomalinidae	*Hanzawaia*	*concentrica*	1	1	0	1	8	5	0	2	2	0	0
26	Bolivinitidae	*Bolivina*	sp.	0	0	2	2	7	0	0	0	0	2	2
27	Buliminidae	*Bulimina*	sp.	2	2	0	0	0	2	0	2	8	0	0
28	Calcarinidae	*Calcarina*	sp.	0	0	1	2	4	1	10	0	0	0	0
29	Calcarinidae	*Calcarina*	sp.2	0	0	3	1	0	2	0	2	4	1	0
30	Discorbidae	*Discorbinella*	*montereyensis*	1	0	0	6	3	0	0	0	0	0	1
31	Discorbidae	*Rotalia*	sp.	0	0	0	1	15	5	0	2	0	4	0
32	Discorbidae	*Rosalina*	*bertheloti*	2	1	2	0	2	4	4	0	0	0	1
33	Discorbidae	*Rosalina*	*bradyi*	1	2	0	2	0	0	0	2	4	0	0
34	Discorbidae	*Rosalina*	*globularis*	0	0	0	0	3	2	0	0	0	8	1
35	Discorbidae	*Rotalia*	*calcar*	0	2	2	4	3	1	0	0	2	0	0
36	Elphidiidae	*Eliphidium*	sp.	1	2	0	0	21	0	3	0	0	0	5
37	Elphidiidae	*Eliphidium*	*crispum*	2	2	1	0	18	1	0	0	1	7	0
38	Hauerinidae	*Milionella*	sp.	0	1	1	5	4	1	2	0	0	0	10
39	Hauerinidae	*Quinoqueloculina*	*seminulam*	0	0	0	0	0	0	0	0	1	0	4
40	Hauerinidae	*Quinoqueloculina*	sp.	0	1	2	2	2	1	0	1	0	0	0
41	Hauerinidae	*Quinoqueloculina*	*agglutinans*	1	4	0	2	8	0	2	0	0	0	3
42	Hauerinidae	*Triloculina*	sp.	2	0	3	1	0	0	2	0	1	5	0
43	Lagenidae	*Lagena*	sp.	0	0	0	2	3	0	0	0	0	0	2
44	Lagenidae	*Lagena*	sp.2	0	0	4	1	4	0	0	0	0	0	0
45	Milioidae	*Hauerina*	*fragilissima*	0	0	0	1	4	4	0	4	2	2	5

46	Nodosariidae	*Legena*	*semistriata*	1	0	4	0	2	0	0	0	1	1	0
47	Nonionidae	*Nonion*	sp.	0	0	0	4	0	3	0	0	0	0	5
48	Opthalmidiidae	*Edentostomina*	sp.	2	1	1	0	2	0	0	3	1	11	0
49	Peneroplidae	*Peneroplis*	sp.	0	0	1	2	0	1	0	0	0	0	2
50	Rotaliidae	*Ammonia*	*beccarii*	0	2	1	3	8	4	2	0	3	8	0
51	Rotaliidae	*Ammonia*	sp.	0	1	4	0	20	5	1	18	0	16	8
52	Rotaliidae	*Ammonia*	*tepida*	0	0	0	1	8	2	0	0	0	9	0
53	Rotaliidae	*Asterorotalia*	*trispinosa*	1	4	1	1	5	0	0	0	1	0	1
54	Spiroloculinidae	*Spiroloculina*	sp.	0	1	5	2	3	3	2	5	0	8	5
55	Spiroloculinidae	*Spiroloculina*	*depressa*	2	2	0	0	0	0	0	0	8	0	0
56	Textlariidae	*Textularia*	sp.	0	0	2	0	4	0	0	0	0	0	0
	Cumaceans													
57	Chalcidoidae	*Nannastacus*	*inflats*	0	0	0	0	1	0	0	0	3	0	2
58	Gynodiastylidae	*Gynodiasytlis*	sp.	2	1	2	2	0	0	0	2	2	2	0
	Harpacticoides													
59	Armadillodae	*Microsetella*	*rosea*	1	1	0	1	2	1	1	0	0	0	2
60	Armadillodae	*Microsetella*	*gracilis*	0	0	3	0	0	2	0	1	1	1	0
61	Canuellidae	*Canuella*	sp.	4	0	0	3	1	0	0	0	0	1	0
62	Miraciidae	*Macrosetella*	sp.	0	1	2	4	2	1	0	0	0	0	0
63	Tachidiidae	*Euterpina*	sp.	5	0	0	0	0	0	0	1	2	4	2
	Ostrocodes													
64	Cypridinae	*Cypridina*	sp.	1	0	1	1	0	0	1	2	3	0	0
65	Cypridinae	*Strandesia* sp.	sp.	0	1	0	0	2	1	0	0	2	2	1
66	Cypridinae	*Parastenocypris*	*canalicuta*	0	1	3	0	0	0	3	0	0	0	0
67	Halocyprididae	*Conchoecia*	*elegans*	0	3	0	0	4	2	0	1	0	0	3

68	Trachyleberididae	*Basslerites*	*liebaui*	0	0	2	3	3	0	1	3	1	1	1
	Others													
69	Corycaeidae	*Corycaeus*	sp.	0	2	0	1	0	4	0	0	4	0	0
70	Harpacticidae	*Zaus*	*spinarus*	1	2	0	2	5	0	5	2	0	1	2
71	Laophontidae	*Laophonte*	*thoracica*	2	0	2	0	0	2	1	0	0	2	0
72	Pycnophyidae	*Pycnophyes*	sp.	0	1	0	0	2	0	0	1	2	0	4
73	Enchytraeidae	*Grania*	sp.1	0	0	2	0	0	0	5	0	0	3	0
74	Enchytraeidae	*Grania*	sp.2	2	0	1	0	1	11	0	0	3	0	3
75	-	Unkonwn	Polychaete larvae	0	3	0	0	0	1	2	1	0	4	0
76	-	Unknown	Polychaete	4	0	2	3	0	0	1	0	2	3	0

2. Kosasthalaiyar River waters

a. Macro Faunal community

The macrobenthic faunas were collected in the Kosasthalaiyar River which were covered between Ennore Greek and Pulicat area with a total of 13 stations. The macrobenthic organisms were represented by six groups *viz*., Polychaetes, Gastropods, Bivalves, Amphipods, Isopods and others. A total of 34 species from 28 genera comprised with 22 families was found in the River waters. Totally 451 macrobenthic faunal individuals was recorded in the study area. Among the groups, Polychaetes was predominantly occurs in the River sediments with 267 individuals followed by Amphipods with 66 individuals while low abundance was exhibited for the Bivalves and Isopods with 22 and 18 individuals (Table 3.4.3). The analysis of diversity indices showed that Shannon diversity (H') value ranged between 2.07 and 2.68 and Evenness (J) was ranged between 0.86 and 0.97. Highest value was found at R10 and R12, lowest at R13 (Fig. 3.4.22,23,24). Multivariate results are given in the Fig. 3.421&22.

Polychaetes

The Polycheates community relatively greater abundance was found in the all Stations. *Spiophanes* (93 ind.) and Capitellidae (43 ind.) were the most common families which represented as greater density. *Spiophanes* sp., *Cossura sp., Capitella* sp., and *Scololepis* sp., were the dominant species found in the study area. Highest abundance was recorded in station R10 with 51 nos./0.0256m^2 followed by R7 with 37 nos./0.0256m^2 whilst poor occurrence had reported in R11 with 11 nos./0.0256m^2 respectively.

Gastropods

Five species belonging to 3 families of gastropods was represented in the study area. Of which, *Cerithum* sp., *Littorina veligers* sp., and *Umbonium* sp. was the common species. Highest abundance was recorded in station R7 with 7 ind. nos./0.0256m^2 followed by R12 with 5nos./0.0256m^2. Low abundance was marked in R2, R9 and R13 with 1 nos./0.0256m^2 Gastropods assemblages was absent in R1, R5 and R8.

Bivalves

In Bivalves, least species richness was represented in this group with 2 species. Of these, *Anadara* sp.was dominated species in the sediments. Maximum density was found to be in R5, and R10 with 4 nos./0.0256m^2 followed by R11 with 3 nos./0.0256m^2 and low density recorded in R7, R12 with1 nos./0.0256m^2. Bivalves assemblages was absent in R1, R4, and R6.

Amphipods

Low occurrence of Amphipods in terms of diversity and abundance were represented in the sediments. Four species from two families have been sighted, of these, *Amphithoe rubricate*, and *Amphithoe* sp., being the predominant organisms in the study area. Highest was counted in R12 with 11 nos./0.0256m^2 and low numbers were obtained for the stations R1, R3, and R7 with 3 nos./0.0256m^2.

Isopods

The isopods are sparse density was found to be in the river sediments. Only two species from two families are represented, among them, Eurydice sp. and Asellota sp. were the common communities in this region. Highest was counted in R3 with 4 nos./0.0256m^2 and low numbers were obtained for the stations R2, R4,R6, R8 and R13 with 1 nos./0.0256m^2. Isopods assemblages was absent in R4, R10, and R11.

Others

The others are sparse density was found to be in the River waters. Two species from two families are represented, *Shrimp larvae*, and Unknown sp. are common community in river water. Highest was counted in R12 with 7 nos./0.0256m^2 and low numbers were obtained for the stations R1 with 1 nos./0.0256m^2. Others assemblages was absent in R7. Details of diversity and abundance are represented in Table 3.4.3.

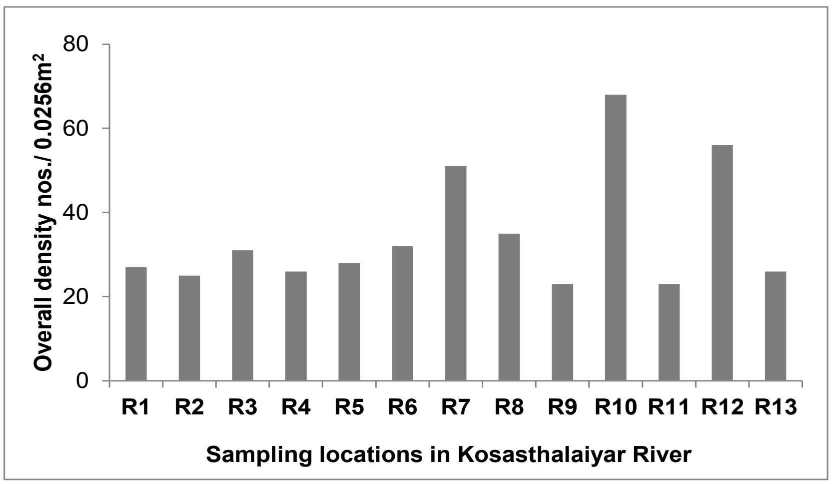


Fig. 3.4.17: Macro benthic faunal density in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

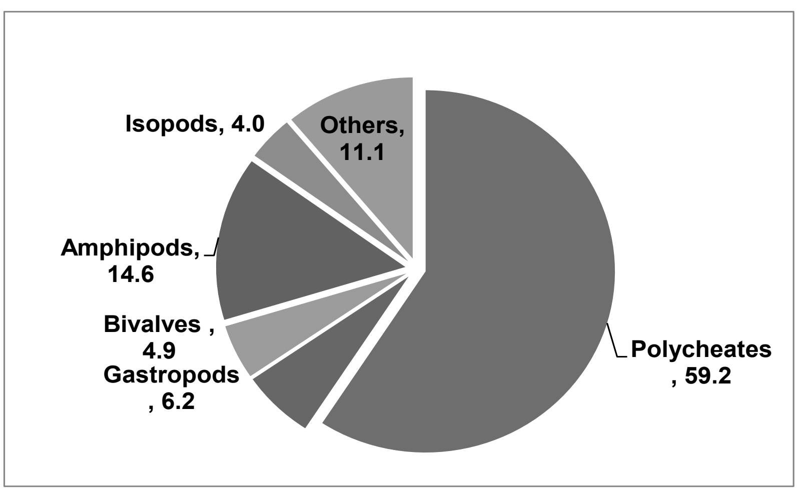


Fig. 3.4.18: Macro benthic community percentage composition in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

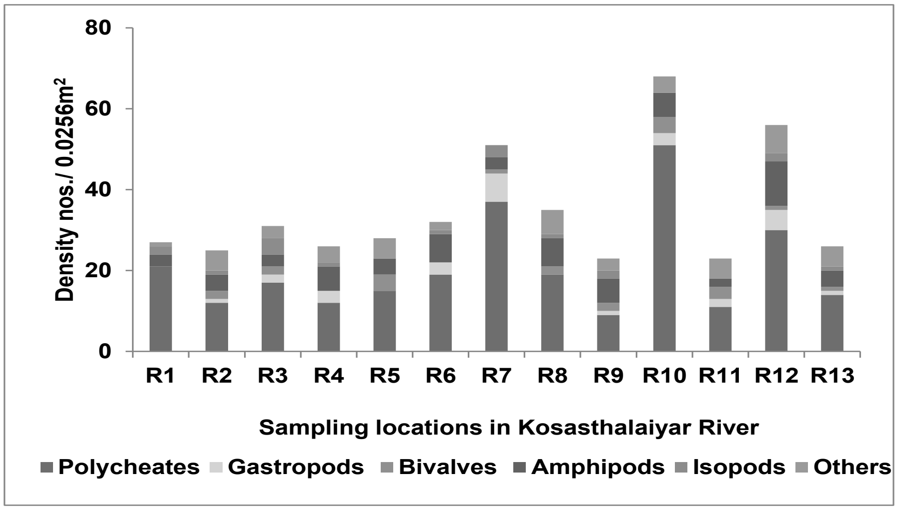


Fig. 3.4.19: Macro benthic community density in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

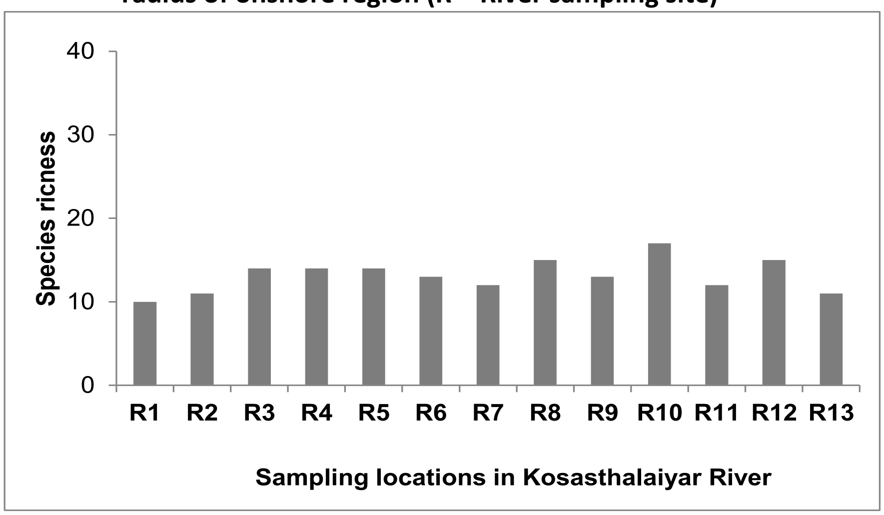


Fig. 3.4.20: Macro faunal species richness in Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

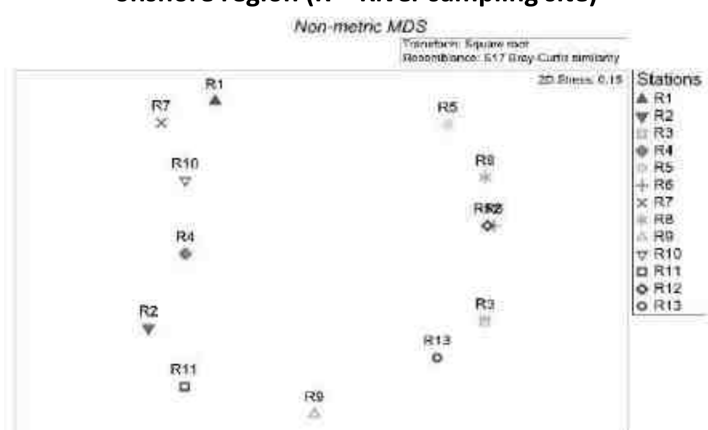


Fig. 3.4.21: MDS plot indicating macro benthic communities in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

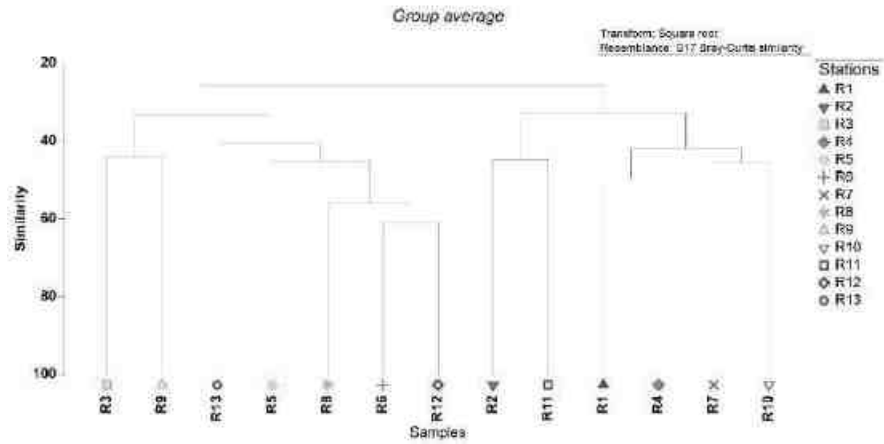


Fig. 3.4.22: Dendrogram of hierarchical cluster analysis showed the similarity of community structure among sampling sites in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

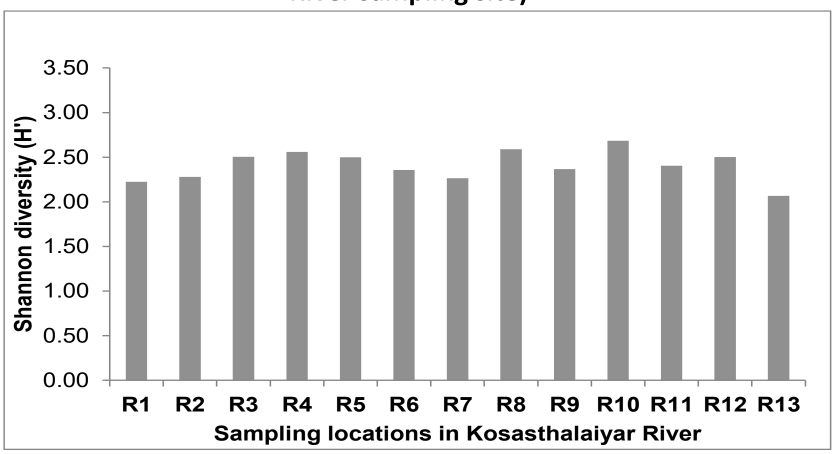


Fig. 3.4.23: Macro faunal Diversity (H') in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

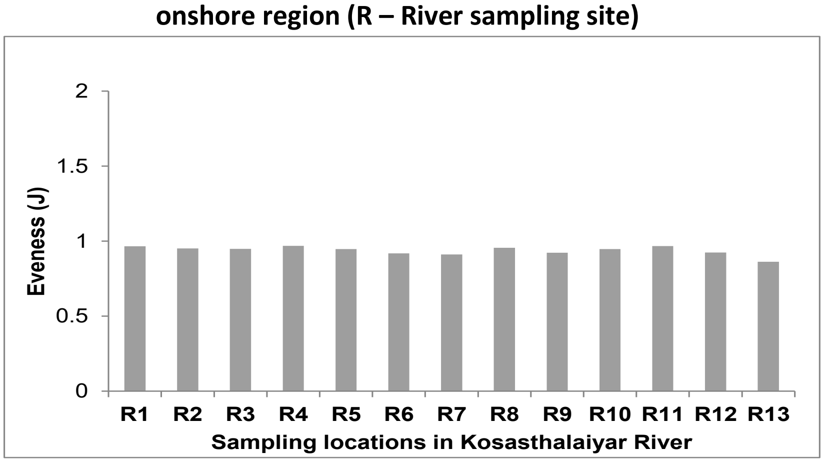


Fig. 3.4.24: Macro faunal evenness in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

Table 3.4.3: Macro benthic faunal density in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

S. No.	Family	Genus	Species	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13
	Polychaetes															
1	Capitellidae	*Capitella*	*capitata*	3	0	0	2	0	0	3	0	0	0	1	1	0
2	Capitellidae	*Capitella*	sp.	1	0	2	0	2	0	12	0	2	6	0	0	0
3	Capitellidae	*Notomastus*	sp.	0	0	0	0	0	0	0	4	1	3	0	0	0
4	Cirratulidae	*Cirratulus*	sp.	0	0	0	1	5	2	3	0	0	0	2	0	0
5	Cossuridae	*Cossura*	sp.	0	0	1	0	1	0	0	4	0	0	0	12	8
6	Glyceridae	*Glycera*	sp.	3	0	0	2	0	0	0	0	1	4	3	0	0
7	Lumbrineridae	*Lumbreneris*	sp.	0	0	2	0	0	4	0	2	2	0	0	0	0
8	Lumbrineridae	*Lumbrineris*	*aberans*	0	0	0	2	0	0	0	0	0	3	0	0	0
9	Nereididae	*Nereis*	sp.	0	0	1	0	0	0	0	0	0	0	0	0	0
10	Opheliidae	*Armandia*	*intermedia*	3	0	0	2	0	0	6	0	1	4	3	0	0
11	Orbiniidae	*Orbinia*	sp.	0	0	2	0	0	5	0	2	2	0	0	4	1
12	Phyllodocidae	*Phyllodace*	sp.	0	2	0	2	1	0	0	0	0	3	0	3	0
13	Pilargidae	*Ancistrosylls*	sp.	0	3	0	0	0	0	6	1	0	6	1	0	0
14	Spionidae	*Prionospio*	*pinnata*	0	2	0	0	1	0	4	0	0	3	1	0	1
15	Spionidae	*Prionospio*	sp.	4	0	4	0	0	0	0	0	0	8	0	0	0
16	Spionidae	*Scololepis*	sp.	3	0	0	0	2	4	1	2	0	0	0	7	4
17	Spionidae	*Scololepis*	*squamata*	0	0	0	0	2	0	2	1	0	0	0	0	0
18	Spionidae	*Spiophanes*	sp.	0	5	0	0	0	0	0	0	0	1	0	0	0
19	Spionidae	*Spionidae*	sp.	4	0	5	1	1	4	0	3	0	10	0	3	0
	Gastropods groups															
20	Littorinidae	*Littorina*	*veligers*	0	0	2	0	0	2	0	0	0	0	0	3	0

21	Potamididae	*Cerithum*	sp.	0	1	0	3	0	1	7	0	1	3	0	2	1
22	Trochidae	*Umbonium*	sp.	0	0	0	0	0	0	0	0	0	0	2	0	0
	Bivalves groups															
23	Arcidae	*Anadara*	sp.	0	2	0	0	4	0	1	2	0	3	1	0	0
24	Veneridae	*Meretrix*	sp.	0	0	2	0	0	0	0	0	2	1	2	1	1
	Amphipods groups															
25	Ampithoidae	*Amphithoe*	sp.	0	3	2	3	0	0	0	0	6	0	2	0	1
26	Ampithoidae	*Amphithoe*	*ramondi*	0	0	0	1	2	1	0	4	0	4	0	2	0
27	Ampithoidae	*Amphithoe*	*Rubricate*	3	1	0	2	0	5	3	1	0	2	0	6	3
28	Gammaridae	*Gammarus*	sp.	0	0	1	0	2	1	0	2	0	0	0	3	0
	Isopods groups															
29	Apoidae	*Eurydice*	sp.	0	1	4	0	0	1	0	1	0	0	0	3	0
30	Asellidae	*Asellota*	sp.	2	0	0	1	0	0	3	0	2	0	0	0	0
	Others															
31	Cumacea	*Cumacea*	sp.	0	0	1	0	2	1	0	2	0	0	0	3	1
32	Nannastacidae	*Campylaspis*	sp.	0	0	2	1	2	1	0	0	1	4	0	0	3
33	-	Shrimp larvae	sp.	1	3	0	3	0	0	0	0	1	0	2	0	1
34	-	Unknown	Unknown sp.	0	2	0	0	1	0	0	4	1	0	3	4	0

(ii) Meio Faunal community structure in river habitat

The benthic meiofauna community in terms of diversity and density showed to be high in the shallow water region and river sediments. Totally six major groups were represented, which are Nematodes, Foraminifera, Cumaceans, Harpacticoids, Ostrocods, and Others groups. It comprised 66 species from 50 genera belonging to 41 families (Table 3.4.4). Of the group, Nematodes, Foraminifera, were the most dominant in this region, whereas least population density has been found for the others and Cumaceans. The Shannon diversity (H') value ranged between 3.08 and 3.32 and Evenness (J) was ranged between 0.90 and 0.97. Highest value was found at R9, and R3 and, lowest at R8 (Fig. 3.4.25,26,27). Multivariate results are given in the Fig. 3.421&22.

Nematodes

In the nematodes, reasonable amount of species richness and density were accounted in the study area. *Astomonema* sp., *Theristus* sp., *Mesacanthion* sp., and *Viscosia* sp., were the most sighted species with greater abundance. Among the stations, highest density was exhibited in R3 with 52 nos./10cm^2 followed by R5 with 46 nos./10cm^2 whilst poor assemblages was found in R1 with 11 nos./10cm^2 respectively.

Foraminifera

In the Foraminifera, relatively reasonable amount of population density were accounted in the study area. *Ammonia* sp., *Eliphidium* sp., *Rotaliai* sp.. and *Hanzawaia* sp., represented as dominant species with greater abundance. Across the stations, greatest density was observed in R5 with 118 nos./10cm^2 followed by R10 with 104 nos./10cm^2 whilst poor assemblages was found in R13 with 20 nos./10cm^2.

Cumaceans

In the Cumaceans, relatively reasonable amount of population density were accounted in the study area. *Gynodiasytlis* sp. represented as dominant species with greater abundance. Across the stations, greatest density was observed in R12 with 5 nos./10cm^2 , poor assemblages was found in R1, R2, R4, R6 and R13 with 1 nos./10cm^2 whilst Cumaceans assemblages was absent in R8, and R10.

Harpacticoids

In the Harpacticoids, relatively reasonable amount of population density were accounted in the study area. *Euterpina* sp., *Diathrodes* sp., and *Microsetella* sp., represented dominant species with greater abundance. Across the stations, maximum density was observed in R7 with 15 nos./10cm^2 followed by R10 with 12 nos./10cm^2 poor assemblages was found in R1 , R8, R9 and R11 with 5 ind./10cm^2.

Ostrocods

In the Ostrocods, relatively reasonable amount of population density were accounted in the study area. *Bairdoppilata* sp., *Basslerites* sp., and *Strandesia* sp., were represented dominant species with greater abundance. Across the stations, greatest density was observed in R3 with 16nos./10cm^2 followed by R8 with 15 nos./10cm^2 whilst poor assemblages was found in R13 with 3 nos./10cm^2.

Others

In the others, relatively sparse amount of population density were accounted in the study area. For the species include Unknown sp., *Grania* sp., Polychaete larvae, and *Thoracica* sp. were the most represented species. Among the stations, greatest density was observed in R13 with 14 nos.10cm^2 followed by R7 with 11 nos. /10cm^{2}whereas poor assemblages was found in R2 with 4 nos./10cm^2. Details of diversity and abundance are represented in Table 3.4.4.

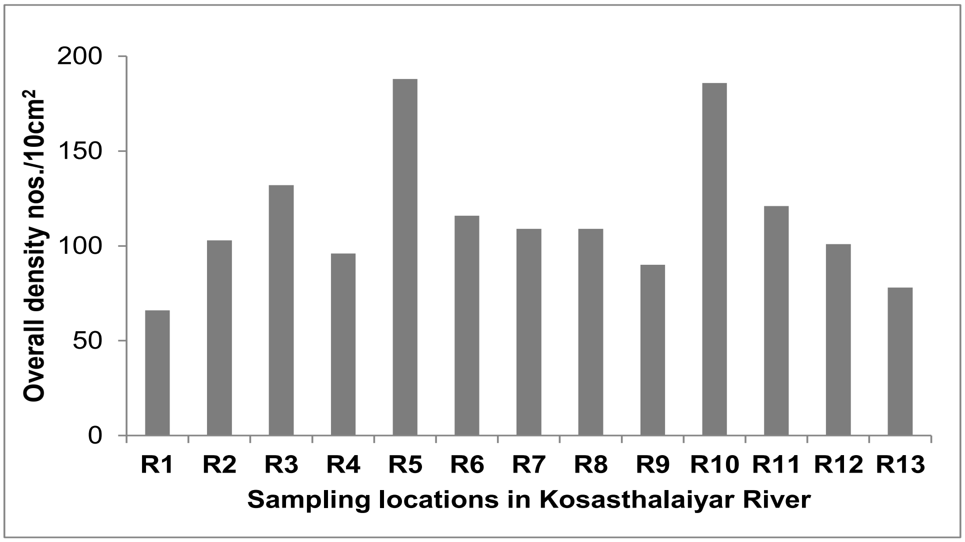


Fig. 3.4.25: Meio benthic faunal density in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

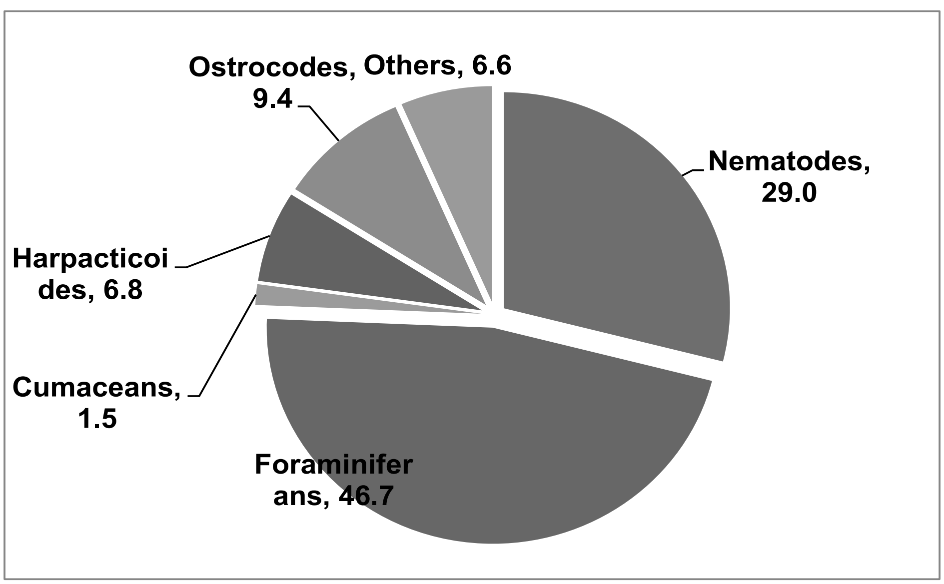


Fig. 3.4.26: Meio benthic community percentage composition in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

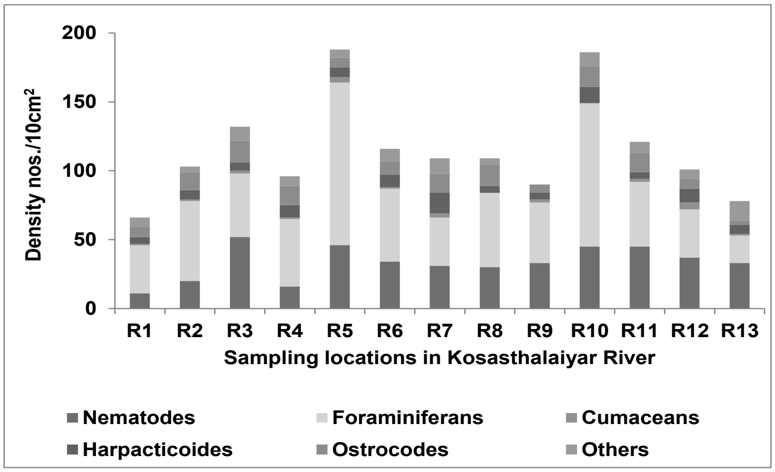


Fig. 3.4.27: Meio benthic community density in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

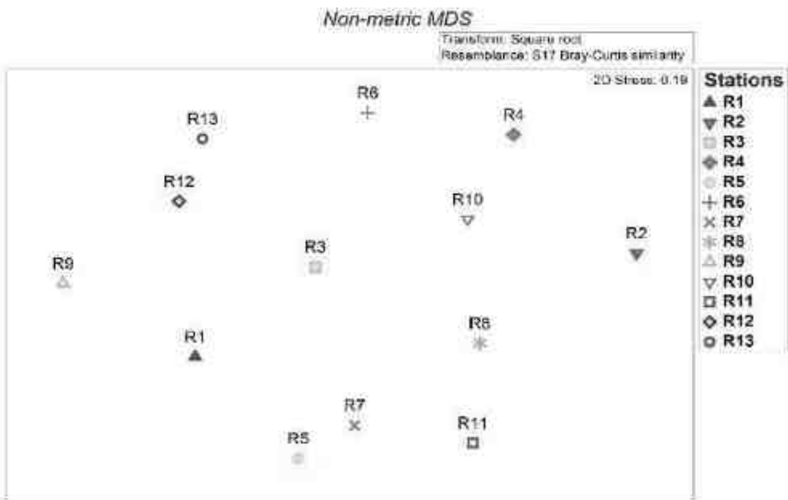


Fig. 3.4.28: MDS plot indicating meio benthic communities in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

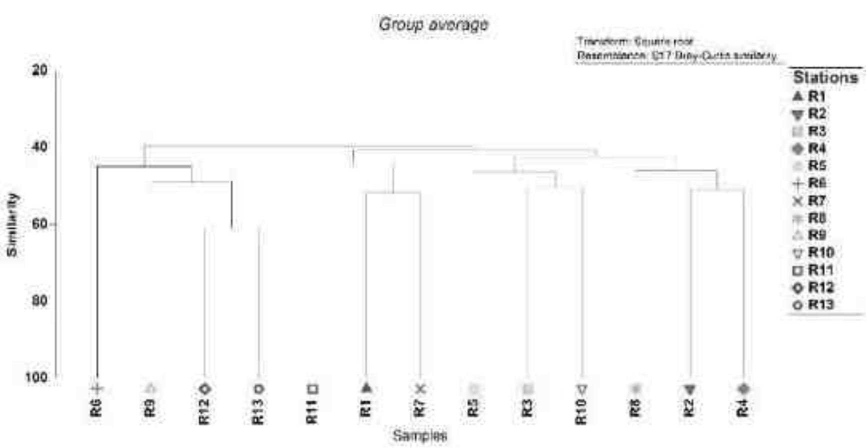


Fig. 3.4.29: Dendrogram of hierarchical cluster analysis showed the similarity of community structure among sampling sites in the Kosasthalaiyar river sediments within 10 km radius

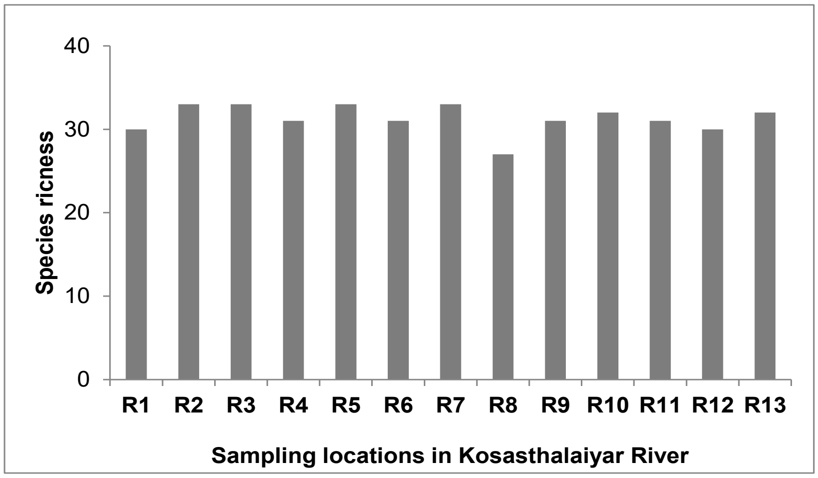


Fig. 3.4.30: Meio faunal species richness in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

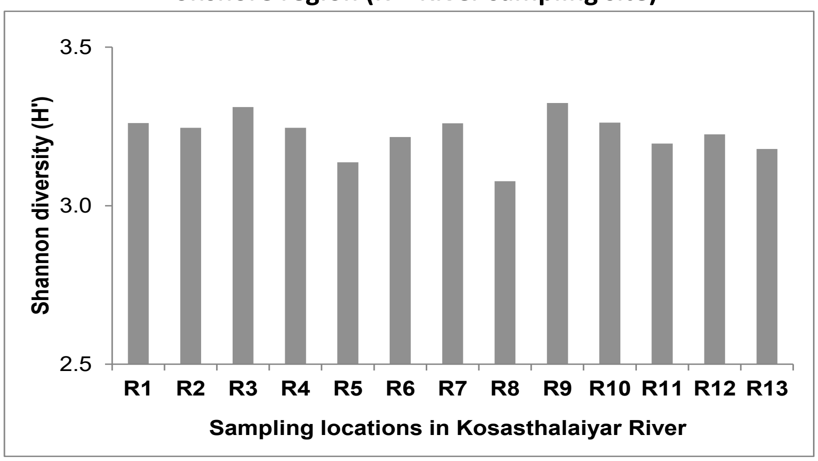


Fig. 3.4.31: Meio faunal Diversity (H') in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

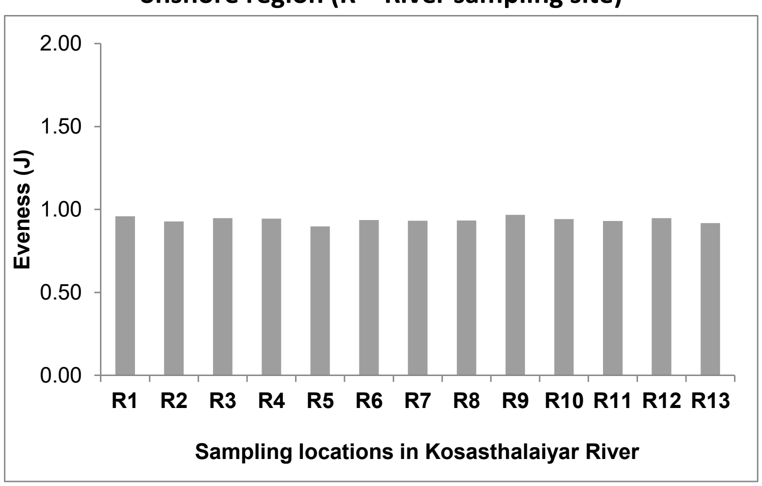


Fig. 3.4.32: Meio faunal evenness in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

Table 3.4.4: Meio benthic faunal density in the Kosasthalaiyar river sediments within 10 km radius of onshore region (R – River sampling site)

S.No.	Family	Genus	Species	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13
	Nematodes															
1	Axonolaimidae	*Odontophora*	*longisetosa*	0	2	0	0	4	0	0	0	3	0	0	4	2
2	Axonolaimidae	*Odontophora*	*sp.*	3	0	0	0	0	0	4	3	0	0	4	0	0
3	Comesomatidae	*Sabatieria*	sp.	0	0	6	0	0	4	0	6	1	6	0	3	0
4	Comesomatidae	*Sabatieria*	*paracupida*	0	3	0	0	0	0	0	0	0	0	0	0	0
5	Desmodoridae	*Desmodora*	sp.	0	0	3	0	2	0	4	0	0	0	4	0	0
6	Desmoscolecidae	*Desmoscolex*	sp.	2	0	0	4	0	6	1	2	0	0	0	2	2
7	Desmoscolecidae	*Tricoma*	sp.	0	4	0	0	0	1	2	0	0	0	0	0	0
8	Linhomoeidae	*Paralinhomoeus*	sp.	0	0	0	0	0	0	0	0	4	4	3	0	0
9	Microlaimidae	*Microlaimus*	*conothelis*	0	0	0	0	1	0	0	0	2	0	3	2	0
10	Microlaimidae	*Microlaimus*	*sp.*	0	2	4	3	7	0	0	5	0	0	0	0	7
11	Oncholamidae	*Viscosia*	sp.	1	0	0	0	0	5	0	0	6	3	11	5	1
12	Oxystominidae	*Oxystomina*	sp.	0	0	3	0	0	0	4	0	1	0	4	0	0
13	Oxystominidae	*Halalaimus*	*Filum*	2	5	11	0	2	0	0	0	4	4	1	0	0
14	Siphonolaimidae	*Astomonema*	*jenneri*	0	3	10	0	14	0	10	9	3	15	0	9	11
15	Thoracostomopsidae	*Enoploides*	sp.	2	0	0	6	0	1	0	4	2	6	0	0	1
16	Thoracostomopsidae	*Mesacanthion*	sp.	0	0	9	0	6	0	2	0	0	3	5	6	4
17	Xyalidae	*Daptonema*	*conicum*	0	1	0	0	10	0	0	1	0	0	6	0	0
18	Xyalidae	*Daptonema*	sp.	0	0	4	0	0	6	0	0	2	0	4	0	0
19	Xyalidae	*Theristus*	sp.	1	0	2	3	0	11	4	0	5	4	0	6	5
	Foraminiferans															
20	Ammoniidae	*Ammonia*	*beccarii*	2	12	4	0	12	3	2	4	0	9	7	11	2
21	Ammoniidae	*Ammonia*	sp.	5	0	5	3	22	9	4	6	2	15	10	2	0

22	Ammoniidae	*Ammonia*	*tepida*	0	3	3	4	0	5	0	0	0	13	0	1	0
23	Bolivinitidae	*Bolivina*	sp.	2	0	2	0	8	0	2	0	3	0	0	2	3
24	Calcarinidae	*Calcarina*	sp.	2	4	0	0	0	1	2	1	0	0	1	0	1
25	Diffusilinidae	*Diffusilina*	sp.	0	1	0	3	5	0	1	0	2	6	0	0	0
26	Discorbinellidae	*Hanzawaia*	*concentrica*	0	3	0	5	0	5	0	4	0	3	0	0	0
27	Elphidiidae	*Eliphidium*	sp.	5	3	3	4	15	0	6	12	0	10	6	0	0
28	Elphidiidae	*Eliphidium*	*crispum*	0	6	2	1	0	0	0	0	3	0	3	0	1
29	Elphidiidae	*Elphidium*	*claticulatum*	0	3	4	0	6	2	1	3	0	0	0	0	0
30	Hauerinidae	*Milionella*	sp.	2	0	0	1	2	0	1	0	0	0	0	0	2
31	Hauerinidae	*Quinqueloculina*	*seminulam*	0	0	0	0	0	0	2	0	3	0	0	2	1
32	Hauerinidae	*Quinqueloculina*	sp.	2	4	5	0	2	0	0	3	0	6	0	0	0
33	Hauerinidae	*Quinqueloculina*	*agglutinans*	2	0	1	0	9	1	2	0	3	0	0	2	0
34	Hauerinidae	*Triloculina*	sp.	0	6	0	6	0	10	0	5	0	3	4	0	0
35	Hauerinidae	*Hauerina*	*fragilissima*	0	1	0	3	5	0	1	0	2	6	0	0	1
36	Lagenidae	*Lagena*	sp.	0	1	3	0	0	0	0	0	5	4	0	2	2
37	Nonionidae	*Nonion*	sp.	7	0	6	0	0	3	0	4	7	0	1	4	0
38	Opthalmidiidae	*Edentostomina*	sp.	0	0	0	1	2	0	0	0	3	0	0	0	0
39	Peneroplidae	*Peneroplis*	sp.	0	0	0	0	0	1	2	0	0	3	0	0	0
40	Rosalinidae	*Rosalina*	*bertheloti*	2	4	0	1	2	0	0	0	0	1	0	0	0
41	Rosalinidae	*Rosalina*	*bradyi*	0	0	1	5	0	0	4	3	0	0	5	2	1
42	Rosalinidae	*Rosalina*	*globularis*	0	1	0	1	2	0	0	1	0	0	0	0	0
43	Rotaliidae	*Rotalia*	sp.	0	2	0	5	20	3	5	6	3	10	6	0	0
44	Rotaliidae	*Rotalia*	*calcar*	2	0	3	3	3	3	0	0	2	7	0	2	1
45	Rotaliidae	*Rotalia*	*translucens*	0	3	0	0	0	3	0	0	0	8	0	0	0
46	Spiroloculinidae	*Spiroloculina*	sp.	0	0	2	0	3	3	0	1	4	0	0	5	2
47	Spiroloculinidae	*Spiroloculina*	*depressa*	0	1	0	3	0	0	0	1	0	0	0	0	1

48	Textlariidae	*Textularia*	sp.	2	0	2	0	0	1	0	0	2	0	4	0	2
	Cumaceans															
49	Chalcidoidae	*Nannastacus*	*inflats*	1	0	0	0	3	1	1	0	1	0	2	2	1
50	Gynodiastylidae	*Gynodiasytlis*	*sp.*	0	1	2	1	1	0	2	0	1	0	0	3	0
	Harpacticoides															
51	Armadilloidae	*Microsetella*	*gracilis*	2	0	0	0	5	4	0	2	3	0	0	2	1
52	Canuellidae	*Canuella*	*sp.*	0	3	0	4	0	0	5	0	0	1	1	0	2
53	Noctuoidae	*Macrosetella*	*sp.*	0	1	3	2	2	3	0	0	0	0	0	2	2
54	Noctuoidae	*Diathrodes*	*major*	1	3	3	3	0	2	0	0	0	7	1	4	2
55	Tachidiidae	*Euterpina*	*sp.*	2	0	0	0	0	0	10	3	2	4	3	2	0
	Ostrocodes															
56	Bairdiidae	*Bairdoppilata*	*scaura*	3	10	5	10	5	6	2	10	3	0	11	3	1
57	Cypridinae	*Cypridina*	*sp.*	2	0	0	3	0	0	2	0	3	0	0	0	0
58	Cypridinae	*Strandesia sp.*	*sp.*	0	3	0	0	0	4	0	0	0	4	3	4	2
59	Trachyleberididae	*Basslerites*	*liebaui*	2	0	11	1	2	0	10	5	0	11	0	0	0
	Others															
60	capitellidae	*Capitella*	*Capitella* larvae	2	1	0	2	0	0	0	0	0	0	1	3	3
61	Enchytraeidae	*Grania*	sp.	1	0	2	0	3	0	4	0	0	4	0	0	2
62	Laophontidae	*Laophonte*	*thoracica*	1	0	3	0	0	3	2	0	0	1	1	0	0
63	Pycnophyidae	*Pycnophyes*	sp.	2	2	0	0	1	0	2	1	0	0	0	1	0
64	Sabellidae	*Sabellidae*	*Sabellidae* larvae	0	0	2	1	0	0	0	4	0	1	3	0	0
65	-	Unkonwn	Polychaete larvae	1	1	0	1	2	4	3	0	0	0	2	0	2
66	-	Unkonwn	Polychates sp.	0	0	3	3	0	2	0	0	0	4	1	3	7

3. Buckingham canal

Macro Faunal community

The macrobenthic faunas were collected in the Buckingham canal waters which were covered between Ennore Greek and Pulicat area with a total of 12 stations. The macrobenthic organisms were represented by six groups *viz*., Polychaetes, Gastropods, Bivalves, Amphipods, Isopods and others. A total of 27 species from 19 genera comprised with 17 families was found in the River waters. Totally 374 macrobenthic faunal individuals was recorded in the study area. Among the groups, Polychaetes was predominantly occurs in the Buckingham canal sediments with 199 individuals followed by Amphipods with 46 individuals, while low abundance was exhibited for the Bivalves and Gastropods with 25 and 23 individuals (Table 3.4.5). The analysis of diversity indices showed that Shannon diversity (H') value ranged between 2.58 and 3.04 and Evenness (J) was ranged between 0.92 and 0.97. Highest value was found at B12 and B10 and, lowest at B6 (Fig. 3.4.39,40,41).

Polychaetes

The Polycheates community relatively greater abundance was found in few stations and abundance was varied between 10 and 30 nos. *Spiophanes* (57 ind.) and *Pilargidae* (39 nos.) were the most common families which represented as greater density. *Ancistrosyllis* sp., *Spiophanes* sp., *Costae* sp., and *Glycera* sp., were the dominant species found in the study area. Highest abundance was recorded in station B10 with 30 nos.0.0256m^2 followed by B7 with 26 nos.0.0256m^2 whilst poor occurrence had reported in B1 and B2 with 10 nos./0.0256m^2 respectively.

Gastropods

Two species belonging to 2 families of gastropods was represented in the study area. Of which, *Cerithum* sp. *columnaris* sp., was the common species.

Highest abundance was recorded in station B 11 with 4 nos./0.0256m^2 followed by B9, B8 with 2 nos./0.0256m^2. Low abundance was marked in B3, B4 and B6, with 1nos./0.0256m^2 Gastropods assemblages was absent in B1.

Bivalves

In Bivalves, least species richness was represented in this group with 3 species. Of these, *opima* sp.,was dominated species in the sediments. Maximum density was found to be in B9 with 5 nos./0.0256m^2 followed by B1 with 4 nos./0.0256m^2 and low density recorded in B7, and B12 with1 nos./0.0256m^2. Bivalves assemblages was absent in B5 and B6.

Amphipods

Low occurrence of Amphipods in terms of diversity and abundance were represented in the sediments. Two species from two families have been sighted, of these, *Gammarus* sp., and *Ampithoe* sp., being the predominant organisms in the study area. Highest was counted in B9 with 9 nos./0.0256m^2 followed by B7 with 7 nos./0.0256m^2 and low numbers were obtained for the stations B2 and B3 with 1 nos./0.0256m^2.

Isopods

The isopods are sparse density was found to be in the Buckingham canal sediments. Only two species from two families are represented, among them, *Asellota* sp., and *Anisopoda* sp., were the common beings in this region. Highest was counted in B1 and B10 with 5 nos./0.0256m^2 followed by B3 with 4 nos. /0.0356m^2 and low numbers were obtained for the stations B7 and B8 with 2 nos./0.0256m^2.Isopods assemblages was absent in B6.

Others

The others are sparse density was found to be in the Buckingham canal waters. Four species from one family are represented include Unknown sp. and *Penaeus* sp. are common community in Buckingham canal waters. Highest was counted in B12 and B4 with 6 nos./0.0256m^2 followed by B11 with 5 nos./0.0356m^2 and low numbers were obtained for the stations B3 and B9 with 2 nos./0.0256m^2. Details of diversity and abundance are represented in Table 3.4.5.

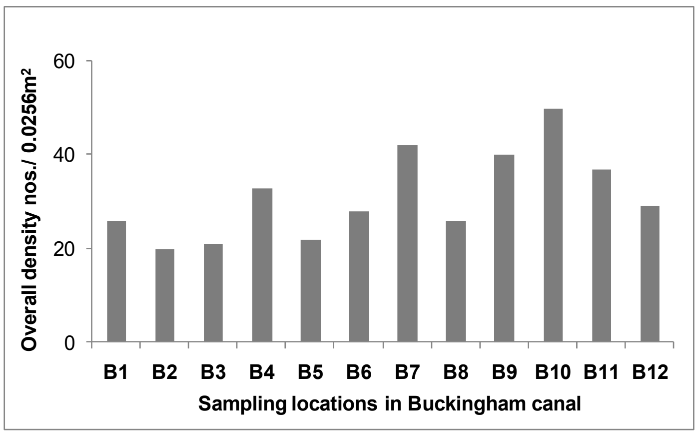


Fig. 3.4.33: Macro benthic faunal density in the Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

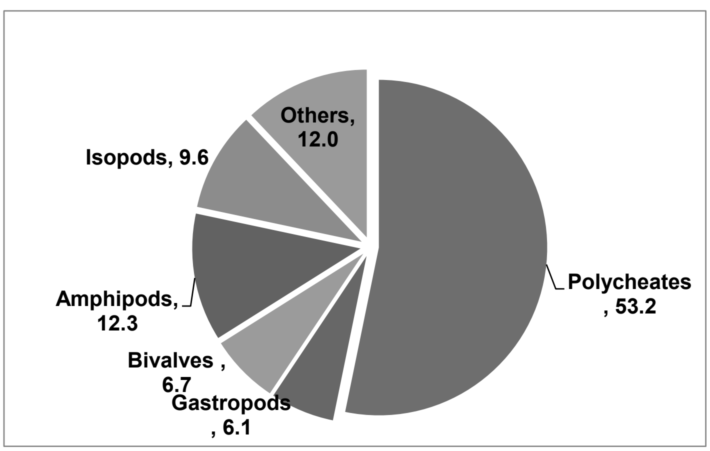


Fig. 3.4.34: Macro benthic community percentage composition in the Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

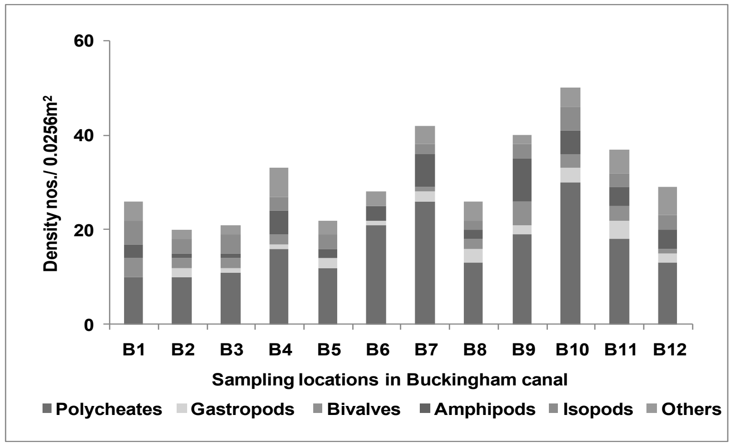


Fig. 3.4.35: Macro benthic community density in the Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

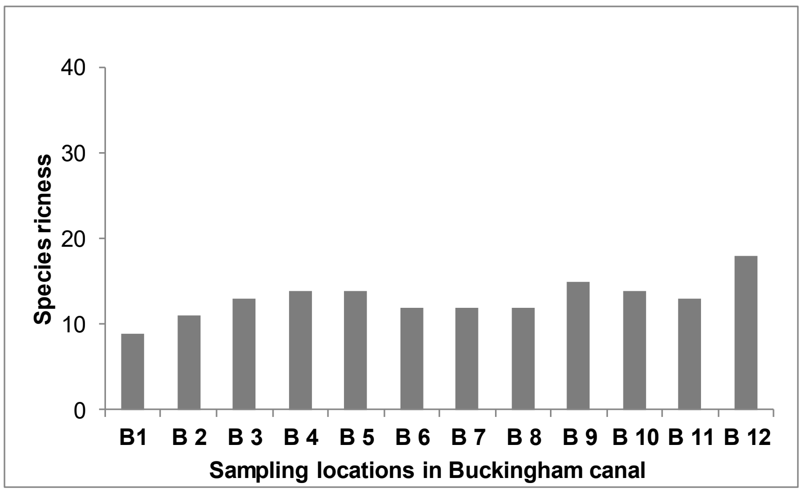


Fig. 3.4.36: Macro faunal species richness in Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

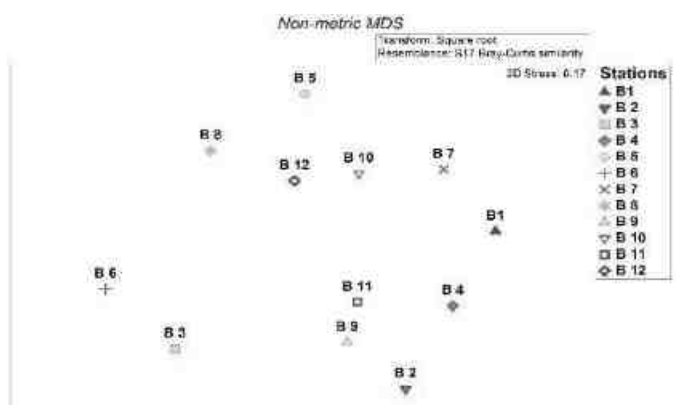


Fig. 3.4.37: MDS plot indicating macro benthic communities in the Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

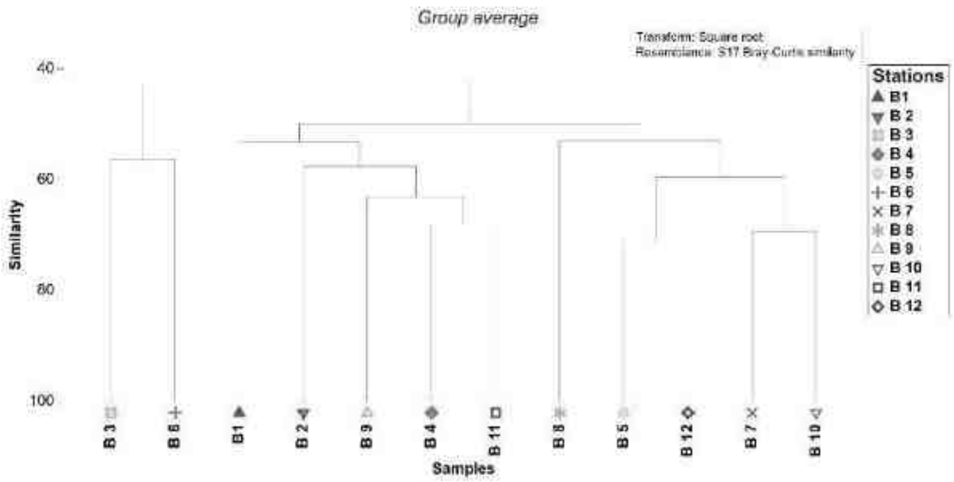


Fig. 3.4.38: Dendrogram of hierarchical cluster analysis showed the similarity of community structure among sampling sites in the Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

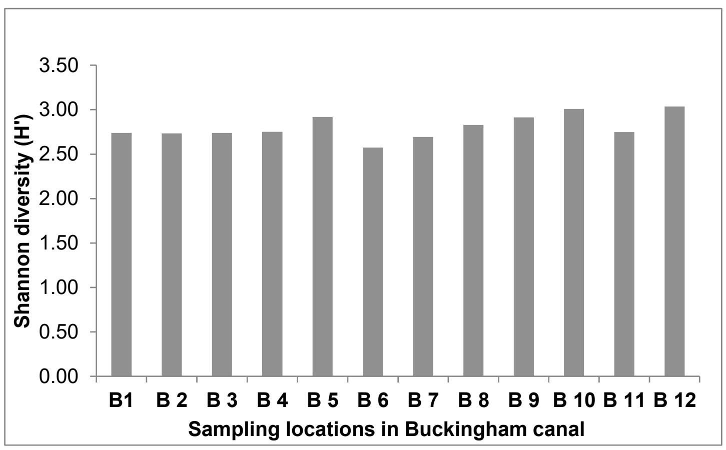


Fig. 3.4.39: Macro faunal Diversity (H') in the Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

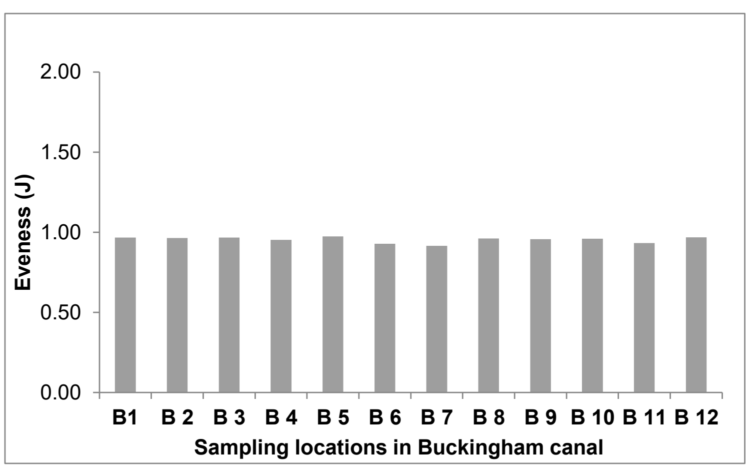


Fig. 3.4.40: Macro faunal evenness in the Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

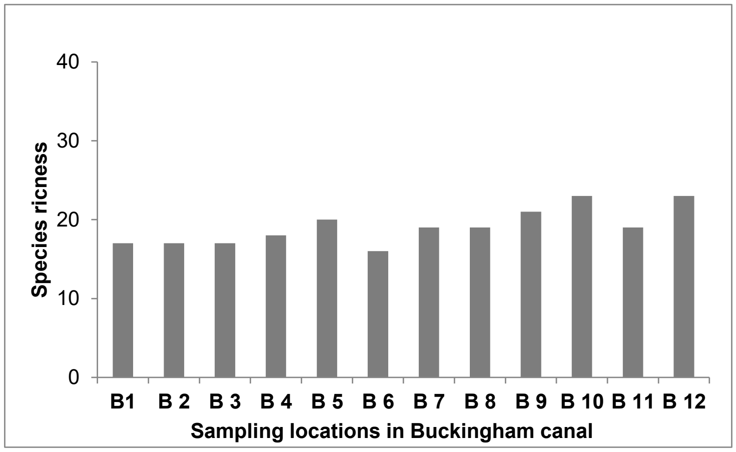


Fig. 3.4.41: Macro faunal species ricness in Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

Table 3.4.5: Macro benthic faunal density in the Buckingham canal sediments within 10 km radius of Kattuapalli Port (B – Buckingham sampling site)

Sl.No	Family	Genus	Species	Buckingham canal Samples											
				B1	B 2	B 3	B 4	B 5	B 6	B 7	B 8	B 9	B 10	B 11	B12
	Polycheates Groups														
1	Capitellidae	*Capitella*	*capitata*	1	1	0	0	2	1	2	0	0	5	2	2
2	Capitellidae	*Capitella*	sp.	0	0	1	0	3	0	8	3	0	0	0	0
3	Cossuridae	*Cossura*	sp.	0	2	1	0	0	2	0	0	2	1	3	0
4	Cossuridae	*Cossura*	*delta*	3	0	0	2	0	2	1	0	0	1	0	2
5	Glyceridae	*Glycera*	sp.	0	0	1	3	0	0	2	3	2	2	2	1
6	Lumbrineridae	*Lumbreneris*	sp.	0	0	1	0	0	5	0	1	3	0	1	0
7	Nereididae	*Ceretonereis*	*costae*	0	1	0	0	2	2	6	0	0	4	0	2
8	Orbiniidae	*Orbinia*	sp.	1	0	0	0	1	0	1	0	0	2	0	1
9	Pilargidae	*Ancistrosyllis*	sp.	3	2	2	2	0	6	2	0	3	3	0	0
10	Pilargidae	*Ancistrosyllis*	*constricta*	0	1	0	5	2	0	2	0	0	4	2	0
11	Spionidae	*Prionospio*	*pinnata*	0	3	0	2	0	0	0	3	4	0	0	1
12	Spionidae	*Prionospio*	sp.	0	0	3	0	0	3	0	1	2	3	0	0
13	Spionidae	*Spiophanes*	sp.	2	0	0	0	1	0	2	2	0	5	0	1
14	Spionidae	*Spionidae*	sp.	0	0	2	2	1	0	0	0	3	0	8	3
	Gastropods groups														
15	Potamididae	*Cerithum*	sp.	0	1	0	1	1	0	2	1	1	2	1	1
16	Turritellidae	*Turritella*	*columnaris*	0	1	1	0	1	1	0	2	1	1	3	1
	Bivalves groups														
17	Mactridae	*Mactra*	*laevis*	1	0	1	0	0	0	0	1	1	1	1	0
18	Veneridae	*Marcia*	*opima*	2	1	0	1	0	0	1	1	2	2	1	1
19	Veneridae	*Meretrix*	sp.	1	1	1	1	0	0	0	0	2	0	1	0

	Amphipods groups														
20	Gammaridae	*Gammarus*	sp.	2	0	0	1	1	1	2	1	5	2	2	1
21	Ampithoidae	*Amphithoe*	sp.	1	1	1	4	1	2	5	1	4	3	2	3
	Isopods groups														
22	Asellidae	*Asellota*	sp.	3	2	2	1	1	0	1	1	2	2	1	2
23	Janiridae	*Microjaera*	*anisopoda*	2	1	2	2	2	0	1	1	1	3	2	1
	Others														
24	Penaeidae	Unknown	sp.	0	1	0	1	1	0	1	0	0	2	1	1
25	-	Unknown	Crab sp.	1	0	2	2	1	2	1	0	1	1	2	3
26	-	Unknown	Fish larvae	1	1	0	0	0	1	2	1	1	1	0	1
27	-	Unknown	Unknown sp.	2	0	0	3	1	0	0	3	0	0	2	1

(ii) Meio Faunal community

The benthic meiofauna community in terms of diversity and density showed to be high in the Buckingham canal sediments. Totally six major groups were represented, which are Nematodes, Foraminifera, Cumaceans, Harpacticoids, Ostrocods, and Others groups. It comprised 58 species from 48 genera belonging to 38 families (Table 3.4.6). Of the group, Nematodes, Foraminifera, were the most dominant in the sediment, whereas least population density has been found for the others and Cumaceans. The Shannon diversity (H') value ranged between 2.92 and 3.39 and Evenness (J) was ranged between 0.98 and 0.89. Highest value was found at B1, lowest at B6 (Fig. 3.4.47,48, 49).

Nematodes

In the nematodes, reasonable amount of species richness and density were accounted in the study area. *Astomonema* sp*., Viscosia* sp., *Theristus*sp.*,* and *Filum* sp. were the most sighted species with greater abundance. Among the stations, highest density was exhibited in B6 with 46 nos./10cm^{2}followed by B9 with 37 nos./10cm^2 whilst poor assemblages was found in B2 with 11 nos./10cm^2 respectively.

Foraminifera

In the Foraminifera, relatively reasonable amount of population density were accounted in the study area. *Ammonia* sp*., Eliphidium* sp*.,* and *Beccarii* sp*.,* represented as dominant species with greater abundance. Across the stations, greatest density was observed in B9 with 58 nos./10cm^2 followed by B10 with 56 ind./10cm^2 whilst poor assemblages was found in B2with 26 nos./10cm^2.

Cumaceans

In the Cumaceans, relatively reasonable amount of population density were accounted in the study area. *Campylaspis* sp*.,* represented dominant species with greater abundance. Across the stations, greatest density was observed in B2 with 4 nos./10cm^2, poor assemblages was found in B9 with 3 nos./10cm^2 whilst Cumaceans assemblages was absent in B1, B4, B6, B8, B11, and B12.

Harpacticoids

In the Harpacticoids, relatively reasonable amount of population density were accounted in the study area. *Laophonte* sp*., Major* sp*.,* represented dominant species with greater abundance. Across the stations, maximum density was observed in B3, B10 and B12 with 7 nos./10cm^2 followed by B1, B5 and B9 with 6 ind./10cm^{2}poor assemblages was found in B4, B6 and B11 with 4 nos./10cm^2.

Ostrocods

In the Ostrocods, relatively reasonable amount of population density were accounted in the study area. *Strandesia* sp. *Liebaui* sp*.,* and scaura sp. represented dominant species with greater abundance. Across the stations, greatest density was observed in B5 with 36 ind./10cm^2 followed by B8 with 23 nos./10cm^2 whilst poor assemblages was found in B6 with 4 nos./10cm^2.

Others

In the others, relatively sparse amount of population density were accounted in the study area. *Turbellarian* sp.*,* Polychaete larvae were the most represented species. Among the stations, greatest density was observed in B7 and B2 with 9 nos. /10cm^2 followed by B5, and B10 with 6 nos. /10cm^2 wherea spoor assemblages was found in B8 with 8 nos./10cm^2. Details of diversity and abundance are represented in Table 3.4.6.

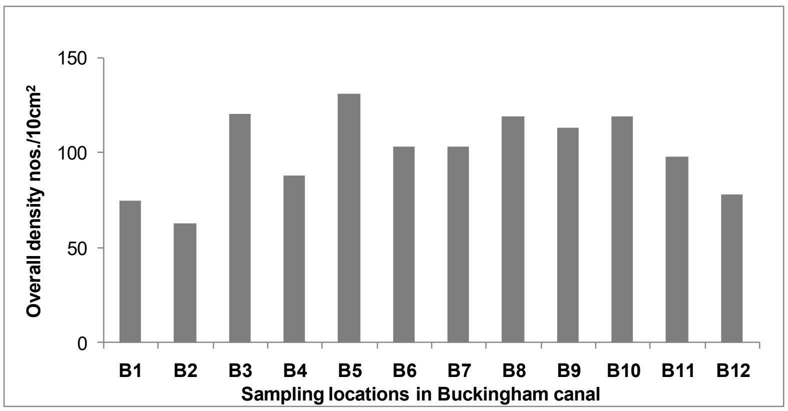


Fig. 3.4.42: Meio benthic faunal density in the Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

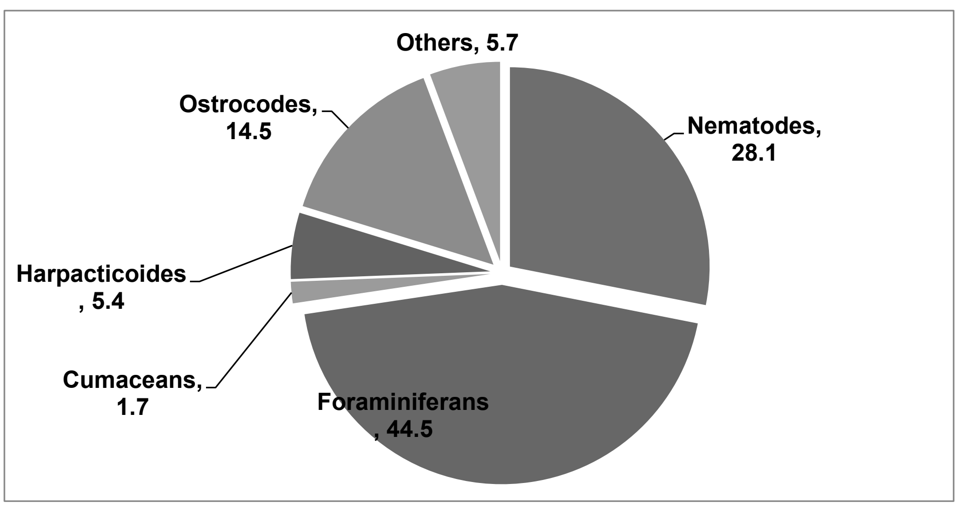


Fig. 3.4.43: Meio benthic community percentage composition in the Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

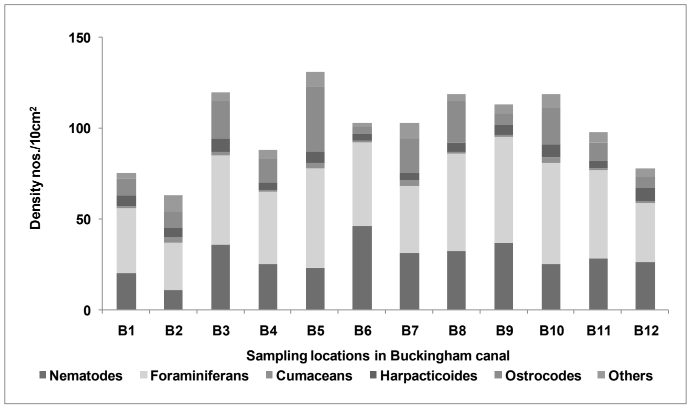


Fig. 3.4.44: Meio benthic community density in the Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

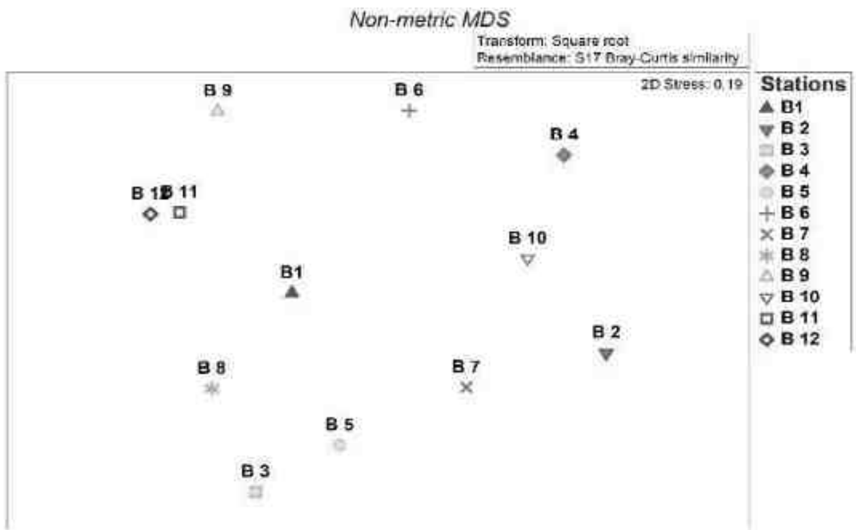


Fig. 3.4.45: MDS plot indicating meio benthic communities in the Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

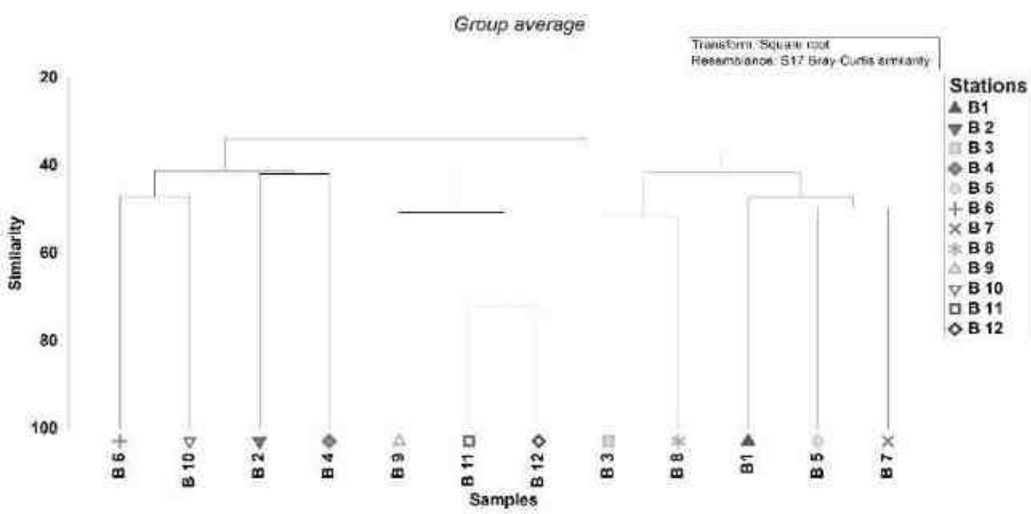


Fig. 3.4.46: Dendrogram of hierarchical cluster analysis showed the similarity of community structure among sampling sites in the Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

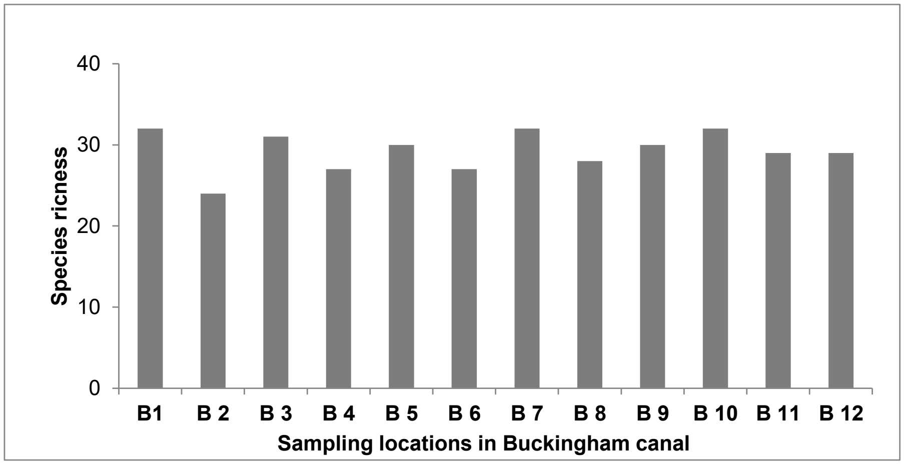


Fig. 3.4.47: Meio faunal species richness in Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

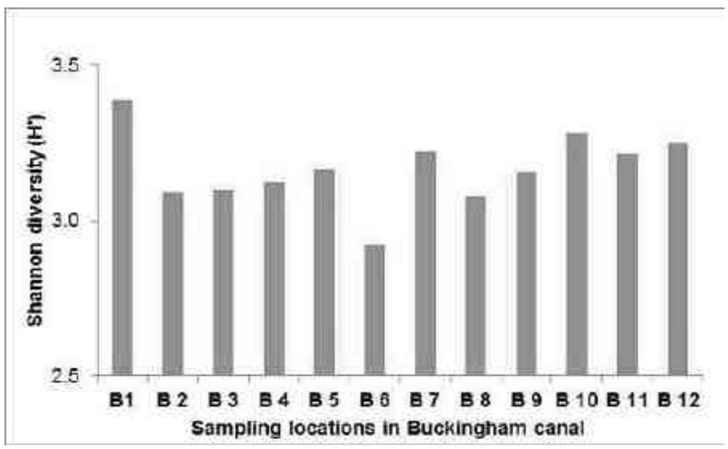


Fig. 3.4.48: Meio faunal Diversity (H') in Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

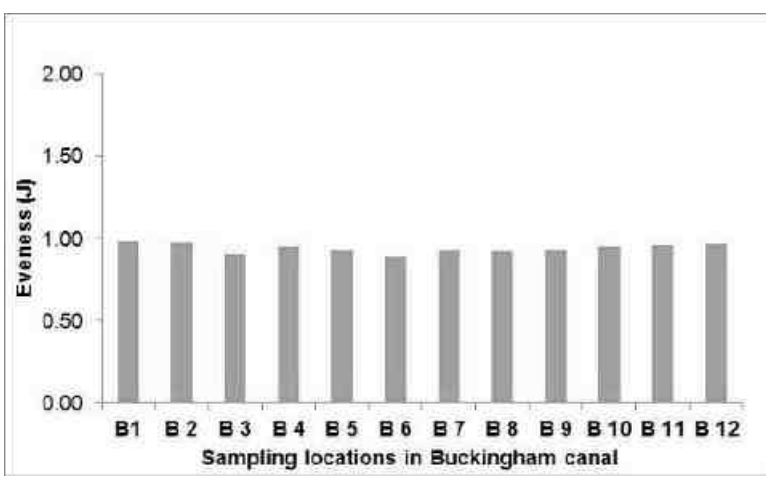


Fig. 3.4.49: Meio faunal evenness in Buckingham canal sediments within 10 km radius of onshore region (B – Buckingham sampling site)

Table 3.4.6: Meio benthic faunal density in the Buckingham canal sediments within 10 km radius of Kattupalli Port (B – Buckingham sampling site)

Sl. No	Family	Genus	Species	Buckingham canal samples											
				B1	**B 2**	**B 3**	**B 4**	**B 5**	**B 6**	**B 7**	**B 8**	**B 9**	**B 10**	**B 11**	**B 12**
	Nematodes														
1	Axonolaimidae	*Odontophora*	sp.	1	2	2	1	0	3	0	5	0	0	0	1
2	Comesomatidae	*Sabatieria*	sp.	3	0	3	0	2	2	5	0	3	0	1	2
3	Camacolaimidae	*Diodontolaimus*	sp.	0	1	0	2	0	0	0	2	5	2	2	2
4	Desmodoridae	*Desmodora*	sp.	0	0	1	1	3	0	2	0	3	0	1	3
5	Desmodoridae	*Spirinia*	sp.	0	0	2	1	2	2	0	3	0	0	0	0
6	Desmoscolecidae	*Tricoma*	sp.	2	2	2	1	0	3	1	0	2	5	3	0
7	Leptosomatidae	*Synonchus*	sp.	0	0	0	0	2	0	1	2	3	0	2	0
8	Linhomoeidae	*Paralinhomoeus*	sp.	0	0	0	1	0	2	0	0	2	4	1	2
9	Microlaimidae	*Microlaimus*	*conothelis*	1	2	3	0	0	0	2	0	2	0	2	0
10	Microlaimidae	*Microlaimus*	sp.	0	0	2	2	5	0	1	6	0	0	0	1
11	Oncholamidae	Viscosia	sp.	2	0	0	3	3	5	0	8	5	3	10	2
12	Oxystominidae	*Halalaimus*	*filum*	3	1	0	8	2	0	2	0	3	2	2	1
13	Siphonolaimidae	*Astomonema*	sp.	0	0	12	0	0	15	7	5	2	0	0	2
14	Thoracostomopsidae	*Mesacanthion*	sp.	5	0	2	0	2	2	3	0	0	5	0	3
15	Thoracostomopsidae	*Thoracostomopsis*	sp.	2	2	0	2	0	1	5	1	2	2	2	2
16	Xyalidae	*Daptonema*	sp.	0	0	4	0	2	1	0	0	1	1	1	5
17	Xyalidae	*Theristus*	sp.	1	1	3	3	0	10	2	0	4	1	1	0
		Foraminiferans													
18	Ammoniidae	Ammonia	beccarii	1	1	0	0	1	2	10	1	11	3	4	2

19	Ammoniidae	Ammonia	sp.	2	2	0	3	5	3	2	2	12	8	3	1
20	Ammoniidae	Ammonia	tepida	2	3	2	2	2	5	0	0	1	6	5	0
21	Bolivinitidae	Bolivina	sp.	3	2	2	1	5	4	1	2	5	0	0	2
22	Calcarinidae	Calcarina	sp.	2	1	2	0	4	5	1	1	0	0	2	1
23	Diffusilinidae	*Diffusilina*	sp.	2	2	0	1	0	2	3	2	1	3	0	0
24	Elphidiidae	Eliphidium	sp.	3	0	12	2	5	0	0	10	0	0	3	5
25	Elphidiidae	Eliphidium	crispum	1	2	0	4	3	0	0	1	1	0	5	2
26	Elphidiidae	*Elphidium*	*claticulatum*	0	1	1	5	2	1	2	1	0	5	0	2
27	Hauerinidae	*Milionella*	sp.	5	0	3	3	0	0	0	5	2	0	2	1
28	Hauerinidae	*Quinqueloculina*	sp.	3	2	2	0	1	3	0	1	0	4	3	3
29	Hauerinidae	*Quinqueloculina*	agglutinans	1	3	1	0	3	0	1	5	5	2	0	0
30	Hauerinidae	Triloculina	sp.	0	2	2	2	0	8	0	2	0	1	5	2
31	Hauerinidae	Hauerina	sp.	0	2	2	2	5	0	2	0	1	6	2	0
32	Lagenidae	Lagena	sp.	3	1	0	3	0	0	3	0	3	5	0	0
33	Nonionidae	Nonion	sp.	1	0	6	3	0	2	1	5	1	2	1	4
34	Rosalinidae	Rosalina	*bradyi*	0	0	2	1	3	1	5	1	0	2	3	2
35	Rosalinidae	Rosalina	*globularis*	1	0	0	0	4	0	0	1	2	0	0	1
36	Rotaliidae	Rotalia	sp.	0	1	2	3	5	3	2	0	2	1	5	0
37	Rotaliidae	Rotalia	*calcar*	3	0	0	1	0	1	0	5	0	1	0	2
38	Spiroloculinidae	Spiroloculina	sp.	1	0	5	2	3	2	1	3	5	5	0	0
39	Soritidae	*Sorites*	sp.	0	0	2	2	2	3	1	3	1	2	2	2
40	Textlariidae	*Textularia*	sp.	2	1	3	0	2	1	2	3	5	0	4	1
	Cumaceans														
41	Nannastacidae	Nannastacus	inflats	0	2	1	0	1	0	1	0	0	2	0	0
42	Nannastacidae	Campylaspis	sp.	0	2	1	0	2	0	2	0	1	1	0	0
	Harpacticoides														

43	Armadilloidae	Microsetella	gracilis	0	0	1	0	0	0	0	2	3	0	1	2
44	Cylindropsyllidae	*Cylindropsyllus*	*sp.*	2	2	1	1	1	3	1	0	0	2	0	0
45	Noctuoidae	Macrosetella	sp.	1	1	0	0	0	0	1	0	2	0	3	3
46	Laophontidae	*Laophonte*	*sp.*	0	0	3	1	5	0	0	3	0	0	0	2
47	Noctuoidae	*Diathrodes*	*major*	2	2	2	2	0	1	0	0	0	5	0	0
48	Tachidiidae	*Euterpina*	*euterpina*	1	0	0	0	0	0	2	0	1	0	0	0
49	Ostrocods														
50	Bairdiidae	*Bairdoppilata*	*scaura*	3	4	0	0	6	2	3	12	0	0	5	3
51	Cypridinae	Cypridina	*sp.*	0	2	0	3	0	0	2	0	1	5	0	0
52	Cypridinae	Parastenocypris	*sp.*	3	0	10	0	12	2	0	0	2	0	3	2
53	Cypridinae	*Strandesia* sp.	*sp.*	1	3	5	7	15	0	6	5	3	3	2	1
54	Trachyleberididae	Basslerites	liebaui	2	0	6	3	3	0	8	6	0	12	0	0
	Others														
55	Enchytraeidae	*Grania*	*sp.*	1	0	1	0	4	0	0	0	2	4	0	0
56	Pycnophyidae	*Pycnophyes*	*sp.*	0	2	2	2	0	0	4	2	0	0	0	0
57	-	Unknown	Polychaete larvae	2	0	0	3	0	0	0	0	3	0	5	3
58	-	Unknown	Polychaete sp.1	0	4	0	0	4	2	3	0	0	4	1	2
59	-	Unknown	Polychaete sp.2	0	3	2	0	0	0	2	2	0	0	0	0

4. Pulicat lake and Ennore creek

(i). Macro Faunal community

The macrobenthic faunas were collected in the waters of Pulicat lake and ennore creek with total of 6 Station and 5 Station respectively. The macrobenthic organisms were represented by six groups *viz*., Polychaetes, Gastropods, Bivalves, Amphipods, Isopods and others. A total of 43 species from 35 genera comprised with 27 families was found in the Ennore Creek and Pulicat waters. Totally 489 macro benthic faunal individuals was recorded in the study area. In the Ennore Creek area, Polychaetes was predominantly occurs in the sediments with 130 individuals followed by Amphipods with 31 individuals while low abundance was exhibited for the Bivalves and Gastropods with 13 and 13 individuals (Table 3.4.7). In the study area, Polychaetes was predominantly occurs in the sediments with 190 individuals followed by others with 31 individuals while low abundance was exhibited for the Bivalves and Isopods with 15 and 5 individuals. The analysis of diversity in Pulicate lake indices showed that Shannon diversity (H') value ranged between 2.17 and 2.47 and Evenness (J) was ranged between 0.89 and 0.99. Highest value was found at Pu3 and Pu2 and lowest at Pu2 and Pu4. In Ennoregrek Shannon diversity (H') value ranged between 2.23 and 2.72 and Evenness (J) was ranged between 0.84 and 0.99. Highest value was found at En4 and, lowest at En5 and En3 (Fig. 3.4.56,57).

Polychaetes

The Polycheates community relatively greater abundance was found in the all Stations. Capitellidae (90 ind.) and *Spiophanes* (63 ind.) were the most common families which represented as greater density. *Perinereis* sp., *Armandia* sp., *Lumbreneris* sp., and *Glycera* sp., were the dominant species found in the study area. In Ennore Creek area, Highest abundance was recorded in station En2 with 42 nos./0.0256m^2 followed by En3, En4 with 28 nos./0.0256m^2 whilst poor occurrence had reported in En5 with 13 nos./0.0256m^2 respectively. In Pulicat lake area, Highest abundance was recorded in station Pu4 with 50 nos./0.0256m^2 followed by Pu5 with 33 nos./0.0256m^2 whilst poor occurrence had reported in Pu2 with 23 nos./0.0256m^2 respectively

Gastropods

Three species belonging to 2 families of gastropods was represented in the study area. Of which, *Cerithum attenuate* and *Columnaris* sp. were the common species. In Ennore Creek area, Highest abundance was recorded in station En3 and En1 with 4 nos./0.0256m^2 followed by En5 with 3 nos./0.0256m^2 whilst poor occurrence had reported in En4 with 2 nos. /0.0256m^2 respectively. Gastropods assemblages was absent in En2. In Pulicat lake Maximum density was found to be in Pu3 with 8 nos. /0.0256m^2 and low density recorded in Pu2, Pu5 and Pu6 with 2 nos ./0.0256m^2. Gastropods assemblages was absent in Pu4.

Bivalves

In Bivalves, least species richness was represented in this group with 3 species. Of these, *Opima* sp. and *meretrix* sp was dominated species in the sediments. In Ennore Creek area, Highest abundance was recorded in station En1 with 5 nos./0.0256m^2 followed by En3, En5 with 3 nos./0.0256m^{2}whilst poor occurrence had reported in En2 with 2 nos./0.0256m^2 respectively. Bivalves assemblages was absent in En4. In Pulicat lake Maximum density was found to be in Pu6 with 5 nos./0.0256m^2 and low density recorded in Pu1,Pu3 and Pu4 with 2 nos./0.0256m^2. Bivalves assemblages was absent in Pu5.

Amphipods

Low occurrence of Amphipods in terms of diversity and abundance were represented in the sediments. Of these, *Amphithoe* sp., and *Ampelisca* sp., was dominated organisms in the study area. In Ennore Creek area, Highest abundance was recorded in station En5 with 11 nos./0.0256m^2 followed by En4 with 10 nos./0.0256m^2 whilst poor occurrence had reported in En1, En2 with 3 nos./0.0256m^2 respectively. In Pulicat lake highest was counted in Pu2, Pu5 with 7 nos./0.0256m^2 , low numbers were obtained for the stations Pu1 with 3 nos. /0.0256m^2.

Isopods

The isopods are sparse density was found to be in the Buckingham canal sediments. Only one species are represented, among them, *Asellota* sp., were the common beings in this region. In Ennore Creek area Isopods were absent. In Pulicat lake Highest was counted in Pu4 with 5 nos./0.0256m^2 other stations, Isopods assemblages was absent.

Others

The others are sparse density was found to be in the Buckingham canal waters. Four species from four families are represented, Unknown sp., and *Sipunculus* sp., are common community in Buckingham canal waters. In Ennore Creek area, Highest abundance was recorded in station En1 with 4 nos./0.0256m^2 followed by En2, En3 with 3 nos./0.0256m^2 whilst poor occurrence had reported in En4 and En5 with 2 nos./0.0256m^2 respectively. In Pulicat lake Highest was counted in Pu2, Pu3 and Pu4 with 7 nos./0.0256m^2 followed by Pu1 with 5 nos./0.0356m^2 and low numbers were obtained for the stations Pu6 with 2 nos./0.0256m^2. Details of diversity and abundance are represented in Table 3.4.7.

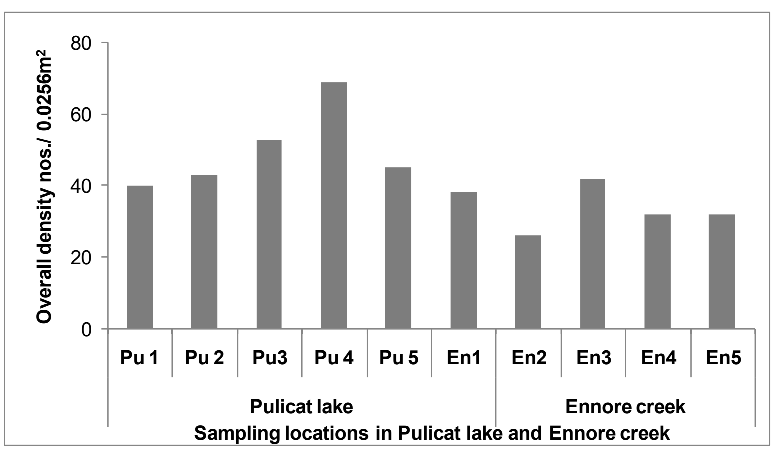


Fig. 3.4.50: Macro benthic faunal density in the Pulicatlake and Ennore Creek sediments

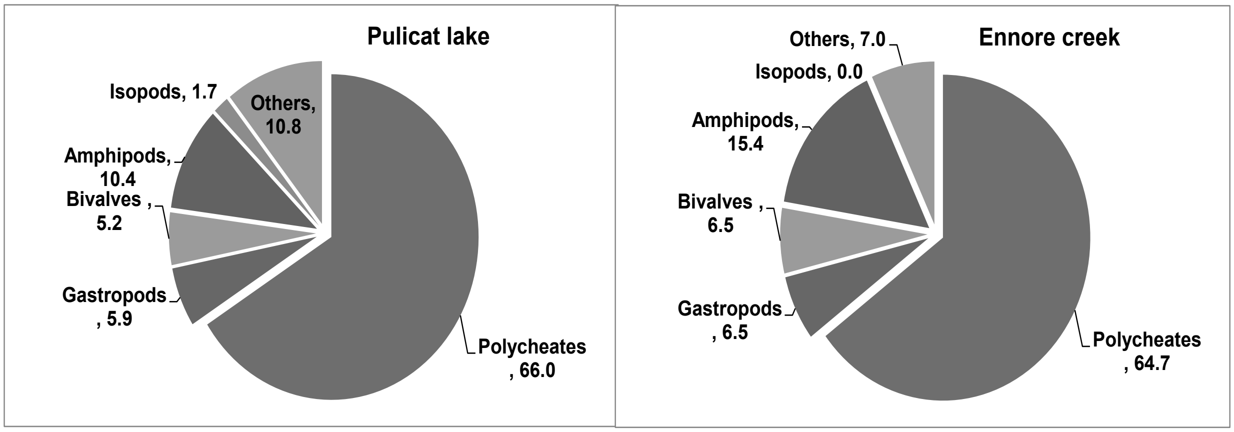


Fig. 3.4.51: Macro benthic community percentage composition in the Pulicatlake and Ennore Creek

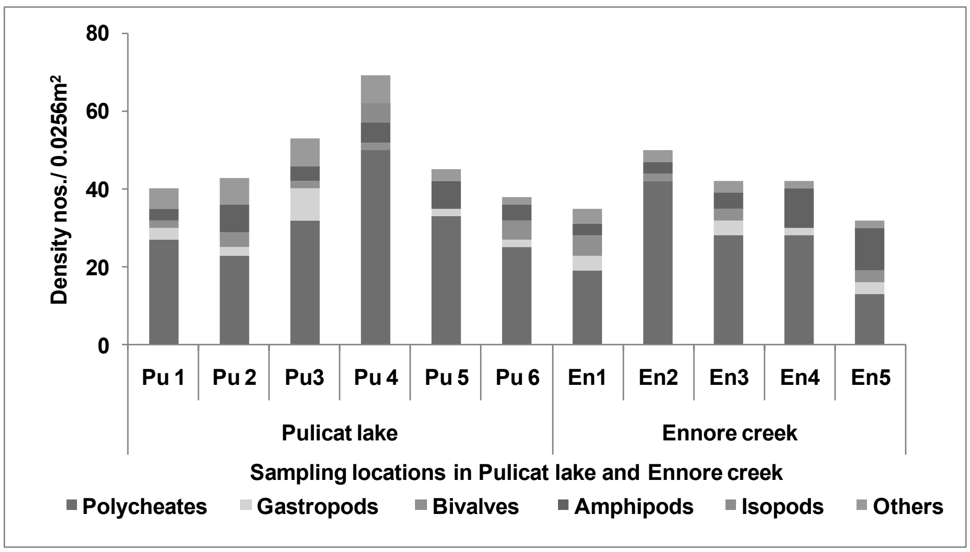


Fig. 3.4.52: Macro benthic community density in the Pulicatlake and Ennore Creek

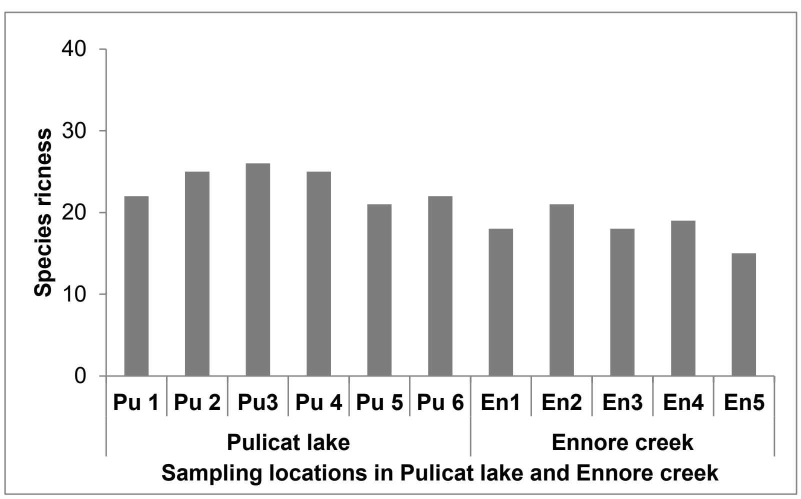


Fig. 3.4.53: Macro faunal species richness in Pulicatlake and Ennore Creek

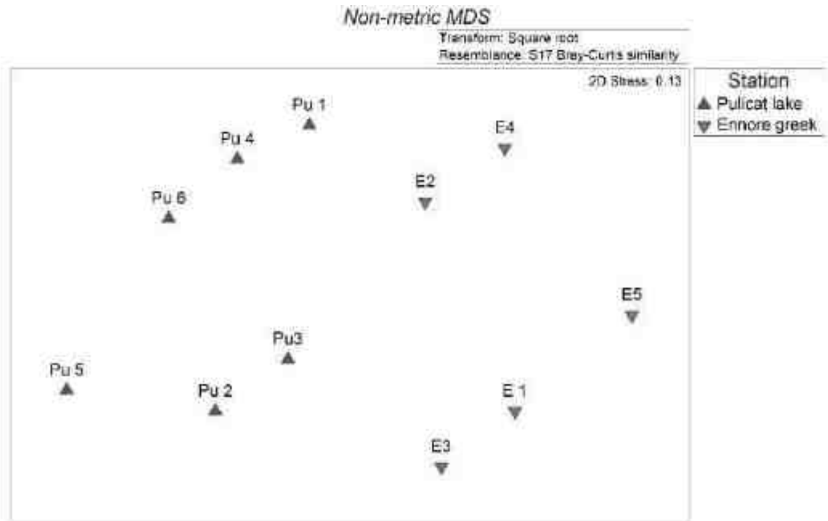


Fig. 3.4.54: MDS plot indicating macro benthic communities in the Pulicat Lake and Ennore

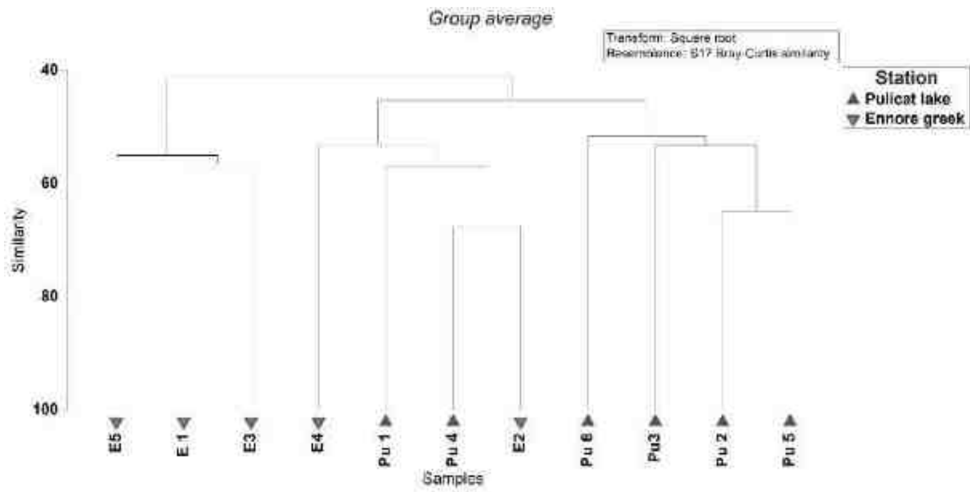


Fig. 3.4.55: Dendrogram of hierarchical cluster analysis showed the similarity of community structure among sampling sites in the Pulicatlake and Ennore Creek

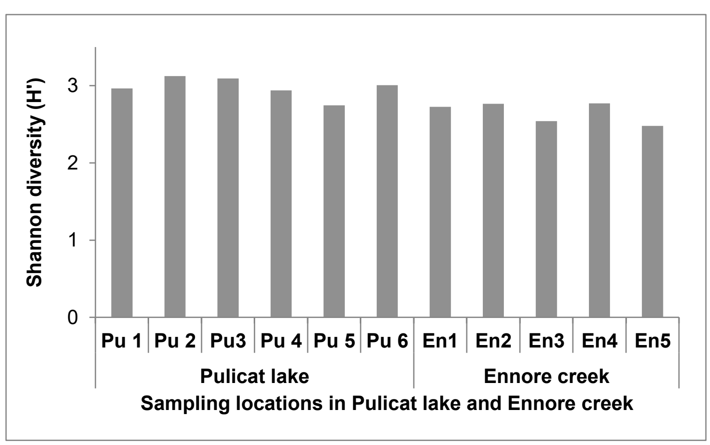


Fig. 3.4.56: Macro faunal Diversity (H') in Pulicat Lake and Ennore Creek

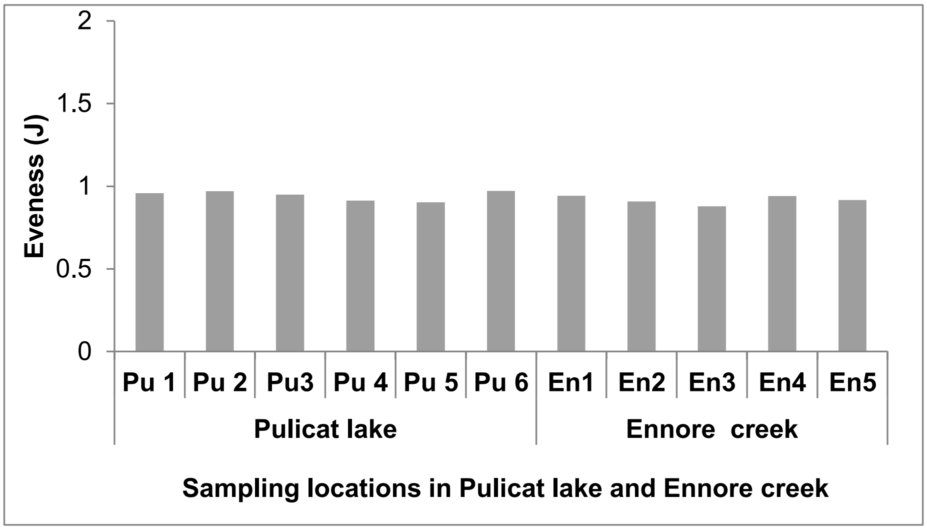


Fig. 3.4.57: Macro faunal evenness in Pulicatlake and Ennore Creek

Table 3.4.7: Macro benthic faunal density in the Pulicatlake and Ennore Creek habitat

Sl. no	Family	Genus	Species	Pulicat lake Samples						Ennore Creek Samples				
				Pu 1	Pu 2	Pu3	Pu 4	Pu 5	Pu 6	E 1	E2	E3	E4	E5
	Polycheates Groups													
1	Capitellidae	*Capitella*	*capitata*	1	2	0	3	2	3	2	1	1	5	2
2	Capitellidae	*Capitella*	sp.	3	1	3	8	0	0	1	2	2	2	3
3	Capitellidae	*Notomastus*	sp.	5	2	2	3	10	2	0	1	2	0	0
4	Capitellidae	*Heteromastus*	*filiformis*	2	1	0	5	2	0	0	2	2	2	0
5	Cossuridae	*Cossura*	sp.	0	2	1	0	3	1	0	0	0	0	0
6	Glyceridae	*Glycera*	sp.	0	0	0	1	0	3	1	2	1	3	2
7	Goniadidae	*Goniada*	*emerita*	1	0	1	0	0	0	2	3	0	2	2
8	Hesionidae	*Hesione*	*Intertexta*	2	3	2	0	1	0	1	0	0	0	0
9	Lumbrineridae	*Lumbreneris*	sp.	0	2	3	2	1	2	0	2	1	1	0
10	Maldanidae	*Euclymene*	*annandalei*	0	1	0	1	1	0	0	0	0	0	0
11	Nephtyidae	*Nephthys*	sp.	0	0	1	0	0	0	5	2	2	3	1
12	Nereididae	*Nereis*	sp.	1	0	0	1	0	2	1	1	0	2	0
13	Nereididae	*Perinereis*	sp.	2	0	1	2	0	0	3	3	0	1	0
14	Nereididae	*Perinereis*	*cultrifera*	0	0	2	0	0	2	0	0	0	0	1
15	Nereididae	*Dendronereis*	*heteropoda*	2	2	2	2	0	0	0	2	0	1	0
16	Onuphidae	*Onuphis*	*eremita*	0	2	0	0	3	0	1	0	1	0	0
17	Onuphidae	*Diopatra*	sp.	3	0	1	0	0	0	0	3	12	2	1
18	Opheliidae	*Armandia*	sp.	0	1	4	1	2	1	1	2	1	2	0

19	Opheliidae	*Armandia*	*lintermedia*	2	0	3	1	1	1	0	1	0	0	1
20	Pilargidae	*Ancistrosyllis*	sp.	1	0	0	2	0	2	0	0	0	1	0
21	Spionidae	*Prionospio*	sp.	0	1	1	10	5	1	1	12	1	1	0
22	Spionidae	*Prionospio*	*cirrifera*	0	1	5	5	2	3	0	2	0	0	0
23	Spionidae	*Spionidae*	sp.	2	2	0	3	0	2	0	1	2	0	0
	Gastropods groups													
24	Cerithiidae	*Cerithum*	sp.	2	1	3	0	1	1	1	0	0	1	0
25	Turritellidae	*Turritella*	*attenuata*	1	1	2	0	0	1	2	0	3	1	2
26	Turritellidae	*Turritella*	*columnaris*	0	0	3	0	1	0	1	0	1	0	1
	Bivalves groups													
27	Veneridae	*Meretrix*	*meretrix*	1	2	1	1	0	2	3	1	1	0	2
28	Veneridae	*Marcia*	*opima*	1	2	1	1	0	3	2	1	2	0	1
29	Veneridae	*Meretrix*	*casta*	0	0	0	0	0	0	0	0	0	0	0
	Amphipods groups													
30	Eriopisidae	*Eriopisa*	*chilkensis*	1	2	1	1	1	2	0	0	0	0	0
31	Talitridae	*Parorchestia*	*morini*	0	1	1	2	1	0	0	0	0	0	0
32	Aoridae	*Grandidirella*	*gravipes*	1	1	1	1	1	1	0	0	0	0	0
33	Ampeliscidae	*Ampelisca*	sp.	0	2	1	0	3	0	3	0	0	6	0
34	Ampithoidae	*Amphithoe*	sp.	1	0	0	1	1	1	0	3	0	4	8
35	Ampithoidae	*Amphithoe*	sp.2	0	0	0	0	1	1	0	0	0	0	0
36	Gammaridae	*Gammarus*	sp.	0	1	0	0	0	0	0	0	4	0	3
	Isopods groups													

37	Asellidae	*Asellota*	*sp.*	0	0	0	5	0	0	0	0	0	0	0
	Others													
38	Diogenidae	*Clibanarius*	*clibanarius*	3	0	0	4	0	0	0	0	0	0	0
39	Diogenidae	*Clibanarius*	sp.	0	0	0	0	0	2	0	0	0	0	0
40	Portuninae	*Portunus*	sp.	2	0	5	0	0	0	0	0	0	0	0
41	Penaeidae	*Penaeus*	*penaeus*	0	3	0	0	3	0	0	0	0	0	0
42	Sipunculidae	*Sipunculus*	sp.	0	0	0	3	0	0	0	3	0	2	0
43	-	Unknown	Unknown sp.	0	4	2	0	0	0	4	0	3	0	2

5. Marine zone

Marine zone

(i). Macro Faunal community

The macrobenthic faunas were collected in the marine sediments which were covered between Ennore creek and Pulicat area with a total of 86 stations from 8 zones. The macrobenthic organisms were represented by six groups *viz*., Polychaetes, Gastropods, Bivalves, Amphipods, Isopods and others. A total of 110 species was found in the marine zones. Totally 687 macrobenthic faunal individuals was recorded in the study area. Among the groups, Polychaetes was predominantly occurs in the marine sediments with 301 individuals followed by Gastropods with 132 individuals while low abundance was exhibited for the Isopods and Bivalves with 42 and 47 individuals (Table 3.4.9). The analysis of diversity indices showed that Shannon diversity (H') value ranged between 3.71 and 4.07 and Evenness (J) was ranged between 0.90 and 0.97. Highest value was found at zone 2 and 1, lowest at zone 8 (Fig. 3.4.72,73,74).

Polychaetes

The Polycheates community relatively greater abundance was found in the all Stations. *Glycinnde* sp. *Spiophanes* sp. *Capitella* sp*., Phyllodace* sp*.,* and *Polydora* sp. were the most common families which represented as greater density. *Glycinnde* sp., *Spiophanes* sp., *Capitella* sp*., Phyllodace* sp*., and Polydora* sp. were the dominant species found in the study area. Highest abundance was recorded in station zone1 with 52 nos./0.0256m^2 followed by zone2 with 47 nos./0.0256m^2 whilst poor occurrence had reported in zone7 with 26 nos./0.0256m^2 respectively.

Gastropods

In this taxa, 22 species belonging to 3 families of gastropods was represented in the study area. Of which, *Duplicaria Duplicate, Turricula Javana, Architectonica laevigata* and *Turris sp.*were the most common species recorded. Highest abundance was recorded in station zone1 with 22 nos./0.0256m^2 followed by zone3 with 20 nos./0.0256m^2. Low abundance was marked in 8 with 8 nos./0.0256m^2

Bivalves

In Bivalves, least species richness was represented in this group with 8 species. Of these, *Marcia opima* was dominated species in the sediments. Maximum density was found to be zone1 with 9 nos./0.0256m^2 followed by zone5 with 5 nos./0.0256m^2 and low density recorded in zone8 with1 nos./0.0256m^2.

Amphipods

Low occurrence of Amphipods in terms of diversity and abundance were represented in the sediments. *Amphithoe* sp. *and Ampelisca* sp. represented by being the predominant organisms witnessed in across all stations. Highest was counted in zone7 with 15 nos./0.0256m^2 followed by zone2 with 13 nos./0.0256m^2 and low numbers were obtained for the stations zone6 with 7 nos./0.0256m^2.

Isopods

The isopods are sparse density was found to be in the marine waters. *Eurydice pulchra, and Cymodoce* sp. are represented were the common beings in this region. Highest was counted in zone3 and 5 with 7 nos./0.0256m^2 and low numbers were obtained for the stations zone1 with 2 nos./0.0256m^2.

Others

The others are sparse density was found to be in the zone waters. *Sipunculus nudus and Cumacea* sp. were represented in zone water. Highest was counted in zone7 with 17 nos./0.0256m^2 followed by zone4 with 14 nos./0.0256m^2 and low numbers were obtained for the stations zone6 with 6 nos./0.0256m^2.Details of diversity and abundance are represented in Table 3.4.9.

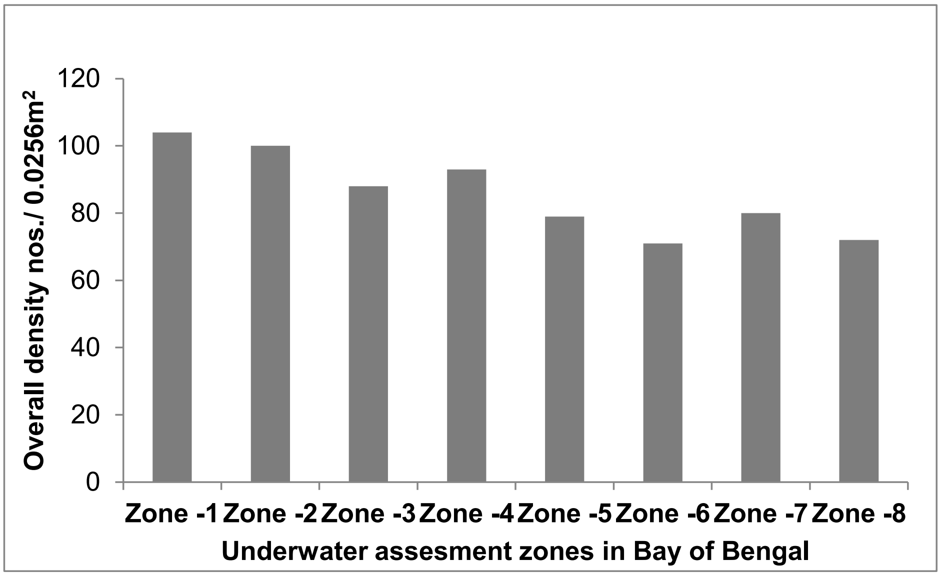


Fig. 3.4.66: Macro benthic faunal density in the marine zone within the 10km radius in the Bay of Bengal

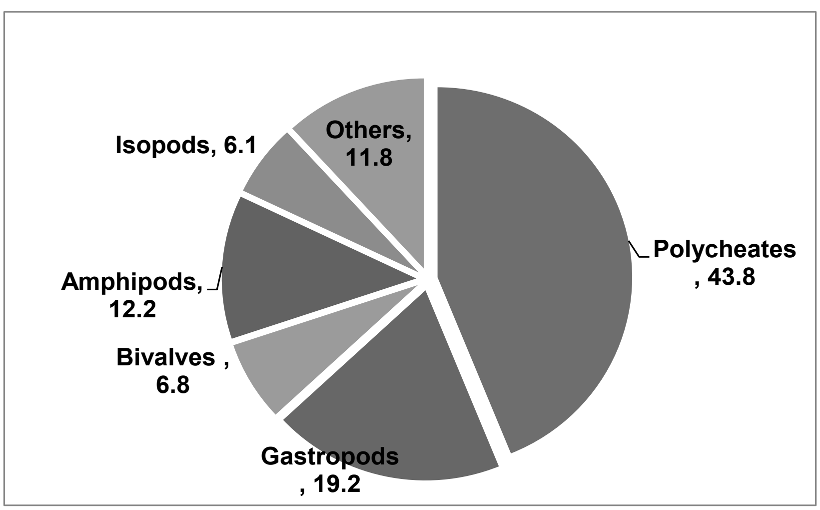


Fig. 3.4.67: Macro benthic community percentage composition in the marine zone

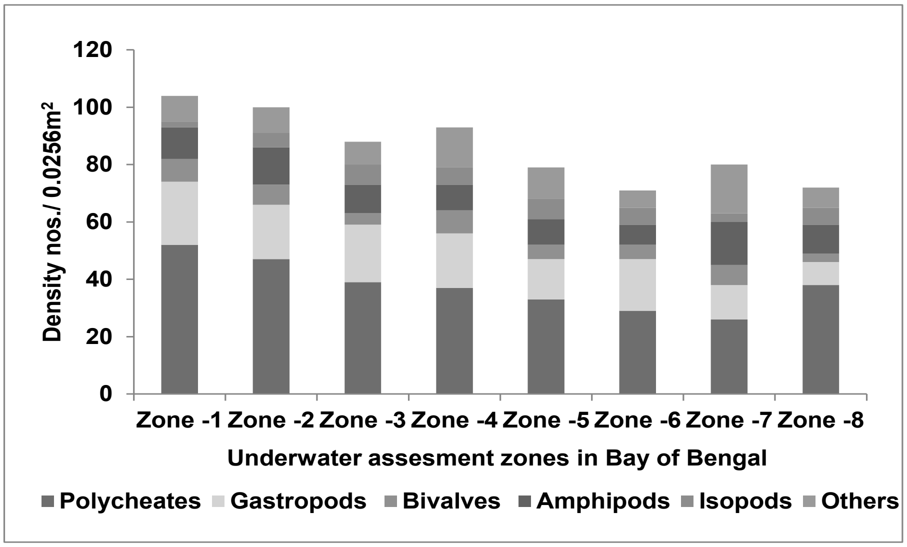


Fig. 3.4.68: Macro benthic community density in the marine zone within the 10km radius in the Bay of Bengal

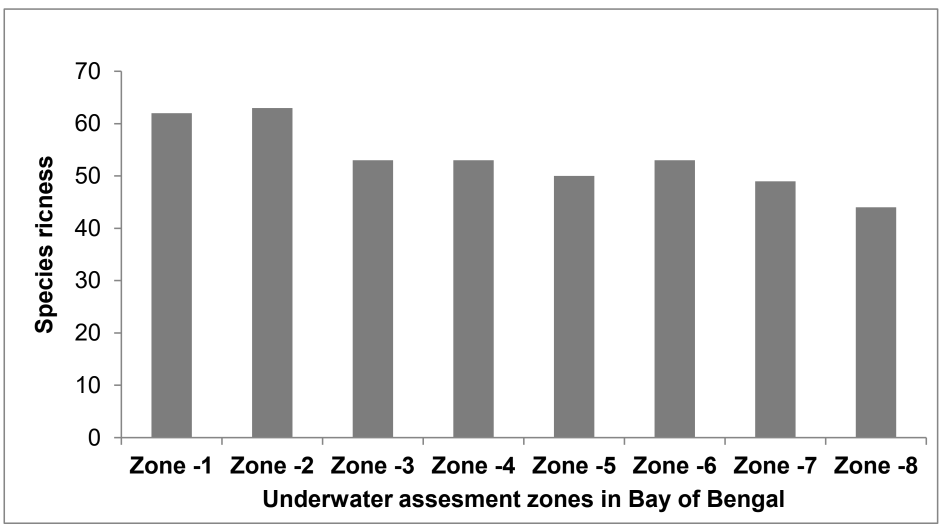


Fig. 3.4.69: Macro faunal species richness in marine zone within the 10km radius in the Bay of Bengal

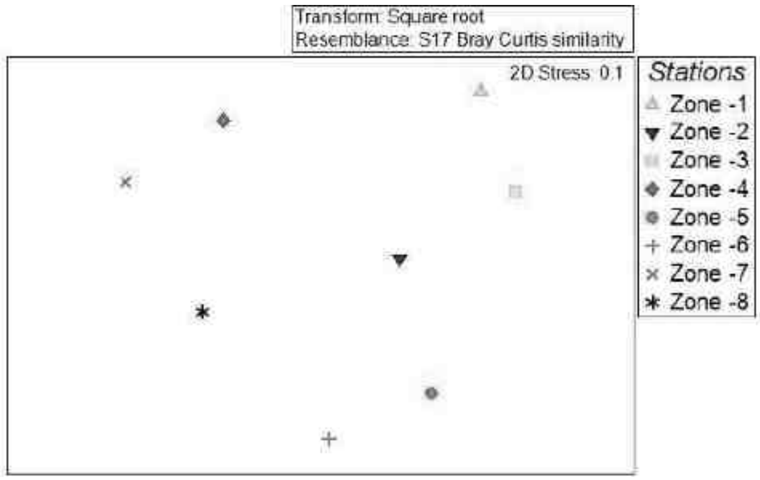
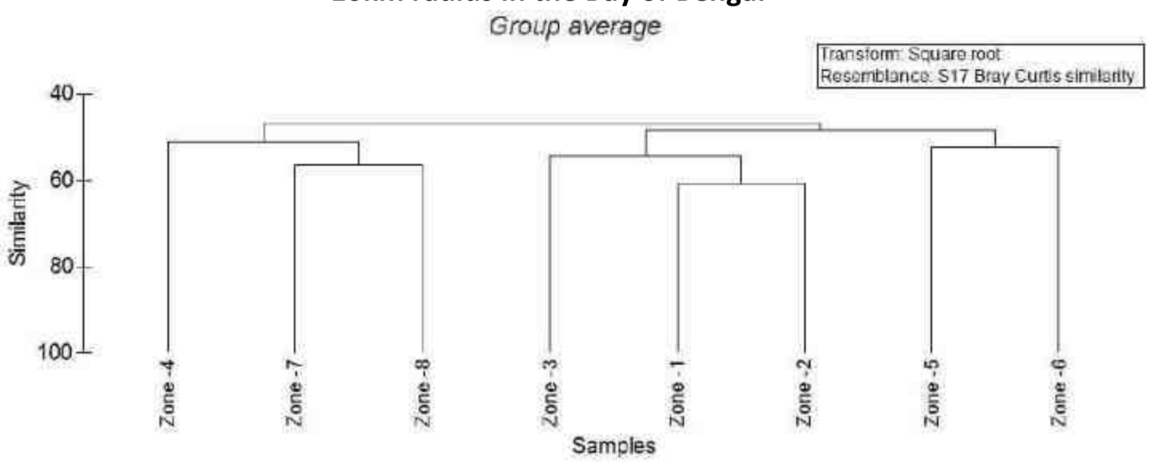


Fig. 3.4.70.MDS plot indicating macro benthic communities in the marine zone within the 10km radius in the Bay of Bengal

Fig.



3.4.71: Dendrogram of hierarchical cluster analysis showed the similarity of community structure among sampling sites in the marine zone

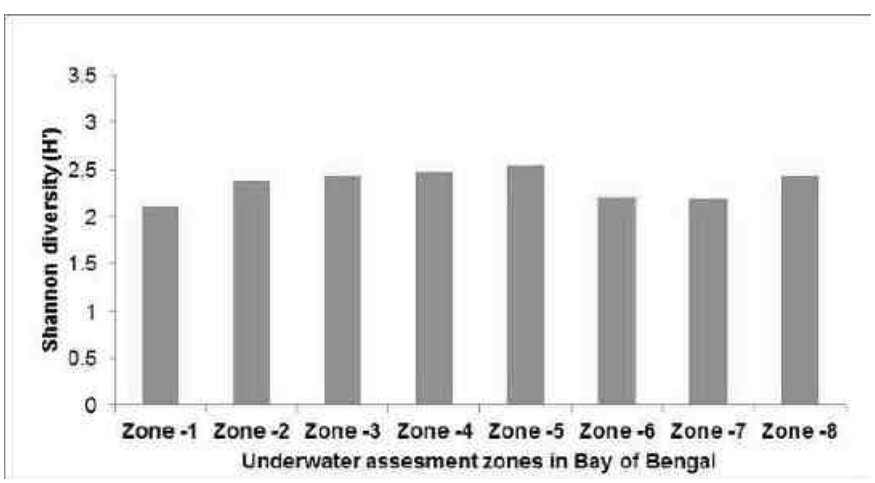


Fig. 3.4.72: Macro faunal Diversity (H') in marine zone within the 10km radius in the Bay of Bengal

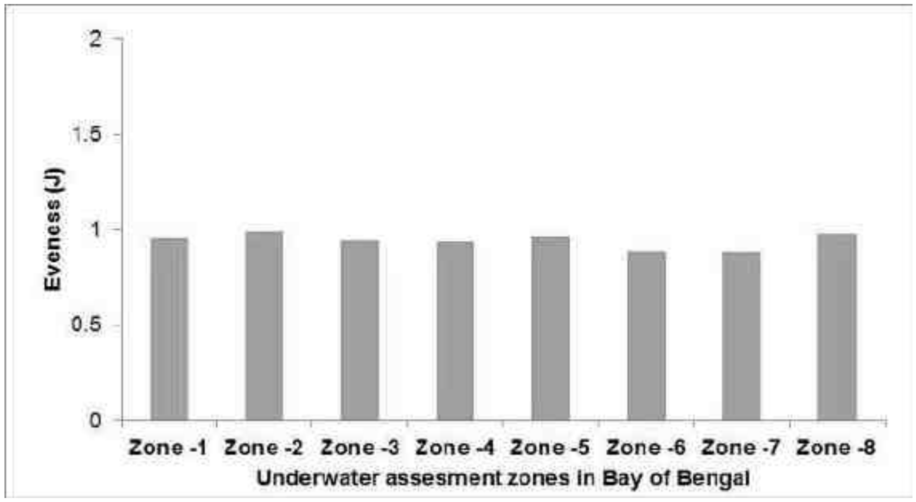


Fig. 3.4.73: Macro faunal evenness in marine zone within the 10km radius in the Bay of Bengal

Table 3.4.9: Macro benthic faunal density in the marine zone

Sl. No		Zone -1	Zone -2	Zone -3	Zone -4	Zone -5	Zone -6	Zone -7	Zone -8
	Polychaetes								
1.	*Amphicteis* sp.	0	1	0	0	0	2	1	0
2.	*Chloeia inermis*	1	0	2	2	1	0	0	0
3.	*Eurythoe* sp.	0	0	0	0	0	1	0	1
4.	*Capitella capitata*	1	1	2	0	2	2	0	0
5.	*Capitella* sp.	0	0	1	0	0	0	2	2
6.	*Heteromastus* sp.	2	2	0	0	1	0	0	0
7.	*Heteromastus similis*	0	1	2	1	0	0	0	1
8.	*Notomastus aberrans*	0	1	0	0	0	0	0	2
9.	*Notomastus* sp.	0	1	0	0	1	2	1	0
10.	*Cirratlidae* sp.	1	2	0	2	0	0	0	3
11.	*Cirratulus* sp.	2	1	1	1	0	2	1	1
12.	*Cossura coasta*	0	0	0	0	0	0	0	2
13.	*Cossura* sp.	1	1	1	0	1	0	0	0
14.	*Dorvillea* sp.	0	0	1	2	2	2	0	1
15.	*Eunice* sp.	2	1	0	0	0	0	1	0
16.	*Glycera alba*	0	2	1	0	2	2	1	2
17.	*Glycinnde capensis*	2	1	2	0	0	0	2	1
18.	*Glycinnde* sp.	0	3	0	2	2	0	0	0
19.	*Goniada emeriti*	1	0	1	0	0	1	0	2
20.	*Goniada* sp.	0	1	0	2	1	0	0	0
21.	*Hesione* sp.	1	0	1	0	0	1	2	0
22.	*Lumbreneris* sp.	0	2	0	0	1	0	0	2
23.	*Lumbrineris aberans*	1	0	0	0	2	1	0	0
24.	*Nephtys* sp.	0	0	2	0	1	0	2	1
25.	*Nereis capensis*	2	0	1	1	0	0	0	2
26.	*Nereis* sp.	0	2	2	0	1	0	0	0
27.	*Platynereis* sp.	1	0	0	1	0	1	2	0
28.	*Euchone rosea*	0	0	1	0	2	1	0	0
29.	*Arabella mutans*	0	0	3	2	0	0	0	2
30.	*Diopatra* sp.	1	0	1	1	1	0	0	0
31.	*Epidiopatra gilchristi*	0	2	0	3	0	0	1	1
32.	*Onuphis* sp.	2	0	0	0	0	0	2	0
33.	*Ophelia* sp.	0	1	2	2	0	1	0	0
34.	*Armandia* sp.	0	2	0	0	1	0	0	3
35.	*Orbinia* sp.	2	0	0	2	2	0	1	1
36.	*Phyllodace* sp.	4	0	2	1	0	1	0	0
37.	*Phyllodoce capensis*	0	0	2	0	1	0	2	0

38.	*Harmothoe* sp.	3	2	1	0	1	1	0	1
39.	*Chone* sp.	3	0	1	2	0	0	1	0
40.	*Chone collaris*	1	0	0	0	0	0	0	2
41.	*Oriopsis* sp.	2	0	0	0	0	1	0	0
42.	*Serpula* sp.	0	1	0	0	0	0	0	1
43.	*Polydora ciliate*	1	0	0	1	2	1	0	0
44.	*Polydora* sp.	2	2	1	2	0	0	1	0
45.	*Prionospio pinnata*	0	1	0	2	0	0	0	1
46.	*Prionospio* sp.	1	0	0	0	2	0	0	0
47.	*Prionospio sexoculata*	2	1	0	0	0	1	0	1
48.	*Scololepis* sp.	0	2	1	0	0	0	1	0
49.	*Spiophanes bombyx*	3	2	1	2	0	1	0	0
50.	*Spiophanes* sp.	1	2	1	0	1	1	0	0
51.	*Sternapsis scutata*	0	0	0	0	0	0	2	1
52.	*Sternapsis* sp.	2	1	0	2	1	2	0	0
53.	*Exogone* sp.	0	0	1	1	1	0	0	0
54.	*Syllis gracilis*	0	2	0	0	0	0	0	0
55.	*Syllis* sp.	3	0	0	0	0	0	0	0
56.	*Unknown* sp.	0	2	1	0	0	0	0	1
	Total	52	47	39	37	33	29	26	38
	Gastropods								
57.	*Architectonica* sp.	1	0	0	0	1	0	0	0
58.	*Architectonica laevigata*	1	1	3	1	2	0	1	0
59.	*Dentalium* sp.	2	2	0	0	0	1	1	0
60.	*Epitonium* sp.	0	0	2	2	0	1	0	0
61.	*Epitonium scalare*	2	1	0	0	1	0	0	0
62.	*Marginella* sp.	0	0	1	2	0	1	1	0
63.	*Bullia vitata*	0	2	0	0	0	2	0	2
64.	*Bullia* sp.	1	1	0	0	0	0	0	0
65.	*Bullia belangari*	2	0	0	2	1	1	2	0
66.	*Polinices* sp.	0	0	2	0	0	1	1	0
67.	*Oliva* sp.	2	1	2	2	0	1	0	0
68.	*Duplicaria Duplicate*	1	2	0	0	2	2	1	2
69.	*Turritella columnaris*	2	2	0	2	0	2	0	0
70.	*Turritella attenuata*	0	0	1	0	1	1	1	0
71.	*Turricula Javana*	2	2	0	1	3	0	1	0
72.	*Turris* sp.	0	0	3	2	0	1	1	2
73.	*Turritella* sp.	2	1	1	0	0	2	1	0
74.	*Telescopium telescopium*	1	0	2	0	0	0	0	2
75.	*Turritella duplicate*	1	2	0	1	2	1	0	0

76.	*Umbonium vestiarium*	0	2	1	0	0	0	0	0
77.	*Unknown* sp.	2	0	2	2	0	0	1	0
	Bivalves								
78.	*Anadara* sp.	1	2	0	0	0	1	0	1
79.	*Anadara granosa*	2	0	2	2	2	0	0	0
80.	*Anadara veligers*	1	2	0	3	0	0	2	0
81.	*Cardium* sp.	1	1	0	2	2	0	1	0
82.	*Marcia opima*	2	0	0	1	0	1	3	0
83.	*Gafrarium* sp.	1	1	0	0	0	0	0	0
84.	*Unknown* sp.	0	0	2	0	1	0	1	2
	Amphipods								
85.	*Ampelisca* sp.	0	2	2	0	1	2	1	3
86.	*Grandidierella* sp.	1	3	0	0	3	0	0	0
87.	*Gammarus salinus*	1	1	0	2	0	1	1	2
88.	*Gammaropis thompsoni*	2	0	2	0	0	2	0	0
89.	*Gammarus* sp.	0	2	0	1	0	0	3	1
90.	*Nannonyx* sp.	0	0	1	2	0	1	2	0
91.	*Amphithoe* sp.	3	0	0	0	1	0	1	1
92.	*Amphithoe ramondi*	3	1	0	0	3	0	3	2
93.	*Urothoe pulchella*	0	3	0	1	1	0	2	0
94.	*Urothoe* sp.	1	1	3	2	0	0	2	0
95.	*Unknown* sp.	0	0	2	1	0	1	0	1
	Isopods								
96.	*Eurydice* sp.	0	0	3	0	0	2	0	1
97.	*Eurydice pulchra*	2	3	0	1	3	0	0	3
98.	*Angeliera* sp.	0	0	0	3	0	2	0	0
99.	*Anthura gracillis*	0	1	2	0	0	1	1	0
100.	*Cymodoce* sp.	0	0	0	2	3	0	2	2
101.	*Unknown* sp.	0	1	2	0	1	1	0	0
	Others								
102.	*Cumacea* sp.	1	0	0	3	2	1	4	2
103.	*Penaeus indicus*	0	1	2	1	0	0	0	0
104.	*Penaeus* sp.	2	2	0	2	1	1	3	2
105.	*Portunus* sp.	1	0	1	0	2	0	2	0
106.	*Tanaids* sp.	0	3	0	1	2	1	0	2
107.	*Balanus amphitrite*	1	1	0	0	0	0	2	0
108.	*Branchiostoma* sp.	0	0	3	2	2	1	0	0
109.	*Sipunculus nudus*	4	2	2	2	0	2	3	0
110.	Unknown sp.	0	0	0	3	2	0	3	1

(ii) Meio Faunal community

The benthic meiofauna presented as fair occurrence were seen in the marine zones. Totally six major groups were represented which are Nematodes, Foraminifera, Cumaceans, Harpacticoids, Ostrocods, and Others groups. It comprised 102 species was recorded (Table 3.4.10). Of the group, Nematodes, Foraminifera, were the most dominant in the sediments while least population density has been found for the others and *Cumaceans*. *Astomonema* sp., *Eliphidium* sp., *Diffusilina* sp., *Ammonia tepida* and *Macrosetella* sp. were the most encountered meiofaunal species observed. The Shannon diversity (H') value ranged between 3.81 and 4.06 and Evenness (J) was ranged between 0.95 and 0.98. Highest value was found at zone 8, and zone 3 and, lowest at zone 6 (Fig. 3.4.79,80,81).

Nematodes

In the nematodes, moderate species richness and density were accounted in the study area. *Astomonema jenneri, Daptonema conicum, Microlaimus sp., Haplaomus sp.* and *Theristus* sp. the most sighted species with greater abundance. Among the stations, highest density was exhibited in zone 1 with 52 nos./10cm^2 followed by zone 2 with 43 nos./10cm^2 whilst poor assemblages was found in zone 7 with 21 nos./10cm^2 respectively.

Foraminifera

In the Foraminifera, relatively reasonable amount of population density were accounted in the study area*. Ammonia beccarii, Calcarina* sp., *Rosalina globularis, Elphidium rapandus* and *Cornoboides* sp. represented as dominant species with greater abundance. Across the stations, greatest density was observed in zone1 with 55 nos./10cm^2 followed by zone2 with 45 nos./10cm^2 whilst poor assemblages was found in zone7 with 21 nos./10cm^2.

Cumaceans

In the Cumaceans, relatively reasonable amount of population density were accounted in the study area. *Gynodiastylis lata, Unknown* sp.*,* represented dominant species with greater abundance. Across the stations, greatest density was observed in zone 1with 8 nos./10cm^2 , followed by zone1 & 7 with 9 nos./10cm^2 poor assemblages was found in zone4 with 3 nos./10cm^2.

Harpacticoids

In the Harpacticoids, relatively reasonable amount of population density were accounted in the study area. *Microsetella gracilis, and Euterpina* sp. represented dominant species with greater abundance. Across the stations, maximum density was observed in zone2 with 15 nos./10cm^2 followed by zone5 with 14 nos./10cm^2 poor assemblages was found in zone8 with 7 nos./10cm^2.

Ostrocods

In the Ostrocods, relatively reasonable amount of population density were accounted in the study area. *Parastenocypris* sp., Unknown sp.*, Stenocypris major* and *Cypridina* sp. represented dominant species with greater abundance. Across the stations, greatest density was observed in zone7 with 15 nos./10cm^2 followed by zone1 with 14 nos./10cm^2 whilst poor assemblages was found in zone4 with 6 nos./10cm^2.

Others

In the others, relatively sparse amount of population density were accounted in the study area. *Apseudes spinosus* and *Olichochaetes* were the most represented species. Among the stations, greatest density was observed in zone4 with 12 nos./10cm^2 followed by zone8 with 11 nos./10cm^{2}whereas poor assemblages was found in zone5 with 4 nos./10cm^2. Details of diversity and abundance are represented in Table 3.4.10.

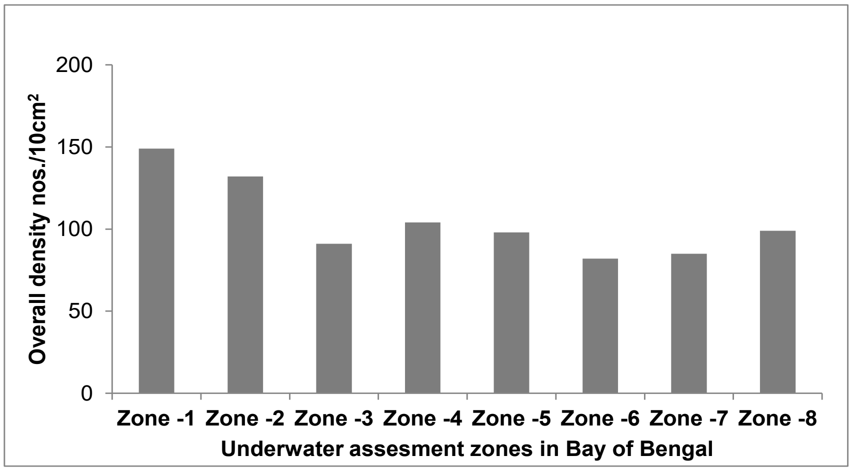


Fig. 3.4.74.Meio benthic faunal density in the marine zone habitat within the 10km radius in the Bay of Bengal

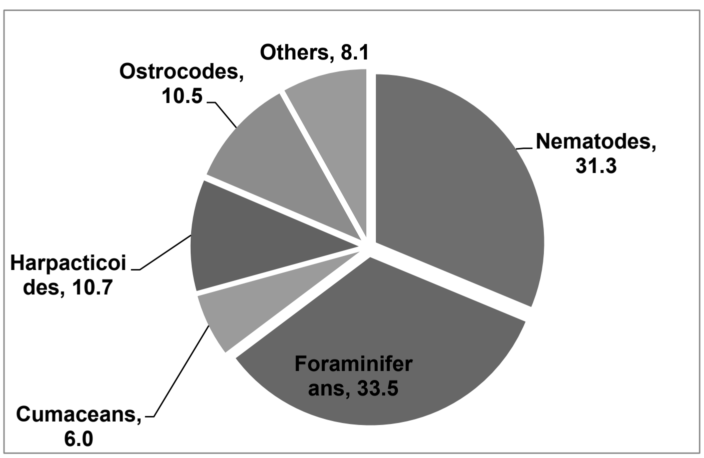


Fig. 3.4.75: Meio benthic community percentage composition in the marine zone

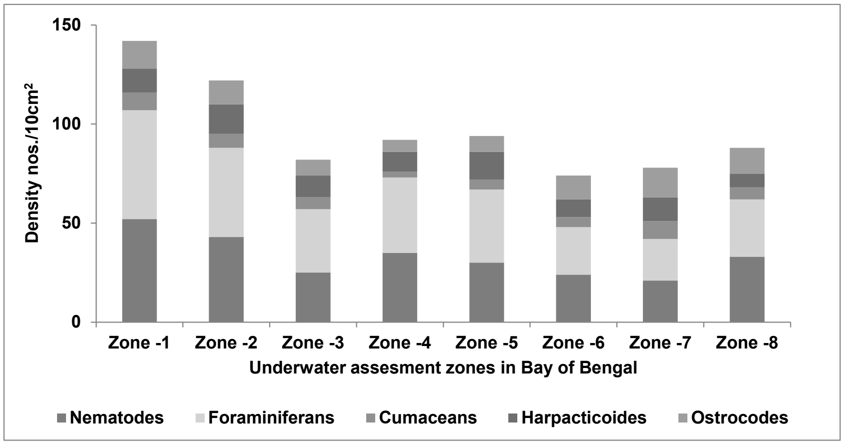


Fig. 3.4.76: Meio benthic community density in the marine zone within the 10km radius in the Bay of Bengal

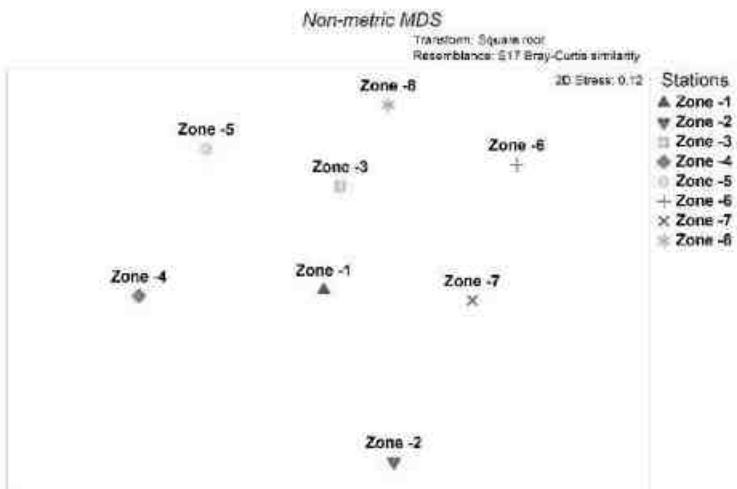


Fig. 3.4.77: MDS plot indicating meio benthic communities in the marine zone within the 10km radius in the Bay of Bengal

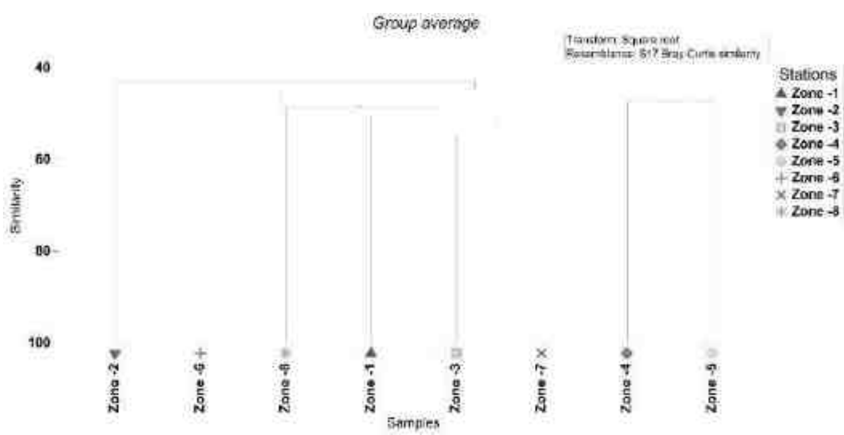


Fig. 3.4.78: Dendrogram of hierarchical cluster analysis showed the similarity of community structure among sampling sites in the marine zone

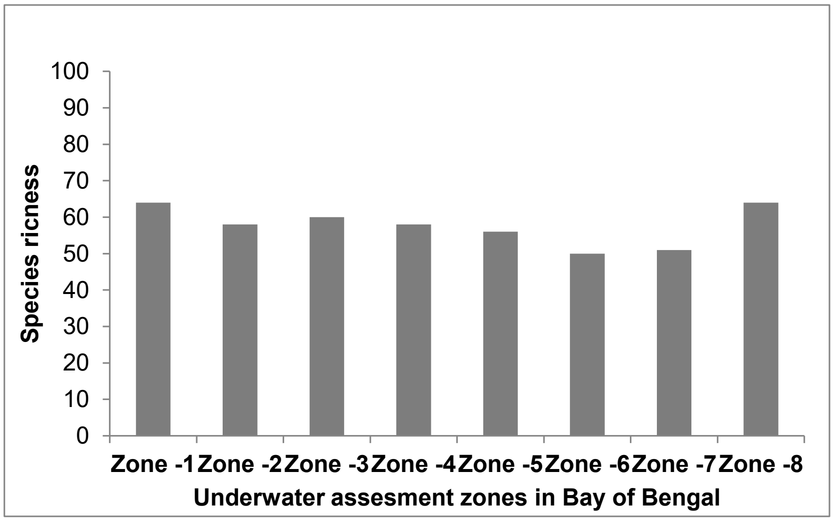


Fig. 3.4.79: Meio faunal species richness in marine zone within the 10km radius in the Bay of Bengal

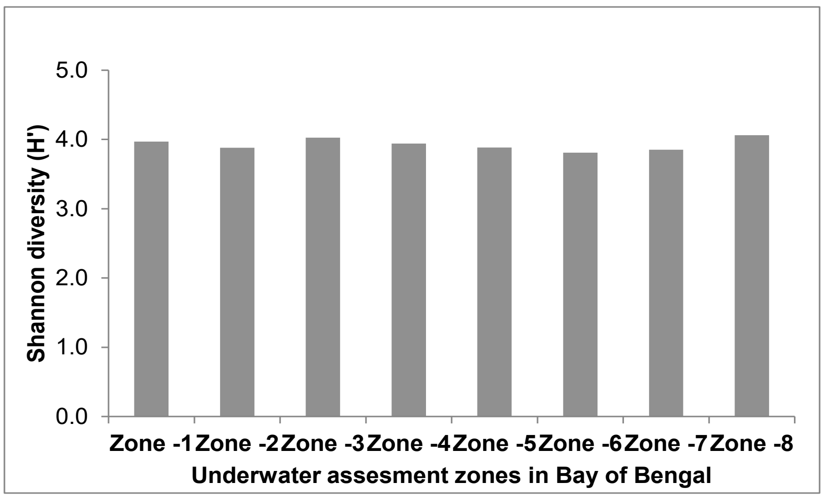


Fig. 3.4.80: Meio faunal Diversity (H’) in marine zone within the 10km radius in the Bay of Bengal

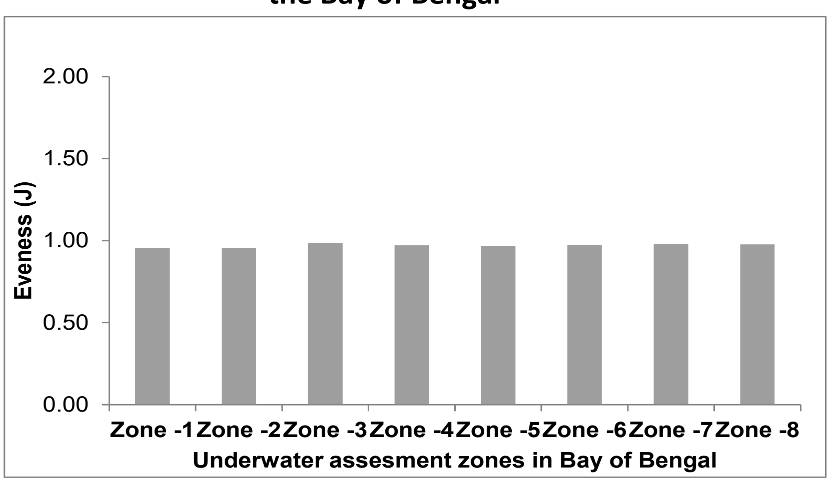


Fig. 3.4.81: Meio faunal evenness in marine zone within the 10km radius in the Bay of Bengal

Table 3.4.10: Meio benthic faunal density in the marine zone habitat

Sl. No	Species	Zone -1	Zone -2	Zone -3	Zone -4	Zone -5	Zone -6	Zone -7	Zone -8
	Nematodes								
1.	*Odontophora* sp.	1	0	0	2	1	0	0	1
2.	*Sabatieria* sp.	0	2	0	0	0	2	1	0
3.	*Desmoscolex* sp.	1	2	0	0	1	2	1	1
4.	*Draconema* sp.	0	0	1	0	0	0	0	2
5.	*Desmodora* sp.	5	0	0	1	2	2	0	0
6.	*Epsilonema* sp.	0	1	0	0	0	0	1	2
7.	*Enoplolaimus* sp.	1	2	0	2	1	1	0	0
8.	*Greeffiella* sp.	2	0	2	0	0	0	2	4
9.	*Spirinia* sp.	8	0	0	2	0	1	0	1
10.	*Tricoma* sp.	0	2	0	4	1	0	1	0
11.	*Synonchus* sp.	3	0	1	0	2	1	0	1
12.	*Polygastrophora* sp.	0	2	0	1	0	0	0	2
13.	*Pandolaimus* sp.	1	1	1	2	0	0	1	0
14.	*Paralinhomoeus* sp.	0	4	1	0	1	1	0	1
15.	*Microlaimus conothelis*	4	0	2	2	0	0	0	4
16.	*Microlaimus* sp.	0	8	0	0	2	1	1	1
17.	*Viscosia* sp.	0	2	2	2	4	0	0	2
18.	*Haplaomus* sp.	2	5	2	1	0	1	2	0
19.	*Halalaimus filum*	3	0	0	0	2	0	0	1
20.	*Astomonema jenneri*	7	6	2	3	0	0	1	1
21.	*Astomonema* sp.	0	0	1	0	1	1	0	2
22.	*Mesacanthion* sp.	0	0	0	3	0	0	0	2
23.	*Thoracostomopsis* sp.	1	0	1	0	0	2	1	2
24.	*Daptonema conicum*	5	1	2	2	5	0	2	0
25.	*Stepanolaimus* sp.	0	2	0	0	2	0	0	1
26.	*Daptonema* sp.	5	0	1	2	0	2	2	0
27.	*Rhynchonema* sp.	0	1	1	1	1	4	0	0
28.	*Quadricoma* sp.	1	2	0	0	0	1	1	1
29.	*Theristus* sp.	0	0	2	5	3	1	2	0
30.	*Unknown* sp.	2	0	1	0	1	1	2	1
	Foraminifera								
31.	*Ammonia beccarii*	3	5	2	1	1	2	0	0
32.	*Ammonia* sp.	5	0	0	2	2	0	1	1
33.	*Ammonia tepida*	0	2	1	0	0	0	2	2
34.	*Asterorotalia trispinosa*	5	1	0	1	0	0	0	0
35.	*Amphisorus hemprichii*	0	0	2	2	3	1	0	0
36.	*Bolivina abbreviata*	0	2	1	0	0	0	3	0
37.	*Bolivina* sp.	2	0	0	1	4	0	0	3
38.	*Calcarina* sp.	3	5	2	0	0	1	0	2
39.	*Cyclammina cancellata*	0	0	1	2	1	0	0	0

40.	*Cornoboides* sp.	1	6	0	0	2	1	0	1
41.	*Cibicides lobatulus*	0	0	2	0	0	0	2	0
42.	*Globigerinoides sacculiferra*	2	0	1	2	1	0	0	1
43.	*Diffusilina* sp.	0	2	0	0	3	0	0	0
44.	*Eliphidium* sp.	0	0	1	1	1	0	0	1
45.	*Elphidium rapandus*	4	1	2	2	1	1	0	0
46.	*Eliphidium crispum*	0	2	0	0	1	0	2	1
47.	*Elphidium claticulatum*	0	0	0	4	0	2	0	0
48.	*Milionella* sp.	2	2	0	0	3	0	1	1
49.	*Quinqueloculina agglutinans*	1	0	1	0	0	1	0	0
50.	*Quinqueloculina* sp.	0	1	2	0	0	2	0	2
51.	*Triloculina* sp.	2	0	0	2	1	1	0	0
52.	*Hauerina* sp.	0	2	0	1	0	0	0	1
53.	*Hauerina fragilissima*	2	4	2	0	1	0	0	0
54.	*Lagena* sp.	1	0	1	2	1	1	1	2
55.	*Lagena semistriata*	3	2	1	1	0	0	0	1
56.	*Nanion depressulum*	0	1	1	2	2	0	0	0
57.	*Nonion* sp.	0	0	0	0	4	0	1	2
58.	*Rosalina bradyi*	2	0	2	3	0	2	2	0
59.	*Rosalina globularis*	3	1	1	2	1	3	0	1
60.	*Rotalia* sp.	1	0	0	0	0	1	0	1
61.	*Rotalia translucens*	0	0	1	1	0	0	0	0
62.	*Rotalia calcar*	1	1	0	0	1	0	0	2
63.	*Spirillina lateseptata*	2	2	1	0	0	1	2	1
64.	*Spiroloculina* sp.	4	0	2	0	0	2	2	1
65.	*Sorites* sp.	1	0	1	2	1	1	0	0
66.	*Textularia* sp.	1	1	0	0	0	1	0	1
67.	*Unknown* sp.	4	2	1	2	2	0	1	0
	Cumaceans								
68.	*Nannastacus inflatus*	2	0	3	0	2	0	0	0
69.	*Nannastacus* sp.	0	2	0	2	0	1	2	1
70.	*Gynodiastylis* sp.	2	0	0	0	0	2	0	2
71.	*Gynodiastylis lata*	2	4	0	1	0	0	3	0
72.	*Campylaspis minor*	1	0	1	0	1	2	2	1
73.	*Unknown* sp.	2	0	2	0	2	0	2	2
	Harpacticoids								
74.	*Microsetella rosea*	0	2	3	0	2	1	1	1
75.	*Microsetella norvegica*	1	0	1	1	0	0	3	0
76.	*Microsetella gracilis*	3	1	2	4	2	0	1	1
77.	*Canulla* sp.	1	4	0	1	0	0	0	0
78.	*Cylindropsyllus* sp.	3	1	2	0	1	2	2	0
79.	*Macrosetella* sp.	0	2	1	2	0	0	0	1
80.	*Laophonte thoracica*	1	0	0	1	2	0	0	0

81.	*Laophonte* sp.	2	1	1	0	3	0	2	1
82.	*Euterpina* sp.	1	3	1	1	1	3	2	0
83.	*Unknown* sp.	0	1	0	0	3	2	1	1
	Ostrocods								
84.	*Bairdoppilata scaura*	0	2	2	1	1	0	2	0
85.	*Conchoecia elegans*	1	1	0	0	0	2	0	1
86.	*Cypridina* sp.	3	3	0	2	0	0	1	3
87.	*Parastenocypris* sp.	2	0	2	1	1	3	2	3
88.	*Strandesia elongata*	0	3	1	0	0	0	4	2
89.	*Stenocypris major*	4	2	0	1	3	0	2	0
90.	*Strandesia* sp.	0	0	1	0	2	1	0	2
91.	*Basslerites liebaui*	1	1	0	0	0	3	2	0
92.	*Unknown* sp.	2	0	2	1	1	3	2	1
	Others								
93.	*Grania* sp.	0	2	1	2	1	0	2	0
94.	*Pycnophyes* sp.	0	0	2	0	1	1	0	2
95.	Polychaete larvae	1	0	0	1	0	0	1	0
96.	*Turbellarian* sp.	2	2	0	0	1	0	0	2
97.	*Rotaria rototoria*	0	0	2	1	0	0	0	2
98.	*Pycnophyes greenlandicus*	1	1	0	3	0	0	1	2
99.	*Apseudes spinosus*	0	0	2	3	1	3	2	1
100.	*Cephalodasys* sp.	1	3	0	1	0	0	0	0
101.	*Olichochaetes*	2	0	2	0	0	2	1	2
102.	Unknown sp.	0	2	0	1	0	2	0	0

Summary results and remarks

Sediment samples were collected from all the zones to assess the density and diversity of macro and meiofaunal communities. Density and diversity of both macro and meiofaunal communities were reasonably good in the study area. A total of six groups such as polychaetes, gastropods, bivalves, amphipods, isopods and others were categorised from the samples collected. Among them, polychaetes were the dominant group followed by gastropods. Meiofaunal groups within the study area include six major groups such as nematodes, Foraminifera, cumaceans, Harpacticoids, Ostrocods, and others. A total of 40 macrofaunal species and 73 species of meiofauna were observed in the mangrove waters. In Kosasthalaiyar River, a total of 34 macrofaunal species and 66 meiofaunal species were recorded. In the canal samples, 27 species of macrofauna and 58 species of meiofauna were identified. Samples from Pulicat Lake and Ennore Creek revealed 42 macrofaunal species and 58 meiofaunal species. From the marine samples, a total of 110 species of macrofauna and 102 species of meiofauna were observed.

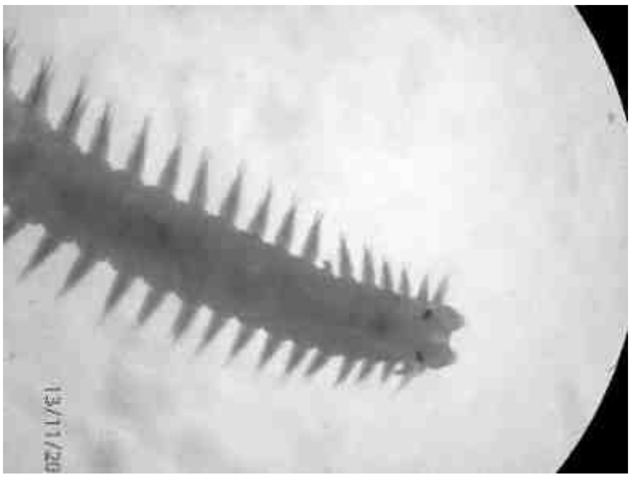
Macro and meio benthic species in Mangrove waters

***Spionidae* sp.**

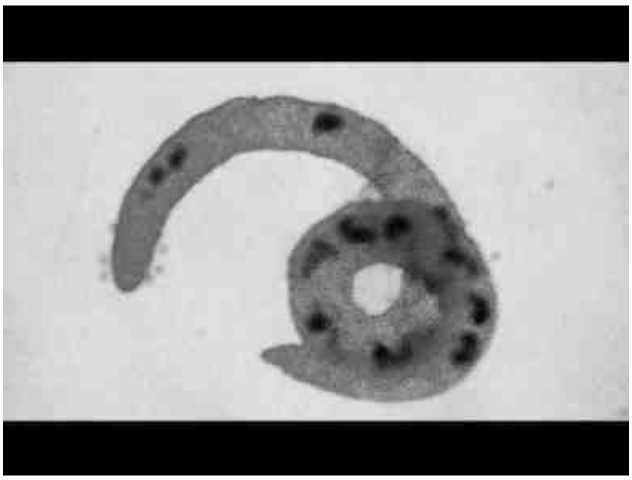
***Syllis* sp.**

Nereis capensis

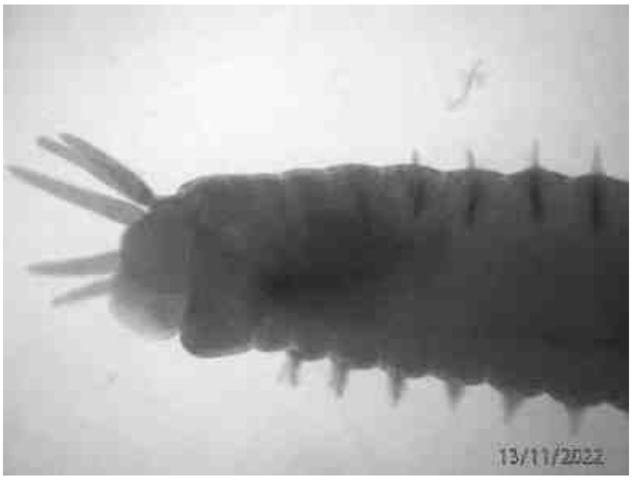
Polychaetes larvae



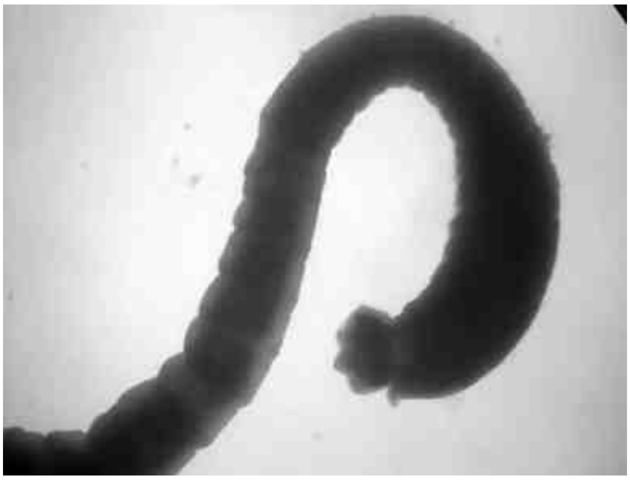
Polychaetes larvae 2



Prionospio pinnata



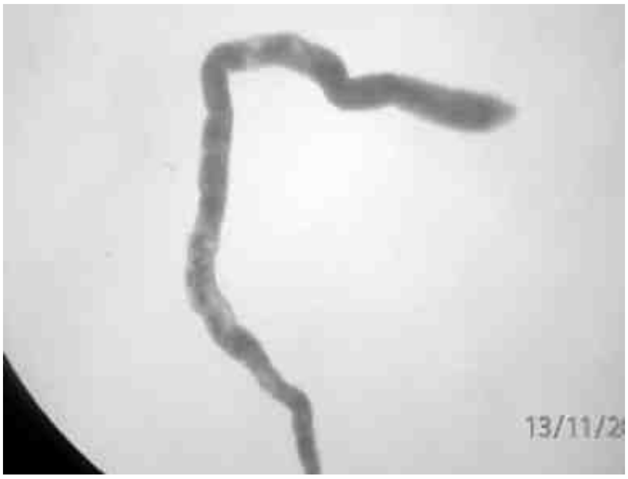
Eunice indica



***Capitellidae* sp.**

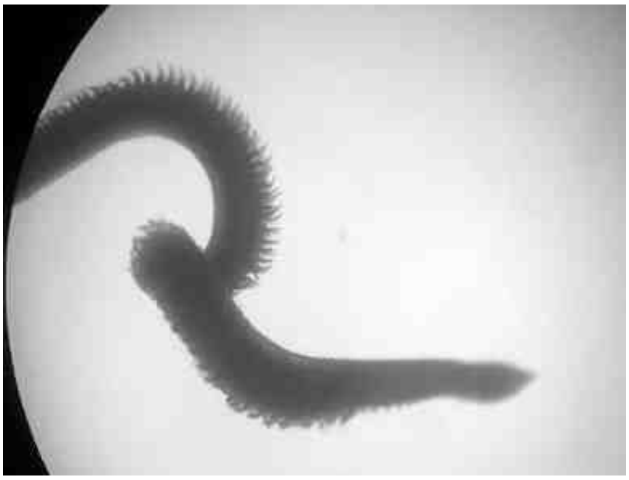
***Boccardia* sp.**

Capitella capitata



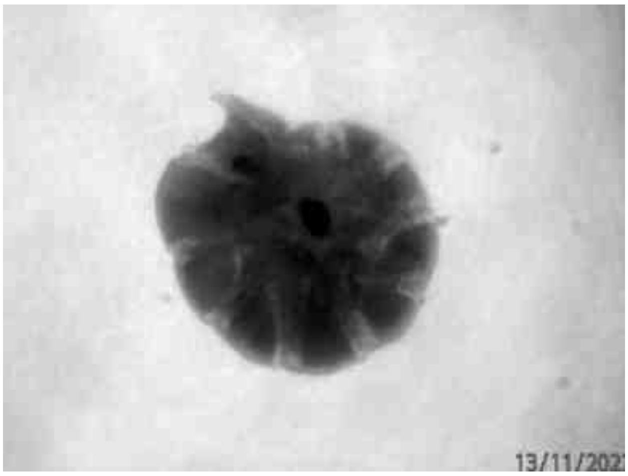
***Lumbrineris* sp.**

Polychetes larvae 2

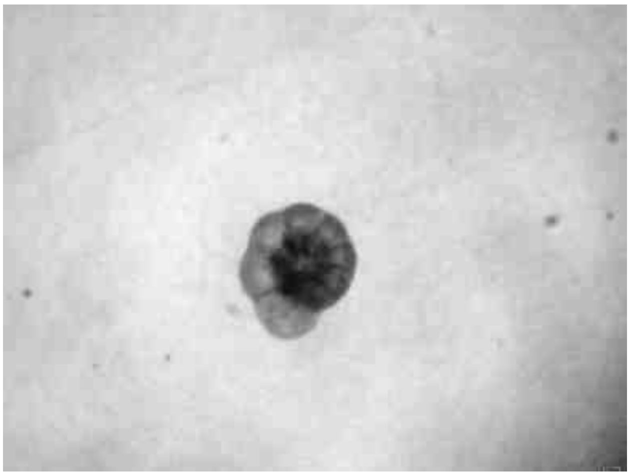


Orbinia angrapequensis

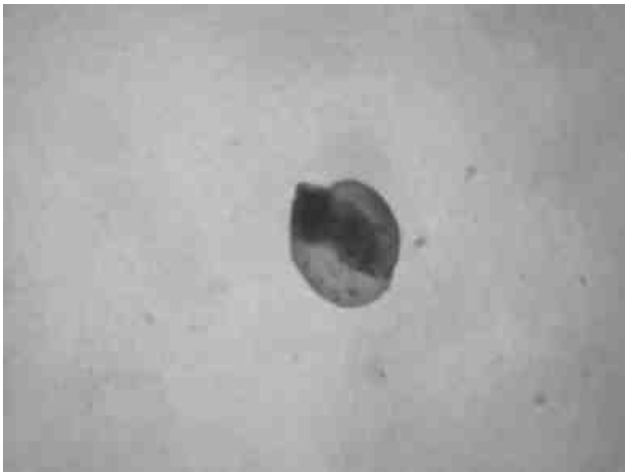
***Rotalia* sp.**



***Ammonia* sp.**



Rosalina bradyi



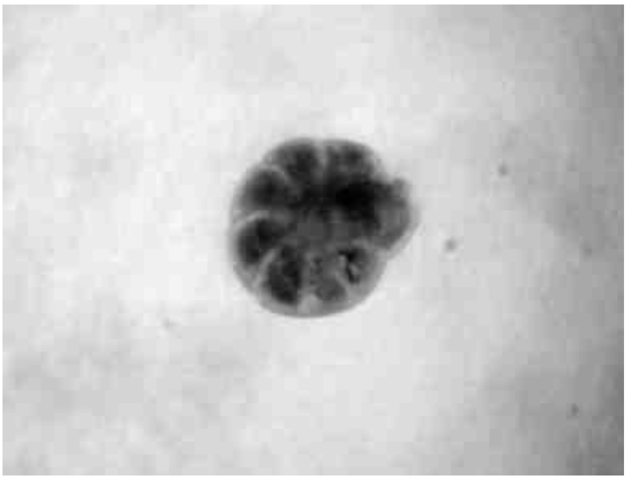
***Milionella* sp.**

Eliphidium crispum

***Triloculina* sp.**

***Nanion* sp.**

Spiroloculina depressa

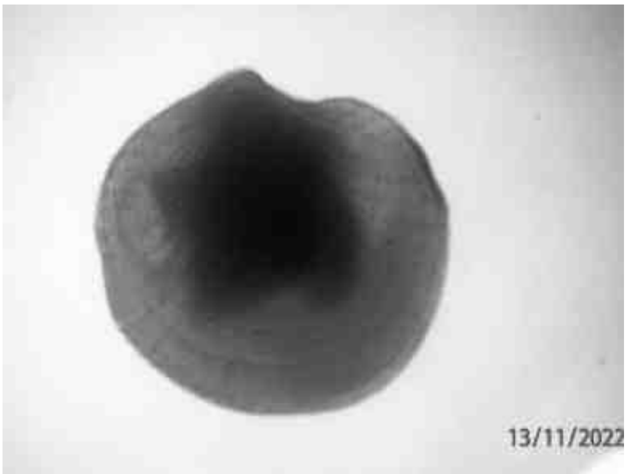


***Cornoboides* sp.**

Nassarius stolatus

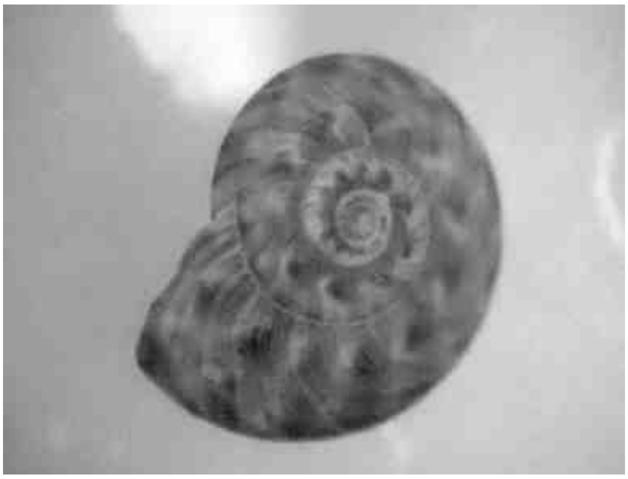
Cerithedea cingulata

***Donax* sp.**



Bivalve veliger

***Amphithoe* sp.**

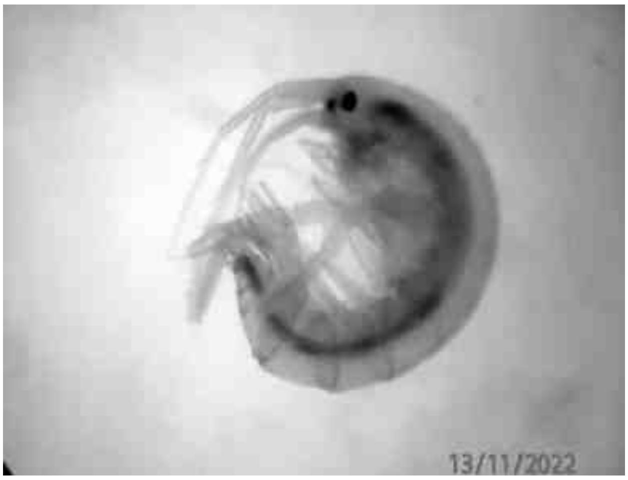


Umbonium vestiarum

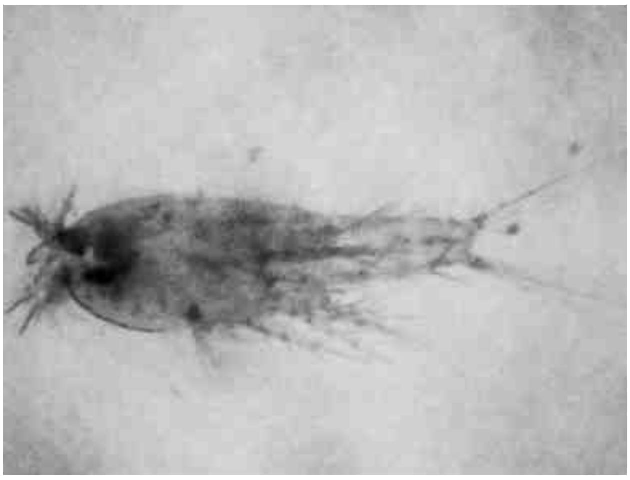
***Asellota* sp.**

Umbonium vestiarium 2

Halalaimus **sp.**



Gammarus **sp.**



Euterpina **sp.**

Desmodora **sp.**

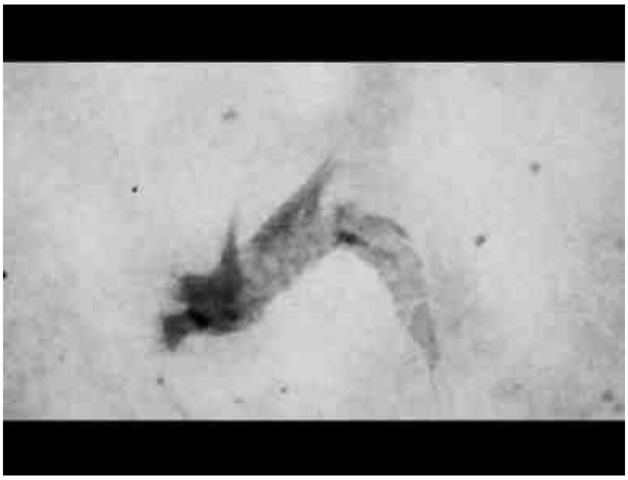
Crab **sp.**

Isopods **sp.**

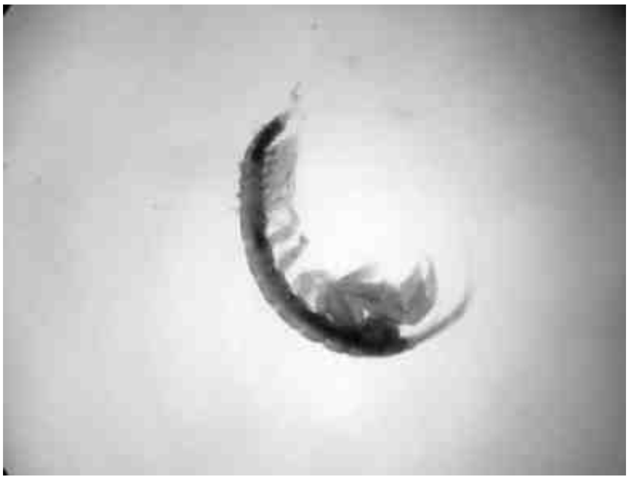
Eunice indica

***Ostrocod* sp,**

***Nereis* sp.**



Macrosetella* sp. *2



***Janiroidae* sp.**

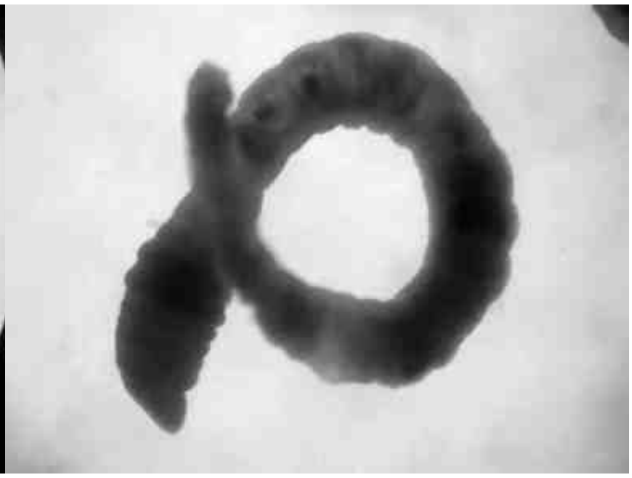
***Penaeus* sp.**

Macro and meio benthic species in Kosasthalaiyar River

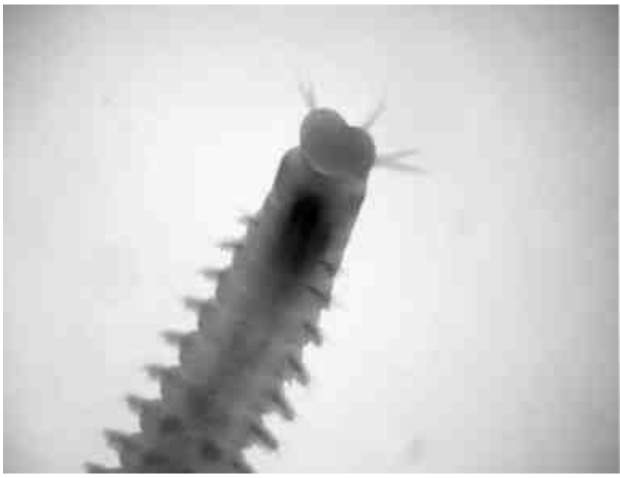
Boccardia **sp.**

Capitella **sp.*3***

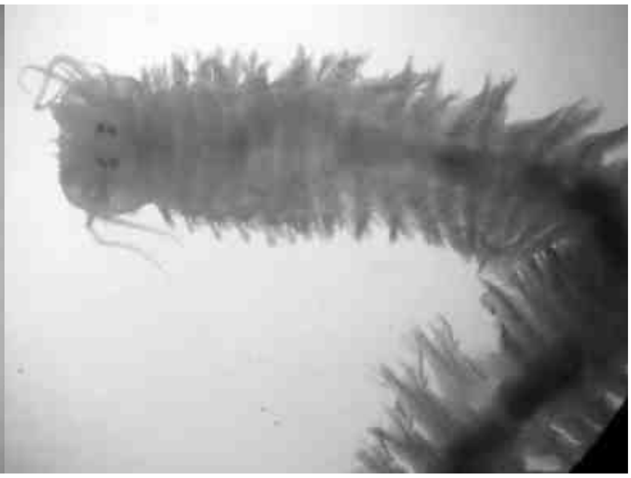
Capitellidae **sp.*2***



Lumbrineris **sp.*3***

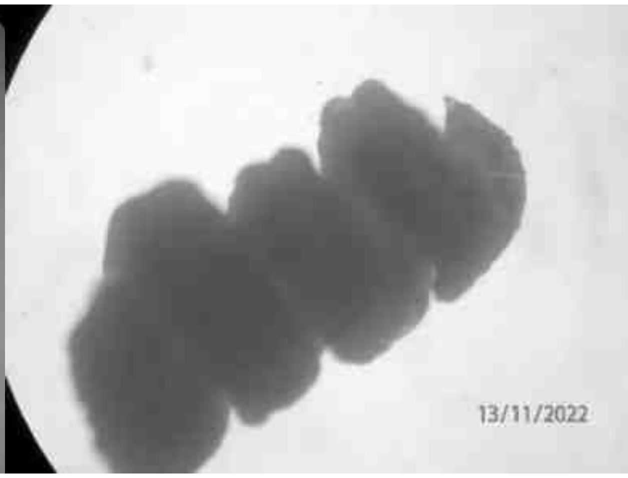


Eunice **sp.**



Nereis **sp.**

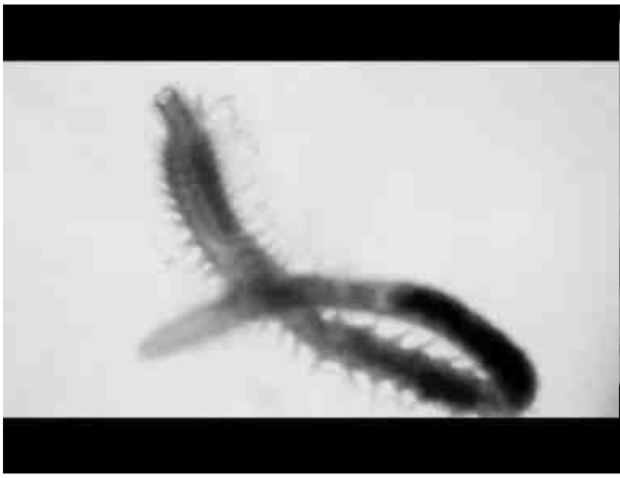
Orbinia angrapequensis 2



Orbinia **sp.2**

Polychaeta **sp.**

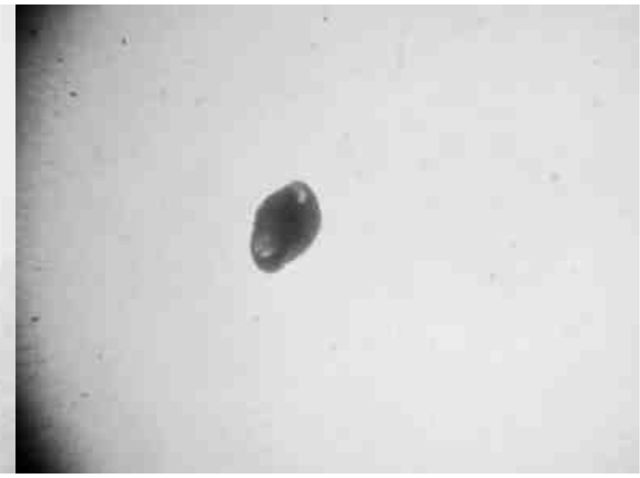
Spionidae head



Syllis **sp.2**

Cornoboides sp.2

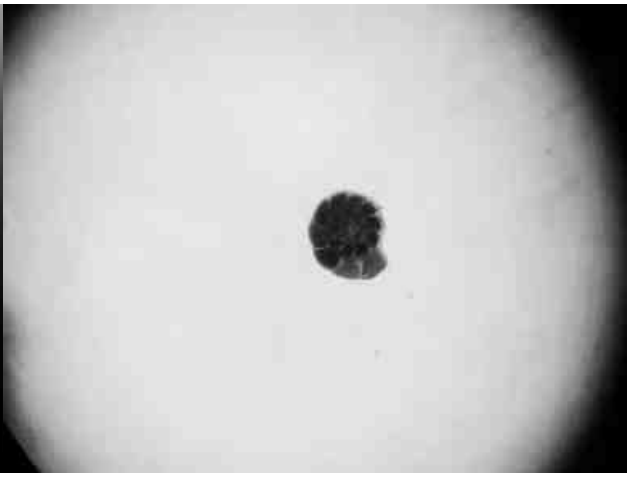

Rosalina sp.


Triloculina sp.

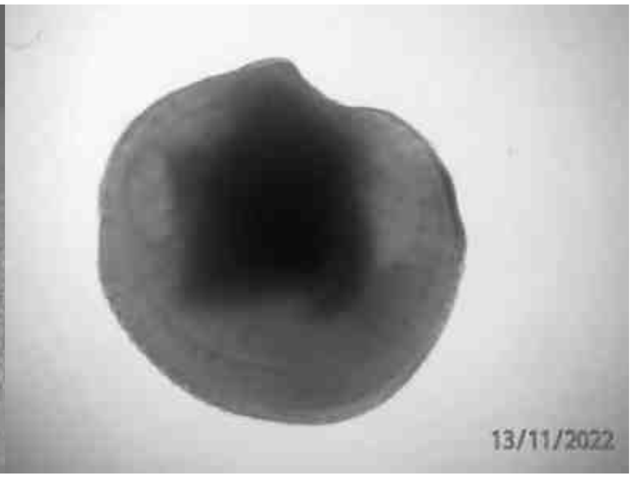

Cerithedea sp.2


Nassarius sp.


Umbonium sp.

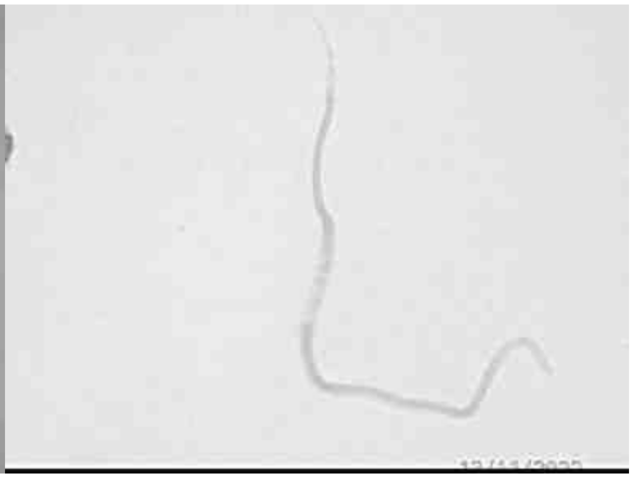

Umbonium vestiarum

Donax **sp.**

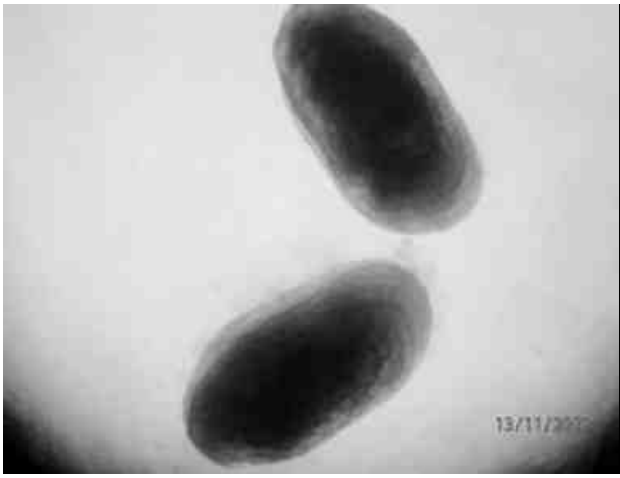


Bivalve veliger

Amphithoe **sp.*2***



Halalaimus **sp. *2***



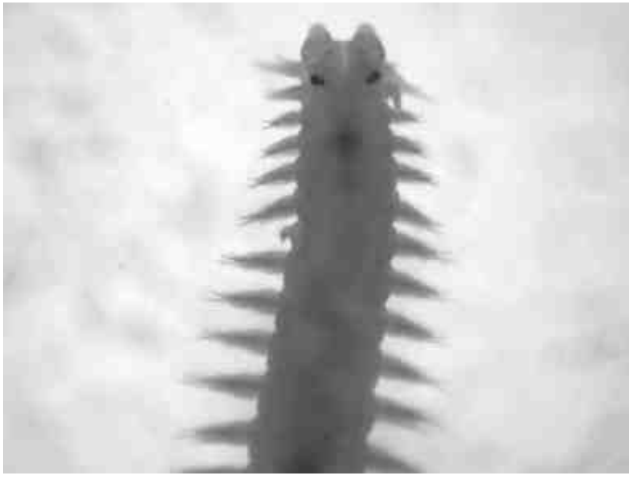
Ostrocod **sp. *2***

Penaeus **sp. *2***

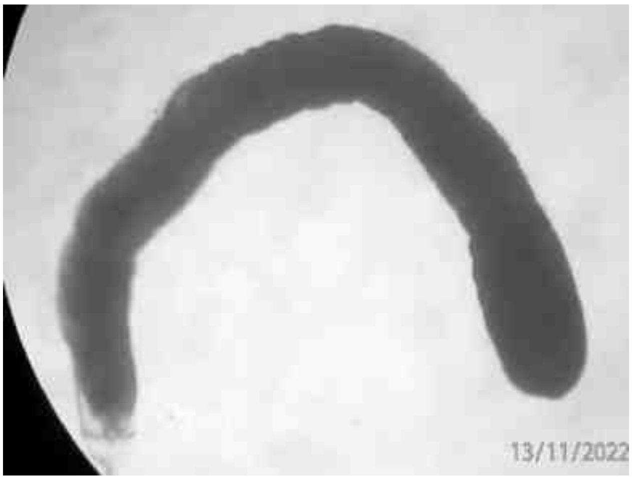
Macro and meio benthic species in Buckingham canal

Prionospio pinnata 2

Capitella capitata

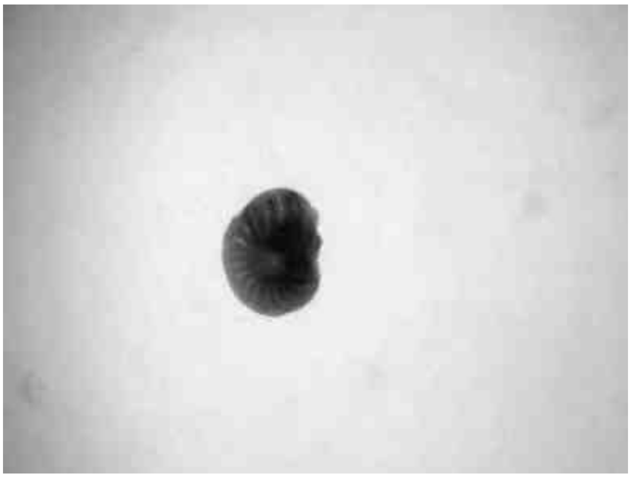


Nereis* sp. *2

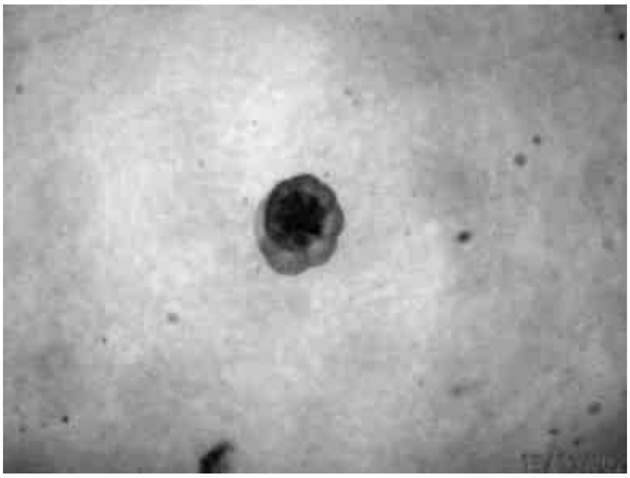


***Capitellidae* sp.**

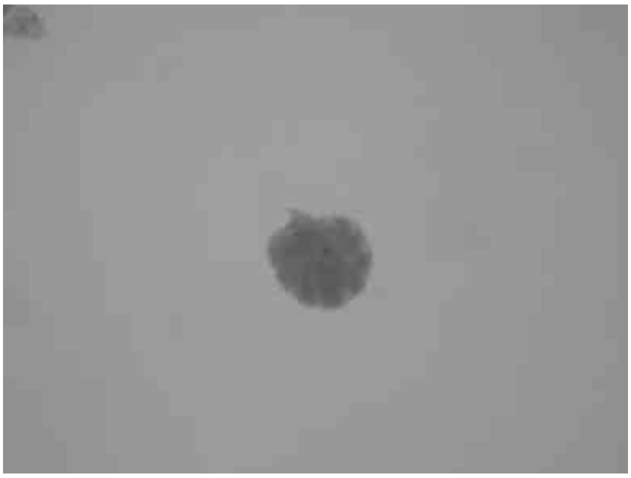
Spionidae* sp. *2



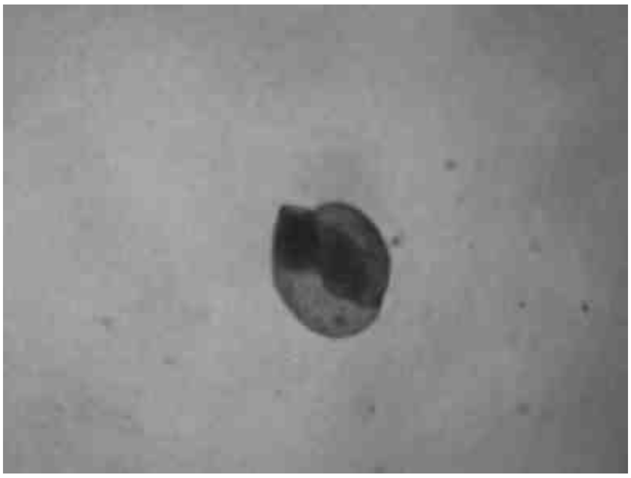
***Eliphidium* sp.**



***Rosalina* sp.**

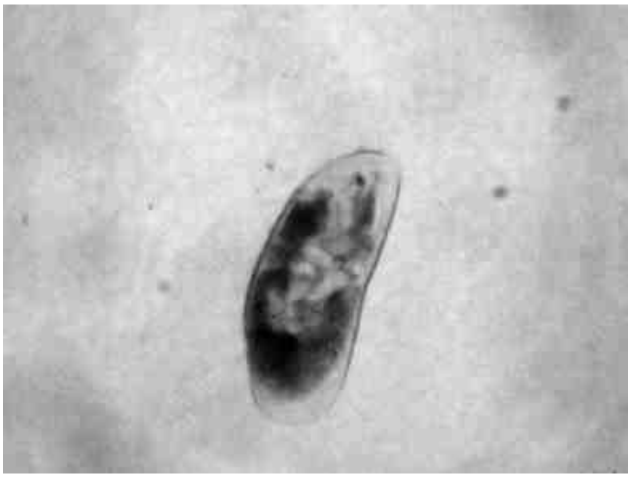


***Ammonia* sp.**

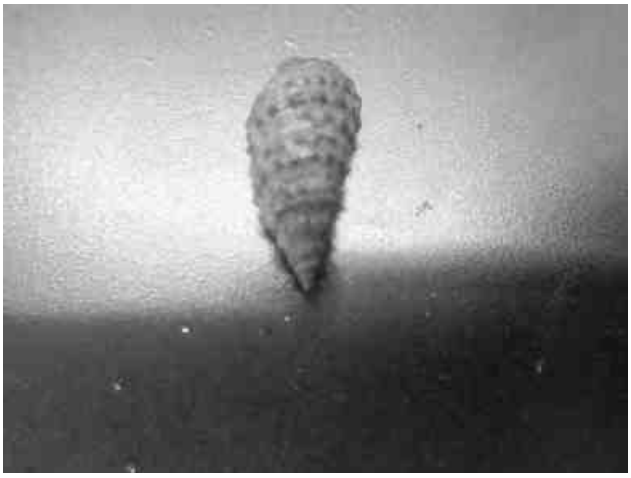


Triloculina* sp. *2

Janiroides* sp. *2



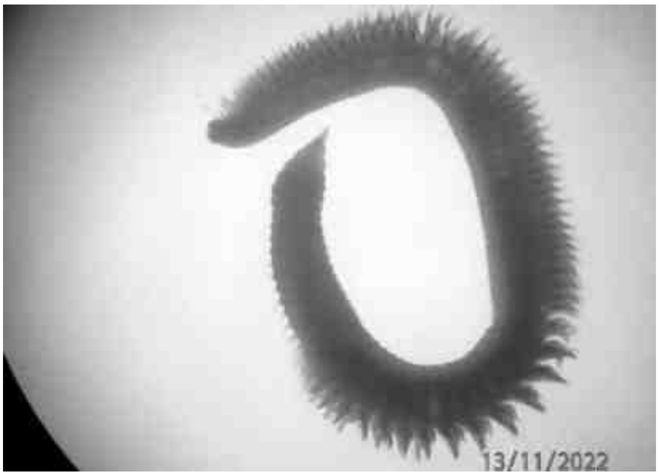
***Spionidae* sp.**



***Cerithidea* sp.**

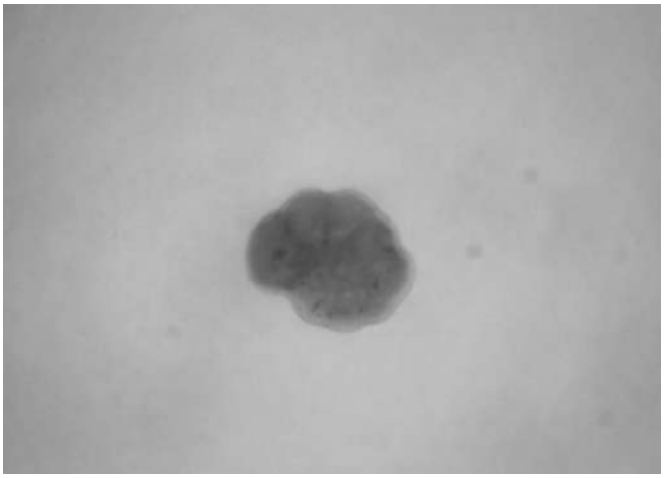
Macro and meio benthic species in Pulicat lake and Ennore creek

***Lumbrineris* sp.2**

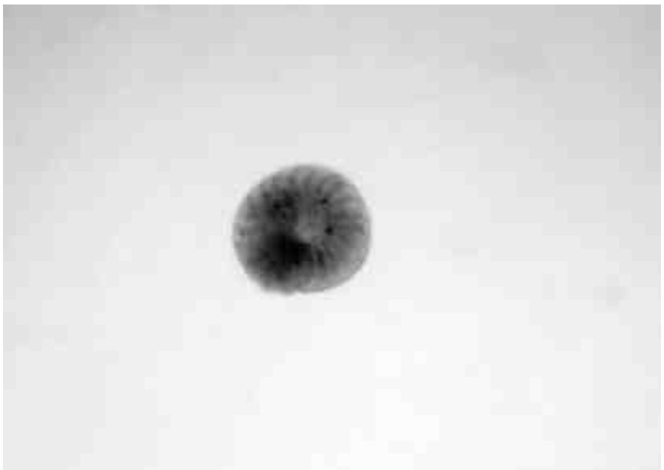


***Orbinia* sp .**

***Prionospio* sp.**



***Cornoboides* sp. 2**



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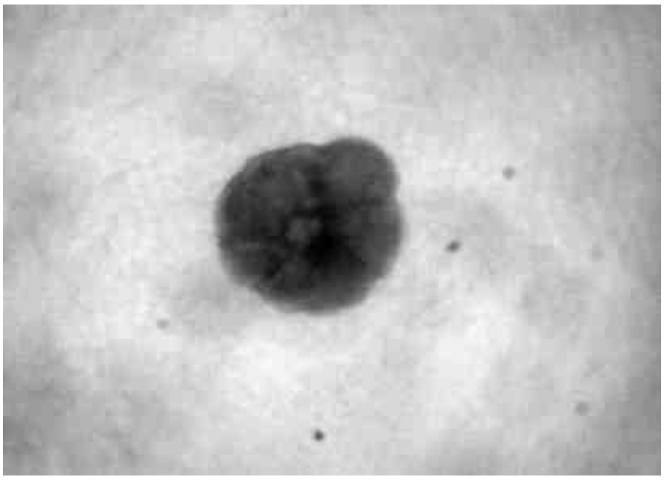
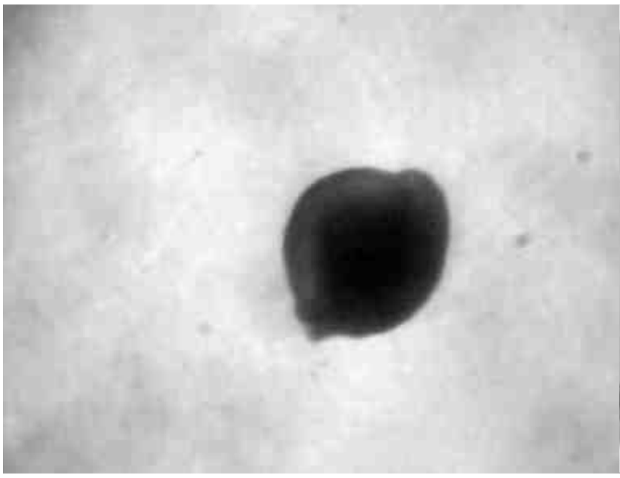
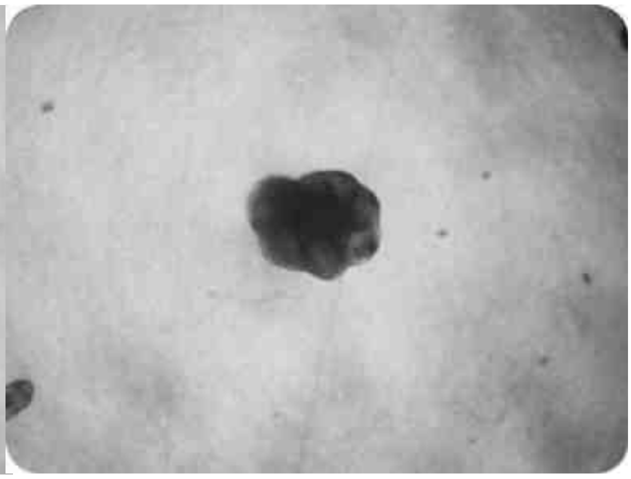


***Globorotalia* sp.**



***Milionella* sp.2**



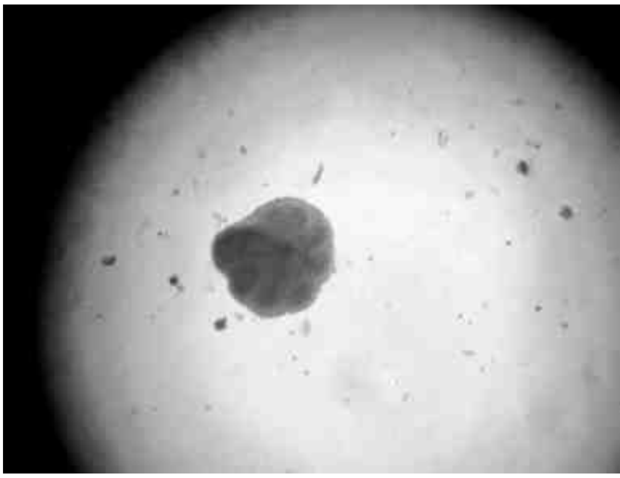
***Rosalina* sp.2**

***Nanion* sp.2**

***Rotalia* sp. 1**

***Spiroloculina* sp.**

***Triloculina* sp.2**

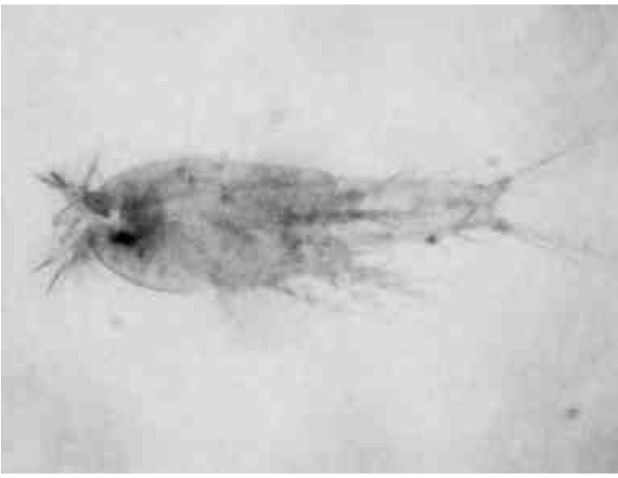


Rotalia **sp.2**

Umbonium **sp.**

Oxystomina **sp.2**

Macrosetella **sp.**



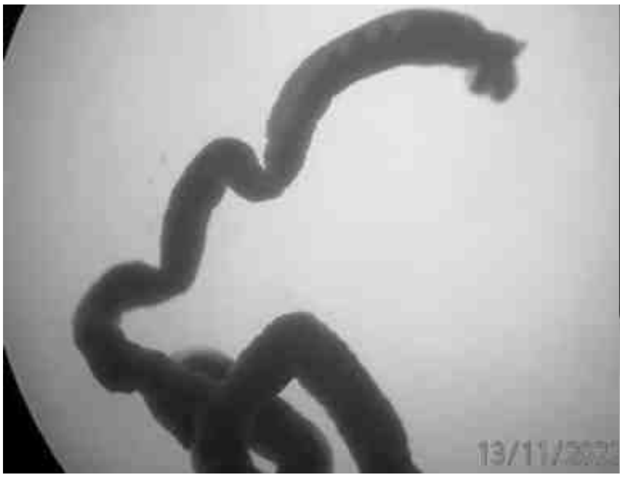
Euterpina **sp.2**

Ostrocod **sp.**

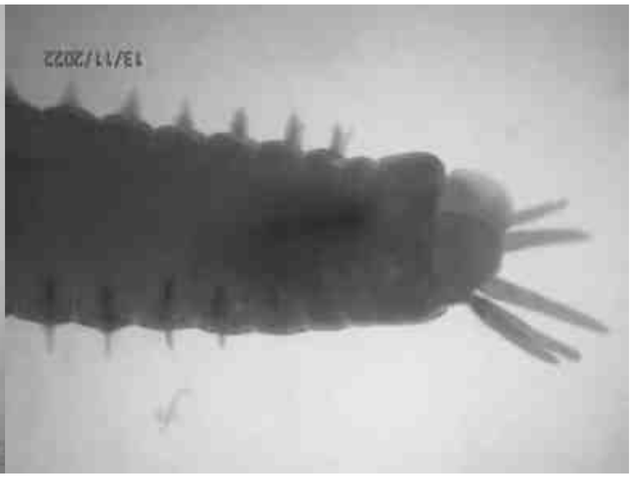
Macro and meio benthic species in Marine zone

Boccardia sp.2

Capitella capitata

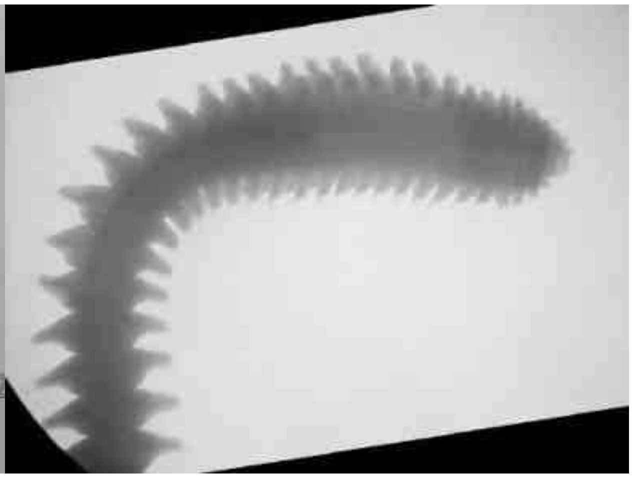


Capitellidae sp.1



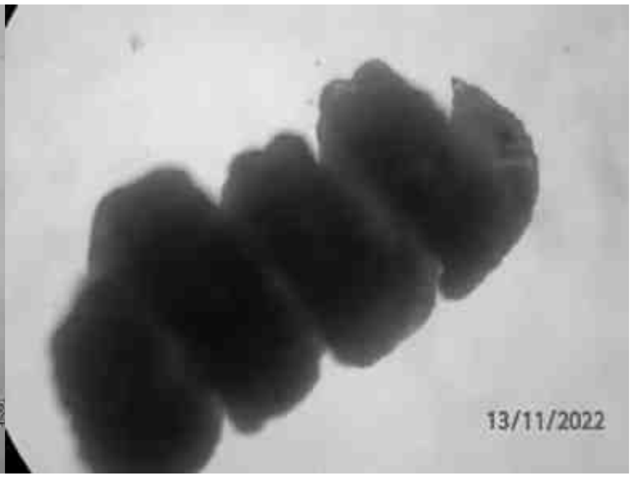
Eunice sp.

Lumbrineris sp.1



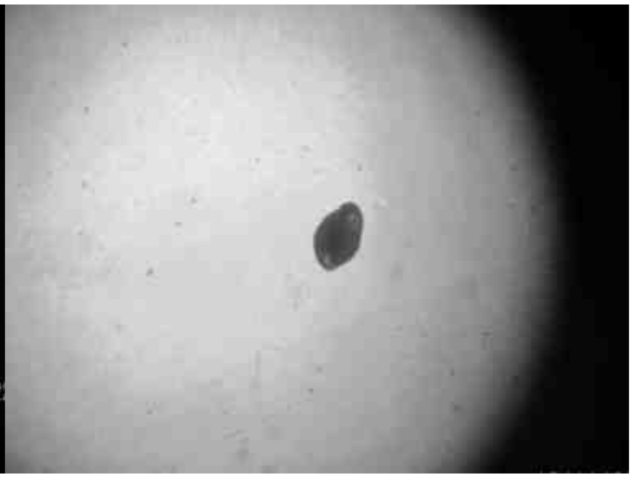
Nereis sp.

Orbinia sp.1

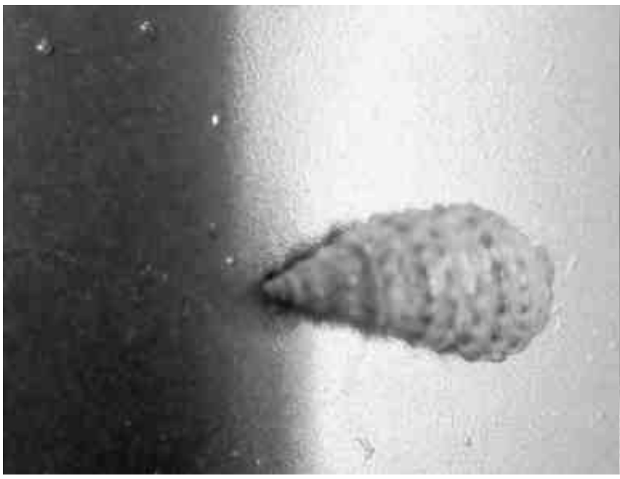


Orbinia sp

Cornoboides sp.1

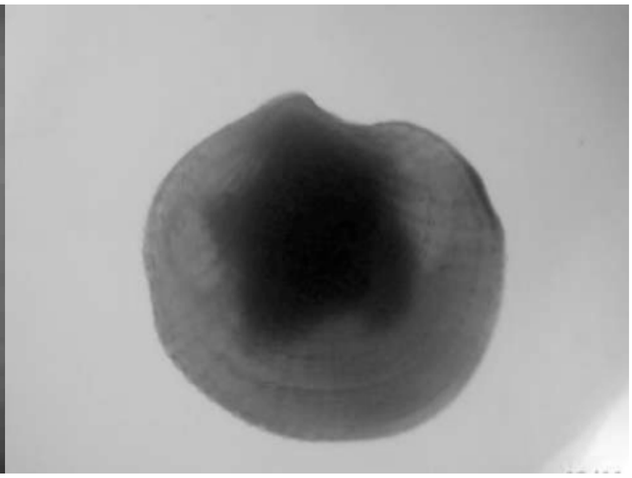


Triloculina sp.1



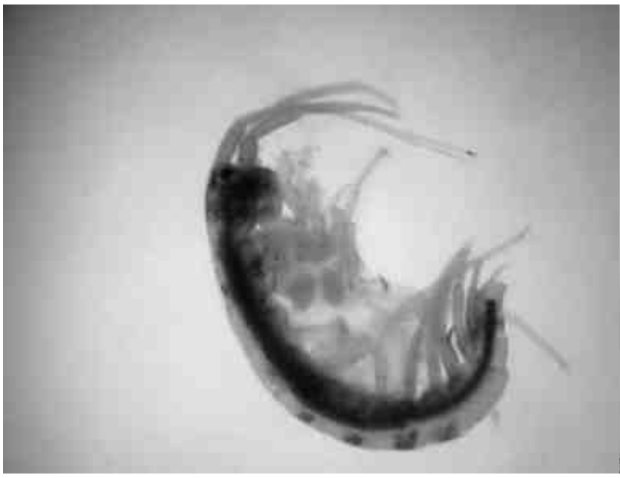
Cerithidea sp.

Nassarius sp.



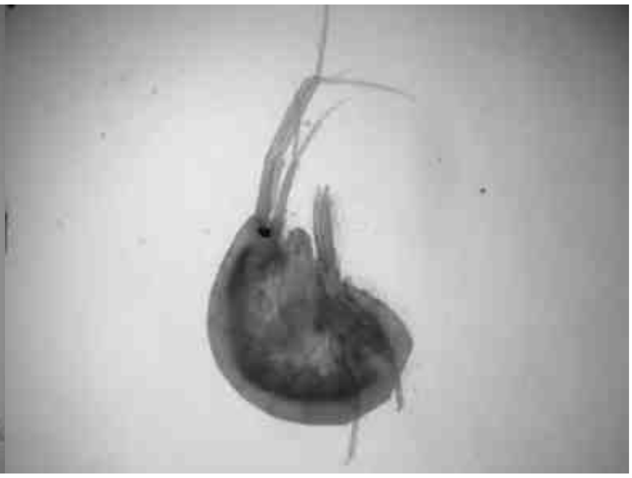
***Umbonium* sp.**

***Bivalve* sp.**



***Amphithoe* sp.1**

***Asellota* sp.2**



***Decapoda* sp.**

***Gammarus* sp.1**

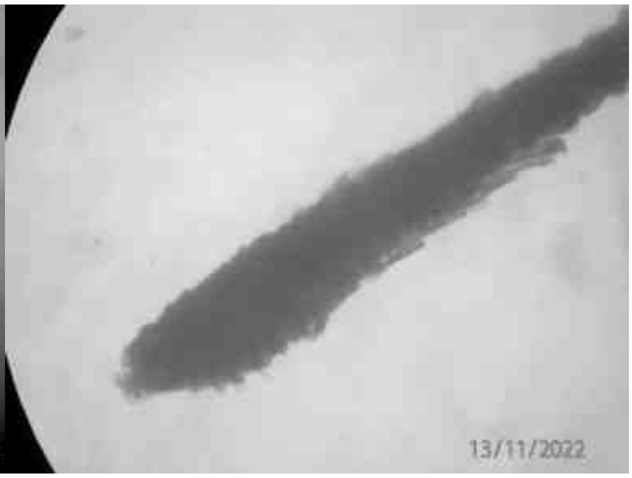
Macrosettella sp.

Ostrocod sp.4

Penaeus sp.

Unidentified sp.2

Unidentified sp.2



Unidentified sp.3

v. Phytoplankton and zooplankton community structure

1. Phytoplankton

a. Buckingham canal

A total of 14 phytoplankton species belonging to three groups such as Diatoms, Dinoflagellates and Cyanophyceae were recorded from the 12 sampling stations collected in Buckingham canal waters. Phytoplankton density in the sampling site showed a range of 100-4000 cells/l (Table.3.5.1). Four sites showed presence of phytoplankton. Amongst the groups, Diatoms showed to be the most dominant among the 14 recorded species (Table.3.5.2).

In Buckingham canal, the chlorophyll 'a' in water sample varied from 0.33 to 3.74 mg/m^3 with maximum at B12 and minimum at B5. The chlorophyll 'b' content varied from 0.11 to 2.92 mg/m^3 with maximum in B12 and the minimum was observed in B10. The primary productivity values varied from 110.52 to 340.63 $mgCm^{-3}d^{-1}$ with the maximum value was recorded at the B12 and minimum value was at B3 (Table.3.5.4).

Table 3.5.1: Phytoplankton density at Buckingham canal

SITES	Plankton Density (Cells/l)
B1	0
B2	100
B3	0
B4	0
B5	0
B6	0
B7	500
B8	800
B9	0
B10	0
B11	0
B12	4000

Table 3.5.2: Phytoplankton species recorded in Buckingham canal

S.No	Phytoplankton
	Bacillariophyceae (Diatoms)
1	*Bacillaria* sp.
2	*Coscinodiscus centralis*
3	*Coscinodiscus* sp.
4	*Hemidiscus hardmannianus*
5	*Navicula* sp.

6	*Pleurosigma* sp.
7	*Thalassionema nitzschioides*
8	*Thalassiothrix fraunfeldii*
9	*Triceratium* sp.
10	*Rhizosolenia* sp.
	Dinoflagellates
11	*Pyrophacus steinii*
12	*Ceratium* sp.
	Cyanophyceae (Blue-greens)
13	*Oscillatoria* sp.
14	*Trichodesmium erythraeum*

Table 3.5.3: Occurrence of phytoplankton species in Buckingham canal

Plankton Species	**STATIONS**											
Bacillariophyceae (Diatoms)	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**
Bacillaria sp.	-	-	-	-	-	-	+	-	-	-	-	-
Coscinodiscus centralis	-	-	-	-	-	-	-	-	-	-	-	+
Coscinodiscus sp.	-	+	-	-	-	-	-	-	-	-	-	+
Hemidiscus hardmannianus	-	-	-	-	-	-	+	-	-	-	-	+
Navicula sp.	-	-	-	-	-	-	-	+	-	-	-	-
Pleurosigma sp.	-	-	-	-	-	-	+	+	-	-	-	-
Rhizosolenia sp.	-	+	-	-	-	-	-	-	-	-	-	-
Thalassionema nitzschioides	-	-	-	-	-	-	-	-	-	-	-	+
Thalassiothrix fraunfeldii	-	-	-	-	-	-	-	+	-	-	-	+
Triceratium sp.	-	-	-	-	-	-	-	-	-	-	-	-
Dinoflagellates												
Pyrophacus steinii	-	-	-	-	-	-	-	+	-	-	-	-
Ceratium sp.	-	+	-	-	-	-	+	-	-	-	-	+
Cyanophyceae (Blue-greens)												
Oscillatoria sp.	-	-	-	-	-	-	-	-	-	-	-	+
Trichodesmium erythraeum	-	-	-	-	-	-	-	-	-	-	-	+

***+ Present; *- Absent**

Table 3.5.4: Chlorophyll ‘a’, ‘b’ and primary productivity at Buckingham canal

Sampling sites (Canal)	Chlorophyll ‘a’ (mg/m^3)	Chlorophyll ‘b’ (mg/m^3)	Primary productivity (mg c/m^3/day)
B1	0.73	0.31	120.33
B2	1.84	1.25	201.15
B3	0.80	0.14	110.52
B4	0.45	0.22	120.65
B5	0.33	0.19	130.83
B6	0.61	0.43	150.39
B7	1.33	1.17	200.23
B8	1.72	1.10	250.47
B9	0.55	0.40	120.51
B10	0.41	0.11	160.15
B11	0.51	0.21	190.01
B12	3.74	2.92	340.63

b. Ennore creek

A total of 17 phytoplankton species belonging to two groups such as Diatoms and Dinoflagellates were recorded from the 5 sampling stations collected in Ennore water region. Phytoplankton density in the sampling site showed a range of 200-4100 cells/l (Table. 3.5.5). Five sites showed the presence of phytoplankton. Amongst the groups Diatoms showed to be the most dominant among the 17 recorded species (Table.3.5.6).

In Ennore Creek, the chlorophyll ‘a’ in water sample varied from 1.14 to 5.25 mg/m^3 with maximum at En4 and minimum at En1. The chlorophyll ‘b’ content varied from 0.99 to 3.96mg/m^3 with maximum in En4 and the minimum was observed in En1. The primary productivity was measured using the dark and light reaction method. The values varied from 109.45 to 245.87$mgCm^{-3}d^{-1}$ with the maximum value was recorded at the En4 and minimum value was at En1 (Table.3.5.8).

Table 3.5.5: Phytoplankton density at Ennore creek

SITES	Plankton Count (Cells/l)
En1	**200**
En2	**1700**
En3	**3300**
En4	**4100**
En5	**3900**

Table 3.5.6: Phytoplankton species recorded in Ennore creek

S.No	Phytoplankton
	Bacillariophyceae (Diatoms)
1	*Bacteriastrum delicatulum*

2	*Chaetoceros affinis*
3	*Chaetoceros* sp.
4	*Coscinodiscus* sp.
5	*Cyclotella* sp.
6	*Hemidiscus hardmannianus*
7	*Navicula* sp.
8	*Nitzschia* sp.
9	*Pleurosigma* sp.
10	*Thalassionema nitzschioides*
11	*Thalassiothrix fraunfeldii*
12	*Triceratium* sp.
	Dinoflagellates
13	*Ceratium furca*
14	*Ceratium macroceros*
15	*Ceratium trichoceros*
16	*Ornithocercus steinii*
17	*Protoperidinium depressum*

Table 3.5.7: Occurence of phytoplankton species in Ennore creek

Plankton Species	STATIONS				
Bacillariophyceae (Diatoms)	**En1**	**En2**	**En3**	**En4**	**En5**
Bacteriastrum delicatulum	-	+	-	+	-
Chaetoceros affinis	-	-	-	+	-
Chaetoceros sp.	+	+	-	+	+
Coscinodiscus sp.	-	+	+	+	+
Cyclotella sp.	-	+	-	-	-
Hemidiscus hardmannianus	+	-	+	+	-
Navicula sp.	-	-	-	+	+
Nitzschia sp.	-	-	-	+	-
Pleurosigma sp.	+	-	+	-	+
Thalassionema nitzschioides	-	+	-	+	+
Thalassiothrix fraunfeldii	-	-	-	+	-
Triceratium sp.	-	-	+	-	+
Dinoflagellates					
Ceratium furca	+	-	-	-	+
Ceratium macroceros	-	+	-	+	-
Ceratium trichoceros	-	+	-	-	+
Ornithocercus steinii	-	+	-	-	-
Prorocentrum maximum	-	-	-	+	-
Protoperidinium depressum	-	-	+	-	+

+ Present; - Absent

Table 3.5.8: Chlorophyll 'a', 'b' and primary productivity at Ennore creek

Sampling sites (Ennor creek)	Chlorophyll 'a' (mg/m^3)	Chlorophyll 'b' (mg/m^3)	Primary productivity (mg c/m^3/day)
En1	1.14	0.99	108.45
En2	2.23	1.75	195.32
En3	4.24	3.51	206.18
En4	5.25	3.96	245.87
En5	4.69	3.84	231.51

C. Mangrove waters

A total of 10 phytoplankton species belonging to the Diatoms and Dinoflagellates group were recorded from the 11 sampling stations collected in Mangrove region. Phytoplankton density in the sampling site showed a range of 500-9300 cells/l (Table.3.5.9). All 11 sites showed the presence of phytoplankton. Amongst the groups Diatoms showed to be the most dominant among the 10 recorded species (Table.3.5.10).

In Mangrove area, the chlorophyll 'a' in water sample varied from 1.46 to 8.53 mg/m^3 with maximum at M3 and minimum at M5. The chlorophyll 'b' content varied from 1.11 to 2.75 mg/m^3 with maximum in M11 and the minimum was observed in M5. The primary productivity values varied from 200.66 to 501.24 mgCm^{-3}d^{-1} with the maximum value was recorded at the M3 and minimum value was at M6 (Table. 3.5.12).

Table 3.5.9: Phytoplankton density at Mangrove waters

SITES	Plankton Count (Cells/l)
M1	**6500**
M2	**7100**
M3	**9300**
M4	**6700**
M5	**500**
M6	**1200**
M7	**3400**
M8	**3700**
M9	**4100**
M10	**4500**
M11	**6600**

Table 3.5.10:Phytoplankton species recorded in Mangrove waters

S.No	Phytoplankton
	Bacillariophyceae (Diatoms)
1	*Chaetoceros affinis*
2	*Chaetoceros* sp.
3	*Coscinodiscus* sp.

4	*Hemidiscus hardmannianus*
5	*Navicula* sp.
6	*Rhizosolenia* sp.
7	*Thalassionema nitzschioides*
8	*Thalassiothrix fraunfeldii*
	Dinoflagellates
9	*Dinophysis caudata*
10	*Noctiluca* sp.

Table 3.5.11:Occurence of phytoplankton species in Mangrove waters

Plankton Species	**STATIONS**										
Bacillariophyceae (Diatoms)	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**
Chaetoceros affinis	-	-	+	+	-	+	+	-	+	+	-
Chaetoceros sp.	+	+	+	+	-	+	-	+	+	-	+
Coscinodiscus sp.	+	-	+	+	+	-	+	+	+	+	+
Hemidiscus hardmannianus	-	+	+	-	-	-	+	-	-	+	+
Navicula sp.	-	-	-	-	+	-	-	-	-	+	-
Rhizosolenia sp.	+	+	+	-	-	-	-	+	+	+	-
Thalassionema nitzschioides	+	+	+	-	-	+	-	+	-	-	+
Thalassiothrix fraunfeldii	-	+	-	+	-	-	-	+	+	-	+
Dinoflagellates											
Dinophysis caudata	-	+	-	-	-	+	+	-	-	+	-
Noctiluca sp.	-	-	-	-	-	-	+	-	-	+	+

+ Present; - Absent

Table 3.5.12: Chlorophyll ‘a’ , ‘b’ and primary productivity at Mangrove waters

Sampling sites (Mangrove)	**Chlorophyll ‘a’ (mg/m^3)**	**Chlorophyll ‘b’ (mg/m^3)**	**Primary productivity (mg c/m^3/day)**
M1	7.39	2.31	450.55
M2	7.94	2.56	480.69
M3	8.53	2.71	501.24
M4	7.36	2.09	420.41
M5	1.46	1.11	266.73
M6	2.15	1.82	200.66
M7	4.44	2.16	350.91
M8	4.67	1.92	390.14
M9	5.45	2.28	440.56
M10	5.67	2.53	470.45
M11	6.24	2.75	490.88

d. Pulicat Lake

A total of 16 phytoplankton species belonging to Diatoms, Dinoflagellates and Cyanophyceae groups were recorded from the 6 sampling stations collected in the Pulicat lake region. Phytoplankton density in the sampling site showed a range of 6500-12700 cells/l (Table.3.5.13). All 6 sites showed the presence of phytoplankton. Amongst the groups Diatoms showed to be the most dominant among the 16 recorded species (Table.3.5.14).

In Pulicat Lake, the chlorophyll ‘a’ in water sample varied from 2.75 to 3.92 mg/m3 with maximum at Pu5 and minimum at Pu1. The chlorophyll ‘b’ content varied from 0.99 to 2.39 mg/m3 with maximum in Pu5 and the minimum was observed in Pu1. The primary productivity was measured using the dark and light reaction method. The values varied from 310.73 to 455.61 $mgCm^{-3}d^{-1}$ with the maximum value was recorded at the Pu5 and minimum value was at Pu1 (Table.3.5.16).

Table 3.5.13: Phytoplankton density at Pulicat Lake

SITES	Plankton Count (Cells/l)
Pu1	6500
Pu2	7200
Pu3	10600
Pu4	11100
Pu5	12700
Pu6	12400

Table 3.5.14: Phytoplankton species recorded in Pulicat Lake

S.No	Phytoplankton
	Bacillariophyceae (Diatoms)
1	*Chaetoceros affinis*
2	*Chaetoceros* sp.
3	*Coscinodiscus* sp.
4	*Navicula* sp.
5	*Ditylum* sp.
6	*Nitzschia* sp.
7	*Planktoniella sol*
8	*Pleurosigma* sp.
9	*Rhizosolenia* sp.
10	*Thalassionema nitzschioides*
	Dinoflagellates
11	*Ceratium furca*
12	*Ceratium macroceros*
13	*Dinophysis caudata*
14	*Noctiluca* sp.
15	*Protoperidinium depressum*
	Cyanophyceae (Blue-greens)
16	*Oscillatoria* sp.

Table 3.5.15: Occurence of phytoplankton species in Pulicat Lake

Plankton Species	Stations					
Bacillariophyceae (Diatoms)	**Pu1**	**Pu2**	**Pu3**	**Pu4**	**Pu5**	**Pu6**
Chaetoceros affinis	-	+	-	-	+	-
Chaetoceros sp.	+	-	-	+	+	+
Coscinodiscus sp.	+	+	+	+	+	+
Ditylum sp.	-	-	-	-	-	+
Navicula sp.	+	-	+	-	+	-
Nitzschia sp.	-	-	-	+	-	+
Planktoniella sol	-	-	-	+	-	-
Pleurosigma sp.	-	+	+	-	+	+
Thalassionema nitzschioides	-	-	+	+	+	-
Dinoflagellates						
Ceratium furca	-	-	+	+	+	+
Ceratium macroceros	+	-	-	+	-	+
Dinophysis caudata	+	-	-	-	+	-
Noctiluca sp.	-	-	-	+	+	-
Protoperidinium depressum	+	-	-	-	+	-
Cyanophyceae (Blue-greens)						
Oscillatoria sp.	-	-	-	+	-	+

+ Present; - Absent

Table 3.5.16: Chlorophyll ‘a’, ‘b’ and primary productivity values at Pulicat Lake

Sampling sites (Pulicat Lake)	Chlorophyll ‘a’ (mg/m^3)	Chlorophyll ‘b’ (mg/m^3)	Primary productivity (mg c/m^3/day)
Pu1	2.75	0.99	310.73
Pu2	2.99	1.19	330.69
Pu3	3.25	1.17	350.56
Pu4	3.43	1.55	390.92
Pu5	3.92	2.39	455.61
Pu6	3.76	2.16	430.89

e. Kosathalaiyar River

A total of 10 phytoplankton species belonging to the Diatoms group were recorded from the 13 sampling stations collected in River waters. Phytoplankton density in the sampling site showed a range of 700-4100 cells/l (Table.3.5.17). 12 sites showed the presence of phytoplankton. Amongst the groups Diatoms showed to be the most dominant among the 10 recorded species (Table.3.5.18).

In River, the chlorophyll ‘a’ in water sample varied from 0.74 to 4.46 mg/m^3 with maximum at R5 and minimum at R8. The chlorophyll ‘b’ content varied from 0.33 to 2.58 mg/m3 with maximum in R13 and the minimum was observed in R8. The primary productivity values varied from 120.41 to 380.67 $mgCm^{-3}d^{-1}$ with the maximum value was recorded at the R5 and minimum value was at R8 (Table.3.5.20).

Table 3.5.17: Phytoplankton density at Kosathalaiyar River

SITES	Plankton Count (Cells/l)
R1	2400
R2	1800
R3	1000
R4	3700
R5	4100
R6	3900
R7	700
R8	0
R9	800
R10	1300
R11	1500
R12	2100
R13	2700

Table 3.5.18: Phytoplankton species recorded in the sampling stations of Kosathalaiyar River

S.No	Phytoplankton
	Bacillariophyceae (Diatoms)
1	*Coscinodiscus* sp.
2	*Chaetoceros* sp.
3	*Cyclotella* sp.
4	*Hemidiscus hardmannianus*
5	*Navicula* sp.
6	*Pleurosigma elongatum*
7	*Pleurosigma* sp.
8	*Rhizosolenia* sp.
9	*Skeletonema* sp.
10	*Triceratium* sp.

Table 3.5.19: Presence of phytoplankton species in various sampling stations of Kosathalaiyar River

Plankton Species	STATIONS												
Bacillariophyceae (Diatoms)	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**	**R13**
Coscinodiscus sp.	+	-	+	+	-	+	-	-	+	+	+	+	+
Chaetoceros sp.	+	+	-	+	+	+	-	-	+	-	+	+	+
Cyclotella sp.	-	-	-	-	-	+	-	-	-	-	-	-	-

Hemidiscus hardmannianus	-	+	-	+	+	+	-	-	+	-	+	-	+
Navicula sp.	-	-	-	+	-	+	-	-	-	-	-	+	-
Pleurosigma elongatum	+	-	+	-	+	+	-	-	-	-	-	+	-
Pleurosigma sp.	-	-	-	-	+	+	-	-	-	-	-	+	-
Rhizosolenia sp.	+	+	-	-	+	-	-	-	-	-	-	+	+
Skeletonema sp.	-	+	-	-	-	-	+	-	-	-	+	-	-
Triceratium sp.	+	-	-	-	+	-	-	-	-	+	-	+	-

+ Present; - Absent

Table 3.5.20: Chlorophyll 'a', 'b' and primary productivity values at River stations

Sampling sites (River)	Chlorophyll 'a' (mg/m^3)	Chlorophyll 'b' (mg/m^3)	Primary productivity (mg c/m^3/day)
R1	3.54	2.33	320.72
R2	2.96	1.85	260.18
R3	1.52	0.99	170.53
R4	4.25	1.99	350.54
R5	4.46	2.15	380.67
R6	4.38	1.96	370.93
R7	1.31	0.88	140.50
R8	0.74	0.33	120.41
R9	1.65	0.93	190.95
R10	2.73	1.44	240.84
R11	2.86	1.61	250.31
R12	3.39	2.19	310.49
R13	3.62	2.58	340.66

f. Marine zone

A total of 54 phytoplankton species belonging to Diatoms, Dinoflagellates and Cyanophyceae groups were recorded from the 86 sampling within the 10 km radius in the marine zone. Phytoplankton density in the sampling site showed a range of 100-42500 cells/l (Table.3.5.21). Amongst the 86 sites, 79 sites showed the presence of phytoplankton. Amongst the groups Diatoms showed to be the most dominant among the 54 recorded species (Table.3.5.22).

In marine zone, the chlorophyll 'a' in water sample varied from 0.42 to 18.49 mg/m^3 with maximum at S38 and minimum at S26. The chlorophyll 'b' content varied from 0.17 to 10.86 mg/m^3 with maximum in S38 and the minimum was observed in S26. The primary productivity he values varied from 60.01 to 530.94 mgCm^{-3}d^{-1} with the maximum value was recorded at the S38 and minimum value was at S26 (Table.3.5.24).

Table 3.5.21: Phytoplankton density at Marine zone

Stations	Plankton Count (Cells/l)
S1	14500
S2	8200
S3	14000
S4	12700
S5	19000
S6	15200
S7	13800
S8	17100
S9	12500
S10	13100
S11	12400
S12	9300
S13	11400
S14	16800
S15	13400
S16	22100
S17	18500
S18	10300
S19	17200
S20	25100
S21	6800
S22	5100
S23	4100
S24	2800
S25	3700
S26	42500
S27	11400
S28	23100
S29	400
S30	3600
S31	10200
S32	2800
S33	3400
S34	5800
S35	9100
S36	6400
S37	0
S38	0
S39	25200
S40	3500
S41	13200

S42	19400
S43	6500
S44	8800
S45	7100
S46	200
S47	0
S48	0
S49	5800
S50	4700
S51	13800
S52	14200
S53	7900
S54	0
S55	4200
S56	10200
S57	4000
S58	2400
S59	3600
S60	9700
S61	7400
S62	6300
S63	2900
S64	1800
S65	6200
S66	8600
S67	200
S68	700
S69	1200
S70	100
S71	3200
S72	2800
S73	5400
S74	4800
S75	6100
S76	4200
S77	4300
S78	900
S79	0
S80	800
S81	600
S82	3600
S83	10400
S84	0
S85	12100

S86	2000

Table 3.5.22: Phytoplankton species recorded in Marine zone

S.No	Phytoplankton
	Bacillariophyceae (Diatoms)
1	*Asterionella* sp.
2	*Bacillaria* sp.
3	*Bacteriastrum delicatulum*
4	*Bacteriastrum cosmosum*
5	*Bacteriastrum hyalinum*
6	*Chaetoceros affinis*
7	*Chaetoceros brevis*
8	*Chaetoceros coarctatus*
9	*Chaetoceros* sp.
10	*Coscinodiscus centralis*
11	*Coscinodiscus gigas*
12	*Coscinodiscus granii*
13	*Coscinodiscus* sp.
14	*Cyclotella* sp.
15	*Cylindrotheca closterium*
16	*Ditylum brightwellii*
17	*Ditylum* sp.
18	*Eucampia* sp.
19	*Fragillaria* sp.
20	*Hemidiscus hardmannianus*
21	*Lauderia* sp.
22	*Navicula* sp.
23	*Nitzschia* sp.
24	*Odontella sinensis*
25	*Planktoniella sol*
26	*Pleurosigma elongatum*
27	*Pleurosigma* sp.
28	*Rhizosolenia alata*
29	*Rhizosolenia castracanei*
30	*Rhizosolenia* sp.
31	*Rhizosolenia stolterfothii*
32	*Skeletonema* sp.
33	*Synedra* sp.
34	*Thalassionema nitzschioides*
35	*Thalassiosira subtilis*
36	*Thalassiothrix fraunfeldii*
37	*Triceratium favus*

38	*Triceratium* sp.
	Dinoflagellates
39	*Ceratium azoricum*
40	*Ceratium furca*
41	*Ceratium macroceros*
42	*Ceratium trichoceros*
43	*Ceratocorys horrida*
44	*Dinophysis caudata*
45	*Gymnodinium* sp.
46	*Noctiluca* sp.
47	*Ornithocercus steinii*
48	*Prorocentrum maximum*
49	*Protoperidinium depressum*
50	*Pyrophacus horologicum*
51	*Pyrophacus steinii*
	Cyanophyceae (Blue-greens)
52	*Oscillatoria* sp.
53	*Trichodesmium erythraeum*
	Chlorophyceae (Greens)
54	*Volvox* sp.

Table 3.5.23: Occurence of phytoplankton species in Marine zone

Plankton Species	STATIONS																			
Bacillariophyceae (Diatoms)	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**	**S19**	**S20**
Asterionella sp.	+	-	+	+	+	-	-	-	-	-	-	-	-	+	-	+	-	-	-	+
Bacillaria sp.	-	+	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	+	-
Bacteriastrum delicatulum	+	+	+	-	+	+	-	+	-	+	+	+	+	+	-	+	+	+	+	+
Bacteriastrum cosmosum	-	-	-	+	+	-	+	-	-	-	-	-	-	-	-	+	+	+	-	-
Bacteriastrum hyalinum	+	-	-	+	-	-	-	-	+	-	+	-	-	-	-	+	-	-	-	+
Chaetoceros affinis	+	-	+	+	+	+	+	+	-	+	+	-	+	+	+	+	+	+	+	+
Chaetoceros brevis	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Chaetoceros coarctatus	-	-	+	-	+	-	-	+	-	-	-	-	-	+	-	-	-	+	+	+
Chaetoceros sp.	+	-	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	+	+
Coscinodiscus centralis	-	-	+	-	-	+	-	-	-	-	-	-	-	+	-	-	+	+	-	-
Coscinodiscus gigas	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+
Coscinodiscus granii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Coscinodiscus sp.	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cyclotella sp.	-	-	-	-	-	-	-	-	-	+	+	+	-	-	-	+	-	-	+	+
Cylindrotheca closterium	-	-	+	-	-	-	-	+	-	-	-	-	-	+	-	+	+	+	-	-
Ditylum brightwellii	-	-	-	+	+	-	-	-	-	-	-	-	-	-	+	-	+	-	-	+
Ditylum sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	+	-
Eucampia sp.	-	-	-	-	-	+	+	-	+	+	+	-	+	-	-	+	+	-	-	+
Fragillaria sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Hemidiscus hardmannianus	+	-	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+
Lauderia sp.	+	-	-	-	+	-	-	-	-	+	-	-	-	+	-	+	+	+	+	+

Navicula sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Nitzschia sp.	-	-	-	-	-	+	-	-	-	-	+	+	-	-	-	+	-	-	+	-
Odontella sinensis	+	-	+	+	+	-	+	-	-	-	-	-	-	-	-	+	+	-	-	+
Planktoniella sol	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+	+	-	-	+
Pleurosigma elongatum	-	-	+	-	+	-	-	-	+	-	-	-	-	-	-	-	-	+	+	+
Pleurosigma sp.	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	+	-	-	+
Rhizosolenia alata	-	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	-	+	-
Rhizosolenia castracanei	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Rhizosolenia sp.	+	-	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	+	+	+
Rhizosolenia stolterfothii	-	-	+	+	+	-	-	-	-	+	-	-	-	+	-	-	+	+	-	+
Skeletonema sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Synedra sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thalassionema nitzschioides	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Thalassiosira subtilis	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	+	+	+	-	+
Thalassiothrix fraunfeldii	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+
Triceratium favus	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Triceratium sp.	-	+	-	-	+	-	-	+	-	+	+	-	+	+	+	-	-	+	+	+
Dinoflagellates																				
Ceratium azoricum	-	+	-	+	-	+	+	-	+	-	-	-	-	+	-	+	+	-	-	-
Ceratium furca	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium macroceros	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Ceratium trichoceros	+	+	+	+	+	-	+	+	+	+	-	+	+	+	+	+	+	+	+	+
Ceratocorys horrida	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-	-	-	-	-
Dinophysis caudata	+	+	+	+	+	-	-	-	+	+	+	-	+	+	+	+	-	+	+	+
Gymnodinium sp.	-	+	-	-	-	-	+	+	-	+	-	-	-	+	-	-	-	-	+	-
Noctiluca sp.	-	-	+	+	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	+
Ornithocercus steinii	+	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	+	+	+	-
Prorocentrum maximum	-	-	-	-	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-

Protoperidinium depressum	+	+	-	+	+	-	-	-	-	-	+	-	-	-	+	+	-	-	-	+
Pyrophacus horologicum	+	-	-	-	-	-	-	-	-	+	+	-	-	-	-	+	+	+	+	+
Pyrophacus steinii	+	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	+	+	-	+
Cyanophyceae (Blue-greens)																				
Oscillatoria sp.	-	-	+	-	+	-	-	-	-	-	+	-	+	+	-	+	-	+	-	+
Trichodesmium erythraeum	+	+	-	-	-	+	-	-	+	+	-	-	-	+	+	+	+	-	+	+
Chlorophyceae (Greens)																				
Volvox sp.	+	-	-	-	+	-	+	+	-	-	-	-	-	+	-	+	-	-	-	+

Plankton Species	**STATIONS**																			
Bacillariophyceae (Diatoms)	**S21**	**S22**	**S23**	**S24**	**S25**	**S26**	**S27**	**S28**	**S29**	**S30**	**S31**	**S32**	**S33**	**S34**	**S35**	**S36**	**S37**	**S38**	**S39**	**S40**
Asterionella sp.	-	-	-	-	-	+	-	+	-	+	-	-	-	+	-	-	-	-	-	-
Bacillaria sp.	+	-	+	-	+	-	-	-	+	-	+	+	+	-	-	-	-	-	-	-
Bacteriastrum delicatulum	-	-	-	-	-	+	+	+	-	-	-	-	-	-	+	+	-	-	+	+
Bacteriastrum cosmosum	-	-	-	-	-	+	+	-	-	-	+	-	-	-	-	-	-	-	-	-
Bacteriastrum hyalinum	-	-	-	-	+	+	-	+	-	-	+	-	-	-	+	+	-	-	+	+
Chaetoceros affinis	-	-	-	-	-	+	-	+	-	+	+	-	+	+	+	+	-	-	-	-
Chaetoceros brevis	-	-	-	-	-	-	+	+	-	+	-	-	-	-	+	-	-	-	-	-
Chaetoceros coarctatus	-	-	-	-	+	+	-	+	+	-	-	-	-	-	-	+	-	-	-	-
Chaetoceros sp.	+	-	+	+	+	+	-	+	-	+	+	+	+	+	+	+	-	+	+	+
Coscinodiscus centralis	-	-	-	-	-	+	-	-	-	-	-	-	+	+	+	-	-	-	-	-
Coscinodiscus gigas	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-

Coscinodiscus granii	+	-	-	-	-	+	-	+	-	+	+	-	+	+	-	-	-	-	-	-
Coscinodiscus sp.	+	-	-	-	+	+	+	+	+	+	+	-	+	+	+	+	-	+	+	+
Cyclotella sp.	-	-	-	-	-	+	+	+	-	-	+	+	-	-	+	-	-	-	-	-
Cylindrotheca closterium	+	-	-	-	-	+	-	+	-	+	-	-	-	+	-	+	-	-	-	-
Ditylum brightwellii	-	-	-	-	+	+	+	-	-	-	+	-	+	-	+	-	-	-	+	+
Ditylum sp.	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-
Eucampia sp.	-	-	-	-	-	+	+	-	-	+	-	-	-	-	-	-	-	-	-	-
Fragillaria sp.	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemidiscus hardmannianus	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+
Lauderia sp.	-	-	-	-	+	+	-	-	-	-	+	-	-	-	+	-	-	-	-	-
Navicula sp.	-	-	+	-	-	+	+	+	-	-	+	-	-	-	-	+	-	-	-	-
Nitzschia sp.	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Odontella sinensis	-	-	-	-	-	+	-	+	+	+	+	-	+	+	+	-	-	-	-	-
Planktoniella sol	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pleurosigma elongatum	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Pleurosigma sp.	-	-	-	-	-	+	+	+	+	-	+	-	+	+	-	+	-	-	-	-
Rhizosolenia alata	+	+	-	-	+	+	+	+	+	+	+	-	-	-	+	-	-	-	-	-
Rhizosolenia castracanei	-	-	-	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-
Rhizosolenia sp.	+	+	+	-	+	+	+	+	+	+	+	+	-	+	+	+	-	+	+	+
Rhizosolenia stolterfothii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Skeletonema sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+
Synedra sp.	-	-	-	-	-	+	-	+	-	-	+	-	-	-	+	+	-	-	-	-
Thalassionema nitzschioides	+	+	+	+	+	+	+	+	-	-	+	+	+	+	+	+	-	-	-	-

Thalassiosira subtilis	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-	-	-	-	-
Thalassiothrix fraunfeldii	+	+	-	+	+	+	+	+	-	-	-	-	+	+	+	+	-	-	-	-
Triceratium favus	-	-	-	-	-	+	-	+	-	-	-	-	-	+	+	-	-	-	-	-
Triceratium sp.	-	-	-	-	-	+	+	-	-	-	+	-	+	-	-	-	-	-	-	-
Dinoflagellates																				
Ceratium azoricum	-	-	-	-	-	+	-	+	-	-	-	+	+	-	-	-	-	-	-	-
Ceratium furca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium macroceros	+	+	+	-	+	+	+	+	+	+	-	-	-	-	+	+	-	-	-	-
Ceratium trichoceros	+	+	+	+	+	+	+	+	-	-	+	+	-	+	+	+	-	-	-	-
Ceratocorys horrida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinophysis caudata	+	+	-	+	+	+	+	+	+	+	-	-	+	-	-	+	-	-	-	-
Gymnodinium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Noctiluca sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ornithocercus steinii	-	-	-	-	-	+	-	-	-	+	+	-	+	-	-	-	-	-	-	-
Prorocentrum maximum	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Protoperidinium depressum	-	-	-	-	-	+	+	+	-	-	+	-	+	+	-	+	-	-	-	-
Pyrophacus horologicum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyrophacus steinii	-	-	-	-	-	+	-	+	-	-	+	-	-	-	-	-	-	-	-	-
Cyanophyceae (Blue-greens)																				
Oscillatoria sp.	-	-	-	-	-	+	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Trichodesmium erythraeum	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorophyceae (Greens)																				
Volvox sp.	-	-	-	-	-	+	-	+	-	-	+	-	-	-	-	-	-	-	-	-

Plankton Species	**STATIONS**																			
Bacillariophyceae (Diatoms)	**S41**	**S42**	**S43**	**S44**	**S45**	**S46**	**S47**	**S48**	**S49**	**S50**	**S51**	**S52**	**S53**	**S54**	**S55**	**S56**	**S57**	**S58**	**S59**	**S60**
Asterionella sp.	-	+	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-
Bacillaria sp.	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-
Bacteriastrum delicatulum	-	+	-	+	+	-	-	-	+	-	-	+	+	-	-	-	+	+	+	-
Bacteriastrum cosmosum	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Bacteriastrum hyalinum	-	-	-	-	-	-	-	-	+	-	-	+	-	-	+	+	-	-	-	-
Chaetoceros affinis	-	+	-	+	+	-	-	-	-	+	+	+	+	-	+	-	+	+	+	-
Chaetoceros brevis	+	+	+	+	-	-	-	-	-	-	+	+	+	-	+	-	+	-	-	-
Chaetoceros coarctatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros sp.	+	+	-	-	-	-	-	-	+	+	+	+	+	-	+	-	+	-	-	+
Coscinodiscus centralis	+	-	+	+	+	-	-	-	-	-	+	+	+	-	+	-	-	-	-	+
Coscinodiscus gigas	-	+	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	+
Coscinodiscus granii	+	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Coscinodiscus sp.	-	+	+	+	-	-	-	-	+	+	+	+	+	-	+	-	+	+	-	+
Cyclotella sp.	+	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	+	+
Cylindrotheca closterium	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Ditylum brightwellii	+	+	-	+	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-
Ditylum sp.	+	-	+	+	+	-	-	-	-	-	+	+	+	-	+	-	+	-	+	+
Eucampia sp.	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-
Fragillaria sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemidiscus hardmannianus	+	+	-	-	-	-	-	-	+	+	+	+	+	-	+	-	+	-	+	+
Lauderia sp.	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+
Navicula sp.	+	+	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-
Nitzschia sp.	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Odontella sinensis	-	+	-	+	+	-	-	-	-	-	+	+	+	-	-	+	-	-	-	-

Planktoniella sol	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Pleurosigma elongatum	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Pleurosigma sp.	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Rhizosolenia alata	+	+	-	+	+	-	-	-	-	+	+	+	-	-	-	+	-	-	-	-
Rhizosolenia castracanei	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+
Rhizosolenia sp.	+	+	-	+	-	-	-	-	+	+	-	+	+	-	-	-	-	-	-	-
Rhizosolenia stolterfothii	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Skeletonema sp.	+	-	+	+	+	-	-	-	+	+	+	+	-	-	-	+	+	-	-	-
Synedra sp.	+	-	-	+	-	-	-	-	-	-	+	+	-	-	+	-	+	+	+	+
Thalassionema nitzschioides	+	+	+	+	+	-	-	-	-	-	-	+	+	-	+	+	+	+	-	+
Thalassiosira subtilis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thalassiothrix fraunfeldii	+	+	+	+	+	-	-	-	-	-	+	+	+	-	+	-	+	+	+	+
Triceratium favus	+	-	+	-	+	-	-	-	-	-	-	+	+	-	-	-	+	-	-	-
Triceratium sp.	-	+	+	+	+	-	-	-	+	-	+	+	+	-	-	+	-	-	-	-
Dinoflagellates																				
Ceratium azoricum	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Ceratium furca	+	+	-	+	-	-	-	-	+	-	-	+	-	-	+	-	-	-	-	-
Ceratium lineatum				-	-	-	-	-	+	-	+	-	-	-	-	-	+	-	-	-
Ceratium macroceros	-	-	-	-	-	+	-	-	-	+	+	+	-	-	-	-	-	-	-	+
Ceratium trichoceros	-	-	-	+	-	-	-	-	-	+	-	+	-	-	-	-	-	-	+	+
Ceratocorys horrida	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Dinophysis caudata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gymnodinium sp.	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Noctiluca sp.	+	+	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-
Ornithocercus steinii	-	+	+	+	+	-	-	-	-	+	+	+	+	-	+	+	+	+	+	+
Prorocentrum maximum	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Protoperidinium depressum	+	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	+	-	-	+

Pyrocystis lunula	-	+	-	-	-		-	-	-	-	+	+	-	-	-	-	-	-	-	-
Pyrophacus horologicum	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Pyrophacus steinii	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+
Cyanophyceae (Blue-greens)																				
Oscillatoria sp.	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+
Trichodesmium erythraeum	+	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	+
Chlorophyceae (Greens)																				
Volvox sp.	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-
Plankton Species	**STATIONS**																			
Bacillariophyceae (Diatoms)	**S61**	**S62**	**S63**	**S64**	**S65**	**S66**	**S67**	**S68**	**S69**	**S70**	**S71**	**S72**	**S73**	**S74**	**S75**	**S76**	**S77**	**S78**	**S79**	**S80**
Asterionella sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacillaria sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacteriastrum delicatulum	+	-	+	-	+	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Bacteriastrum cosmosum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacteriastrum hyalinum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros affinis	-	-	-	-	+	+	-	-	-	-	-	-	+	+	+	-	+	-	-	-
Chaetoceros brevis	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	+	-	-	-
Chaetoceros coarctatus	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Chaetoceros sp.	-	+	-	+	-	+	-	-	-	-	+	+	-	+	-	+	+	+	-	+
Coscinodiscus centralis	+	+	+	+	+	+	-	-	-	-	-	+	+	+	+	+	+	+	-	+
Coscinodiscus gigas	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-
Coscinodiscus granii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Coscinodiscus sp.	+	+	+	+	+	+	-	-	-	-	+	+	+	+	+	+	+	+	-	+
Cyclotella sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Cylindrotheca closterium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ditylum brightwellii	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-

Ditylum sp.	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	+	-	-	-
Eucampia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragillaria sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemidiscus hardmannianus	+	+	-	+	+	+	-	-	-	-	+	+	+	-	+	+	+	+	-	+
Lauderia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Navicula sp.	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Nitzschia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Odontella sinensis	+	-	-	-	+	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Planktoniella sol	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pleurosigma elongatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pleurosigma sp.	+	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhizosolenia alata	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Rhizosolenia castracanei	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Rhizosolenia sp.	-	-	-	-	-	+	-	-	-	-	+	-	-	+	-	-	-	-	-	-
Rhizosolenia stolterfothii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stephanopyxis sp.				-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Skeletonema sp.	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Synedra sp.	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thalassionema nitzschioides	+	+	+	+	+	+	-	-	-	-	-	+	-	+	+	+	+	+	-	+
Thalassiosira subtilis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thalassiothrix fraunfeldii	+	+	-	+	+	+	-	-	-	-	+	+	+	+	+	+	+	+	-	+
Triceratium favus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triceratium sp.	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Dinoflagellates																				
Ceratium azoricum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium furca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium lineatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Ceratium macroceros	+	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Ceratium trichoceros	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratocorys horrida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinophysis caudata	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-
Gymnodinium sp.	-	-	-	-	-	-	-	-	-	-	-		-	-	-	+	-	-	-	-
Noctiluca sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ornithocercus steinii	+	-	+	-	+	-	-	-	-	-	+	+	+	+	+	-	+	-	-	-
Prorocentrum maximum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Protoperidinium depressum	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyrophacus horologicum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyrophacus steinii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-
Cyanophyceae (Blue-greens)																				
Oscillatoria sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Trichodesmium erythraeum	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorophyceae (Greens)																				
Volvox sp.	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-

Plankton Species	STATIONS					
Bacillariophyceae (Diatoms)	**S81**	**S82**	**S83**	**S84**	**S85**	**S86**
Asterionella sp.	-	-	-	-	+	-
Bacillaria sp.	-	-	-	-	+	-
Bacteriastrum delicatulum	-	+	-	-	-	-
Bacteriastrum cosmosum	-	-	-	-	+	-
Bacteriastrum hyalinum	-	-	-	-	-	+
Chaetoceros affinis	-	-	+	-	+	-
Chaetoceros brevis	-	-	+	-	+	-
Chaetoceros coarctatus	-	-	-	-	-	-
Chaetoceros sp.	+	+	+	-	+	+
Coscinodiscus centralis	-	+	+	-	+	-
Coscinodiscus gigas	-	-	-	-	+	-
Coscinodiscus granii	-	-	-	-	-	-
Coscinodiscus sp.	-	+	+	-	+	+
Cyclotella sp.	-	-	-	-	-	-
Cylindrotheca closterium	-	-	-	-	-	-
Ditylum brightwellii	-	-	+	-	+	-
Ditylum sp.	+	-	+	-	+	-
Eucampia sp.	-	-	-	-	+	-
Fragillaria sp.	-	-	-	-	-	-
Hemidiscus hardmannianus	+	+	-	-	+	-
Lauderia sp.	-	-	-	-	+	-
Navicula sp.	-	-	-	-	+	-
Nitzschia sp.	-	-	-	-	-	-
Odontella sinensis	-	-	-	-	+	-
Planktoniella sol	-	-	-	-	+	-
Pleurosigma elongatum	-	-	-	-	-	-
Pleurosigma sp.	-	-	-	-	+	-
Rhizosolenia alata	-	-	-	-	+	-
Rhizosolenia castracanei	-	-	+	-	+	-
Rhizosolenia sp.	-	+	+	-	-	+
Rhizosolenia stolterfothii	-	-	-	-	-	-
Skeletonema sp.	-	+	+	-	+	-
Synedra sp.	-	-	-	-	+	-
Thalassionema nitzschioides	+	+	+	-	+	-
Thalassiosira subtilis	-	-	-	-	-	-

Thalassiothrix fraunfeldii	-	+	+	-	+	-
Triceratium favus	-	-	+	-	-	-
Triceratium sp.	-	-	-	-	-	-
Dinoflagellates						
Ceratium azoricum	-	-	-	-	-	-
Ceratium furca	-	-	+	-	-	-
Ceratium macroceros	-	-	-	-	+	+
Ceratium trichoceros	-	-	-	-	+	+
Ceratocorys horrida	-	-	-	-	-	-
Dinophysis caudata	-	-	+	-	-	-
Gymnodinium sp.	-	-	+	-	-	-
Noctiluca sp.	-	-	+	-	-	-
Ornithocercus steinii	-	-	-	-	+	-
Prorocentrum maximum	-	-	-	-	-	-
Protoperidinium depressum	-	-	+	-	-	+
Pyrophacus horologicum	-	-	+	-	-	-
Pyrophacus steinii	-	-	-	-	-	-
Cyanophyceae (Blue-greens)						
Oscillatoria sp.	-	-	-	-	-	-
Trichodesmium erythraeum	-	-	+	-	+	-
Chlorophyceae (Greens)						
Volvox sp.	-	-	-	-	-	-

+ Present; - Absent

Table 3.5.24: Chlorophyll 'a' , 'b' and primary productivity values at Marine zone sea stations

Sampling sites (Sea)	Chlorophyll 'a' (mg/m^3)	Chlorophyll 'b' (mg/m^3)	Primary productivity (mg c/m^3/day)
S1	7.30	4.72	410.02
S2	4.12	3.20	340.14
S3	6.84	4.46	430.31
S4	4.99	3.17	300.62
S5	8.99	5.47	440.41
S6	7.72	4.29	435.10
S7	5.94	3.47	330.92
S8	8.10	5.15	460.49
S9	4.52	3.00	290.82
S10	5.21	3.46	330.40
S11	4.47	2.89	270.96
S12	4.98	3.58	360.18
S13	3.74	2.69	250.46
S14	7.84	4.99	440.28
S15	5.27	3.36	310.04
S16	10.59	6.82	470.15
S17	8.61	5.04	400.75
S18	5.22	3.95	390.08
S19	7.97	5.06	420.16
S20	12.69	7.93	490.72
S21	3.79	2.38	280.46
S22	3.16	2.07	220.97
S23	2.86	1.89	180.79
S24	1.42	0.97	140.48
S25	2.37	2.09	220.63
S26	18.49	10.86	530.94
S27	3.72	2.67	250.32
S28	11.40	9.84	280.75
S29	1.01	0.42	90.60
S30	2.30	1.95	190.37
S31	5.09	3.58	380.40
S32	1.38	0.95	140.16
S33	2.06	1.85	190.33
S34	2.75	1.91	230.73
S35	4.89	3.27	320.40
S36	3.48	2.11	250.92
S37	0.51	0.22	60.28
S38	0.42	0.17	60.01
S39	12.85	8.13	510.05
S40	2.02	1.86	210.49
S41	5.01	3.06	290.66
S42	8.35	5.87	450.18
S43	3.52	2.11	250.36

S44	4.76	2.69	428.36
S45	4.12	2.50	382.69
S46	2.23	1.02	440.26
S47	3.91	2.83	211.07
S48	3.73	2.42	400.55
S49	3.78	2.30	308.96
S50	3.36	2.20	259.67
S51	4.98	2.91	490.26
S52	5.24	2.98	495.98
S53	4.32	2.59	408.49
S54	8.24	4.28	390.11
S55	4.35	2.07	395.19
S56	4.85	2.75	453.21
S57	3.12	1.94	232.47
S58	2.76	1.70	219.53
S59	3.03	1.92	229.59
S60	4.82	2.71	440.67
S61	4.19	2.57	397.05
S62	3.98	2.42	360.18
S63	2.93	1.79	225.67
S64	2.72	1.52	218.68
S65	3.92	2.39	329.15
S66	4.67	2.62	417.21
S67	2.25	1.21	209.56
S68	2.39	1.39	209.68
S69	2.65	1.50	214.67
S70	2.18	0.88	209.39
S71	2.98	1.81	228.64
S72	2.81	1.78	247.21
S73	3.59	2.27	293.38
S74	3.48	2.22	276.43
S75	3.85	2.35	319.44
S76	3.15	2.12	239.78
S77	3.27	2.18	247.28
S78	2.59	1.48	214.36
S79	2.88	2.03	270.27
S80	2.46	1.44	210.39
S81	2.33	1.30	207.91
S82	3.08	1.99	227.56
S83	4.89	2.82	469.32
S84	2.61	1.18	395.35
S85	4.92	2.86	488.52
S86	2.72	1.65	225.06

2. Zooplankton

a. Buckingham canal

A total of 15 zooplankton species belonging to 6 classes such as Maxillopoda, Spirotrichea, Crustacea, Pisces, Monogononta and Hexanauplia were recorded from the 12 sampling stations collected in Buckingham canal. Zooplankton density in the sampling site showed a range of 100-3460 no/m^3 (Table.3.5.25). All 12 sites showed presence of zooplankton. Amongst the classes, Maxillopoda, Crustacea and Hexanauplia showed to be the most dominant among the 15 recorded species (Table.3.5.26).

Table 3.5.25: Zooplankton density at Buckingham Canal

SITES	Zooplankton Count (no/m^3)
B1	140
B2	100
B3	400
B4	980
B5	1740
B6	2180
B7	2680
B8	500
B9	3460
B10	320
B11	690
B12	1660

Table 3.5.26: Zooplankton species recorded in Buckingham Canal

S.No	Zooplankton Species
	Class-Maxillopoda
1	*Centropages* sp.
2	*Acrocalanus gracilis*
3	*Acrocalanus* sp.
4	Barnacle Molt
5	*Cirripede nauplius*
	Class-Spirotrichea
6	*Tintinnopsis nordqvisti*
7	*Tintinnopsis* sp.
8	Dictyocysta sp.
	Class-Crustacea
9	Shrimp larvae
	Class-Pisces

10	Fish Larvae
	Class-Monogononta
11	*Brachionus* sp.
	Class-Hexanauplia
12	*Acartia* sp.
13	*Copepod nauplii*
14	*Macrosetella gracilis*
15	*Temora* sp.

Table 3.5.27: Occurrence of zooplankton species in Buckingham canal

S.No	Zooplankton Species	Stations											
		B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
	Class-Maxillopoda												
1	*Centropages* sp.	+	+	-	+	+	+	-	+	+	-	-	+
2	*Acrocalanus gracilis*	+	-	-	-	+	-	+	-	-	-	+	+
3	*Acrocalanus* sp.	+	-	+	+	-	-	+	-	+	-	+	+
4	Barnacle Molt	-	-	-	+	-	-	-	-	-	+	-	-
5	*Cirripede nauplius*	-	-	+	+	-	+	+	+	+	-	+	+
	Class-Spirotrichea												
6	*Tintinnopsis nordqvisti*	-	-	-	-	+	-	+	-	-	-	-	-
7	*Tintinnopsis* sp.	+	-	-	+	-	+	-	-	+	+	+	+
8	*Dictyocysta* sp.	-	+	+	-	-	-	-	-	+	-	-	+
	Class-Crustacea												
9	Shrimp larvae	-	-	-	-	+	+	+	-	+	-	-	-
	Class-Pisces												
10	Fish Larvae	-	+	+	-	-	-	+	-	+	-	-	+
	Class-Monogononta												
11	*Brachionus sp*	-	-	+	-	+	+	+	-	-	-	-	+
	Class-Hexanauplia												
12	*Acartia* sp.	-	-	-	-	+	-	+	-	+	-	-	-
13	*Copepod nauplii*	+	+	+	+	-	+	+	+	+	+	+	+
14	*Macrosetella gracilis*	-	+	-	-	+	-	-	-	+	-	-	-
15	*Temora sp.*	-	-	-	-	+	-	-	+	-	-	-	-

+ Present; - Absent

b. Ennore creek

A total of 10 zooplankton species belonging to the classes Maxillopoda, Hexanauplia, Spirotrichea, Appendicularia, Globothalamea, Pisces and Polychaeta were recorded from the 5 sampling stations collected in Ennore waters. Zooplankton density in the sampling site showed a range of 200-1260 no/m^3 (Table.3.5.28). 4 sites showed presence of zooplankton. Amongst the classes, Maxillopoda showed to be the most dominant among the 10 recorded species (Table.3.5.29).

Table 3.5.28: Zooplankton density at Ennore creek

SITES	Zooplankton Count (no/m^3)
E1	200
E2	690
E3	1260
E4	420
E5	0

Table 3.5.29: Zooplankton species recorded in Ennore creek

S.No	Zooplankton Species
	Class-Maxillopoda
1	*Centropages* sp.
2	*Acrocalanus gracilis*
3	*Centropages furcatus*
	Class-Hexanauplia
4	*Copepod nauplii*
5	*Acartia* sp.
	Class-Spirotrichea
6	Dictyocysta sp.
	Class-Appendicularia
7	*Oikopleura* sp.
	Class-Globothalamea
8	*Globigerina* sp.
	Class-Pisces
9	Fish Larvae
	Class-Polychaeta
10	Polychaete larvae

Table 3.5.30: Occurrence of zooplankton species in Ennore creek

S.No	Plankton Species	STATIONS				
		E1	E2	E3	E4	E5
	Class-Maxillopoda					
1	*Centropages* sp.	-	+	+	-	-
2	*Acrocalanus gracilis*	+	-	-	+	-
3	*Centropages furcatus*	-	+	+	-	-
	Class-Hexanauplia					
4	*Copepod nauplii*	-	+	+	+	-
5	*Acartia* sp.	+	-	-	+	-
	Class-Spirotrichea					

6	Dictyocysta sp.	-	-	+	-	-
	Class-Appendicularia					
7	*Oikopleura* sp.	-	+	+	-	-
	Class-Globothalamea					
8	*Globigerina* sp.	-	-	+	-	-
	Class-Pisces					
9	Fish Larvae	-	+	+	-	-
	Class-Polychaeta					
10	Polychaete larvae	+	-	+	+	

+ Present; - Absent

C. Mangrove waters

A total of 14 zooplankton species belonging to the classes Maxillopoda, Hexanauplia, Pisces, Spirotrichea, Bivalvia, Crustacea and Gastropoda were recorded from the 11 sampling stations collected from the mangrove. Zooplankton density in the sampling site showed a range of 420-3600 no/m^3 (Table.3.5.31). All 11 sites showed presence of zooplankton. Amongst the classes, Maxillopoda showed to be the most dominant among the 14 recorded species (Table.3.5.32).

Table 3.5.31: Zooplankton density in Mangrove waters

SITES	Zooplankton Count (no/m^3)
M1	1980
M2	2240
M3	3600
M4	2940
M5	3360
M6	420
M7	960
M8	1240
M9	1320
M10	720
M11	1860

Table 3.5.32: Zooplankton species recorded in Mangrove waters

S.No	Zooplankton Species
	Class-Maxillopoda
1	*Acrocalanus gracilis*
2	*Acrocalanus gibber*
3	*Centropages furcatus*

4	*Cirripede nauplius*
	Class-Hexanauplia
5	*Copepod nauplii*
6	*Acartia* sp.
7	*Temora sp.*
	Class-Pisces
8	Fish eggs
9	Fish Larvae
	Class-Spirotrichea
10	Dictyocysta sp.
11	Favella sp.
	Class-Bivalvia
12	Bivalve veliger
	Class-Crustacea
13	Shrimp larvae
	Class-Gastropoda
14	Gastropod veliger

Table 3.5.33: Occurrence of zooplankton species in Mangrove waters

S.No	Plankton Species	Stations										
		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
	Class-Maxillopoda											
1	*Acrocalanus gracilis*	+	+	+	-	-	-	-	+	-	+	-
2	*Acrocalanus gibber*	-	-	+	-	+	-	-	-	-	-	-
3	*Centropages furcatus*	+	-	+	+	+	+	+	-	+	-	+
4	*Cirripede nauplius*	-	+	+	+	+	-	+	-	+	-	+
	Class-Hexanauplia											
5	*Copepod nauplii*	+	+	+	+	+	+	+	+	+	+	+
6	*Acartia* sp.	-	-	-	+	-	-	+	-	+	-	+
7	*Temora* sp.	-	+	-	-	+	-	-	-	-	-	-
	Class-Pisces											
8	Fish eggs	-	+	-	+	-	-	-	-	-	-	-
9	Fish Larvae	-	-	+	-	+	-	+	-	-	-	-
	Class-Spirotrichea											
10	Dictyocysta sp.	-	+	-	-	+	-	-	-	+	-	-
11	Favella sp.	+	-	+	+	-	+	+	+	+	+	+
	Class-Bivalvia											
12	Bivalve veliger	+	-	+	-	-	-	-	+	-	+	-
	Class-Crustacea											
13	Shrimp larvae	-	-	+	-	+	+	-	+	-	-	+
	Class-Gastropoda											
14	Gastropod veliger	-	-	+	-	+	+	-	-	-	+	-

+ Present; - Absent

d. Pulicat Lake

A total of 12 zooplankton species belonging to the classes, Pisces, Appendicularia, Maxillopoda, Bivalvia, Spirotrichea, Monogononta, Hexanauplia and Sagittoidea were recorded from the 6 sampling stations collected from Pulicat Lake. Zooplankton density in the sampling site showed a range of 2460-6110 nos/m3 (Table.3.5.34). All 6 sites showed presence of zooplankton. Amongst the classes, Maxillopoda showed to be the most dominant among the 12 recorded species (Table.).

Table 3.5.34: Zooplankton density at Pulicat Lake

SITES	Zooplankton Count (no/m^3)
PU1	2460
PU2	3120
PU3	3540
PU4	3380
PU5	6720
PU6	6110

Table 3.5.35: Zooplankton species recorded in Pulicat Lake

S.No	Plankton Species
	Class-Pisces
1	Fish eggs
2	Fish Larvae
	Class-Appendicularia
3	*Oikopleura* sp.
	Class-Maxillopoda
4	*Acrocalanus gracilis*
5	Barnacle molt
6	*Centropages* sp.
	Class-Bivalvia
7	Bivalve veliger
	Class-Spirotrichea
8	*Tintinnopsis* sp.
9	*Favella* sp.
	Class-Monogononta
10	*Brachionus* sp.
	Class-Hexanauplia
11	*Copepod nauplii*
	Class-Sagittoidea
12	*Saggita* sp.

Table 3.5.36: Occurrence of zooplankton species in Pulicat Lake

S.No	Plankton Species	Stations					
		PU1	PU2	PU3	PU4	PU5	PU6
	Class-Pisces						
1	Fish eggs	+	-	+	-	+	-
2	Fish Larvae	+	-	+	-	+	+
	Class-Appendicularia						
3	*Oikopleura* sp.	-	+	+	+	-	+
	Class-Maxillopoda						
4	*Acrocalanus gracilis*	+	+	-	-	+	+
5	Barnacle molt	-	-	+	+	-	+
6	*Centropages* sp.	-	-	+	-	+	+
	Class-Bivalvia						
7	Bivalve veliger	-	-	+	+	-	-
	Class-Spirotrichea						
8	*Tintinnopsis* sp.	-	-	+	-	+	-
9	*Favella* sp.	+	+	+	-	-	+
	Class-Monogononta						
10	*Brachionus* sp.	-	+	-	-	-	+
	Class-Hexanauplia						
11	*Copepod nauplii*	+	+	+	+	+	+
	Class-Sagittoidea						
12	*Saggita* sp.	-	-	+	-	-	+

+ Present; - Absent

e. Kosathalaiyar River

A total of 12 zooplankton species belonging to the classes, Appendicularia, Maxillopoda, Bivalvia, Spirotrichea, Monogononta, Crustacea, Hexanauplia and Gastropoda were recorded from the 13 sampling stations collected from the Kosathaliayar River. Zooplankton density in the sampling site showed a range of 260-2040 no/m^3 (Table.). All 13 sites showed presence of zooplankton. Amongst the classes, Crustacea and Spirotrichea showed to be the most dominant among the 12 recorded species (Table.).

Table 3.5.37: Zooplankton density at Kosathalaiyar River

SITES	Zooplankton Count (no/m^3)
R1	320
R2	560
R3	600

R4	1020
R5	440
R6	380
R7	260
R8	920
R9	1760
R10	2040
R11	1180
R12	1760
R13	1420

Table 3.5.38: Zooplankton species recorded in Kosathalaiyar River

S.No.	Zooplankton Species
	Class-Monogononta
1	*Brachionus* sp.
	Class-Spirotrichea
2	*Favella* sp.
3	*Favella serrata*
4	Tintinnopsis sp.
	Class-Appendicularia
5	*Oikopleura* sp.
	Class-Bivalvia
6	Bivalve veliger
	Class- Crustacea
7	Copepod nauplii
8	Shrimp Larvae
	Class-Hexanauplia
9	Macrosetella gracilis
	Class-Maxillopoda
10	*Acrocalanus gibber*
11	*Cirripede nauplius*
	Class-Gastropoda
12	Gastropod veliger

Table 3.5.39: Occurrence of zooplankton species in Kosathalaiyar River

S.No.	Zooplankton Species	STATIONS												
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13
	Class-Monogononta													
1	*Brachionus* sp.	-	-	-	-	+	-	-	+	-	+	-	-	-
	Class-Spirotrichea													
2	*Favella* sp.	-	+	+	+	-	-	-	-	+	+	+	+	+
3	*Favella serrata*	-	-	-	-	-	+	-	-	-	-	-	+	-

4	*Tintinnopsis* sp.	-	-	+	+	-	-	-	+	-	-	+	-	-
	Class-Appendicularia													
5	*Oikopleura* sp.	+	-	-	-	+	-	-	+	-	+	+	-	+
	Class-Bivalvia													
6	Bivalve veliger	-	-	-	+	-	-	+	-	+	+	-	-	-
	Class- Crustacea													
7	*Copepod nauplii*	+	+	+	+	-	+	+	+	+	+	-	+	-
8	Shrimp Larvae	-	-	+	+	-	-	+	-	+	+	-	-	+
	Class-Hexanauplia													
9	*Macrosetella gracilis*	+	-	-	+	-	-	+	-	+	+	-	+	-
	Class-Maxillopoda													
10	*Acrocalanus gibber*	-	-	-	+	-	-	-	+	+	-	+	+	+
11	*Cirripede nauplius*	-	+	-	-	+	+	-	-	-	-	+	-	+
	Class-Gastropoda													
12	Gastropod veliger	-	+	-	+	-	-	-	-	+	+	-	+	-

+ Present; - Absent

f. Marine zone

A total of 34 zooplankton species belonging to the classes, Appendicularia, Crustacea, Maxillopoda, Bivalvia, Ophiuroidea, Polychaeta, Pisces, Globothalamea, Sagittoidea, Branchiopoda Spirotrichea, Monogononta, Hexanauplia and Gastropoda were recorded from the 86 sampling stations in the marine zone. Zooplankton density in the sampling site showed a range of 90-5200 no/m^3 (Table.). 79 sites showed presence of zooplankton. Amongst the classes, Maxillopoda and Hexanauplia showed to be the most dominant among the 34 recorded species (Table.).

Table 3.5.40: Zooplankton density at Marine zone

SITES	Zooplankton Count (no/m^3)
S1	3520
S2	2850
S3	1860
S4	3650
S5	2580
S6	4100
S7	1520
S8	4970
S9	1460
S10	1720
S11	3630
S12	2160

S13	3480
S14	2940
S15	1920
S16	720
S17	1420
S18	2650
S19	3450
S20	3610
S21	1140
S22	1720
S23	2260
S24	940
S25	1570
S26	620
S27	2370
S28	410
S29	370
S30	1260
S31	1130
S32	420
S33	1370
S34	1690
S35	1250
S36	2510
S37	90
S38	1940
S39	900
S40	840
S41	910
S42	790
S43	960
S44	1340
S45	1420
S46	350
S47	480
S48	800
S49	5200
S50	2190
S51	970
S52	1760
S53	2850
S54	0
S55	1270
S56	360

S57	1860
S58	3000
S59	2870
S60	1890
S61	2120
S62	1730
S63	0
S64	0
S65	350
S66	2480
S67	560
S68	390
S69	1260
S70	1180
S71	0
S72	680
S73	190
S74	0
S75	170
S76	0
S77	570
S78	790
S79	460
S80	710
S81	1100
S82	1250
S83	1680
S84	0
S85	2020
S86	1870

Table 3.5.41: Zooplankton species recorded in Marine zone

S.No.	Zooplankton Species
	Class-Appendicularia
1	*Oikopleura* sp.
	Class-Spirotrichea
2	*Tintinnopsis* sp.
3	*Tintinnopsis nordqvisti*
4	*Favella* sp.
5	*Favellaserrata*
6	*Dictyocysta* sp.
	Class-Bivalvia
7	Bivalve veliger
	Class-Crustacea
8	*Copepod nauplii*
9	*Barnacle nauplii*
10	Shrimp larvae
	Class-Gastropoda
11	Gastropod veliger
	Class-Maxillopoda
12	*Acrocalanus gracilis*
13	*Acrocalanus longicornis*
14	*Acrocalanus gibber*
15	*Candacia catula*
16	*Centropages furcatus*
17	*Centropages* sp.
18	*Cirripede nauplius*
19	Barnacle Molt
20	*Tortanus* sp.
	Class-Monogononta
21	*Brachionus* sp.
	Class-Ophiuroidea
22	Ophiopluteus larva
	Class Polychaeta
23	Polychaete larvae
	Class-Pisces
24	Fish eggs
25	Fish Larvae
	Class-Hexanauplia
26	*Macrosetella gracilis*
27	*Paracalanus* sp.
28	*Temora* sp.
29	*Acartia danae*
30	*Acartia erythraea*

31	*Acartia spinicauda*
	Class-Globothalamea
32	*Globigerina* sp.
	Class-Sagittoidea
33	*Saggita* sp.
	Class-Branchiopoda
34	*Penilia* sp.

Table 3.5.42: Occurence of zooplankton species in Marine zone

S.No.	Zooplankton Species	STATIONS																			
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
	Class-Appendicularia																				
1	*Oikopleura* sp.	-	+	+	+	-	+	-	+	-	+	+	+	+	-	+	-	-	+	+	+
	Class-Spirotrichea																				
2	*Tintinnopsis* sp.	+	-	-	+	+	-	-	+	-	-	+	+	-	-	-	-	+	-	-	+
3	*Tintinnopsis nordqvisti*	-	+	-	-	-	+	-	+	-	-	-	-	+	+	-	+	-	-	+	-
4	*Favella* sp.	-	-	-	+	+	-	+	+	+-	-	+	-	+	-	+	-	+	-	+	-
5	*Favellaserrata*	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-	+	-	+
6	*Dictyocysta* sp.	+	-	+	-	-	+	-	-	-	+	-	-	+	-	-	-	-	-	-	-
	Class-Bivalvia																				
7	Bivalve veliger	+	-	-	+	-	+	-	+	+-	-	-	+	-	-	+	-	-	-	+	+
	Class-Crustacea																				
8	*Copepod nauplii*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
9	*Barnacle nauplii*	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
10	Shrimp larvae	-	-	-	+	-	+	-	+	-	-	+	+	+	-	+	-	-	-	-	+
	Class-Gastropoda																				
11	Gastropod veliger	-	-	-	+	+	+	-	+	-	-	+	-	-	+	+	-	+	-	+	+
	Class-Maxillopoda																				
12	*Acrocalanus gracilis*	+	-	+	+	+	+	-	+	+	+	+	+	+	-	+	-	+	-	-	-
13	*Acrocalanus longicornis*	-	+	+	-	-	-	+	-	-	+	+	-	+	-	-	-		-	-	-
14	*Acrocalanus gibber*	-	+	-	-	-	+	+	+	+	+	+	-	+	-	+	-		-	+	-
15	*Candacia catula*	+	-	-	+	-	-	-	+	-	-	-	+	+	+	-	+		+	-	+
16	*Centropages furcatus*	-	+	+	-	-	-	-	+	-	-	+	-	+	-	-	+	+	-	-	-
17	*Centropages* sp.	-	+	-	+	+	+	+	+	-	+	+	+	+	-	+	-	-	-	+	+
18	*Cirripede nauplius*	-	-	+	-	-	+	-	-	-	-	+	-	-	+	+	-	-	-	-	-

19	Barnacle Molt	-	-	-	-	-	-	+	-	+	-	+	-	-	-	-	-	-	-	-	-
20	*Tortanus* sp.	-	-	-	+	-	+	-	+	-	-	-	-	+	+	-	-	-	+	-	+
	Class-Monogononta																				
21	*Brachionus* sp.	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	+	-	-	+	-
	Class-Ophiuroidea																				
22	Ophiopluteus larva	+	-	-	+	+	-	-	+	-	-	+	+	-	-	-	-	+	-	-	-
	Class Polychaeta																				
23	Polychaete larvae	-	+	-	+	-	-	-	+	+-	-	+	-	+	+	-	-	-	+	-	+
	Class-Pisces																				
24	Fish eggs	+	-	+	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	+	-
25	Fish Larvae	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-
	Class-Hexanauplia																				
26	*Macrosetella gracilis*	+	+	+	-	-	-	+	+	-	-	+	-	+	-	-	-	-	+	+	+
27	*Paracalanus* sp.	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
28	*Temora sp.*	-	+	-	-	-	-	-	-	+	-	+	-	-	-	-	-	+	-	-	-
29	*Acartia danae*	+	-	-	-	+	-	-	+	-	+	-	+	-	+	-	-	-	+	+	-
30	*Acartia erythraea*	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-	-	-	-	-	+
31	*Acartia spinicauda*	-	-	-	-	-	-	-	-	-	-	+	+	-	-	+	-	-	-	+	+
	Class-Globothalamea																				
32	*Globigerina* sp.	-	+	-	+	+	+	+	-	-	+	-	-	+	+	-	-	-	-	-	-
	Class-Sagittoidea																				
33	*Saggita* sp.	-	-	-	-	-	+	-	-	-	-	+	+	+	+	-	-	-	+	+	-
	Class-Branchiopoda																				
34	*Penilia* sp.	+	-	-	+	-	+	-	+	-	-	+	-	+	-	-	-	+	-	+	+

S.NO.	**Zooplankton Species**	**STATIONS**																			
		S21	**S22**	**S23**	**S24**	**S25**	**S26**	**S27**	**S28**	**S29**	**S30**	**S31**	**S32**	**S33**	**S34**	**S35**	**S36**	**S37**	**S38**	**S39**	**S40**
	Class-Appendicularia																				
1	*Oikopleura* sp.	+	-	+	-	-	+	+	+	-	+	-	-	+	+	-	+	-	+	+	-
	Class-Spirotrichea																				
2	*Tintinnopsis* sp.	-	+	-	-	+	-	+	-	-	+	-	-	-	-	+	+	-	-	-	+
3	*Tintinnopsis nordqvisti*	+	-	+	-	-	-	-	+	-	-	+	-	+	+	+	-	-	-	+	-
4	*Favella* sp.	-	+	+	+	+	-	+	-	-	+	-	+	+	-	-	-	-	+	-	-
5	*Favellaserrata*	-	-	-	-	-	+	+	-	-	-	+	-	-	+	-	-	-	+	+	-
6	*Dictyocysta* sp.	-	+	-	-	-	-	-	-	+	+	+	-	-	-	+	+	-	-	-	+
	Class-Bivalvia																				
7	Bivalve veliger	-	-	+	-	-	-	+	+	-	-	-	-	-	-	-	+	-	-	-	-
	Class-Crustacea																				
8	*Copepod nauplii*	+	+	+	+	+	+	+	+	-	-	+	+	-	+	+	+	-	-	+	+
9	*Barnacle nauplii*	-	-	+	-	-	-	+	-	-	-	-	-	+	-	+	-	-	+	-	+
10	Shrimp larvae	-	+	-	-	-	-	+	-	-	+	-	-	-	+	-	-	-	+	-	-
	Class-Gastropoda																				
11	Gastropod veliger	+	-	-	+	-	+	+	-	-	+	+	-	+	-	-	+	-	-	+	+
	Class-Maxillopoda																				
12	*Acrocalanus gracilis*	+	+	+	-	+	-	-	-	-	-	-	+	-	+	-	+	-	-	-	-

13	*Acrocalanus longicornis*	-	+	+	+	+	-	+	+	+	+	-	-	+	+	-	+	-	+	-	-
14	*Acrocalanus gibber*	-	-	+	-	+	+	-	+	-	+	-	-	+	+	-	+	-	-	-	+
15	*Candacia catula*		-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	+	-	-
16	*Centropages furcatus*	-	-	+	-	-	+	-	+	-	-	+	-	+	-	+	+	-	-	+	-
17	*Centropages* sp.	-	-	-	+	+	-	+	-	-	+	+	+	-	-	+	-	-	-	-	+
18	*Cirripede nauplius*	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	Barnacle Molt	-	-	+	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-
20	*Tortanus* sp.	-	+	-	-	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-
	Class-Monogononta																				
21	*Brachionus* sp.	+	-	-	-	+	-	-	-	+	-	+	-	-	+	+	-	-	+	-	+
	Class-Ophiuroidea																				
22	Brachiolaria larva	-	+	-	+	-	-	-	+	-	+	-	-	-	-	+	-	+	-	+	-
	Class Polychaeta																				
23	Polychaete larvae	-	-	+	-	+	-	+	-	-	-	+	-	-	-	-	+	-	-	-	+
	Class-Pisces																				
24	Fish eggs	-	-	-	-	+	-	-	-	-	+	-	-	+	+	-	-	-	-	-	-
25	Fish Larvae	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	+	-	+
	Class-Hexanauplia																				
26	*Macrosetella gracilis*	-	-	-	-	-	+	-	-	-	-	-	-	+	+	-	+	-	-	-	+

27	*Paracalanus* sp.	+	-	-	-	-	-	-	-	-	+	-	-	+	-	+	-	-	+	+	-
28	*Temora* sp.	-	-	-	-	+	-	-	-	+	+	-	-	-	+	-	+	-	-	-	-
29	*Acartia danae*	-	-	+	-	+	-	-	-	-	+	+	+	-	+	-	-	-	-	+	-
30	*Acartia erythraea*	-	+	-	-	+	-	-	-	-	-	-	+	+	-	+	-	-	-	+	-
31	*Acartia spinicauda*	+	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	+	-	-	-
	Class-Globothalamea																				
32	*Globigerina* sp.	-	+	-	+	-	-	+	-	+	-	-	-	-	-	-	+	-	-	-	+
	Class-Sagittoidea																				
33	*Saggita* sp.	-	-	+	-	-	-	-	-	-	+	-	+	-	+	+	+	-	+	-	-
	Class-Branchiopoda																				
34	*Penilia* sp.	+	-	-	-	-	-	+	-	-	+	-	-	+	-	+	-	-	-	-	-

S.NO.	**Zooplankton Species**	**STATIONS**																			
		S41	**S42**	**S43**	**S44**	**S45**	**S46**	**S47**	**S48**	**S49**	**S50**	**S51**	**S52**	**S53**	**S54**	**S55**	**S56**	**S57**	**S58**	**S59**	**S60**
	Class-Appendicularia																				
1	*Oikopleura* sp.	-	-	-	+	+	-	+	+	+	-	-	-	+	-	+	-	-	+	-	+
	Class-Spirotrichea																				
2	*Tintinnopsis* sp.	-	-	-	-	+	-	-	-	+	-	-	-	+	-	-	-	-	+	+	+

3	*Tintinnopsis nordqvisti*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	*Favella* sp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	*Favellaserrata*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	*Dictyocysta* sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Class-Bivalvia																				
7	Bivalve veliger	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	+
	Class-Crustacea																				
8	*Copepod nauplii*	+	+	+	+	+	-	+	+	+	+	-	+	+	-	+	-	+	+	+	+
9	*Barnacle nauplii*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	Shrimp larvae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Class-Gastropoda																				
11	Gastropod veliger	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+
	Class-Maxillopoda																				
12	*Acrocalanus gracilis*	-	+	+	+	-	-	-	-	+	+	+	+	-	-	+	-	+	+	+	+
13	*Acrocalanus longicornis*	-	-	+	-	+	-	+	+	+	-	+	-	+	-	-	-	-	+	-	+
14	*Acrocalanus gibber*	-	-	-	+	-	-	-	-	-	+	-	+	+	-	-	-	+	+	+	+
15	*Candacia catula*	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
16	*Centropages furcatus*	+	+	+	-	-	-	+	+	+	+	+	+	+	-	-	-	-	+	+	+
17	*Centropages* sp.	-	-	-	+	-	-	-	-	+	+	-	+	+	-	+	-	+	+	+	+

18	*Cirripede nauplius*	-	-	-	-	+	-	+	+	+	+	-	+	+	-	-	-	-	+	+	+
19	Barnacle Molt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	*Tortanus* sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
	Class-Monogononta						-										-				
21	*Brachionus* sp.	-	-	-	-	-		-	-	+	-	-	-	-	-	-		-	-	+	-
	Class-Ophiuroidea																				
22	Brachiolaria larva	-	-	-	+	+	-	-	-	+	+	-	+	+	-	+	-	-	+	+	+
	Class Polychaeta																				
23	Polychaete larvae	-	-	-	-	-	+	-	-	-	-	-	-	+	-	+	-	-	+	-	-
	Class-Pisces																				
24	Fish eggs	-	+	-	-	+	-	-	-	+	+	-	-	+	-	+	-	-	+	+	+
25	Fish Larvae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Class-Hexanauplia																				
26	*Macrosetella gracilis*	+	-	+	+	+	-	+	+	+	+	+	-	-	-	+	+	-	-	-	-
27	*Paracalanus* sp.	-	-	-	-	+	+	-	-	-	+	+	+	+	-	+	+	-	+	+	+
28	*Temora* sp.	-	-	-	+	+	-	-	-	+	+	-	+	+	-	-	+	-	+	+	-
29	*Acartia danae*	-	-	-	-	+	+	-	-	-	+	+	+	+	-	+	+	-	+	+	-
30	*Acartia erythraea*	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	*Acartia spinicauda*	-	-	-	-	-	-	-	-	+	+	+	-	+	-	-	-	-	+	+	-
	Class-Globothalamea																				

32	*Globigerina* sp.	-	-	-	+	-	-	-	-	-	+	-	+	+	-	-	-	-	-	-	-
	Class-Sagittoidea																				
33	*Saggita* sp.	-	-	-	+	+	-	-	+	+	+	+	+	-	-	-	-	-	+	+	-
	Class-Branchiopoda																				
34	*Penilia* sp.	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-

S.NO.	**Zooplankton Species**	**STATIONS**																			
		S61	**S62**	**S63**	**S64**	**S65**	**S66**	**S67**	**S68**	**S69**	**S70**	**S71**	**S72**	**S73**	**S74**	**S75**	**S76**	**S77**	**S78**	**S79**	**S80**
	Class-Appendicularia																				
1	*Oikopleura* sp.	-	+	-	-	-	+	-	-	+	-	-	-	+	-	-	-	-	-	-	-
	Class-Spirotrichea																				
2	*Tintinnopsis* sp.	+	-	-	-	-	+	-	-	+	+	-	-	+	-	-	-	-	-	+	-
3	*Tintinnopsis nordqvisti*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	*Favella* sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	*Favellaserrata*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	*Dictyocysta* sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Class-Bivalvia																				
7	Bivalve veliger	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	+	-	-
	Class-Crustacea																				
8	*Copepod nauplii*	+	+	-	-	-	+	-	-	+	+	-	+	+	-	-	-	+	+	+	+
9	*Barnacle nauplii*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	Shrimp larvae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
	Class-Gastropoda																				
11	Gastropod veliger	+	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-
	Class-Maxillopoda																				

12	*Acrocalanus gracilis*	+	+	-	-	-	-	+	-	+	+	-	+	-	-	-	-	+	+	-	-
13	*Acrocalanus longicornis*	-	-	-	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	+	+
14	*Acrocalanus gibber*	+	+	-	-	-	+	-	-	-	+	-	+	-	-	-	-	-	-	-	-
15	*Candacia catula*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	*Centropages furcatus*	+	-	-	-	-	+	+	-	==	-	-	-	-	-	-	-	-	-	-	-
17	*Centropages* sp.	+	+	-	-	-	+	+	+	-	+	-	+	-	-	-	-	-	-	-	-
18	*Cirripede nauplius*	+	-	-	-	-	+	-	-	-	-	-	-	+	-	-	-	+	+	+	+
19	Barnacle Molt	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
20	*Tortanus* sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Class-Monogononta																				
21	*Brachionus* sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Class-Ophiuroidea																				
22	Brachiolaria larva	+	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	+	+	+	-
	Class Polychaeta																				
23	Polychaete larvae	-	-	-	-	-	-	+	+	+	+	-	-	-	-	-	-	-	+	-	-
	Class-Pisces																				
24	Fish eggs	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	Fish Larvae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Class-Hexanauplia																				
26	*Macrosetella gracilis*	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+
27	*Paracalanus* sp.	+	+	-	-	+	+	-	-	-	-	-	+	-	-	+	-	+	-	-	-
28	*Temora* sp.	+	+	-	-	+	+	-	+	-	-	-	+	-	-	+	-	-	-	-	-
29	*Acartia danae*	+		-	-	+	+	-	+	-	-	-	-	-	-	-	-	+	-	-	+
30	*Acartia erythraea*	-	+	-	-	-	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-
31	*Acartia spinicauda*	+	+	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Class-Globothalamea																				
32	*Globigerina* sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Class-Sagittoidea																				

33	*Saggita* sp.	+	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Class-Branchiopoda																				
34	*Penilia* sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

+ Present; - Absent

S.No.	Zooplankton Species	STATIONS					
		S81	**S82**	**S83**	**S84**	**S85**	**S86**
	Class-Appendicularia						
1	*Oikopleura* sp.	-	-	+	-	+	+
	Class-Spirotrichea						
2	*Tintinnopsis* sp.	-	-	-	-	-	-
3	*Tintinnopsis nordqvisti*	-	-	-	-	-	-
4	*Favella* sp.	-	-	-	-	-	-
5	*Favellaserrata*	-	-	+	-	-	+
6	*Dictyocysta* sp.	-	-	-	-	-	-
	Class-Bivalvia						
7	Bivalve veliger	-	-	-	-	+	+
	Class-Crustacea						
8	*Copepod nauplii*	+	+	+	-	+	+
9	*Barnacle nauplii*	-	-	-	-	-	-
10	Shrimp larvae	-	-	+	-	+	+
	Class-Gastropoda						
11	Gastropod veliger	-	-	-	-	+	-
	Class-Maxillopoda						
12	*Acrocalanus gracilis*	+	+	+	-	+	+
13	*Acrocalanus longicornis*	-	+	-	-	-	+
14	*Acrocalanus gibber*	-	-	-	-	+	+
15	*Candacia catula*	-	-	-	-	-	-
16	*Centropages furcatus*	-	+	-	-	-	+
17	*Centropages* sp.	-	-	-	-	-	-
18	*Cirripede nauplius*	+	+	+	-	+	+
19	Barnacle Molt	-	-	-	-	-	-
20	*Tortanus* sp.	-	-	-	-	-	-
	Class-Monogononta						
21	*Brachionus* sp.	-	-	-	-	-	-
	Class-Ophiuroidea						
22	Brachiolaria larva	-	-	-	-	-	+

	Class Polychaeta						
23	Polychaete larvae	-	-	+	-	+	-
	Class-Pisces						
24	Fish eggs	+	-	-	-	+	+
25	Fish Larvae	-	-	-	-	+	-
	Class-Hexanauplia						
26	*Macrosetella gracilis*	+	+	+	-	+	+
27	*Paracalanus* sp.	+	+	-	-	-	-
28	*Temora* sp.	+	-	-	-	-	-
29	*Acartia danae*	-	+	-	-	+	+
30	*Acartia erythraea*	+	+	-	-	-	-
31	*Acartia spinicauda*	-	+	-	-	-	-
	Class-Globothalamea						
32	*Globigerina* sp.	-	-	-	-	-	-
	Class-Sagittoidea						
33	*Saggita* sp.	-	-	-	-	-	-
	Class-Branchiopoda						
34	*Penilia* sp.	-	-	-	-	-	-

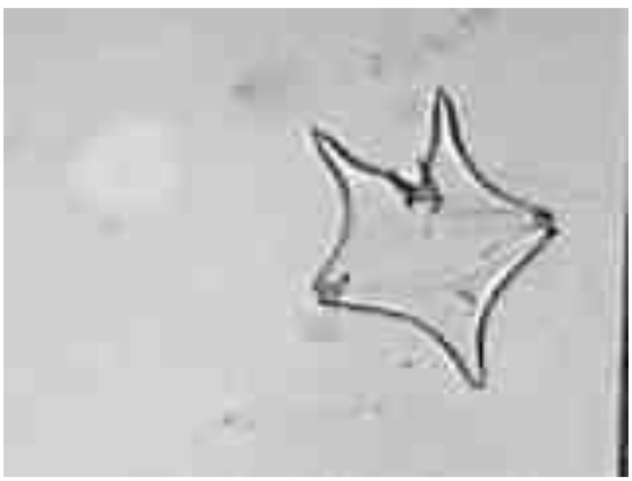
+ Present; - Absent

Summary results and remarks

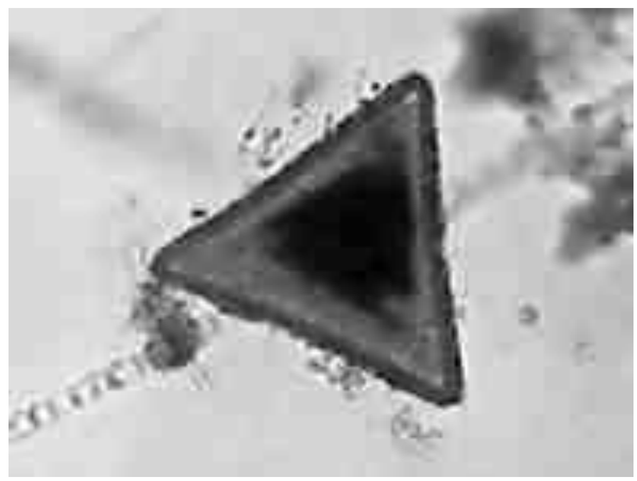
Density and diversity of phyto and zooplankton in the study areas were fair. From the samples collected from Buckingham canal, a total of 14 phytoplankton species belonging to three groups such as diatoms, dinoflagellates and cyanophyceae were observed. Phytoplankton density in the canal samples ranged from 100-4000 cells/l. Chlorophyll 'a' in varied from 0.33 to 3.74 mg/m^3 and chlorophyll 'b' varied from 0.11 to 2.92 mg/m^3 while primary productivity varied from 110.52 to 340.63 mgCm^{-3}d^{-1}. A total of 15 zooplankton species were recorded from the canal samples. Zooplankton density ranged from 100-3460 Nos/m^3. A total of 17 phytoplankton species belonging to diatoms and dinoflagellates were recorded from the samples from Ennore Creek. Phytoplankton density ranged between 200-4100 cells/l. Chlorophyll 'a' in ranged from 1.14 to 5.25 mg/m^3 and chlorophyll 'b' ranged from 0.99 to 3.96 mg/m^3 while primary productivity ranged from 109.45 to 245.87 mgCm^{-3}d^{-1}. A total of 10 zooplankton species were recorded from Ennore Creek where zooplankton density ranged from 200-1260 Nos/m^3. A total of 10 phytoplankton species belonging to the diatoms were observed in the mangrove region. Phytoplankton density in the samples showed a range of 500-9300 cells/l. The chlorophyll ‘a’ content in the mangrove region ranged 1.46 to 8.53 mg/m^3 and chlorophyll ‘b’ content varied from 1.11 to 2.75 mg/m^3 while primary productivity ranged from 200.66 to 501.24 $mgCm^{-3}d^{-1}$. A total of 14 zooplankton species were recorded from the mangrove region where zooplankton density was 420-3600 Nos/m^3. Samples from Pulicat Lake revealed 16 species of phytoplankton belonging to diatoms, dinoflagellates and cyanophyceae. Phytoplankton density in the lake samples showed a range of 6500-12700 cells/l. Chlorophyll ‘a’ varied from 2.75 to 3.92 mg/m^3 and chlorophyll ‘b’ varied from 0.99 to 2.39 mg/m^3 while primary productivity varied from 310.73 to 455.61 $mgCm\text{-}^{3}d^{-1}$. A total of 12 zooplankton species were recorded from the Pulicat Lake where zooplankton density was 2460-6110 Nos/m^3. From the samples collected from Kosathalaiyar River, a total of 10 phytoplankton species belonging to the diatoms and cyanophyceae group were observed. Phytoplankton density showed a range of 700-4100 cells/l. Chlorophyll ‘a’content ranged from 0.74 to 4.46 mg/m^3 and chlorophyll ‘b’ content ranged 0.33 to 2.58 mg/m^3 while primary productivity varied from 120.41 to 380.67 $mgCm^{-3}d^{-1}$. A total of 12 zooplankton species were recorded from Kosathaliayar River. Zooplankton density showed a range of 260-2040 Nos/m^3. In the marine zone, a total of 54 phytoplankton species belonging to diatoms, dinoflagellates and cyanophyceae were recorded where phytoplankton density ranged from 100-42500 cells/l. Chlorophyll ‘a’ in marine samples varied from 0.42 to 18.49 mg/m^3 and chlorophyll ‘b’ content varied from 0.17 to 10.86 mg/m^3 while primary productivity varied from 60.01 to 530.94 $mgCm^{-3}d^{-1}$. A total of 34 zooplankton species were recorded from the marine zone where zooplankton density ranged from 90-5200 $Nos/m^{3.}$

Chaetoceros coarctatus

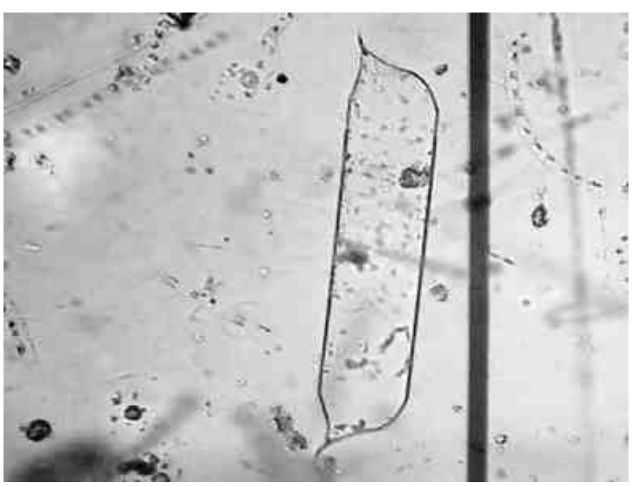
Ceratium furca



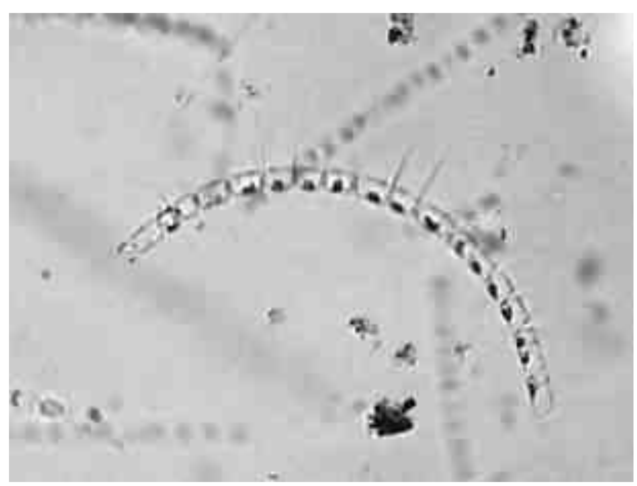
Protoperidinium depressum



***Triceratium* sp.**

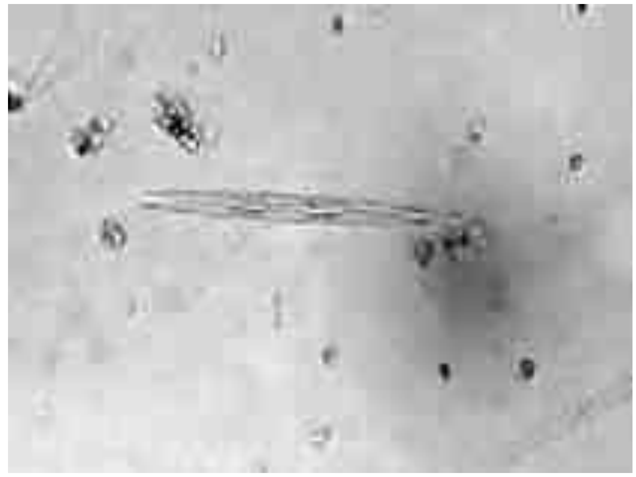


***Rhizosolenia* sp.**

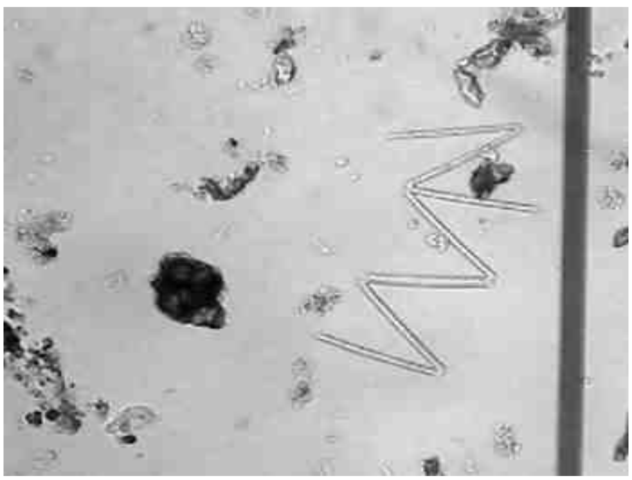


Chaetoceros curvisetus

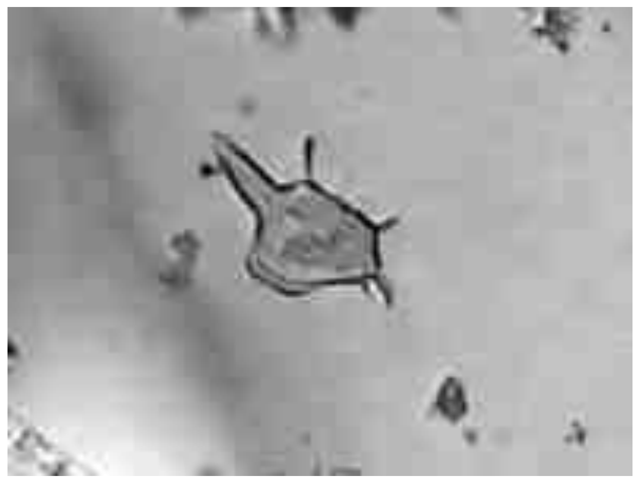
Odontella sinensis



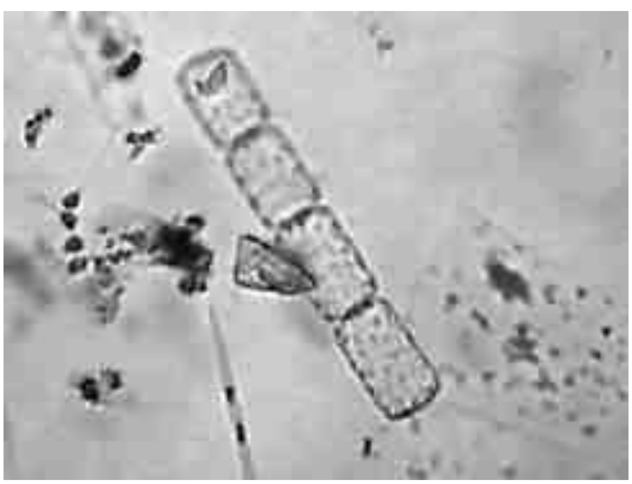
***Navicula* sp.**



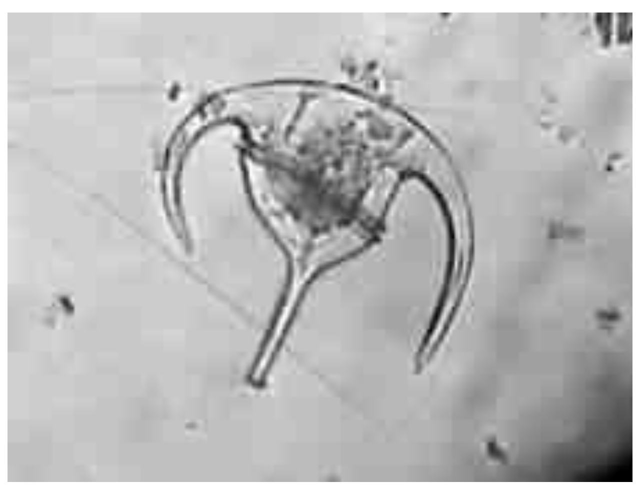
Thalassionema nitzschioides



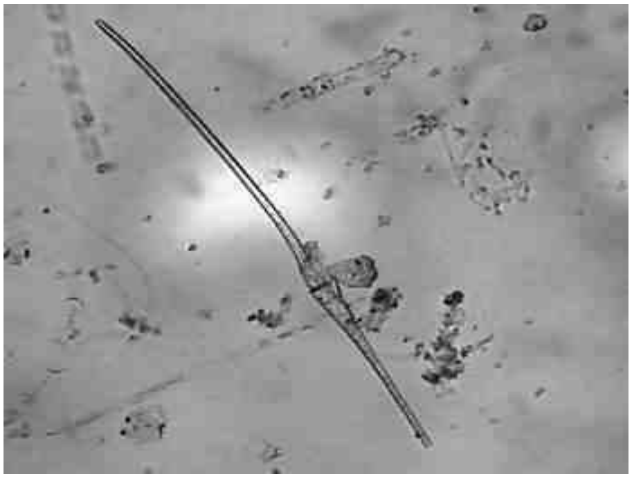
Dinophysis caudata



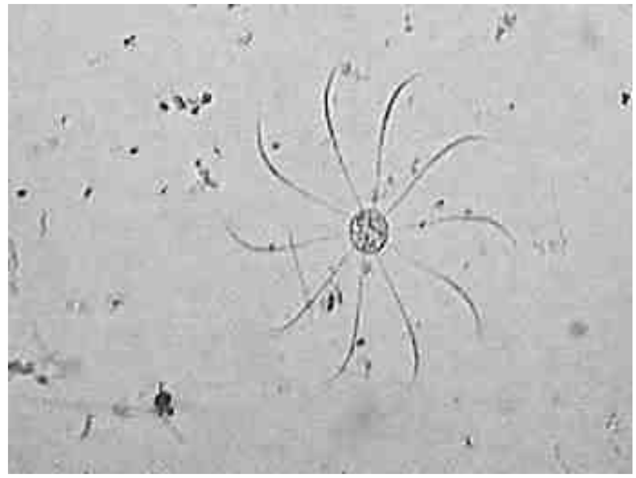
***Lauderia* sp.**



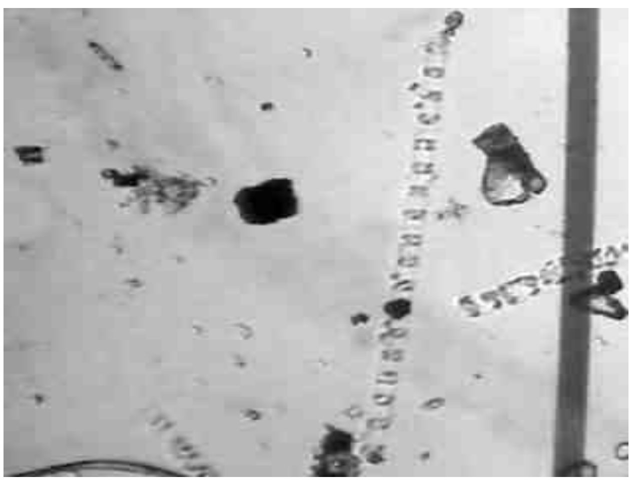
Ceratium azoricum



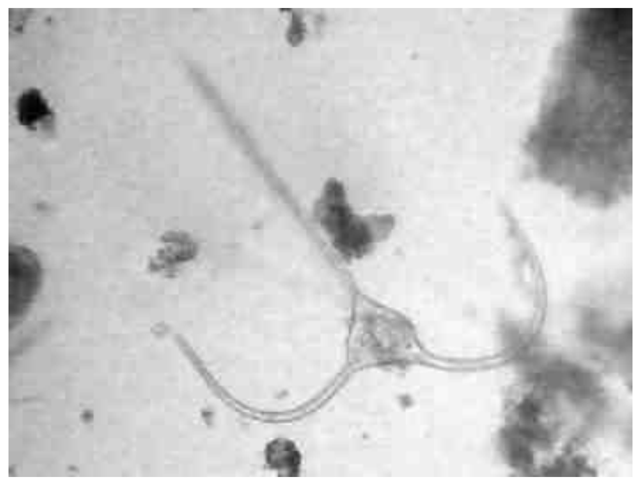
Ceratium sp.



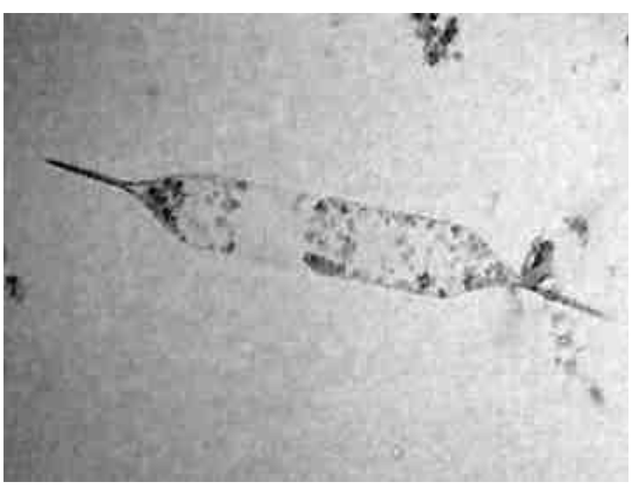
Bacteriastrum delicatulum



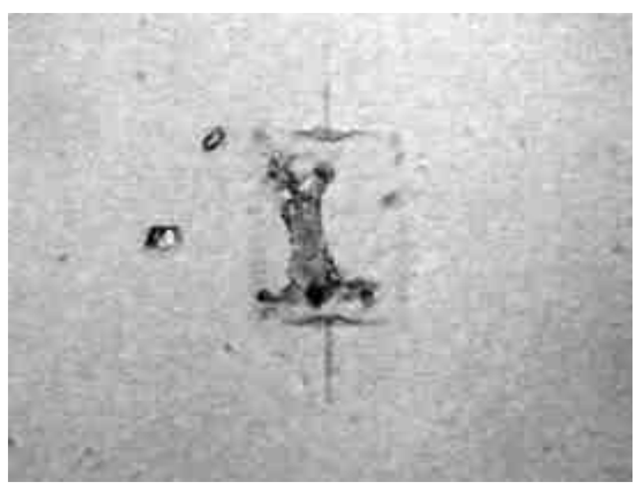
Chaetoceros sp.



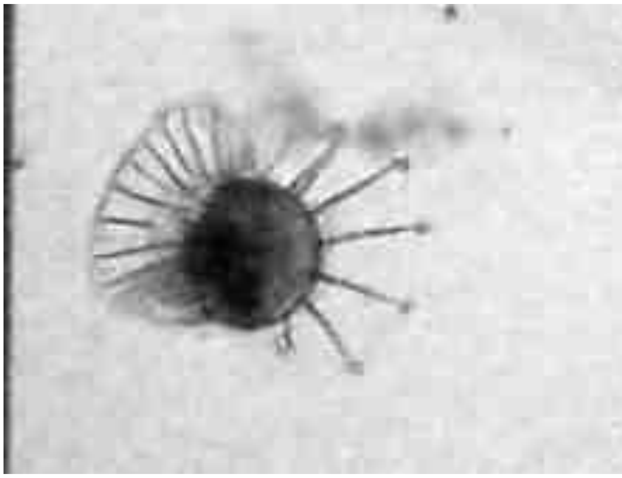
Ceratium sp.



Rhizosolenia sp.

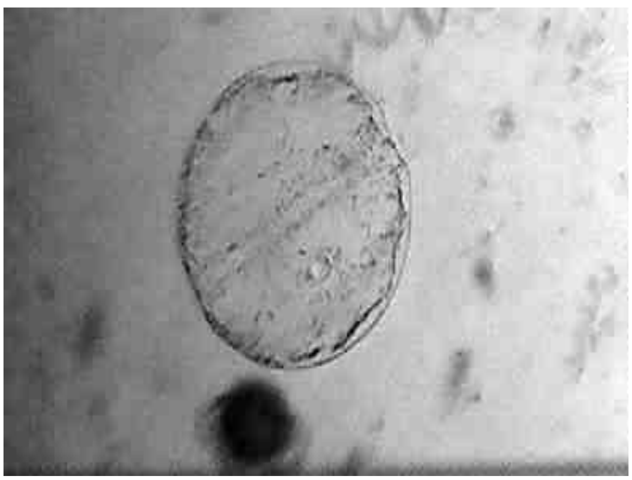


Ditylum sp.



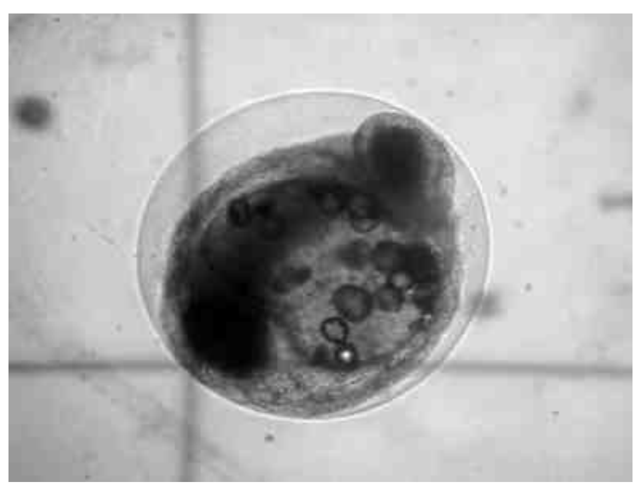
Ornithocercus steinii

Trichodesmium erythraeum



Hemidiscus hardmannianus

Temora sp.

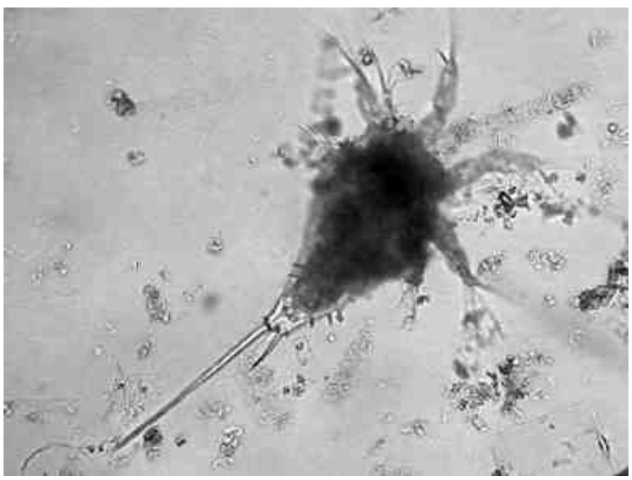


Acrocalanus longicornis

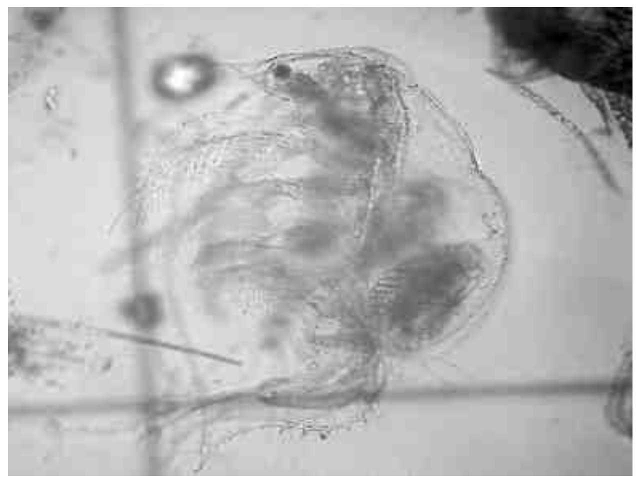
Fish Egg

Oikopleura sp.

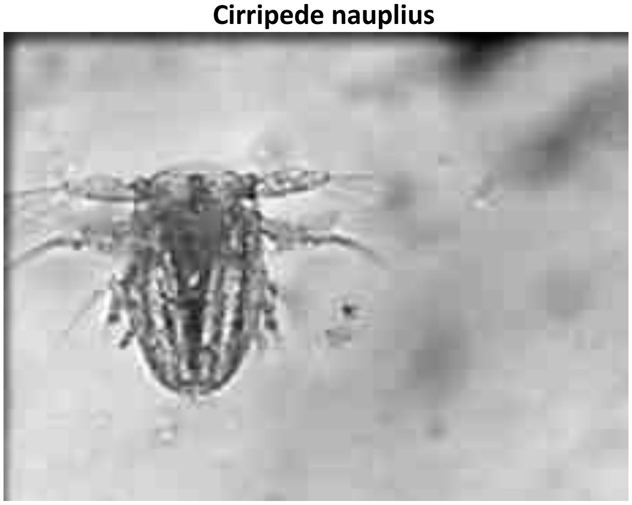
Acrocalanus sp.



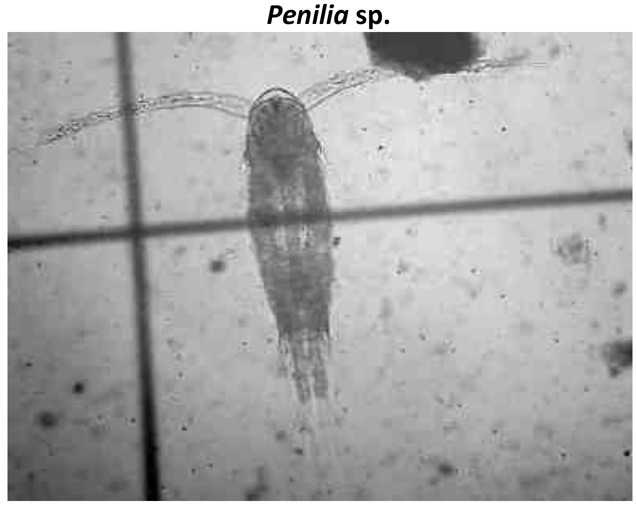
Cirripede nauplius



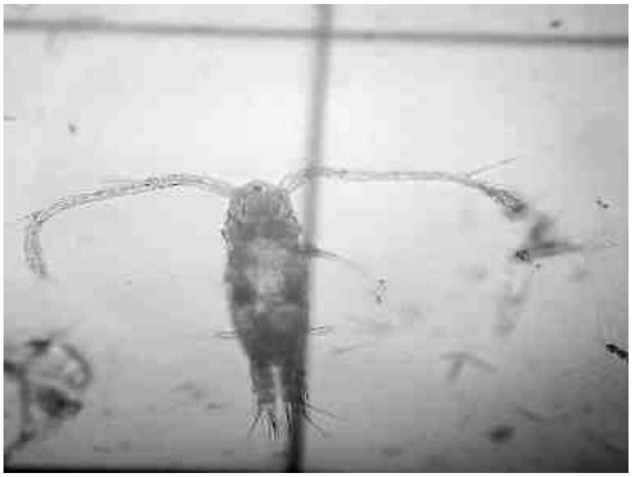
Penilia sp.



Copepod nauplii

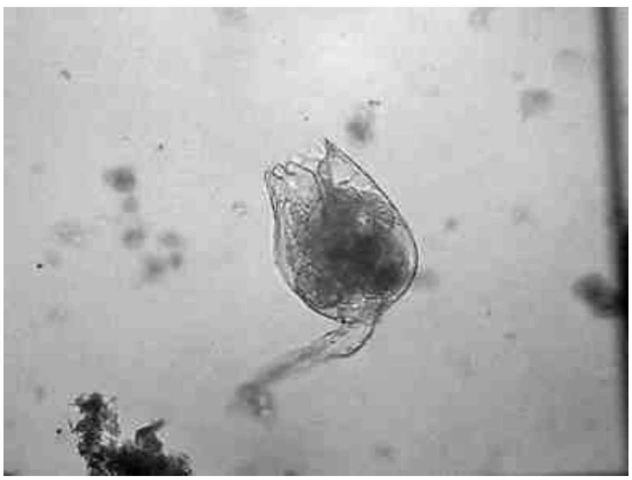


Centropages sp.

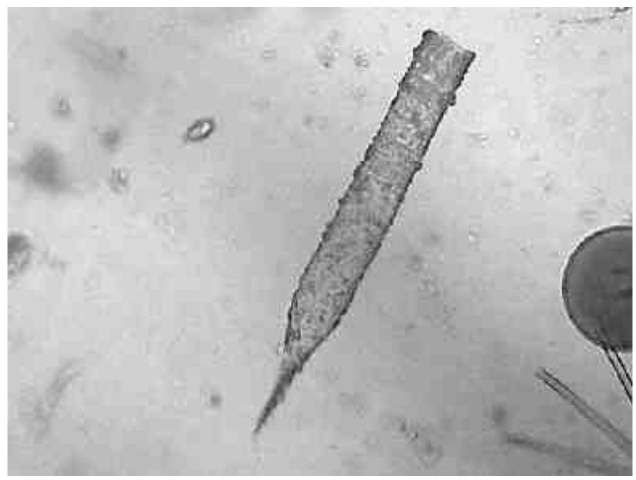


Temora sp.

Acrocalanus sp.

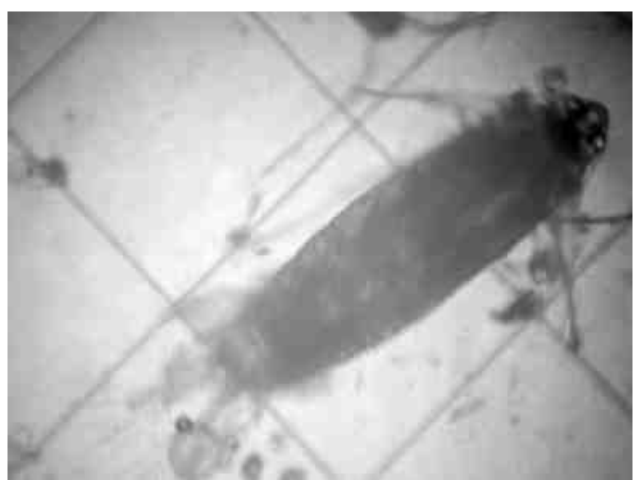


***Brachionus* sp.**



***Tintinnopsis* sp.**

***Macrosetella* sp.**



***Subeucalanus* sp.**

vi. Microbial community estimation

1. Water samples

In Ennore creek, the total viable count in water samples ranged from 6.54x10^4 to 8.10x10^4 CFU/ml. The maximum count was found at En1 and the minimum count was found at En4. The Total coliform count in the samples varied from 1.02x10^4 to 1.89x10^4 CFU/ml with the high colony count was observed at En2 and the low count was observed at En4. The Faecal coliform was found to vary from 0.53x10^4 to 0.98x10^4 CFU/ml with high values was found at En2 and the low value was found at En5. The *E. coli* count ranged from 0.45x10^4 to 0.68x10^4 CFU/ml with a maximum value was found at En2 and the low values were found at En4. The *Shigella* count varied from 0.03x10^4 to 0.09x10^4 CFU/ml with a high value was found at En1 and low value was found at En5. The *Salmonella* colony count varied from 0.33x10^4 to 0.53x10^4 CFU/ml with the high values were found at En1 and the low values at En5. The *Streptococcus faecalis* count ranged from 0.27x10^4 to 0.38x10^4 CFU/ml. The high values were recorded at En3 and the low values were recorded at En1. The *Pseudomonas aeurginosa* count ranged from 0.02x 10^3 to 0.08x10^3 CFU/ml with high values were found at En3 and the low values at En4. *Vibrio parahaemolyticus* colony count varied from 0.11x10^3 to 0.23x10^3 CFU/ml with the high values was found at En1 and low values at En5. The *Vibrio cholera* colony was found to have values from 0.04x10^3 to 0.10x10^3 CFU/ml. The high colony count was observed at En4 and the low count was recorded at En1.

In Pulicat Lake, the total viable count in water samples ranged from 4.49x10^4 to 5.23x10^4 CFU/ml. The maximum count was found at Pu3 and the minimum count was found at Pu2. The Total coliform count in the samples varied from 0.89x10^4 to 1.89x10^4 CFU/ml with the high colony count was observed at Pu3 and the low count was observed at Pu6. The Faecal coliform was found to vary from 0.21x10^4 to 0.93x10^4 CFU/ml with high values was found at Pu3 and the low value was found at Pu6. The *E. coli* count ranged from 0.35x10^4 to 0.89x10^4 CFU/ml with a maximum value was found at Pu2 and the low values were found at Pu5. The *Shigella* count varied from 0.03x10^4 to 0.11x10^4 CFU/ml with a high value was found at Pu3 and low value was found at Pu5. The *Salmonella* colony count varied from 0.21x10^4 to 0.45x10^4 CFU/ml with the high values were found at Pu2 and the low values at Pu5. The *Streptococcus faecalis* count ranged from 0.16x10^4 to 0.29x10^4 CFU/ml. The high values were recorded at Pu2 and the low values were recorded at Pu1. The *Pseudomonas aeurginosa* count ranged from 0.02x 10^3 to 0.09 x10^3 CFU/ml with high values were found at Pu2 and the low values at Pu6. *Vibrio parahaemolyticus* colony count varied from 0.11x10^3 to 0.19x10^3 CFU/ml with the high values was found at Pu2 and low values at Pu3. The *Vibrio cholera* colony was found to have values from 0.01x10^3 to 0.08x10^3 CFU/ml. The high colony count was observed at Pu2 and the low count was recorded at Pu6.

In mangrove area, the total viable count in water samples ranged from 4.12x10^4 to 5.23x10^4 CFU/ml. The maximum count was found at M7 and the minimum count was found at M2. The Total coliform count in the samples varied from 0.65x10^4 to 0.99x10^4 CFU/ml with the high colony count was observed at M2 and the low count was observed at M10. The Faecal coliform was found to vary from 0.51x10^4 to 0.71x10^4 CFU/ml with high values was found at M9 and the low value was found at M6. The *E. coli* count ranged from $0.25x10^4$ to $0.68x10^4$ CFU/ml with a maximum value was found at M4 and the low values were found at M5. The *Shigella* count varied from $0.03x10^4$ to $0.20x10^4$ CFU/ml with a high value was found at M3 and low value was found at M5. The *Salmonella* colony count varied from $0.23x10^4$ to $0.53x10^4$ CFU/ml with the high values were found at M3 and the low values at M6. The *Streptococcus faecalis* count ranged from $0.11x10^3$ to $0.31x10^3$ CFU/ml. The high values were recorded at M3 and the low values were recorded at M4. The *Pseudomonas aeurginosa* count ranged from $0.03x10^4$ to $0.29x10^4$ CFU/ml with high values were found at M2 and the low values at M6. *Vibrio parahaemolyticus* colony count varied from $0.06x10^3$ to $0.31x10^3$ CFU/ml with the high values was found at M2 and low values at M5. The *Vibrio cholera* colony was found to have values from $0.02x10^3$ to $0.23x10^3$ CFU/ml. The high colony count was observed at M8 and the low count was recorded at M5.

In Kosasthalaiyar River, the total viable count in water samples ranged from $5.52x10^3$ to $6.43x10^4$ CFU/ml. The maximum count was found at R9 and the minimum count was found at R11. The Total coliform count in the samples varied from $1.05x10^3$ to $1.41x10^4$ CFU/ml with the high colony count was observed at R10 and the low count was observed at R4. The Faecal coliform was found to vary from $0.52x10^3$ to $0.84x10^4$ CFU/ml with high values was found at R10 and the low value was found at R13. The *E. coli* count ranged from $0.61x10^3$ to $0.88x10^4$ CFU/ml with a maximum value was found at R10 and the low values were found at R11. The *Shigella* count varied from $0.03x10^4$ to $0.18x10^4$ CFU/ml with a high value was found at R9 and low value was found at R1. The *Salmonella* colony count varied from $0.02x10^3$ to $0.15x10^4$ CFU/ml with the high values were found at R5 and the low values at R11. The *Streptococcus faecalis* count ranged from $0.01x10^3$ to $0.18x10^4$ CFU/ml. The high values were recorded at R10 and the low values were recorded at R12. The *Pseudomonas aeurginosa* count ranged from $0.03x10^3$ to $0.11x10^4$ CFU/ml with high values were found at R5 and the low values at R4 and R11. *Vibrio parahaemolyticus* colony count varied from $0.02x10^3$ to $0.19x10^4$ CFU/ml with the high values was found at R1 and low values at R12. The *Vibrio cholera* colony was found to have values from $0.03x10^3$ to $0.16x10^3$ CFU/ml. The high colony count was observed at R5 and the low count was recorded at R1, R6 and R12.

In Buckingham Canal, the total viable count in water samples ranged from $4.09x10^4$ to $5.15x10^4$ CFU/ml. The maximum count was found at B11 and the minimum count was found at B6. The Total coliform count in the samples varied from $0.72x10^4$ to $1.03x10^4$ CFU/ml with the high colony count was observed at B11 and the low count was observed at B2. The Faecal coliform was found to vary from $0.51x10^4$ to $0.82x10^4$ CFU/ml with high values was found at B7 and the low value was found at B2. The *E. coli* count ranged from $0.20x10^4$ to $0.67x10^4$ CFU/ml with a maximum value was found at B12 and the low values were found at B2. The *Shigella* count varied from $0.03x10^4$ to $0.18x10^4$ CFU/ml with a high value was found at B5 and B11 and low value was found at B4. The *Salmonella* colony count varied from $0.23\ x10^4$ to $0.42x10^4$ CFU/ml with the high values were found at B7 and the low values at B1. The *Streptococcus faecalis* count ranged from $0.13x10^3$ to $0.39x10^3$ CFU/ml. The high values were recorded at B7 and the low values were recorded at B10. The *Pseudomonas aeurginosa* count ranged from $0.01x10^4$ to $0.10x10^4$ CFU/ml with high values were found at B12 and the low values at B1.

Vibrio parahaemolyticus colony count varied from $0.12x10^4$ to $0.29x10^4$ CFU/ml with the high values was found at B7 and low values at B2. The *Vibrio cholera* colony was found to have values from $0.03x10^3$ to $0.19x10^3$ CFU/ml. The high colony count was observed at B7 and the low count was recorded at B2.

The total viable count in sea water samples ranged from $2.32x10^4$ to $7.97x10^4$ CFU/ml. The maximum count was found at S19 and the minimum count was found at S62. The Total coliform count in the samples varied from $0.65x10^4$ to $2.09x10^4$ CFU/ml with the high colony count was observed at S18 and S29 and the low count was observed at S45. The Faecal coliform was found to vary from $0.51x10^4$ to $1.45x10^4$ CFU/ml with high values was found at S25 and the low value was found at S62. The *E. coli* count ranged from $0.20x10^4$ to $0.99x10^4$ CFU/ml with a maximum value was found at S18 and the low values were found at S60. The *Shigella* count varied from $0.02x10^4$ to $0.23x10^4$ CFU/ml with a high value was found at S21 and low value was found at S5, S8, S42, S68, S70 and S76. The *Salmonella* colony count varied from $0.10x10^4$ to $0.98x10^4$ CFU/ml with the high values were found at S18 and the low values at S59. The *Streptococcus faecalis* count ranged from $0.11x10^4$ to $0.46x10^4$ CFU/ml. The high values were recorded at S41 and the low values were recorded at S78. The *Pseudomonas aeurginosa* count ranged from 0.01 $x10^3$ to $0.20x10^3$ CFU/ml with high values were found at S9, S43, S58 and S61 and the low values at S3. *Vibrio parahaemolyticus* colony count varied from $0.02x10^3$ to $0.35x10^3$ CFU/ml with the high values was found at S29 and low values at S59. The *Vibrio cholera* colony was found to have values from $0.01x10^3$ to $0.17x10^3$ CFU/ml. The high colony count was observed at S37 and the low count was recorded at S5, S12 and S85.The results were represented in Tables 3.6.1 to 3.6.6.

2. Sediment samples

In Ennore creek, the total viable count in sediment samples ranged from 7.48 $x10^5$ and 8.78 x 10^5 CFU/g. The maximum count was found at En2 and the minimum count was found at En5. The Total coliform count in the samples varied from 1.41 $x10^5$ to 2.01 $x10^5$ CFU/g with the high colony count was observed at En2 and the low count was observed at En5. The Faecal coliform was found to vary from $0.71x10^5$ to $0.93x10^5$ CFU/g with high values was found at En2 and the low value was found at En5. The *E. coli* count ranged from $0.54x10^5$ to $0.84x10^5$ CFU/g with a maximum value was found at En2 and the low values were found at En5. The *Shigella* count varied from $0.02x10^5$ to $0.08x10^5$ CFU/g with a high value was found at En1 and low value was found at En5. The *Salmonella* colony count varied from $0.34x10^5$ to 0.37 $x10^5$ CFU/g with the high values were found at En1 and the low values at En5. The *Streptococcus faecalis* count ranged from 0.31 x 10^5 to 0.46 x 10^5 CFU/g. The high values were recorded at En2 and the low values were recorded at En5. The *Pseudomonas aeruginosa* count ranged from 0.06 x 10^4 to $0.14x10^4$ CFU/g with high values were found at En2 and the low values at En4 & En1. *Vibrio parahaemolyticus* colony count varied from $0.11x10^4$ to $0.21x10^4$ CFU/g with the high values was found at En1 and low values at En4. The *Vibrio cholera* colony was found to have values from $0.07x10^4$ to $0.19x10^4$ CFU/g. The high colony count was observed at En3 and the low count was recorded at En5.

In Pulicat Lake, the total viable count in sediment samples ranged from $4.18x10^5$ to $6.52x10^5$ CFU/g. The maximum count was found at Pu3 and the minimum count was found at Pu6. The Total coliform count in the samples varied from 1.03 $x10^5$ to 2.01 $x10^5$ CFU/g with the high colony count was observed at Pu3 and the low count was observed at Pu6. The Faecal coliform was found to vary from $0.21x10^5$ to $0.81x10^5$CFU/g with high values was found at Pu2 and the low value was found at Pu6. The *E. coli* count ranged from $0.34x10^5$ to $0.88x10^5$ CFU/g with a maximum value was found at Pu2 and the low values were found at Pu6. The *Shigella* count varied from $0.01x10^5$ to $0.09x10^5$ CFU/g with a high value was found at Pu3 and low value was found at Pu5. The *Salmonella* colony count varied from $0.19x10^5$ to $0.48x10^5$ CFU/g with the high values were found at Pu4 and the low values at Pu6. The *Streptococcus faecalis* count ranged from $0.23x10^5$ to $0.35x10^5$ CFU/g. The high values were recorded at Pu3 and the low values were recorded at Pu6. The *Pseudomonas aeurginosa* count ranged from $0.01x10^4$ to 0.07 $X10^4$ CFU/g with high values were found at Pu3 and the low values at Pu1. *Vibrio parahaemolyticus* colony count varied from $0.12x10^4$ to $0.18x10^4$ CFU/g with the high values was found at Pu5 and low values at Pu4. The *Vibrio cholera* colony was found to have values from $0.03x10^4$ to $0.09x10^4$ CFU/g. The high colony count was observed at Pu3 and the low count was recorded at Pu5.

In mangrove area, the total viable count in sediment samples ranged from $5.11x10^5$ to 6.24x 10^5 CFU/g. The maximum count was found at M3 and the minimum count was found at M6. The Total coliform count in the samples varied from $1.77x10^5$ to 2.04 $x10^5$ CFU/g with the high colony count was observed at M1 and the low count was observed at M5. The Faecal coliform was found to vary from $0.69x10^5$ to $1.03x10^5$ CFU/g with high values was found at M11 and the low value was found at M10. The *E. coli* count ranged from $0.64x10^5$ to $0.98x10^5$ CFU/g with a maximum value was found at M2 and the low values were found at M5. The *Shigella* count varied from $0.04x10^4$ to $0.25x10^4$ CFU/g with a high value was found at M2 and low value was found at M4. The *Salmonella* colony count varied from $0.39x10^4$ to $0.68x10^4$ CFU/g with the high values were found at M3 and the low values at M10. The *Streptococcus faecalis* count ranged from $0.21x10^4$ to $0.41x10^4$ CFU/g. The high values were recorded at M3 and the low values were recorded at M8. The *Pseudomonas aeurginosa* count ranged from 0.11 $x10^4$ to $0.29x10^4$ CFU/g with high values were found at M7 and the low values at M6. *Vibrio parahaemolyticus* colony count varied from $0.13x10^4$ to $0.35x10^4$ CFU/g with the high values was found at M7 and low values at M9. The *Vibrio cholera* colony was found to have values from $0.05x10^3$ to $0.31x10^3$ CFU/g. The high colony count was observed at M3 and the low count was recorded at M6.

In Kosasthalaiyar River, the total viable count in sediment samples ranged from $5.99x10^4$ to 6.82 10^5 CFU/g. The maximum count was found at R5 and the minimum count was found at R12. The Total coliform count in the samples varied from 1.11 $x10^4$ to $1.42x10^5$ CFU/g with the high colony count was observed at R10 and the low count was observed at R3. The Faecal coliform was found to vary from $0.63x10^4$ to 1.05 $x10^5$ CFU/g with high values was found at R12 and the low value was found at R2. The *E. coli* count ranged from $0.49x10^4$ to $0.76x10^5$ CFU/g with a maximum value was found at R10 and the low values were found at R11. The *Shigella* count varied from $0.12x10^4$ to $0.26x10^5$ CFU/g with a high value was found at R6 and low value was found at R7. The *Salmonella* colony count varied from $0.04x10^4$ to $0.14x10^5$ CFU/g with the high values were found at R2 and the low values at R11. The *Streptococcus faecalis* count ranged from $0.10x10^4$ to $0.29x10^5$ CFU/g. The high values were recorded at R5 and the low values were recorded at R12. The *Pseudomonas aeurginosa* count ranged from 0.11 $x10^4$ to $0.25x10^5$ to CFU/g with high values were found at R10 and the low values at R12. *Vibrio parahaemolyticus* colony count varied from $0.13x10^4$ to $0.23x10^5$ CFU/g with the high values was found at R4 and low values at R12. The *Vibrio cholera* colony was found to have values from $0.02x10^3$ to $0.11x10^4$ CFU/g. The high colony count was observed at R4and the low count was recorded at R1.

In Buckingham Canal, the total viable count in sediment samples ranged from 4.99 $x10^5$ to 5.95 x 10^5 CFU/g. The maximum count was found at B11 and the minimum count was found at B8. The Total coliform count in the samples varied from 0.74 $x10^5$ to 1.25 $x10^5$ CFU/g with the high colony count was observed at B12 and the low count was observed at B1. The Faecal coliform was found to vary from $0.41x10^5$ to $0.49x10^5$ CFU/g with high values was found at B12 and the low value was found at B5. The *E. coli* count ranged from $0.39x10^5$ to $0.72x10^5$ CFU/g with a maximum value was found at B12 and the low values were found at B9. The *Shigella* count varied from $0.13x10^5$ to $0.26x10^5$ CFU/g with a high value was found at B5 and low value was found at B2. The *Salmonella* colony count varied from $0.21x10^5$ to $0.39x10^5$ CFU/g with the high values were found at B12 and the low values at B8. The *Streptococcus faecalis* count ranged from $0.28x10^5$ to $0.48x10^5$ CFU/g. The high values were recorded at B9 and the low values were recorded at B6. The *Pseudomonas aeurginosa* count ranged from 0.08 x 10^4 to $0.21x10^4$ CFU/g with high values were found at B12 and the low values at B6. *Vibrio parahaemolyticus* colony count varied from $0.08x10^4$ to $0.22x10^4$ CFU/g with the high values was found at B11 and low values at B2. The *Vibrio cholera* colony was found to have values from $0.10x10^3$ to $0.35x10^3$ CFU/g. The high colony count was observed at B12 and the low count was recorded at B5.

The total viable count in sea sediment samples ranged from $1.49x10^5$ to 8.71x 10^5 CFU/g. The maximum count was found at S19 and the minimum count was found at S80. The Total coliform count in the samples varied from 0.72 $x10^5$ to $2.41x10^5$ CFU/g with the high colony count was observed at S18 and the low count was observed at S86 &S9. The Faecal coliform was found to vary from $0.41x10^5$ to $1.22x10^5$ CFU/g with high values was found at S19 and the low value was found at S83. The *E. coli* count ranged from $0.31x10^5$ to $1.31x10^5$ CFU/g with a maximum value was found at S19 and the low values were found at S66. The *Shigella* count varied from $0.01x10^4$ to $0.32x10^4$ CFU/g with a high value was found at S10 & S17 and low value was found at S61. The *Salmonella* colony count varied from $0.18x10^5$ to $1.42x10^5$ CFU/g with the high values were found at S10 &S16 and the low values at S5 & S36. The *Streptococcus faecalis* count ranged from $0.02x10^4$ to $0.31x10^4$ CFU/g. The high values were recorded at S19 & S48 and the low values were recorded at S40, S62 & S67 . The *Pseudomonas aeurginosa* count ranged from 0.02 $x10^4$ to $0.35x10^4$ CFU/g with high values were found at S20 and the low values at S45, S61 & S86. *Vibrio parahaemolyticus* colony count varied from $0.08x10^4$ to $0.59x10^4$ CFU/g with the high values was found at S19 and low values at S45. The *Vibrio cholera* colony was found to have values from $0.03x10^4$ to $0.32x10^4$ CFU/g. The high colony count was observed at S19 and the low count was recorded at S9, S49 & S61.The results were represented in Tables 3.6.7 to 3.6.12.

Bacterial community in Water samples

Table 3.6.1: Bacterial population recorded in water samples in Ennore creek

Microbial parameters	Sampling sites				
	En1	En2	En3	En4	En5
TVC (CFU/ml)	$8.10x10^4$	$7.86X10^4$	$7.05X10^4$	$6.54X10^4$	$6.98X10^4$
TC (CFU/ml)	$1.78X10^4$	$1.89X10^4$	$1.72X10^4$	$1.02X10^4$	$1.18X10^4$
FC (CFU/ml)	$0.76X10^4$	$0.98X10^4$	$0.56X10^4$	$0.89X10^4$	$0.53X10^4$
E.coli (CFU/ml)	$0.63X10^4$	$0.68X10^4$	$0.52X10^4$	$0.45X10^4$	$0.56X10^4$
Shigella sp. (CFU/ml)	$0.09X10^4$	$0.04X10^4$	$0.08X10^4$	$0.06X10^4$	$0.03X10^4$
Salmonella sp. (CFU/ml)	$0.53X10^4$	$0.49X10^4$	$0.41X10^4$	$0.37X10^4$	$0.33X10^4$
Steptococcus faecalis (CFU/ml)	$0.27X10^4$	$0.31X10^4$	$0.38X10^4$	$0.29X10^4$	$0.34X10^4$
Pseudomonas aeruginosa (CFU/ml)	$0.05X10^3$	$0.03X10^3$	$0.08X10^3$	$0.02X10^3$	$0.07X10^3$
Vibrio parahaemolyticus (CFU/ml)	$0.23X104^3$	$0.12X10^3$	$0.17X10^3$	$0.16X10^3$	$0.11X10^3$
Vibrio cholerae (CFU/ml)	$0.04X10^3$	$0.09X10^3$	$0.06X10^3$	$0.10X10^3$	$0.05X10^3$

Table 3.6.2: Bacterial population recorded in water samples recorded in various stations of Pulicat Lake

Microbial parameters	Sampling sites					
	Pu1	Pu2	Pu3	Pu4	Pu5	Pu6
TVC (CFU/ml)	$4.78x10^4$	$4.49X10^4$	$5.23X10^4$	$5.08X10^4$	$4.56X10^4$	$4.83X10^4$
TC (CFU/ml)	$1.23X10^4$	$1.67X10^4$	$1.89X10^4$	$1.16X10^4$	$1.01X10^4$	$0.89X10^4$
FC (CFU/ml)	$0.78X10^4$	$0.56X10^4$	$0.93X10^4$	$0.59X10^4$	$0.47X10^4$	$0.21X10^4$
E.coli (CFU/ml)	$0.45X10^4$	$0.89X10^4$	$0.53X10^4$	$0.76X10^4$	$0.35X10^4$	$0.39X10^4$
Shigella sp. (CFU/ml)	$0.08X10^4$	$0.05X10^4$	$0.11X10^4$	$0.08X10^4$	$0.03X10^4$	$0.06X10^4$
Salmonella sp. (CFU/ml)	$0.27X10^4$	$0.45X10^4$	$0.37X10^4$	$0.31X10^4$	$0.21X10^4$	$0.34X10^4$
Steptococcus faecalis (CFU/ml)	$0.16X10^4$	$0.29X10^4$	$0.22X10^4$	$0.26X10^4$	$0.19X10^4$	$0.20X10^4$

Pseudomonas aeruginosa **(CFU/ml)**	0.03X10^3	0.09X10^3	0.04X10^3	0.07X10^3	0.06X10^3	0.02X10^3
Vibrio parahaemolyticus **(CFU/ml)**	0.12X104^3	0.19X10^3	0.11X10^3	0.15X10^3	0.13X10^3	0.18X10^3
Vibrio cholerae **(CFU/ml)**	0.06X10^3	0.08X10^3	0.03X10^3	0.05X10^3	0.07X10^3	0.01X10^3

Table 3.6.3: Bacterial population recorded in water samples recorded in various stations of Mangrove area

Sites	**TVC (CFU/ml)**	**TC (CFU/ml)**	**FC (CFU/ml)**	***E.coli* (CFU/ml)**	***Shigella* sp. (CFU/ml)**	***Salmonella* sp. (CFU/ml)**	***Steptococcus faecalis* (CFU/ml)**	***Pseudomonas aeruginosa* (CFU/ml)**	***Vibrio parahaemolyticus* (CFU/ml)**	***Vibrio cholerae* (CFU/ml)**
M1	4.87X10^4	0.67X10^4	0.65X10^4	0.56X10^4	0.19 X10^4	0.36 X10^4	0.29 X10^3	0.19 X10^3	0.20 X10^3	0.12X10^3
M2	4.12X10^4	0.99X10^4	0.61X10^4	0.36X10^4	0.10 X10^4	0.42 X10^4	0.20 X10^3	0.29 X10^3	0.31 X10^3	0.21X10^3
M3	4.67X10^4	0.83X10^4	0.56X10^4	0.47X10^4	0.20 X10^4	0.53 X10^4	0.31 X10^3	0.17 X10^3	0.19 X10^3	0.20X10^3
M4	4.98X10^4	0.87X10^4	0.54X10^4	0.68X10^4	0.08 X10^4	0.27 X10^4	0.11 X10^3	0.11 X10^3	0.15 X10^3	0.09X10^3
M5	5.01X10^4	0.69X10^4	0.69X10^4	0.25X10^4	0.03 X10^4	0.35 X10^4	0.19 X10^3	0.09 X10^3	0.06 X10^3	0.02X10^3
M6	4.78X10^4	0.75X10^4	0.51X10^4	0.46X10^4	0.13 X10^4	0.23 X10^4	0.14 X10^3	0.03 X10^3	0.09 X10^3	0.05X10^3
M7	5.23X10^4	0.92X10^4	0.58X10^4	0.34X10^4	0.19 X10^4	0.39X10^4	0.29 X10^3	0.23 X10^3	0.11 X10^3	0.19X10^3
M8	4.93X10^4	0.82X10^4	0.69X10^4	0.39X10^4	0.11 X10^4	0.31 X10^4	0.26 X10^3	0.15 X10^3	0.23 X10^3	0.23X10^3
M9	5.18X10^4	0.78X10^4	0.71X10^4	0.59X10^4	0.15 X10^4	0.27X10^4	0.17 X10^3	0.25 X10^3	0.17 X10^3	0.14X10^3
M10	4.75X10^4	0.65X10^4	0.52X10^4	0.31X10^4	0.16 X10^4	0.49 X10^4	0.15 X10^3	0.08 X10^3	0.08 X10^3	0.07X10^3
M11	5.16X10^4	0.93X10^4	0.62X10^4	0.38X10^4	0.09 X10^4	0.34 X10^4	0.28 X10^3	0.19 X10^3	0.21 X10^3	0.18X10^3

Table 3.6.4: Bacterial population recorded in water samples recorded in various stations of Buckingham canal

Sites	**TVC (CFU/ml)**	**TC (CFU/ml)**	**FC (CFU/ml)**	***E.coli* (CFU/ml)**	***Shigella* sp. (CFU/ml)**	***Salmonella* sp. (CFU/ml)**	***Steptococcus faecalis* (CFU/ml)**	***Pseudomonas aeruginosa* (CFU/ml)**	***Vibrio parahaemolyticus* (CFU/ml)**	***Vibrio cholerae* (CFU/ml)**
B1	4.49X10^4	0.81X10^4	0.69X10^4	0.54X10^4	0.09X10^4	0.23 X10^4	0.19 X10^3	0.01 X10^4	0.19 X10^4	0.09 X10^3
B2	4.27 X10^4	0.72X10^4	0.51X10^4	0.20 X10^4	0.04X10^4	0.31 X10^4	0.29 X10^3	0.05 X10^4	0.12 X10^4	0.03 X10^3
B3	4.67 X10^4	0.83X10^4	0.69X10^4	0.49 X10^4	0.08X10^4	0.39 X10^4	0.15 X10^3	0.03 X10^4	0.16 X10^4	0.07 X10^3
B4	4.49 X10^4	0.79X10^4	0.57X10^4	0.38 X10^4	0.03X10^4	0.38 X10^4	0.31 X10^3	0.02 X10^4	0.13 X10^4	0.04 X10^3
B5	4.28 X10^4	0.98X10^4	0.71X10^4	0.53 X10^4	0.18X10^4	0.33 X10^4	0.24 X10^3	0.09 X10^4	0.18 X10^4	0.10 X10^3
B6	4.09 X10^4	0.75X10^4	0.65X10^4	0.26 X10^4	0.06X10^4	0.37 X10^4	0.28 X10^3	0.06 X10^4	0.16 X10^4	0.05 X10^3
B7	5.10 X10^4	1.00X10^4	0.82X10^4	0.61 X10^4	0.17X10^4	0.42 X10^4	0.39 X10^3	0.07 X10^4	0.29 X10^4	0.19 X10^3
B8	4.79 X10^4	0.89X10^4	0.69X10^4	0.43 X10^4	0.11X10^4	0.31 X10^4	0.26 X10^3	0.03 X10^4	0.20 X10^4	0.10 X10^3
B9	4.56 X10^4	0.98X10^4	0.76X10^4	0.56 X10^4	0.17X10^4	0.36 X10^4	0.38 X10^3	0.08 X10^4	0.15 X10^4	0.13 X10^3
B10	4.79 X10^4	0.83X10^4	0.56X10^4	0.37 X10^4	0.05X10^4	0.28 X10^4	0.13 X10^3	0.06 X10^4	0.14 X10^4	0.09 X10^3
B11	5.15 X10^4	1.03X10^4	0.84X10^4	0.51 X10^4	0.18X10^4	0.29 X10^4	0.37 X10^3	0.09 X10^4	0.27 X10^4	0.17 X10^3
B12	5.01 X10^4	1.01X10^4	0.69X10^4	0.67 X10^4	0.10X10^4	0.36 X10^4	0.34 X10^3	0.10 X10^4	0.21 X10^4	0.12 X10^3

Table 3.6.5: Bacterial population recorded in water samples recorded in various stations of Kosasthalaiyar river

Sites	TVC (CFU/ml)	TC (CFU/ml)	FC (CFU/ml)	*E.coli* (CFU/ml)	*Shigella* sp. (CFU/ml)	*Salmonella* sp. (CFU/ml)	*Steptococcus faecalis*(CFU/ml)	*Pseudomonas aeruginosa*(CFU/ml)	*Vibrio parahaemolyticus*(CFU/ml)	*Vibrio cholerae* (CFU/ml)
R1	5.98X10^4	1.19X10^4	0.63X10^4	0.63X10^4	0.03X10^4	0.05X10^4	0.09X10^4	0.09X10^4	0.19X10^4	0.03X10^3
R2	6.03X10^4	1.08X10^4	0.69X10^4	0.83X10^4	0.07X10^4	0.13X10^4	0.02X10^4	0.04X10^4	0.05X10^4	0.09X10^3
R3	6.19X10^4	1.10X10^4	0.78X10^4	0.78X10^4	0.06X10^4	0.09X10^4	0.10X10^4	0.07X10^4	0.13X10^4	0.05X10^3
R4	6.78X10^4	1.05X10^4	0.65X10^4	0.85X10^4	0.10X10^4	0.12X10^4	0.14X10^4	0.03X10^4	0.12X10^4	0.12X10^3
R5	5.65X10^4	1.27X10^4	0.73X10^4	0.82X10^4	0.14X10^4	0.15X10^4	0.11X10^4	0.11X10^4	0.17X10^4	0.16X10^3
R6	5.99X10^3	1.11X10^3	0.63X10^3	0.62X10^3	0.06X10^3	0.04X10^3	0.04X10^3	0.07X10^3	0.09X10^3	0.03X10^3
R7	6.01X10^4	1.29X10^4	0.79X10^4	0.81X10^4	0.05X10^4	0.08X10^4	0.07X10^4	0.10X10^4	0.03X10^4	0.05X10^3
R8	6.38X10^4	1.21X10^4	0.81X10^4	0.82X10^4	0.09X10^4	0.13X10^4	0.16X10^4	0.04X10^4	0.05X10^4	0.04X10^3
R9	6.43X10^4	1.32X10^4	0.73X10^4	0.84X10^4	0.18X10^4	0.09X10^4	0.10X10^4	0.08X10^4	0.13X10^4	0.15X10^3
R10	6.07X10^4	1.41X10^4	0.84X10^4	0.88X10^4	0.07X10^4	0.14X10^4	0.18X10^4	0.07X10^4	0.15X10^4	0.10X10^3
R11	5.52X10^3	1.09X10^3	0.60X10^3	0.61X10^3	0.04X10^3	0.02X10^3	0.06X10^3	0.03X10^3	0.09X10^3	0.05X10^3
R12	5.78X10^3	1.19X10^3	0.71X10^3	0.79X10^3	0.06X10^3	0.05X10^3	0.01X10^3	0.08X10^3	0.02X10^3	0.03X10^3
R13	5.93X10^3	1.07X10^3	0.52X10^3	0.69X10^3	0.08X10^3	0.06X10^3	0.03X10^3	0.04X10^3	0.05X10^3	0.04X10^3

Table 3.6.6: Bacterial population recorded in water samples recorded in marine zone

Sites	TVC (CFU/ml)	TC (CFU/ml)	FC (CFU/ml)	*E.coli* (CFU/ml)	*Shigella* sp. (CFU/ml)	*Salmonella* sp. (CFU/ml)	*Steptococcus faecalis* (CFU/ml)	*Pseudomonas aeruginosa* (CFU/ml)	*Vibrio parahaemolyticus* (CFU/ml)	*Vibrio cholerae* (CFU/ml)
S1	7.89X10^4	1.67X10^4	1.09X10^4	0.93X10^4	0.09X10^3	0.56X10^4	0.29 X10^3	0.07 X10^3	0.23 X10^3	0.03 X10^3
S2	5.67X10^4	1.29X10^4	0.98X10^4	0.67X10^4	0.05X10^3	0.12X10^4	0.38 X10^3	0.02 X10^3	0.15 X10^3	0.07 X10^3
S3	7.23X10^4	1.82X10^4	1.00X10^4	0.89X10^4	0.04X10^3	0.89X10^4	0.20 X10^3	0.20 X10^3	0.33 X10^3	0.09 X10^3
S4	5.78X10^4	1.16X10^4	0.81X10^4	0.71X10^4	0.06X10^3	0.29X10^4	0.26 X10^3	0.04 X10^3	0.23 X10^3	0.02 X10^3
S5	3.98X10^4	1.19X10^4	0.68X10^4	0.52X10^4	0.02X10^3	0.35X10^4	0.38 X10^3	0.03 X10^3	0.09 X10^3	0.01 X10^3
S6	7.23X10^4	1.82X10^4	1.29X10^4	0.75X10^4	0.10X10^3	0.89X10^4	0.17 X10^3	0.19 X10^3	0.35 X10^3	0.11 X10^3
S7	5.30X10^4	1.29X10^4	0.92X10^4	0.72X10^4	0.04X10^3	0.24X10^4	0.39 X10^3	0.03 X10^3	0.11 X10^3	0.06 X10^3
S8	3.89X10^4	1.10X10^4	0.71X10^4	0.46X10^4	0.02X10^3	0.22X10^4	0.30 X10^3	0.08 X10^3	0.19 X10^3	0.05 X10^3
S9	3.02X10^4	0.92X10^4	0.87X10^4	0.63X10^4	0.05X10^3	0.39X10^4	0.27 X10^3	0.01 X10^3	0.16 X10^3	0.03 X10^3
S10	7.56X10^4	2.01X10^4	1.18X10^4	0.98X10^4	0.17X10^3	0.78X10^4	0.39 X10^3	0.10 X10^3	0.23 X10^3	0.09 X10^3
S11	7.29X10^4	1.87X10^4	1.09X10^4	0.76X10^4	0.08X10^3	0.41X10^4	0.17 X10^3	0.05 X10^3	0.32 X10^3	0.05 X10^3
S12	6.86X10^4	1.23X10^4	0.95X10^4	0.88X10^4	0.06X10^3	0.78X10^4	0.19 X10^3	0.08 X10^3	0.31 X10^3	0.01 X10^3
S13	6.03X10^4	1.67X10^4	0.88X10^4	0.54X10^4	0.04X10^3	0.58X10^4	0.35 X10^3	0.06 X10^3	0.24 X10^3	0.08 X10^3
S14	5.23X10^4	1.45X10^4	0.94X10^4	0.68X10^4	0.11X10^3	0.32X10^4	0.25 X10^3	0.09 X10^3	0.29 X10^3	0.10 X10^3
S15	5.78X10^4	1.11X10^4	0.67X10^4	0.79X10^4	0.09X10^3	0.18X10^4	0.38 X10^3	0.03 X10^3	0.15 X10^3	0.09 X10^3
S16	5.06X10^4	1.78X10^4	0.99X10^4	0.72X10^4	0.03X10^3	0.47X10^4	0.19 X10^3	0.04 X10^3	0.19 X10^3	0.06 X10^3
S17	7.67X10^4	2.03X10^4	1.13X10^4	0.91X10^4	0.12X10^3	0.89X10^4	0.38 X10^3	0.19 X10^3	0.26 X10^3	0.11 X10^3
S18	7.93X10^4	2.09X10^4	1.33X10^4	0.99X10^4	0.18X10^3	0.98X10^4	0.42 X10^3	0.16 X10^3	0.31 X10^3	0.07 X10^3
S19	7.97X10^4	1.97X10^4	1.18X10^4	0.94X10^4	0.11X10^3	0.81X10^4	0.21 X10^3	0.11 X10^3	0.22 X10^3	0.09 X10^3

S20	7.34X10^4	1.67X10^4	1.26X10^4	0.67X10^4	0.03X10^3	0.89X10^4	0.21 X10^3	0.09 X10^3	0.23 X10^3	0.07 X10^3
S21	7.78X10^4	1.81X10^4	1.12X10^4	0.92X10^4	0.23X10^3	0.78X10^4	0.45 X10^3	0.05 X10^3	0.11 X10^3	0.03 X10^3
S22	7.45X10^4	1.78X10^4	1.35X10^4	0.85X10^4	0.10X10^3	0.68X10^4	0.35 X10^3	0.12 X10^3	0.19 X10^3	0.10X10^3
S23	7.89X10^4	1.71X10^4	1.10X10^4	0.76X10^4	0.09X10^3	0.76X10^4	0.29 X10^3	0.06 X10^3	0.26 X10^3	0.06 X10^3
S24	7.16X10^4	1.54X10^4	1.23X10^4	0.98X10^4	0.08X10^3	0.56X10^4	0.20 X10^3	0.09 X10^3	0.30 X10^3	0.02 X10^3
S25	6.95X10^4	1.34X10^4	1.45X10^4	0.85X10^4	0.03X10^3	0.74X10^4	0.15 X10^3	0.06 X10^3	0.15 X10^3	0.09 X10^3
S26	5.78X10^4	1.45X10^4	1.09X10^4	0.45X10^4	0.06X10^3	0.47X10^4	0.13 X10^3	0.04 X10^3	0.28 X10^3	0.05 X10^3
S27	4.34X10^4	1.19X10^4	0.86X10^4	0.65X10^4	0.03X10^3	0.39X10^4	0.30 X10^3	0.08 X10^3	0.09 X10^3	0.07 X10^3
S28	3.56X10^4	1.37X10^4	0.95X10^4	0.57X10^4	0.10X10^3	0.29X10^4	0.45 X10^3	0.05 X10^3	0.19 X10^3	0.09 X10^3
S29	7.36X10^4	2.09X10^4	1.13X10^4	0.94X10^4	0.09X10^3	0.67X10^4	0.38 X10^3	0.06 X10^3	0.35 X10^3	0.10 X10^3
S30	7.69X10^4	1.73X10^4	1.18X10^4	0.74X10^4	0.12X10^3	0.78X10^4	0.29 X10^3	0.15 X10^3	0.18 X10^3	0.04 X10^3
S31	7.56X10^4	1.67X10^4	1.09X10^4	0.62X10^4	0.09X10^3	0.68X10^4	0.19 X10^3	0.07 X10^3	0.29 X10^3	0.10 X10^3
S32	6.89X10^4	1.87X10^4	0.91X10^4	0.59X10^4	0.06X10^3	0.53X10^4	0.29 X10^3	0.11 X10^3	0.20 X10^3	0.06 X10^3
S33	5.81 X10^4	1.47X10^4	0.83X10^4	0.89 X10^4	0.06 X10^3	0.39 X10^4	0.23 X10^3	0.10 X10^3	0.29 X10^3	0.08 X10^3
S34	5.39 X10^4	1.18X10^4	0.67X10^4	0.51X10^4	0.06 X10^3	0.21 X10^4	0.15 X10^3	0.09 X10^3	0.16 X10^3	0.02 X10^3
S35	4.15 X10^4	1.07X10^4	0.85X10^4	0.38 X10^4	0.08 X10^3	0.29 X10^4	0.19 X10^3	0.07 X10^3	0.25 X10^3	0.09 X10^3
S36	3.54 X10^4	1.27X10^4	0.52X10^4	0.59 X10^4	0.05 X10^3	0.33 X10^4	0.28 X10^3	0.02 X10^3	0.18 X10^3	0.03 X10^3
S37	7.29 X10^4	1.78X10^4	1.02X10^4	0.95 X10^4	0.06 X10^3	0.67 X10^4	0.21 X10^3	0.18 X10^3	0.25 X10^3	0.17 X10^3
S38	6.53 X10^4	1.56X10^4	1.09X10^4	0.86 X10^4	0.03 X10^3	0.41 X10^4	0.19 X10^3	0.09 X10^3	0.32 X10^3	0.05 X10^3
S39	6.79 X10^4	1.42X10^4	1.11X10^4	0.72 X10^4	0.06 X10^3	0.79 X10^4	0.12 X10^3	0.15 X10^3	0.26 X10^3	0.07 X10^3
S40	6.52 X10^4	1.69X10^4	0.92X10^4	0.89 X10^4	0.04 X10^3	0.59 X10^4	0.38 X10^3	0.10 X10^3	0.22 X10^3	0.02 X10^3
S41	5.54 X10^4	1.49X10^4	0.96X10^4	0.61 X10^4	0.07 X10^3	0.26 X10^4	0.46 X10^3	0.08 X10^3	0.12 X10^3	0.11 X10^3
S42	5.78 X10^4	1.26X10^4	1.09X10^4	0.42 X10^4	0.02 X10^3	0.67 X10^4	0.19 X10^3	0.07 X10^3	0.29 X10^3	0.04 X10^3
S43	4.21 X10^4	1.10X10^4	0.63X10^4	0.39 X10^4	0.07 X10^3	0.18 X10^4	0.15 X10^3	0.01 X10^3	0.09 X10^3	0.04 X10^3
S44	3.42 X10^4	1.17X10^4	0.88X10^4	0.56 X10^4	0.08 X10^3	0.28 X10^4	0.15 X10^3	0.06 X10^3	0.23 X10^3	0.05 X10^3
S45	2.85 X10^4	0.65X10^4	0.78X10^4	0.69 X10^4	0.18 X10^3	0.32 X10^4	0.17 X10^3	0.04 X10^3	0.16 X10^3	0.03 X10^3
S46	7.45 X10^4	1.83X10^4	1.01X10^4	0.67 X10^4	0.07 X10^3	0.78 X10^4	0.16 X10^3	0.13 X10^3	0.24 X10^3	0.06 X10^3
S47	6.78 X10^4	1.43X10^4	0.90X10^4	0.83 X10^4	0.09 X10^3	0.69 X10^4	0.35 X10^3	0.03 X10^3	0.45 X10^3	0.09 X10^3
S48	6.69 X10^4	1.47X10^4	1.07X10^4	0.73 X10^4	0.05 X10^3	0.73 X10^4	0.21 X10^3	0.17 X10^3	0.29 X10^3	0.08 X10^3
S49	6.16 X10^4	1.57X10^4	0.63X10^4	0.89 X10^4	0.07 X10^3	0.56 X10^4	0.37 X10^3	0.10 X10^3	0.09 X10^3	0.04 X10^3
S50	5.56 X10^4	1.15X10^4	0.87X10^4	0.56 X10^4	0.08 X10^3	0.47 X10^4	0.39 X10^3	0.08 X10^3	0.20 X10^3	0.02 X10^3
S51	5.28 X10^4	1.12X10^4	0.67X10^4	0.74 X10^4	0.06 X10^3	0.22 X10^4	0.16 X10^3	0.04 X10^3	0.27 X10^3	0.05 X10^3
S52	4.78 X10^4	1.24X10^4	0.94X10^4	0.56 X10^4	0.05 X10^3	0.18 X10^4	0.19 X10^3	0.07 X10^3	0.04 X10^3	0.04 X10^3
S53	3.68 X10^4	1.34X10^4	0.73X10^4	0.82 X10^4	0.06 X10^3	0.25 X10^4	0.28 X10^3	0.05 X10^3	0.18 X10^3	0.09 X10^3
S54	7.51 X10^4	1.69X10^4	1.09X10^4	0.73 X10^4	0.09 X10^3	0.69 X10^4	0.32 X10^3	0.17 X10^3	0.34 X10^3	0.05 X10^3
S55	6.63 X10^4	1.85X10^4	1.14X10^4	0.79 X10^4	0.07 X10^3	0.63 X10^4	0.34 X10^3	0.08 X10^3	0.26 X10^3	0.16 X10^3
S56	6.68 X10^4	1.51X10^4	0.91X10^4	0.89 X10^4	0.06 X10^3	0.58 X10^4	0.21 X10^3	0.04 X10^3	0.33 X10^3	0.09 X10^3
S57	5.45 X10^4	1.38X10^4	0.84X10^4	0.68 X10^4	0.08 X10^3	0.53 X10^4	0.29 X10^3	0.08 X10^3	0.34 X10^3	0.02 X10^3
S58	5.25 X10^4	1.19X10^4	0.86X10^4	0.59 X10^4	0.06 X10^3	0.45 X10^4	0.37 X10^3	0.01 X10^3	0.19 X10^3	0.03 X10^3
S59	4.56 X10^4	1.26X10^4	0.79X10^4	0.36 X10^4	0.07 X10^3	0.10 X10^4	0.14 X10^3	0.04 X10^3	0.02 X10^3	0.05 X10^3
S60	4.37 X10^4	1.17X10^4	0.94X10^4	0.20 X10^4	0.04 X10^3	0.16 X10^4	0.26 X10^3	0.03 X10^3	0.18 X10^3	0.06 X10^3
S61	3.89 X10^4	1.28X10^4	0.56X10^4	0.34 X10^4	0.07 X10^3	0.15 X10^4	0.38 X10^3	0.01 X10^3	0.07 X10^3	0.08 X10^3
S62	2.32 X10^4	0.72X10^4	0.51X10^4	0.34 X10^4	0.06 X10^3	0.36 X10^4	0.18 X10^3	0.04 X10^3	0.09 X10^3	0.04 X10^3
S63	7.19 X10^4	1.67X10^4	1.23X10^4	0.75 X10^4	0.08 X10^3	0.49 X10^4	0.35 X10^3	0.07 X10^3	0.19 X10^3	0.15 X10^3
S64	6.51 X10^4	1.45X10^4	1.17X10^4	0.67 X10^4	0.05 X10^3	0.34 X10^4	0.18 X10^3	0.04 X10^3	0.28 X10^3	0.07 X10^3
S65	6.78 X10^4	1.56X10^4	0.99X10^4	0.94 X10^4	0.08 X10^3	0.66 X10^4	0.31 X10^3	0.02 X10^3	0.12 X10^3	0.02 X10^3
S66	5.61 X10^4	1.14X10^4	0.93X10^4	0.51 X10^4	0.06 X10^3	0.56 X10^4	0.38 X10^3	0.04 X10^3	0.15 X10^3	0.06 X10^3
S67	5.56 X10^4	1.25X10^4	0.76X10^4	0.85 X10^4	0.05 X10^3	0.48 X10^4	0.26 X10^3	0.08 X10^3	0.16 X10^3	0.05 X10^3
S68	4.85 X10^4	1.37X10^4	0.87X10^4	0.76 X10^4	0.02 X10^3	0.39 X10^4	0.36 X10^3	0.08 X10^3	0.17 X10^3	0.03 X10^3
S69	4.58 X10^4	1.19X10^4	0.73X10^4	0.41 X10^4	0.04 X10^3	0.18 X10^4	0.35 X10^3	0.02 X10^3	0.07 X10^3	0.05 X10^3

S70	3.24 X10^4	1.26X10^4	0.89X10^4	0.56 X10^4	0.02 X10^3	0.33 X10^4	0.36 X10^3	0.09 X10^3	0.22 X10^3	0.03 X10^3
S71	7.56 X10^4	1.75X10^4	1.09X10^4	0.79 X10^4	0.03 X10^3	0.76 X10^4	0.21 X10^3	0.17 X10^3	0.29 X10^3	0.07 X10^3
S72	6.56 X10^4	1.89X10^4	1.12X10^4	0.82 X10^4	0.08 X10^3	0.69 X10^4	0.25 X10^3	0.19 X10^3	0.24 X10^3	0.16 X10^3
S73	6.77 X10^4	1.56X10^4	1.07X10^4	0.45 X10^4	0.06 X10^3	0.62 X10^4	0.45 X10^3	0.06 X10^3	0.30 X10^3	0.03 X10^3
S74	6.19 X10^4	1.45X10^4	0.92X10^4	0.84 X10^4	0.09 X10^3	0.54 X10^4	0.24 X10^3	0.03 X10^3	0.17 X10^3	0.05 X10^3
S75	5.72 X10^4	1.24X10^4	0.88X10^4	0.51 X10^4	0.04 X10^3	0.31 X10^4	0.38 X10^3	0.07 X10^3	0.27 X10^3	0.09 X10^3
S76	5.65 X10^4	1.28X10^4	1.15X10^4	0.48 X10^4	0.02 X10^3	0.24 X10^4	0.15 X10^3	0.09 X10^3	0.12 X10^3	0.04 X10^3
S77	4.62 X10^4	1.39X10^4	0.87X10^4	0.79 X10^4	0.08 X10^3	0.29 X10^4	0.29 X10^3	0.04 X10^3	0.16 X10^3	0.06 X10^3
S78	4.14 X10^4	1.15X10^4	0.92X10^4	0.41 X10^4	0.09 X10^3	0.18 X10^4	0.11 X10^3	0.02 X10^3	0.07 X10^3	0.09 X10^3
S79	3.54 X10^4	1.34X10^4	0.99X10^4	0.33 X10^4	0.06 X10^3	0.19 X10^4	0.43 X10^3	0.06 X10^3	0.34 X10^3	0.07 X10^3
S80	2.76 X10^4	0.93X10^4	0.67X10^4	0.48 X10^4	0.05 X10^3	0.17 X10^4	0.19 X10^3	0.03 X10^3	0.06 X10^3	0.03 X10^3
S81	6.34 X10^4	1.67X10^4	0.98X10^4	0.89 X10^4	0.06 X10^3	0.63 X10^4	0.35 X10^3	0.09 X10^3	0.25 X10^3	0.08 X10^3
S82	5.06 X10^4	1.27X10^4	0.86X10^4	0.94 X10^4	0.08 X10^3	0.53 X10^4	0.21 X10^3	0.10 X10^3	0.10 X10^3	0.02 X10^3
S83	3.45 X10^4	1.15X10^4	0.78X10^4	0.43 X10^4	0.04 X10^3	0.46 X10^4	0.29 X10^3	0.12 X10^3	0.25 X10^3	0.06 X10^3
S84	6.76 X10^4	1.83X10^4	0.81X10^4	0.97 X10^4	0.03 X10^3	0.57 X10^4	0.44 X10^3	0.08 X10^3	0.13 X10^3	0.14 X10^3
S85	4.89 X10^4	1.16X10^4	0.99X10^4	0.47 X10^4	0.06 X10^3	0.71 X10^4	0.41 X10^3	0.05 X10^3	0.19 X10^3	0.01 X10^3
S86	3.27 X10^4	0.87X10^4	0.78X10^4	0.71 X10^4	0.07 X10^3	0.41 X10^4	0.35 X10^3	0.05 X10^3	0.23 X10^3	0.09 X10^3

Table 3.6.7: Bacterial population recorded in sediment samples recorded in various stations of Ennore creek

Microbial parameters	**Sampling sites**				
	En1	**En2**	**En3**	**En4**	**En5**
TVC (CFU/g)	8.61x10^5	8.78X10^5	8.34X10^5	7.89X10^5	7.48X10^5
TC (CFU/g)	1.91X10^5	2.01X10^5	1.79X10^5	1.52X10^5	1.41X10^5
FC (CFU/g)	0.81X10^5	0.93X10^5	0.81X10^5	0.76X10^5	0.71X10^5
***E.coli* (CFU/g)**	0.79X10^5	0.84X10^5	0.71X10^5	0.62X10^5	0.54X10^5
***Shigella* sp. (CFU/g)**	0.08 X10^5	0.06X10^5	0.07X10^5	0.05X10^5	0.02X10^5
***Salmonella* sp. (CFU/g)**	0.37X10^5	0.35X10^5	0.35X10^5	0.36X10^5	0.34X10^5
***Steptococcus faecalis* (CFU/g)**	0.37X10^5	0.46X10^5	0.35X10^5	0.32X10^5	0.31X10^5
***Pseudomonas aeruginosa* (CFU/g)**	0.07X10^4	0.15X10^4	0.09X10^4	0.03X10^4	0.08X10^4
***Vibrio parahaemolyticus* (CFU/g)**	0.21X104^4	0.15X10^4	0.13X10^4	0.11X10^4	0.19X10^4
***Vibrio cholerae* (CFU/g)**	0.13X10^3	0.19X10^3	0.13X10^3	0.11X10^3	0.07 X10^3

Table 3.6.8: Bacterial population recorded in sediment samples recorded in various stations of Pulicat Lake

Microbial parameters	Sampling sites					
	Pu1	Pu2	Pu3	Pu4	Pu5	Pu6
TVC (CFU/g)	$4.79x10^5$	$6.02X10^5$	$6.52X10^5$	$4.49X10^5$	$4.28X10^5$	$4.18X10^5$
TC (CFU/g)	$1.56X10^5$	$1.84X10^5$	$2.01X10^5$	$1.69X10^5$	$1.30 X10^5$	$1.03X10^5$
FC (CFU/g)	$0.64X10^5$	$0.81X10^5$	$0.79X10^5$	$0.72X10^5$	$0.58X10^5$	$0.21X10^5$
***E.coli* (CFU/g)**	$0.67X10^5$	$0.88X10^5$	$0.77X10^5$	$0.62X10^5$	$0.47X10^5$	$0.39X10^5$
***Shigella* sp. (CFU/g)**	$0.03X10^5$	$0.08X10^5$	$0.09X10^5$	$0.12X10^5$	$0.01X10^5$	$0.08X10^5$
***Salmonella* sp. (CFU/g)**	$0.47X10^5$	$0.43X10^5$	$0.35 X10^5$	$0.48X10^5$	$0.27X10^5$	$0.19X10^5$
***Steptococcus faecalis* (CFU/g)**	$0.28X10^5$	$0.34X10^5$	$0.35X10^5$	$0.30X10^5$	$0.26X10^5$	$0.23X10^5$
***Pseudomonas aeruginosa* (CFU/g)**	$0.01X10^4$	$0.06X10^4$	$0.07X10^4$	$0.03X10^4$	$0.05X10^4$	$0.05X10^4$
***Vibrio parahaemolyticus* (CFU/g)**	$0.14 X 10^4$	$0.17X10^4$	$0.13X10^4$	$0.18X10^4$	$0.12X10^4$	$0.13 X10^4$
***Vibrio cholerae* (CFU/g)**	$0.04X10^4$	$0.06X10^4$	$0.09 X10^4$	$0.05 X10^4$	$0.03 X10^4$	$0.05 X10^4$

Table 3.6.9: Bacterial population recorded in sediment samples recorded in various stations of Mangrove area

Sites	TVC (CFU/g)	TC (CFU/g)	FC (CFU/g)	*E.coli* (CFU/g)	*Shigella* sp. (CFU/g)	*Salmonella* sp. (CFU/g)	*Steptococcus faecalis* (CFU/g)	*Pseudomonas aeruginosa* (CFU/g)	*Vibrio parahaemolyticus* (CFU/g)	*Vibrio cholerae* (CFU/g)
M1	$5.62X10^5$	$2.04X10^5$	$0.98X10^5$	$0.79X10^5$	$0.16X10^4$	$0.52X10^4$	$0.39X10^4$	$0.27X10^4$	$0.32X10^4$	$0.29X10^3$
M2	$5.67X10^5$	$1.92X10^5$	$0.91X10^5$	$0.98X10^5$	$0.25X10^4$	$0.57X10^4$	$0.37X10^4$	$0.26X10^4$	$0.29X10^4$	$0.23X10^3$
M3	$6.24X10^5$	$1.89X10^5$	$1.01X10^5$	$0.82X10^5$	$0.12X10^4$	$0.68X10^4$	$0.41X10^4$	$0.26X10^4$	$0.33X10^4$	$0.31X10^3$
M4	$5.51X10^5$	$1.83X10^5$	$0.84X10^5$	$0.68X10^5$	$0.04X10^4$	$0.42X10^4$	$0.33X10^4$	$0.12X10^4$	$0.14X10^4$	$0.09X10^3$
M5	$5.58X10^5$	$1.77X10^5$	$0.89X10^5$	$0.64X10^5$	$0.13X10^4$	$0.49X10^4$	$0.39X10^4$	$0.24X10^4$	$0.16X10^4$	$0.12X10^3$
M6	$5.11X10^5$	$1.79X10^5$	$0.81X10^5$	$0.68X10^5$	$0.15X10^4$	$0.41X10^4$	$0.32X10^4$	$0.11X10^4$	$0.14X10^4$	$0.05X10^3$
M7	$6.16X10^5$	$1.86X10^5$	$0.84X10^5$	$0.76X10^5$	$0.18X10^4$	$0.61X10^4$	$0.38X10^4$	$0.29X10^4$	$0.35X10^4$	$0.23X10^3$
M8	$5.72X10^5$	$1.97X10^5$	$0.92X10^5$	$0.82X10^5$	$0.22X10^4$	$0.53X10^4$	$0.21X10^4$	$0.19X10^4$	$0.26X10^4$	$0.19X10^3$
M9	$5.62X10^5$	$1.81X10^5$	$0.98X10^5$	$0.83X10^5$	$0.05X10^4$	$0.52X10^4$	$0.37X10^4$	$0.23X10^4$	$0.13X10^4$	$0.16X10^3$
M10	$5.52X10^5$	$1.88X10^5$	$0.69X10^5$	$0.69X10^5$	$0.06X10^4$	$0.39X10^4$	$0.34X10^4$	$0.16X10^4$	$0.19X10^4$	$0.15X10^3$
M11	$6.02X10^5$	$1.91X10^5$	$1.03X10^5$	$0.78X10^5$	$0.17X10^4$	$0.62X10^4$	$0.27X10^4$	$0.14X10^4$	$0.31X10^4$	$0.19X10^3$

Table 3.6.10: Bacterial population recorded in sediment samples recorded in various stations of Kosasthalaiyar River

Sites	TVC (CFU/g)	TC (CFU/g)	FC (CFU/g)	*E.coli* (CFU/g)	*Shigella* sp. (CFU/g)	*Salmonella* sp. (CFU/g)	*Steptococcus faecalis* (CFU/g)	*Pseudomonas aeruginosa* (CFU/g)	*Vibrio parahaemolyticus* (CFU/g)	*Vibrio cholerae* (CFU/g)
R1	$6.34X10^5$	$1.24X10^5$	$0.72X10^5$	$0.65X10^5$	$0.13X10^5$	$0.11X10^5$	$0.13X10^5$	$0.12X10^5$	$0.22X10^5$	$0.02X10^4$
R2	$6.42X10^5$	$1.12X10^5$	$0.63X10^5$	$0.68X10^5$	$0.15X10^5$	$0.14X10^5$	$0.21X10^5$	$0.15X10^5$	$0.16X10^5$	$0.04X10^4$
R3	$6.48X10^5$	$1.11X10^5$	$0.74X10^5$	$0.46X10^5$	$0.14X10^5$	$0.08X10^5$	$0.20X10^5$	$0.16X10^5$	$0.14X10^5$	$0.08X10^4$
R4	$6.72X10^5$	$1.33X10^5$	$0.81X10^5$	$0.54X10^5$	$0.15X10^5$	$0.09X10^5$	$0.18X10^5$	$0.19X10^5$	$0.23X10^5$	$0.11X10^4$
R5	$6.82X10^5$	$1.41X10^5$	$0.93X10^5$	$0.66X10^5$	$0.20X10^5$	$0.13X10^5$	$0.29X10^5$	$0.24X10^5$	$0.21X10^5$	$0.08X10^4$
R6	$6.23X10^5$	$1.25X10^5$	$0.68X10^5$	$0.72X10^5$	$0.26X10^5$	$0.10X10^5$	$0.15X10^5$	$0.18X10^5$	$0.11X10^5$	$0.04X10^4$
R7	$6.25X10^5$	$1.28X10^5$	$0.91X10^5$	$0.75X10^5$	$0.12X10^5$	$0.13X10^5$	$0.13X10^5$	$0.15X10^5$	$0.12X10^5$	$0.10X10^4$
R8	$6.43X10^5$	$1.32X10^5$	$0.83X10^5$	$0.69X10^5$	$0.13X10^5$	$0.12X10^5$	$0.16X10^5$	$0.18X10^5$	$0.20X10^5$	$0.05X10^4$
R9	$6.81X10^5$	$1.31X10^5$	$0.95X10^5$	$0.62X10^5$	$0.23X10^5$	$0.10X10^5$	$0.21X10^5$	$0.12X10^5$	$0.19X10^5$	$0.03X10^4$
R10	$6.51X10^5$	$1.42X10^5$	$1.04X10^5$	$0.76X10^5$	$0.19X10^5$	$0.12X10^5$	$0.23X10^5$	$0.25X10^5$	$0.21X10^5$	$0.10X10^4$
R11	$6.24X10^4$	$1.14X10^4$	$0.85X10^4$	$0.49X10^4$	$0.12X10^4$	$0.04X10^4$	$0.19X10^4$	$0.20X10^4$	$0.22X10^4$	$0.05X10^3$
R12	$5.99X10^4$	$1.12X10^4$	$1.05X10^4$	$0.71X10^4$	$0.17X10^4$	$0.12X10^4$	$0.10X10^4$	$0.11X10^4$	$0.13X10^4$	$0.03X10^3$
R13	$6.22X10^4$	$1.19X10^4$	$0.73X10^4$	$0.73X10^4$	$0.22X10^4$	$0.09X10^4$	$0.17X10^4$	$0.18X10^4$	$0.18X10^4$	$0.04X10^3$

Table 3.6.11: Bacterial population recorded in sediment samples recorded in various stations of Buckingham canal

Sites	TVC (CFU/g)	TC (CFU/g)	FC (CFU/g)	*E.coli* (CFU/g)	*Shigella* sp. (CFU/g)	*Salmonella* sp. (CFU/g)	*Steptococcus faecalis* (CFU/g)	*Pseudomonas aeruginosa* (CFU/g)	*Vibrio parahaemolyticus* (CFU/g)	*Vibrio cholerae* (CFU/g)
B1	$5.23X10^5$	$0.74X10^5$	$0.42X10^5$	$0.42X10^5$	$0.17X10^5$	$0.38 X10^5$	$0.33 X10^5$	$0.12 X10^4$	$0.21 X10^4$	$0.13 X10^3$
B2	$5.69X10^5$	$0.79X10^5$	$0.48X10^5$	$0.52X10^5$	$0.13X10^5$	$0.35X10^5$	$0.29 X10^5$	$0.15 X10^4$	$0.08 X10^4$	$0.23 X10^3$
B3	$5.29X10^5$	$0.94X10^5$	$0.43X10^5$	$0.56X10^5$	$0.16X10^5$	$0.19 X10^5$	$0.34 X10^5$	$0.12 X10^4$	$0.09 X10^4$	$0.11 X10^3$
B4	$5.47X10^5$	$0.92X10^5$	$0.42X10^5$	$0.68X10^5$	$0.23X10^5$	$0.31 X10^5$	$0.32 X10^5$	$0.13 X10^4$	$0.14 X10^4$	$0.14 X10^3$
B5	$5.52X10^5$	$1.08X10^5$	$0.41X10^5$	$0.61X10^5$	$0.26X10^5$	$0.24X10^5$	$0.36 X10^5$	$0.11 X10^4$	$0.19 X10^4$	$0.10 X10^3$
B6	$5.04X10^5$	$0.78X10^5$	$0.44X10^5$	$0.53X10^5$	$0.14X10^5$	$0.32 X10^5$	$0.28 X10^5$	$0.08 X10^4$	$0.20 X10^4$	$0.12 X10^3$
B7	$5.75X10^5$	$0.98X10^5$	$0.42X10^5$	$0.51X10^5$	$0.21X10^5$	$0.25 X10^5$	$0.40 X10^5$	$0.19 X10^4$	$0.13 X10^4$	$0.19X10^3$
B8	$4.99X10^5$	$1.12X10^5$	$0.45X10^5$	$0.61X10^5$	$0.20X10^5$	$0.21 X10^5$	$0.39 X10^5$	$0.13 X10^4$	$0.17 X10^4$	$0.19 X10^3$
B9	$5.61X10^5$	$1.11X10^5$	$0.46X10^5$	$0.52X10^5$	$0.19X10^5$	$0.22 X10^5$	$0.48 X10^5$	$0.12 X10^4$	$0.11 X10^4$	$0.21 X10^3$
B10	$5.66X10^5$	$1.07X10^5$	$0.47X10^5$	$0.39X10^5$	$0.18X10^5$	$0.20 X10^5$	$0.36 X10^5$	$0.14 X10^4$	$0.20 X10^4$	$0.14 X10^3$
B11	$5.95X10^5$	$1.21X10^5$	$0.42X10^5$	$0.61X10^5$	$0.19X10^5$	$0.27 X10^5$	$0.42 X10^5$	$0.20 X10^4$	$0.22 X10^4$	$0.21 X10^3$
B12	$5.83X10^5$	$1.25X10^5$	$0.49X10^5$	$0.72X10^5$	$0.21X10^5$	$0.39 X10^5$	$0.41 X10^5$	$0.21 X10^4$	$0.12 X10^4$	$0.35 X10^3$

Table 3.6.12: Bacterial population recorded in sediment samples recorded in marine zone

Sites	TVC (CFU/g)	TC (CFU/g)	FC (CFU/g)	*E.coli* (CFU/g)	*Shigella* sp. (CFU/g)	*Salmonella* sp. (CFU/g)	*Steptococcus faecalis* (CFU/g)	*Pseudomonas aeruginosa* (CFU/g)	*Vibrio parahaemolyticus* (CFU/g)	*Vibrio cholerae* (CFU/g)
S1	$8.63x10^5$	$2.29 x10^5$	$1.07 x10^5$	$1.21 x10^5$	$0.13 x10^4$	$0.95 x10^5$	$0.22 x10^4$	$0.32 x10^4$	$0.52 x10^4$	$0.25 x10^4$
S2	$6.51 x10^5$	$1.67 x10^5$	$1.04 x10^5$	$0.98 x10^5$	$0.14 x10^4$	$0.52 x10^5$	$0.23 x10^4$	$0.12 x10^4$	$0.38 x10^4$	$0.14 x10^4$
S3	$8.11 x10^5$	$2.31 x10^5$	$1.01 x10^5$	$1.24 x10^5$	$0.19 x10^4$	$0.44 x10^5$	$0.18 x10^4$	$0.36 x10^4$	$0.53 x10^4$	$0.29 x10^4$
S4	$6.36 x10^5$	$1.63 x10^5$	$0.98 x10^5$	$0.89 x10^5$	$0.11 x10^4$	$0.51 x10^5$	$0.17 x10^4$	$0.12 x10^4$	$0.31 x10^4$	$0.10 x10^4$
S5	$4.44 x10^5$	$1.18 x10^5$	$0.90 x10^5$	$0.37 x10^5$	$0.08 x10^4$	$0.18 x10^5$	$0.16 x10^4$	$0.08 x10^4$	$0.11 x10^4$	$0.09 x10^4$
S6	$8.62 x10^5$	$2.32 x10^5$	$1.18 x10^5$	$1.23 x10^5$	$0.31 x10^4$	$0.97 x10^5$	$0.12 x10^4$	$0.30 x10^4$	$0.51 x10^4$	$0.23 x10^4$
S7	$6.69 x10^5$	$1.72 x10^5$	$1.04 x10^5$	$0.93 x10^5$	$0.13 x10^4$	$0.62 x10^5$	$0.11 x10^4$	$0.15 x10^4$	$0.42 x10^4$	$0.12 x10^4$
S8	$3.73 x10^5$	$1.13 x10^5$	$0.88 x10^5$	$0.72 x10^5$	$0.12 x10^4$	$0.31 x10^5$	$0.19 x10^4$	$0.09 x10^4$	$0.19 x10^4$	$0.10 x10^4$
S9	$2.11 x10^5$	$0.72 x10^5$	$0.53 x10^5$	$0.38 x10^5$	$0.11 x10^4$	$0.40 x10^5$	$0.13 x10^4$	$0.11 x10^4$	$0.05 x10^4$	$0.03 x10^4$
S10	$8.03 x10^5$	$2.29 x10^5$	$1.02 x10^5$	$1.20 x10^5$	$0.32 x10^4$	$1.42 x10^5$	$0.26 x10^4$	$0.29 x10^4$	$0.52 x10^4$	$0.21 x10^4$
S11	$7.69 x10^5$	$2.05 x10^5$	$1.11 x10^5$	$0.92 x10^5$	$0.14 x10^4$	$0.52 x10^5$	$0.29 x10^4$	$0.20 x10^4$	$0.39 x10^4$	$0.26 x10^4$
S12	$7.23 x10^5$	$1.89 x10^5$	$1.11 x10^5$	$0.87 x10^5$	$0.12 x10^4$	$0.49 x10^5$	$0.21 x10^4$	$0.13 x10^4$	$0.43 x10^4$	$0.18 x10^4$
S13	$6.09 x10^5$	$1.52 x10^5$	$1.01 x10^5$	$0.94 x10^5$	$0.11 x10^4$	$0.48 x10^5$	$0.23 x10^4$	$0.12 x10^4$	$0.32 x10^4$	$0.12 x10^4$
S14	$5.60 x10^5$	$1.28 x10^5$	$0.95 x10^5$	$0.77 x10^5$	$0.13 x10^4$	$0.43 x10^5$	$0.12 x10^4$	$0.10 x10^4$	$0.28 x10^4$	$0.04 x10^4$
S15	$4.35 x10^5$	$1.12 x10^5$	$0.85 x10^5$	$0.32 x10^5$	$0.12 x10^4$	$0.23 x10^5$	$0.19 x10^4$	$0.11 x10^4$	$0.18 x10^4$	$0.11 x10^4$
S16	$4.04 x10^5$	$1.31 x10^5$	$0.91 x10^5$	$0.82 x10^5$	$0.09 x10^4$	$1.42 x10^5$	$0.15 x10^4$	$0.12 x10^4$	$0.20 x10^4$	$0.09 x10^4$
S17	$8.19 x10^5$	$2.34 x10^5$	$1.19 x10^5$	$1.20 x10^5$	$0.32 x10^4$	$0.44 x10^5$	$0.28 x10^4$	$0.32 x10^4$	$0.53 x10^4$	$0.27 x10^4$
S18	$9.03 x10^5$	$2.41 x10^5$	$1.13 x10^5$	$1.29 x10^5$	$0.12 x10^4$	$0.49 x10^5$	$0.26 x10^4$	$0.28 x10^4$	$0.56 x10^4$	$0.30 x10^4$
S19	$8.71 x10^5$	$2.32 x10^5$	$1.22 x10^5$	$1.31 x10^5$	$0.14 x10^4$	$0.48 x10^5$	$0.31 x10^4$	$0.33 x10^4$	$0.59 x10^4$	$0.32 x10^4$
S20	$8.58 x10^5$	$2.29 x10^5$	$1.18 x10^5$	$1.24 x10^5$	$0.11 x10^4$	$0.99 x10^5$	$0.17 x10^4$	$0.35 x10^4$	$0.58 x10^4$	$0.28 x10^4$
S21	$8.56 x10^5$	$2.30 x10^5$	$1.15 x10^5$	$1.13 x10^5$	$0.22 x10^4$	$0.92 x10^5$	$0.22 x10^4$	$0.29 x10^4$	$0.53 x10^4$	$0.25 x10^4$
S22	$8.41 x10^5$	$2.21 x10^5$	$1.10 x10^5$	$1.12 x10^5$	$0.28 x10^4$	$0.89 x10^5$	$0.15 x10^4$	$0.31 x10^4$	$0.51 x10^4$	$0.19 x10^4$
S23	$7.99 x10^5$	$2.12 x10^5$	$1.04 x10^5$	$1.02 x10^5$	$0.18 x10^4$	$0.81 x10^5$	$0.16 x10^4$	$0.23 x10^4$	$0.41 x10^4$	$0.20 x10^4$
S24	$6.90 x10^5$	$1.72 x10^5$	$1.01 x10^5$	$0.81 x10^5$	$0.07 x10^4$	$0.58 x10^5$	$0.09 x10^4$	$0.12 x10^4$	$0.23 x10^4$	$0.11 x10^4$
S25	$6.03 x10^5$	$1.53 x10^5$	$0.93 x10^5$	$0.79 x10^5$	$0.09 x10^4$	$0.42 x10^5$	$0.08 x10^4$	$0.06 x10^4$	$0.31 x10^4$	$0.10 x10^4$
S26	$5.61 x10^5$	$1.30 x10^5$	$0.95 x10^5$	$0.86 x10^5$	$0.12 x10^4$	$0.40 x10^5$	$0.13 x10^4$	$0.14 x10^4$	$0.28 x10^4$	$0.09 x10^4$
S27	$3.89 x10^5$	$1.22 x10^5$	$0.90 x10^5$	$0.81 x10^5$	$0.09 x10^4$	$0.32 x10^5$	$0.19 x10^4$	$0.11 x10^4$	$0.18 x10^4$	$0.12 x10^4$
S28	$2.79 x10^5$	$0.92 x10^5$	$0.72 x10^5$	$0.61 x10^5$	$0.11 x10^4$	$0.28 x10^5$	$0.22 x10^4$	$0.10 x10^4$	$0.14 x10^4$	$0.08 x10^4$
S29	$8.68 x10^5$	$2.29 x10^5$	$1.07 x10^5$	$1.27 x10^5$	$0.20 x10^4$	$0.42 x10^5$	$0.23 x10^4$	$0.31 x10^4$	$0.50 x10^4$	$0.25 x10^4$
S30	$8.28 x10^5$	$2.15 x10^5$	$1.01 x10^5$	$1.05 x10^5$	$0.23 x10^4$	$0.83x10^5$	$0.28 x10^4$	$0.25 x10^4$	$0.49 x10^4$	$0.24 x10^4$
S31	$8.08 x10^5$	$2.13 x10^5$	$1.14 x10^5$	$1.09 x10^5$	$0.15 x10^4$	$0.82 x10^5$	$0.14 x10^4$	$0.23 x10^4$	$0.46 x10^4$	$0.15 x10^4$
S32	$7.21 x10^5$	$1.92 x10^5$	$1.04 x10^5$	$0.93 x10^5$	$0.13 x10^4$	$0.62 x10^5$	$0.12 x10^4$	$0.17 x10^4$	$0.41 x10^4$	$0.18 x10^4$
S33	$6.58 x10^5$	$1.72 x10^5$	$1.03 x10^5$	$0.87 x10^5$	$0.08 x10^4$	$0.59 x10^5$	$0.11 x10^4$	$0.12 x10^4$	$0.39 x10^4$	$0.11 x10^4$
S34	$5.91 x10^5$	$1.42 x10^5$	$0.99 x10^5$	$0.82 x10^5$	$0.09 x10^4$	$0.47 x10^5$	$0.06 x10^4$	$0.11 x10^4$	$0.38 x10^4$	$0.06 x10^4$
S35	$5.12 x10^5$	$1.18 x10^5$	$0.92 x10^5$	$0.61 x10^5$	$0.11 x10^4$	$0.34 x10^5$	$0.11 x10^4$	$0.09 x10^4$	$0.27 x10^4$	$0.11 x10^4$
S36	$4.12 x10^5$	$1.02 x10^5$	$0.75 x10^5$	$0.25 x10^5$	$0.01 x10^4$	$0.18 x10^5$	$0.04 x10^4$	$0.03 x10^4$	$0.16 x10^4$	$0.13 x10^4$
S37	$8.05 x10^5$	$2.11 x10^5$	$1.11 x10^5$	$1.04 x10^5$	$0.19 x10^4$	$0.82 x10^5$	$0.19 x10^4$	$0.25 x10^4$	$0.43 x10^4$	$0.21 x10^4$
S38	$7.49 x10^5$	$1.88 x10^5$	$1.15 x10^5$	$0.88 x10^5$	$0.10 x10^4$	$0.71 x10^5$	$0.06 x10^4$	$0.18 x10^4$	$0.32 x10^4$	$0.19 x10^4$
S39	$7.09 x10^5$	$1.82 x10^5$	$1.09 x10^5$	$0.81 x10^5$	$0.14 x10^4$	$0.61 x10^5$	$0.27 x10^4$	$0.23 x10^4$	$0.31 x10^4$	$0.09 x10^4$
S40	$6.59 x10^5$	$1.75 x10^5$	$1.14 x10^5$	$0.99 x10^5$	$0.08 x10^4$	$0.58 x10^5$	$0.02 x10^4$	$0.12 x10^4$	$0.49 x10^4$	$0.12 x10^4$
S41	$5.99 x10^5$	$1.48 x10^5$	$1.12 x10^5$	$0.82 x10^5$	$0.11 x10^4$	$0.52 x10^5$	$0.19 x10^4$	$0.14 x10^4$	$0.38 x10^4$	$0.11 x10^4$
S42	$4.92 x10^5$	$1.23 x10^5$	$0.82 x10^5$	$0.64 x10^5$	$0.12 x10^4$	$0.28 x10^5$	$0.26 x10^4$	$0.08 x10^4$	$0.23 x10^4$	$0.12 x10^4$
S43	$3.97 x10^5$	$1.26 x10^5$	$0.92 x10^5$	$0.82 x10^5$	$0.08 x10^4$	$1.38 x10^5$	$0.22 x10^4$	$0.11 x10^4$	$0.21 x10^4$	$0.11 x10^4$
S44	$3.12 x10^5$	$1.06 x10^5$	$0.82 x10^5$	$0.57 x10^5$	$0.09 x10^4$	$0.42 x10^5$	$0.22 x10^4$	$0.05 x10^4$	$0.16 x10^4$	$0.08 x10^4$
S45	$2.56 x10^5$	$0.88 x10^5$	$0.63 x10^5$	$0.42 x10^5$	$0.06x10^4$	$0.25 x10^5$	$0.17 x10^4$	$0.02 x10^4$	$0.08 x10^4$	$0.04 x10^4$

S46	6.92 x10^5	1.72 x10^5	1.02 x10^5	0.83 x10^5	0.09 x10^4	0.58 x10^5	0.29 x10^4	0.18 x10^4	0.34 x10^4	0.12 x10^4
S47	6.17 x10^5	1.53 x10^5	1.04 x10^5	0.82 x10^5	0.08 x10^4	0.52 x10^5	0.27 x10^4	0.08 x10^4	0.31 x10^4	0.07 x10^4
S48	5.61 x10^5	1.28 x10^5	0.93 x10^5	0.81 x10^5	0.06 x10^4	0.43 x10^5	0.31 x10^4	0.12 x10^4	0.27 x10^4	0.10 x10^4
S49	4.84 x10^5	1.17 x10^5	0.95 x10^5	0.59 x10^5	0.08 x10^4	0.30 x10^5	0.24 x10^4	0.06 x10^4	0.28 x10^4	0.03 x10^4
S50	4.13 x10^5	1.14 x10^5	0.80 x10^5	0.32 x10^5	0.10 x10^4	0.23 x10^5	0.19 x10^4	0.05 x10^4	0.18 x10^4	0.11 x10^4
S51	3.68 x10^5	1.11 x10^5	0.82 x10^5	0.76 x10^5	0.08 x10^4	0.31 x10^5	0.20 x10^4	0.03 x10^4	0.16 x10^4	0.05 x10^4
S52	3.08 x10^5	1.04 x10^5	0.65 x10^5	0.63 x10^5	0.10 x10^4	0.36 x10^5	0.27 x10^4	0.07 x10^4	0.19 x10^4	0.04 x10^4
S53	2.73 x10^5	0.91 x10^5	0.72 x10^5	0.50 x10^5	0.06x10^4	0.31 x10^5	0.19 x10^4	0.05 x10^4	0.11 x10^4	0.07 x10^4
S54	6.82 x10^5	1.65 x10^5	1.20 x10^5	0.83 x10^5	0.08 x10^4	0.54 x10^5	0.23 x10^4	0.08 x10^4	0.22 x10^4	0.08 x10^4
S55	5.91 x10^5	1.42 x10^5	0.98 x10^5	0.81 x10^5	0.09 x10^4	0.47 x10^5	0.28 x10^4	0.13 x10^4	0.34 x10^4	0.09 x10^4
S56	5.11 x10^5	1.16 x10^5	0.92 x10^5	0.58 x10^5	0.10 x10^4	0.31 x10^5	0.29 x10^4	0.07 x10^4	0.29 x10^4	0.11 x10^4
S57	4.53 x10^5	1.31 x10^5	1.08 x10^5	0.56 x10^5	0.11 x10^4	0.34 x10^5	0.30 x10^4	0.11 x10^4	0.17 x10^4	0.08 x10^4
S58	4.09 x10^5	1.32 x10^5	0.93 x10^5	0.84 x10^5	0.12 x10^4	1.37 x10^5	0.20 x10^4	0.18 x10^4	0.23 x10^4	0.12 x10^4
S59	3.32 x10^5	1.10 x10^5	0.98 x10^5	0.89 x10^5	0.08 x10^4	0.39 x10^5	0.21 x10^4	0.07 x10^4	0.20 x10^4	0.12 x10^4
S60	3.08 x10^5	1.03 x10^5	0.63 x10^5	0.52 x10^5	0.09 x10^4	0.32 x10^5	0.23 x10^4	0.06 x10^4	0.14 x10^4	0.08 x10^4
S61	2.60 x10^5	0.88 x10^5	0.64 x10^5	0.48 x10^5	0.01 x10^4	0.29 x10^5	0.19 x10^4	0.03 x10^4	0.11 x10^4	0.06 x10^4
S62	2.23 x10^5	0.73 x10^5	0.58 x10^5	0.38 x10^5	0.06 x10^4	0.23 x10^5	0.02 x10^4	0.06 x10^4	0.09 x10^4	0.03 x10^4
S63	6.21 x10^5	1.57 x10^5	1.02 x10^5	0.83 x10^5	0.12 x10^4	0.52 x10^5	0.23 x10^4	0.10 x10^4	0.31 x10^4	0.07 x10^4
S64	5.38 x10^5	1.36 x10^5	1.11 x10^5	0.52 x10^5	0.09 x10^4	0.41 x10^5	0.30 x10^4	0.12 x10^4	0.29 x10^4	0.11 x10^4
S65	4.58 x10^5	1.31 x10^5	1.04 x10^5	0.53 x10^5	0.11 x10^4	0.31 x10^5	0.24 x10^4	0.13 x10^4	0.23 x10^4	0.13 x10^4
S66	4.08 x10^5	1.03 x10^5	0.75 x10^5	0.31 x10^5	0.09 x10^4	0.21 x10^5	0.19 x10^4	0.14 x10^4	0.25 x10^4	0.14 x10^4
S67	3.52 x10^5	1.12 x10^5	0.87 x10^5	0.72 x10^5	0.12 x10^4	0.24 x10^5	0.31 x10^4	0.08 x10^4	0.19 x10^4	0.13 x10^4
S68	3.11 x10^5	0.99 x10^5	0.72 x10^5	0.57 x10^5	0.11 x10^4	0.31 x10^5	0.24 x10^4	0.13 x10^4	0.17 x10^4	0.10 x10^4
S69	3.02 x10^5	1.02 x10^5	0.63 x10^5	0.42 x10^5	0.24 x10^4	0.39 x10^5	0.26 x10^4	0.12 x10^4	0.18 x10^4	0.09 x10^4
S70	2.62 x10^5	0.91 x10^5	0.69 x10^5	0.46 x10^5	0.08 x10^4	0.34 x10^5	0.18 x10^4	0.09 x10^4	0.13 x10^4	0.07 x10^4
S71	5.92 x10^5	1.42 x10^5	0.98 x10^5	0.82 x10^5	0.13 x10^4	0.48 x10^5	0.11 x10^4	0.11 x10^4	0.38 x10^4	0.12 x10^4
S72	5.14 x10^5	1.22 x10^5	0.92 x10^5	0.56 x10^5	0.08 x10^4	0.42 x10^5	0.29 x10^4	0.09 x10^4	0.31 x10^4	0.14 x10^4
S73	4.92 x10^5	1.24 x10^5	1.02 x10^5	0.75 x10^5	0.15 x10^4	0.43 x10^5	0.28 x10^4	0.10 x10^4	0.34 x10^4	0.15 x10^4
S74	4.41 x10^5	1.18 x10^5	0.92 x10^5	0.39 x10^5	0.08 x10^4	0.32 x10^5	0.25 x10^4	0.09 x10^4	0.27 x10^4	0.08 x10^4
S75	3.79 x10^5	1.13 x10^5	0.90 x10^5	0.79 x10^5	0.11 x10^4	0.34 x10^5	0.19 x10^4	0.08 x10^4	0.19 x10^4	0.09 x10^4
S76	3.23 x10^5	1.08 x10^5	0.89 x10^5	0.86 x10^5	0.09 x10^4	0.39 x10^5	0.12 x10^4	0.10 x10^4	0.21 x10^4	0.12 x10^4
S77	2.86 x10^5	0.94 x10^5	0.74 x10^5	0.52 x10^5	0.13 x10^4	0.35 x10^5	0.22 x10^4	0.11 x10^4	0.19 x10^4	0.08 x10^4
S78	2.49 x10^5	0.84 x10^5	0.62 x10^5	0.42 x10^5	0.08 x10^4	0.28 x10^5	0.17 x10^4	0.04 x10^4	0.14 x10^4	0.07 x10^4
S79	2.08 x10^5	0.76 x10^5	0.58 x10^5	0.38 x10^5	0.12 x10^4	0.42 x10^5	0.13 x10^4	0.06 x10^4	0.11 x10^4	0.09 x10^4
S80	1.49 x10^5	0.79 x10^5	0.62 x10^5	0.41 x10^5	0.14 x10^4	0.41 x10^5	0.15 x10^4	0.10 x10^4	0.15 x10^4	0.09 x10^4
S81	4.88 x10^5	1.23 x10^5	1.06 x10^5	0.92 x10^5	0.13 x10^4	0.21 x10^5	0.27 x10^4	0.13 x10^4	0.23 x10^4	0.11 x10^4
S82	3.23 x10^5	1.09 x10^5	0.84 x10^5	0.85 x10^5	0.15 x10^4	0.38 x10^5	0.11 x10^4	0.12 x10^4	0.18 x10^4	0.06x10^4
S83	2.23 x10^5	0.81 x10^5	0.41x10^5	0.41 x10^5	0.08 x10^4	0.29 x10^5	0.16 x10^4	0.07 x10^4	0.09 x10^4	0.09 x10^4
S84	4.56 x10^5	1.23 x10^5	1.09 x10^5	0.92 x10^5	0.13 x10^4	0.21 x10^5	0.19 x10^4	0.12 x10^4	0.19 x10^4	0.11 x10^4
S85	3.34 x10^5	1.09 x10^5	0.99 x10^5	0.89 x10^5	0.12 x10^4	0.39 x10^5	0.12 x10^4	0.10 x10^4	0.15 x10^4	0.13 x10^4
S86	2.14 x10^5	0.72 x10^5	0.62 x10^5	0.40 x10^5	0.21 x10^4	0.43 x10^5	0.15 x10^4	0.08 x10^4	0.11 x10^4	0.09 x10^4

Summary results and remarks

Microbial parameters were within the optimum levels in the study area whereas at Ennore Creek it was comparatively higher. The total viable count in water samples from Ennore Creek ranged from $6.54x10^4$ to $8.10x10^4$ CFU/ml while the total coliform count ranged from $1.02x10^4$ to $1.89x10^4$ CFU/ml. Faecal coliform was found to vary from $0.53x10^4$ to $0.98x10^4$ CFU/ml whereas *E. coli* count ranged from $0.45x10^4$ to $0.68x10^4$ CFU/ml. In the sediment samples, total viable count ranged from 7.48 $x10^5$ and 8.78 x 10^5 CFU/g. Total coliform count in the samples varied from 1.41 $x10^5$ to 2.01 $x10^5$ CFU/g. The Faecal coliform ranged from $0.71x10^5$ to $0.93x10^5$ CFU/g and *E. coli* count ranged from $0.54x10^5$ to $0.84x10^5$ CFU/g. The total viable count in water samples from Pulicat Lake ranged from $4.49x10^4$ to $5.23x10^4$ CFU/ml and Total coliform count varied from $0.89x10^4$ to $1.89x10^4$ CFU/ml. Faecal coliform ranged from $0.21x10^4$ to $0.93x10^4$ CFU/ml and *E. coli* count ranged from $0.35x10^4$ to $0.89x10^4$ CFU/ml. In the sediment samples of Pulicat Lake, total viable count ranged from $4.18x10^5$ to $6.52x10^5$ CFU/g while Total coliform count varied from 1.03 $x10^5$ to 2.01 $x10^5$ CFU/g. The Faecal coliform in the sediment samples ranged from $0.21x10^5$ to $0.81x10^5$ CFU/g while *E. coli* count ranged from $0.34x10^5$ to $0.88x10^5$ CFU/g. In the mangrove region, total viable count in water samples ranged from $4.12x10^4$ to $5.23x10^4$ CFU/ml and total coliform count ranged from $0.65x10^4$ to $0.99x10^4$ CFU/ml. Faecal coliform was found to vary from $0.51x10^4$ to $0.71x10^4$ CFU/ml and *E. coli* count ranged from $0.25x10^4$ to $0.68x10^4$ CFU/ml. In the sediment samples of mangrove region, total viable count ranged from $5.11x10^5$ to 6.24x 10^5 CFU/g and total coliform count ranged from $1.77x10^5$ to 2.04 $x10^5$ CFU/g. Faecal coliform was found to vary from $0.69x10^5$ to $1.03x10^5$ CFU/g while *E. coli* count ranged from $0.64x10^5$ to $0.92x10^5$ CFU/g. In the river samples, total viable count in water samples ranged from $5.52x10^3$ to $6.43x10^4$ CFU/ml and total coliform count ranged from $1.05x10^3$ to $1.41x10^4$ CFU/ml. Faecal coliform was found to vary from $0.52x10^3$ to $0.84x10^4$ CFU/ml while *E. coli* count ranged from $0.61x10^3$ to $0.88x10^4$ CFU/ml. In the sediment samples of river, total viable count ranged from $5.99x10^4$ to 6.82x 10^5 CFU/g and total coliform count varied from 1.11 $x10^4$ to $1.42x10^5$ CFU/g. Faecal coliform ranged from $0.63x10^4$ to $1.05x10^5$ CFU/g while *E. coli* count ranged from $0.49x10^4$ to $0.76x10^5$ CFU/g. In the canal water samples, total viable count ranged from $4.09x10^4$ to $5.15x10^4$ CFU/ml and Total coliform count varied from $0.72x10^4$ to $1.03x10^4$ CFU/ml. Faecal coliform ranged from $0.51x10^4$ to $0.82x10^4$ CFU/ml while *E. coli* count ranged from $0.20x10^4$ to $0.67x10^4$ CFU/ml. In the sediment sample, total viable ranged from 4.99 $x10^5$ to 5.95 x 10^5 CFU/g while Total coliform count in the samples varied from 0.74 $x10^5$ to 1.25 $x10^5$ CFU/g. Faecal coliform ranged from $0.41x10^5$ to $0.49x10^5$ CFU/g and *E. coli* count ranged from $0.39x10^5$ to $0.72x10^5$ CFU/g. In the marine water samples, total viable count ranged from $2.32x10^4$ to $7.97x10^4$ CFU/ml and total coliform count ranged from $0.65x10^4$ to $2.09x10^4$ CFU/ml. Faecal coliform ranged from $0.51x10^4$ to $1.45x10^4$ CFU/ml while *E. coli* count ranged from $0.20x10^4$ to $0.99x10^4$ CFU/ml. In the marine sediment samples, total viable count ranged from $1.49x10^5$ to 8.71x 10^5 CFU/g and total coliform count varied from 0.72 $x10^5$ to $2.41x10^5$ CFU/g. Faecal coliform was found to vary from $0.41x10^5$ to $1.22x10^5$ CFU/g while *E. coli* count ranged from $0.31x10^5$ to $1.31x10^5$ CFU/g.

vii. Brackish and freshwater associated resources

The brackish and freshwater ecosystem of the study area has unique fauna assemblages that support the livelihood of the local fishing communities particularly the poor fisher folks. The fauna seen in this ecosystem uses it as a nursery ground, habitats and breeding ground. The fishes seen here can be classified as true residents, partial residents, tidal visitors and seasonal visitors.

In Kosathalaiyar river, totally seven species of fishes were recorded (Table 3.7.1). They were *Clarias batrachus*, *Brotula* sp., *Arius jella, Trachinocephalus myops, Trichonotuts* sp., *Mugil* sp. and *PNibea maculata.* Five species of crabs were recorded from the river, which includes *Austruca annulipes, Austruca* sp., *Austruca* sp.1, Austruca variegate, *Scylla serrate.* Similarly, Six species of shrimps were recorded from the river, they were *Penaeus monodon, Penaeus japonicas, Metapenaeus* sp., *Penaeus canaliculatus, Penaeus* sp., *Penaeus latisulcatus.* The local fishermen use gears and hand picking methods to catch the shrimps. Mostly local women were involved in hand picking. Polychaetes are recorded in the some intertidal region, which were taken by local fishermen and fisherwomen. Totally 5 species of bivalves were recorded, they includes *Donax scortum, Mactra antiquate, Sunetta meroe, Vasticardium elongatum* and *Vepricardium asiaticum*. Whereas 12 species of Gastropods were recorded, they are *Bufonaria crumena, Bullia tranquebarica, Calliostoma tranquebaricum, Cerithium columna, Clypeomorus bifasciata, Ficus ficus, Ficus gracilis, Ficus variegate, Oliva olive, Oliva vidua, Phalium areola* and *Polinices mammilla.*

Mangrove ecosystem also supports animal population of considerable size and variety. They represent from smaller phyla to birds and mammals. Totally eleven species of fishes are recorded from mangrove region, they are *Etroplus suratensis, Clarias batrachus, Sillago* sp., *Parupeneus* sp., *Siganus javus, Carcharhinus limbatus, Arius jella, Sardinella* sp., *Mugil* sp., *Lutjanus* sp. and *Parastromateus niger.* Whereas in crab, eight species were recorded, they are *Austruca annulipes, Austruca* sp., *Austruca* sp.1, *Austruca variegata, Cordimana* sp., *Portunus pelagicus, Portunus sanguinolentus* and *Scylla serrate* (Table 3.7.1)*.* Similarly, six species of shrimps are recorded; they included *Penaeus monodon, Penaeus japonicas, Metapenaeus* sp., *Penaeus canaliculatus, Penaeus* sp. and *Penaeus latisulcatus.* As far as bivalves are concerned, totally six species are recorded, they are *Anadara gubernaculum, Anadara inaequivalvis, Crossostrea* sp., *Donax scortum. Mactra antiquata* and *Placuna placenta* (Table 3.7.2). Whereas in gastropods, twenty species were recorded, they are *Agaronia gibbosa, Babylonia spirata, Babylonia zeylanica, Bufonaria crumena, Bullia tranquebarica, Cerithium columna, Clypeomorus bifasciata, Ficus gracilis, Ficus variegate, Harpa davidis, Murex carbonnieri, Nassaria coromandelica, Natica cincta, Natica vitellus, Phalium areola, Phalium glaucum, Pirenella cingulate, Polinices mammilla, Turbinella pyrum* and *Turritella attenuata.*

In Buckingham canal, totally five species of fishes were recorded (Table 3.7.1). They are *Etroplus suratensis, Sillago* sp.*, Brotula* sp., *Carcharhinus limbatus, Arius jella*. Whereas in crab, only *Austruca variegata* and *Scylla serrate* were recorded. Totally six species of shrimps were recorded from the Buckingham canal. They were *Penaeus monodon, Penaeus japonicas, Metapenaeus* sp., *Penaeus canaliculatus, Penaeus* sp. and *Penaeus latisulcatus.* Local fishermen use gears across the canal for fishing. Shrimps were catch mostly by picking method. Totally five species of bivalves were recorded, they includes *Donax scortum, Macalia bruguieri, Mactra antiquate, Vasticardium elongatum* and *Vepricardium asiaticum* (Table 3.7.2). In gastropods, eight species were recorded, they are *Agaronia gibbosa, Calliostoma tranquebaricum, Cerithium columna, Clypeomorus bifasciata, Ficus ficus, Nassaria coromandelica, Natica vitellus* and *Phalium glaucum.*

Pulicat lake provides nursery and breeding grounds for many species of marine fauna and supports commercial fishing with major landing centres at Pulicat. Totally nine fish species were recorded from Pulicat lake (Table 3.7.1). They include *Etroplus suratensis, Clarias batrachus, Parupeneus* sp., *Carcharhinus limbatus, Arius jella, Trachinocephalus myops, Sardinella sp., Mugil* sp. and *Nibea maculate.* In crabs, *Cordimana* sp.*, Portunus pelagicus, Portunus sanguinolentus* and *Scylla serrate* were recorded and six species of shrimp recorded were *Penaeus monodon, Penaeus japonicas, Metapenaeus* sp., *Penaeus canaliculatus, Penaeus* sp. and *Penaeus latisulcatus.* Muddy substratum was observed in the Pulicat lake, which are without seagrass and mangroves. These substratums were dominated by polychaetes and other benthic organisms. Totally 7 species of bivalves were recorded, they are *Anadara gubernaculum, Anadara inaequivalvis, Crossostrea* sp., *Donax scortum, Macalia bruguieri, Placuna placenta and Vasticardium elongatum* (Table 3.7.2). Whereas 13 species of gastropods were recorded, they are *Bullia tranquebarica, Cerithium columna, Clypeomorus bifasciata, Ficus gracilis, Harpa davidis, Natica cincta, Natica vitellus, Oliva olive, Oliva vidua, Phalium glaucum, Pirenella cingulate, Polinices mammilla and Turbinella pyrum.*

Ennore creek supports many species of marine fauna and commercial fishing with landing centre at Ennore. Totally Eight fish species were recorded from Pulicat lake (Table 3.7.1). They include *Clarias batrachus, Sillago* sp., *Brotula* sp., *Arius jella, Trachinocephalus myops, Trichonotus sp., Mugil* sp. and *Nibea maculate.* In crabs, *Austruca annulipes, Portunus pelagicus, Portunus sanguinolentus* and *Scylla serrate* were recorded and six species of shrimp recorded were *Penaeus monodon, Penaeus canaliculatus* and *Penaeus latisulcatus were dominant.* Totally 6 species of bivalves were recorded, they are *Anadara gubernaculum, Anadara inaequivalvis, Donax scortum, Macalia bruguieri, Placuna placenta and Sunetta meroe* (Table 3.7.2). Whereas 14 species of gastropods were recorded, they are *Agaronia gibbosa, Bufonaria crumena, Calliostoma tranquebaricum, Cerithium columna, Clypeomorus bifasciata, Ficus variegate, Harpa davidis, Murex carbonnieri, Natica cincta, Phalium areola, Pirenella cingulate, Polinices mammilla, Tibia curta and Turbinella pyrum.*

Table 3.7.1: shows the different types of fishes and crustacean recorded from the Kosasthalaiyar river, Mangrove ecosystem, Buckingham canal, Pulicat lake and Ennore creek

S. No.	Fish species	Kosasthalaiyar River	Mangrove Ecosystem	Buckingham canal	Pulicat lake	Ennore creek
1	*Etroplus suratensis*	-	✓	✓	✓	-
2	*Clarias batrachus*	✓	✓	-	✓	✓
3	*Sillago* sp.	-	✓	✓	-	✓
4	*Brotula* sp.	✓	-	✓	-	✓
5	*Parupeneus* sp.	-	✓	-	✓	-
6	*Siganus javus*	-	✓	-	-	-
7	*Carcharhinus limbatus*	-	✓	✓	✓	-
8	*Arius jella*	✓	✓	✓	✓	✓
9	*Trachinocephalus myops*	✓	-	-	✓	✓
10	*Trichonotus* sp.	✓	-	-	-	✓
11	*Sardinella* sp.	-	✓	-	✓	-
12	*Mugil sp.*	✓	✓	-	✓	✓
13	*Nibea maculata*	✓	-	-	✓	✓
14	*Lutjanus* sp.	-	✓	-	-	-
15	*Parastromateus niger*	-	✓	-	-	-
	Crustacean					
16	*Austruca annulipes*	✓	✓	-	-	✓
17	*Austruca* sp.	✓	✓	-	-	-
18	*Austruca* sp.1	✓	✓	-	-	-
19	*Austruca variegata*	✓	✓	✓	-	-
20	*Cordimana* sp.	-	✓	-	✓	-
21	*Portunus pelagicus*	-	✓	-	✓	✓
22	*Portunus sanguinolentus*	-	✓	-	-	✓
23	*Scylla serrata*	✓	✓	✓	✓	✓
24	*Penaeus monodon*	✓	✓	✓	✓	✓
25	*Penaeus japonicus*	✓	✓	✓	✓	✓
26	*Metapenaeus* sp.	✓	✓	✓	✓	✓
27	*Penaeus canaliculatus*	✓	✓	✓	✓	✓
28	*Penaeus* sp.	✓	✓	✓	✓	✓
29	*Penaeus latisulcatus*	✓	✓	✓	✓	✓

Table 3.7.2: shows the different types of bivalves and gastropods recorded from the Kosasthalaiyar river, Mangroves ecosystem, Buckingham canal, Pulicat lake and Ennore creek

S.No	Species	Kosasthalaiyar River	Mangrove Ecosystem	Buckingham canal	Pulicat lake	Ennore creek
	Bivalves					
1	*Anadara gubernaculum*	-	✓	-	✓	✓
2	*Anadara inaequivalvis*	-	✓	-	✓	✓
3	*Crossostrea* sp.	-	✓	-	✓	-
4	*Donax scortum*	✓	✓	✓	✓	✓
5	*Macalia bruguieri*	-	-	✓	✓	✓
6	*Mactra antiquata*	✓	✓	✓	-	-
8	*Placuna placenta*	-	✓	-	✓	✓
9	*Sunetta meroe*	✓	-	-	-	✓
10	*Vasticardium elongatum*	✓	-	✓	✓	-
11	*Vepricardium asiaticum*	✓	-	✓	-	-
	Gastropods					
12	*Agaronia gibbosa*	-	✓	✓	-	✓
13	*Babylonia spirata*	-	✓	-	-	-
14	*Babylonia zeylanica*	-	✓	-	-	-
15	*Bufonaria crumena*	✓	✓	-	-	✓
16	*Bullia tranquebarica*	✓	✓	-	✓	-
17	*Calliostoma tranquebaricum*	✓	-	✓	-	✓
18	*Cerithium columna*	✓	✓	✓	✓	✓
19	*Clypeomorus bifasciata*	✓	✓	✓	✓	✓
20	*Ficus ficus*	✓	-	✓	-	-
21	*Ficus gracilis*	✓	✓	-	✓	-
22	*Ficus variegata*	✓	✓	-	-	✓
23	*Harpa davidis*	-	✓	-	✓	✓
24	*Murex carbonnieri*	-	✓	-	-	✓
25	*Nassaria coromandelica*	-	✓	✓	-	-
26	*Natica cincta*	-	✓	-	✓	✓
27	*Natica vitellus*	-	✓	✓	✓	-
28	*Oliva olive*	✓	-	-	✓	-
29	*Oliva vidua*	✓	-	-	✓	-
30	*Phalium areola*	✓	✓	-	-	✓
31	*Phalium glaucum*	-	✓	✓	✓	-
32	*Pirenella cingulata*	-	✓	-	✓	✓
33	*Polinices mammilla*	✓	✓	-	✓	✓

34	*Semicassis canaliculata*	-	-	-	-	-
35	*Tibia curta*	-	-	-	-	✓
36	*Turbinella pyrum*	-	✓	-	-	✓
37	*Turritella attenuata*	-	✓	-	✓	-

Summary results and remarks

Because of the availability of marine, brackish and freshwater ecosystems next to each other, associated biodiversity is considerably high in the study area. The fishes seen here can be classified as true residents, partial residents, tidal visitors and seasonal visitors. In Kosathalaiyar River, totally 7 species of fishes, 5 species of crabs, 6 species of shrimps, 5 species of bivalves, 12 species of gastropods and polychaetes were observed. In the mangrove region, 11 species of fishes, 8 species of crabs, 6 species of shrimps, 6 species of bivalves and 20 species of gastropods were observed. In Buckingham canal, 5 species of fishes, 2 species of crab, 6 species of shirimps, 5 species of bivalves and 8 species of gastropods were recorded. Pulicat Lake provides nursery and breeding grounds for many commercially important species in which totally 9 fish species, 3 crab species, 6 shrimp species, 7 bivalve species, 13 gastropod species along with polychaetes were observed. In Ennore creek, 8 fish species, 4 crab species, 6 shrimp species, 6 bivalve species and 14 gastropod species were observed during the study period.

Mugil **sp.**

Nemipterus Japonicus

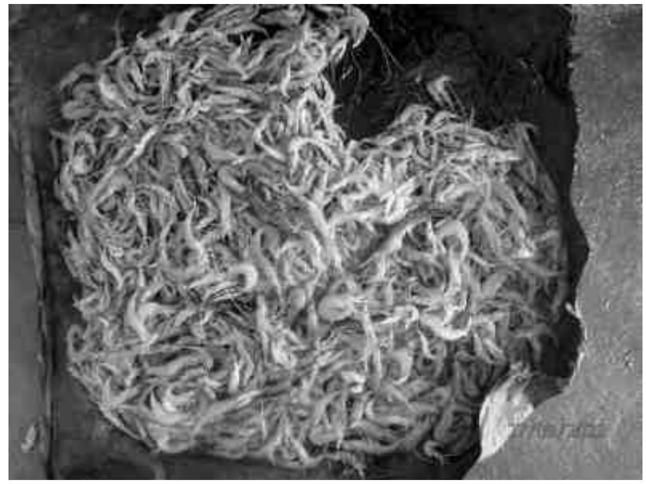
Rachycentron canadum

Parupeneus **sp.**

Scylla serrate

Portunus **sp.**

***Metapenaeus* sp.**



***Metapenaeus* sp.**

***Austruca* sp.**

Austruca variegata

Pseudosesarma glabrum

***Scylla* sp.**

Anadara gubernaculum

***Pirenella* sp.**

Agaronia gibbosa

***Meretrix* sp.**

Volegalea cochlidium

***Volegalea* sp.**

viii. Assessmnet of Avifauna and Mammals

1. Avifauna

The landforms observed in the study area includes, river, intertidal region, waterlogged area, canal, creek, lake, cultivable land, non-cultivable land, coastal sands and coastal track. The diversity of fauna and vegetation, within the landforms influence the distribution of avifauna. Totally 37 species of both migrate and resident birds are recorded from the study area (Table 3.8.1). Avifauna distribution was higher in river, intertidal region, waterlogged area, creek, lake, cultivable and canal, whereas it was lesser in coast track, non-cultivable regions. The availability of food and vegetation for habitat plays the important role in the distribution of higher number of birds. The most dominant avifauna recorded during the field transect are *Ardea intermedia*, *Sterna albifrons, Mycteriya leucocephala, Pelecanus philippensis*, which is most commonly observed in river and creek followed by *Tringa glareola* and *Himantopus himantopus* which is commonly observed in intertidal region.

Table 3.8.1: shows the scientific and common name of avifauna observed in the study area

Sl.No	Scientific Name	Common Name
1	*Acridotheres tristis*	Common myna
2	*Alcedo atthis*	Common kingfisher
3	*Alcedo meninting*	Blue-eared kingfisher
4	*Anastomus oscitans*	Asian openbill
5	*Anthus sp.*	pipits
6	*Apus affinis*	House swift
7	*Ardea cinerea*	Grey heron
8	*Ardea intermedia*	Intermediate egret
9	*Ardea purpurea*	Purple heron
10	*Ardeola grayii*	Indian pond heron
11	*Bubulcus ibis*	Cattle egret
12	*Ceryle rudis*	Pied kingfisher
13	*Corvus macrorhynchos*	Large-billed crow
14	*Corvus splendens*	House crow
15	*Dicrurus macrocercus*	Black drongo
16	*Egretta garzetta*	Little egret
17	*Halcyon smyrnensis*	White breasted kingfisher
18	*Haliastur Indus*	Brahminy kite
19	*Himantopus himantopus*	Black-winged stilt
20	*Hirundo tahitica*	Common swallow
21	*Lanius cristatus*	Brown shrike
22	*Malacocincla abbotti*	Babbler

23	*Milvus migrans govinda*	Black kite
24	*Mycteriya leucocephala*	Painted stork
25	*Pelecanus philippensis*	Spot-billed pelican
26	*Phalacrocorax niger*	Little Cormorant
27	*Psittacula krameri*	Rose-ringed parakeet
28	*Pycnonotus jocosus*	Red whiskered bulbul
29	*Sterna albifrons*	Little tern
30	*Streptopelia chinensis*	Spotted dove
31	*Tringa glareola*	Wood sandpiper
32	*Tringa(Actitis) hypoleucos*	Common sandpiper
33	*Turdoides affinis*	Yello billed babbler
34	*Vanellus indicus*	Red-wattled lapwing
35	*Elanus caeruleus*	Black-winged kite
36	*Columba livia*	Rock pigeon
37	*Prinia socialis*	Ashy prinia
38	*Coracias benghalensis*	Indian roller
39	*Numenius arquata*	Eurasian curlew

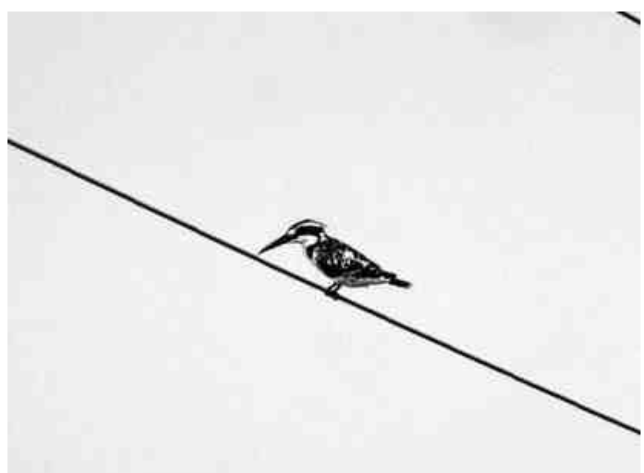
Ardea cinerea

Egretta garzetta

***Egretta* sp.**

Pelecanus philippensis

Mycteriya leucocephala



Ceryle rudis

Tringa glareola

Himantopus himantopus

Acridotheres tristis

Corvus splendens

Anthus sp.

Elanus caeruleus

Dicrurus macrocercus

Numenius arquata

Prinia socialis

Ardeola grayii

Phalacrocorax niger

Coracias benghalensis

2. Mammals and other animals

Mammals recorded from terristial area include cows, buffaloes, squirrel, field mouse, bat, house rat, hare, dog, snake and three lizard (Table 3.8.2). Grazing of mangrove by cow and buffaloes were observed during the study period. Snake were caught in the nets of fishermen in Buckingham canal and Kosasthalaiyar river region during fishing.

Table 3.8.2: shows the scientific and common name of mammals in the study area

S.No.	Common Names	Scientific Names
	Mammals	
1	Cow	*Bos taurus*
2	Buffalo	*Bubalus bubalis*
3	Three striped palm squirrel	*Funambulus palmorum*
4	Field mouse	*Apodemus sylvaticus*
5	Bat	*Cynopterus sphinx*
6	House rat	*Ratus ratus ratus*
7	Black napped hare	*Lepus nigricollis*
8	Dog	*Canis lupus familiaris*
9	Snake	*Craspedocephalsu* sp.
10	Tree lizard	*Urosaurus ornatus*

Buffaloes

Tree lizard

Dog

Snake

Summary results and remarks

In the study area terrestrial mammals recorded include cows, buffaloes, squirrel, field mouse, bat, house rat, hare, snake and three lizard. Water snakes were found entangled in the fishing nets laid in the Buckingham canal and Kosasthalaiyar River. Sea snakes were also observed under the water in the sea. The landforms observed in the study area includes, river, intertidal region, waterlogged area, canal, creek, lake, cultivable land, non-cultivable land, coastal sand and coastal tract. Hence the density and diversity of birds were considerably high. Totally 37 species of migratory and resident birds were sighted during the study period. Avifaunal distribution was higher in river, intertidal region, waterlogged area, creek, lake, cultivable and canal. The dominantly sighted birds include *Ardea intermedia, Sterna albiforns, Mycteriya leucocephala, Pelecanus philippensis*, *Tringa glareola* and *Himantopus himantopus*.

ix. Fishery status

The study area includes 5 coastal villages, in which 4 are fishing village. They are Vairavankuppam, Koraikuppam, Kadalkannikuppam and Kattupalli, whereas Karungali, which is situated in between Kattupalli and Kadalkannikuppam was used by few fishermen from Kattur region for their fishing activities particularly in the Kosasthalaiyar river. These villages are situated from north to centre region of the study area.

Socio-Economic status of coastal communities

The residents of these fishing villages in the study area are engaged in fishing as a primary occupation. Most of them are using traditional method of fishing. Most of the fishermen do not have their own boat and they are working as crew members in the other's boat. The economic conditions of these fishermen are poor. They are not having proper drinking water supply, proper medical and health care facilities. The non-availability of proper transport facilities separates these fishermen from the nearby urban area. Therefore, they have a low standard of living.

Economic activities in the study area

Exploitation of fishes and other fishery resources in the marine, brackish and freshwater zone has been the occupation of several fishermen families living along the coast. They have been in close proximity with the sea, brackish and freshwaters (such as Kosasthalaiyar river, Mangroves, Buckingham canal, Pulicat lake and Ennore creek) and, so that, their life-style, culture, community and social life are centered around the sea and brackish water. During the survey, it has been identified that some of the activities of the fishermen residing in the villages are as follows:

1. Fishing in sea and brackish water zone
2. Hand picking of prawns
3. Shell collection
4. Polychaetes collection
4. Cooli

Fishing

Fishing is the primary economic activity of the people of the fishing villages in the study area. There are about 1534 fishermen living in the fishing village in the study area. The fishermen employ mostly FRP boats fixed with outboard engine. Nearly 229 motorized fibre boats are operated for fishing from this fishing villages (Table 3.9.1), few small non-motorized fibre boats are also available, which are particularly used for fishing in the brackish and freshwater area (mainly in Kosasthalaiyar river and Buckingham canal). The various fishing gears used by the fishermen for fishing are thread net, shrimp net, mani valai, kanni valai, visuru valai, crab net, hooks, gill net, ayala valai, velamen valai, kattu valai and pomfret net, of which kanni valai and visuru valai are mainly used for fishing in brackish and freshwater area (Table

3.9.2). Fishing time of the village is morning 3.00 am to 8.00 am in the marine zone, whereas in the brackish water zone, 6.00 am to 12.00 am, whereas it may extend to 3.00 pm some days.

Fish caught was higher in Koraikuppam, followed by Vairavankuppam, followed by Kattupalli, followed by Karungali and Kadalkannikuppam with 1,990 kg/day, 1,350 kg/day, 1,100 kg/day, 239 kg/day and 120 kg/day respectively (Fig. 3.9.1). In Karungali fishing is done mainly in Kosasthalaiyar River. Totally 58 species of fishes were caught from the region, among the fin fishes, *Rastrelliger kanagurta* was the most landed fish species with 745 kg/day followed by *Alepes djedaba* with 219 kg/day (Table 3.9.3). As far as shell fishes, *Metapenaeus* sp. recorded highest caught followed by *Penaeus monodon* with 291 kg/day and 225 kg/day. Koraikuppam recorded higher number of species caught followed by Vairavankuppam, followed by Kattupalli, followed by Kadalkannikuppam and Karungali with 55, 51, 50, 40 and 8 numbers respectively. Fishes caught in this region are widely seasonal and major fishes caught in this region are recorded during the month of April and May. Total commercial fishery resource of this villages includes 58 species and the overall caught was 4799 kg/day.

Table 3.9.1: shows the types of crafts and gears used by the local fishermen for the studied villages

Craft & gears	Vairavan-kuppam	Korai-kuppam	Kadalkanni-kuppam	Karungali	Kattupalli
Types of crafts	FRB	FRB	FRB	FRB	FRB
No of crafts	110	70	8	9	32
Types of gears	Thread net, Gill net, hooks, kattu valai, mani valai, shrimp net	Hooks, ayala valai, crab net, velameen valai,	Hooks, gillnet, fish net, carb net, pomfret net	Kanni valai, visuru valai	Kanni valai, visuru valai, hooks, velameen valai, ayala valai, hooks
Prefered gears	Hooks	Hooks, ayala valai, velameen valai and crab net	Hooks & gillnet	Kanni valai & visuru valai	Velameen valai & ayala valai

Table 3.9.2: shows the dominant catch, peak seasons and fishing ground for the studied villages

Fishing activities	Vairavan-kuppam	Koraikuppam	Kadalkanni-kuppam	Karungali	Kattupalli
Most dominant fish catch	Ayala, iral, seer fish	Ayala, Paarai, Velameen	Shrimph, lutjanus, promfret	Shrimp	Ayala, ooli, lutjanus
Average catch (Kg) per day	1350	1990	120	239	1100

No of fishing days in a month	20 to 25	26	20 to 24	26	20 to 25
Peak seasons	April, May	April	April, May	All seasons	April
Fishing ground	Sea, lake, canal and river	Sea, lake, canal and river	Sea, lake and river	River and canal	Sea, river and canal

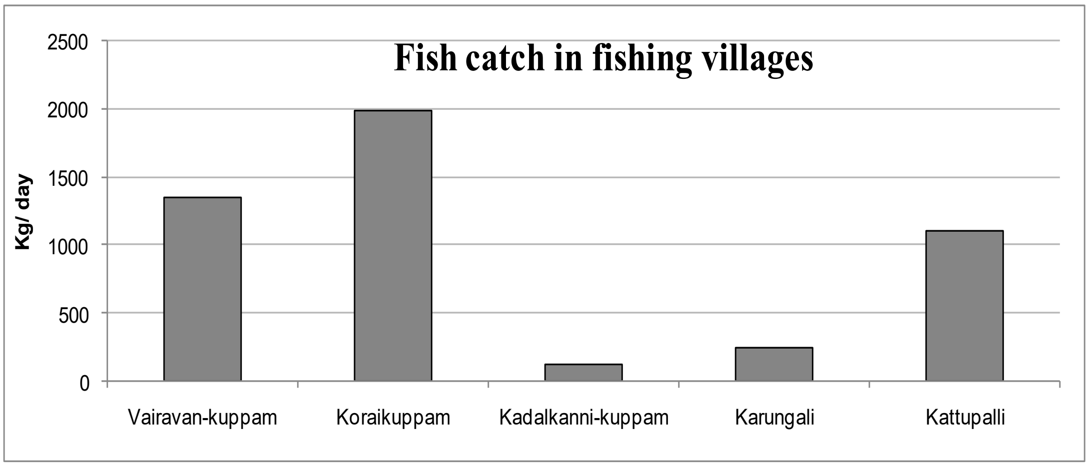


Fig. 3.9.1: Plot showing the fish catch in the fishing villages of the study area

Table 3.9.3: shows the type of fishes landing in the studied villages

S. No.	Fish species	Vairavan-kuppam	Koraikuppam	Kadalkanni-kuppam	Karungali	Kattupalli
		kg/day	kg/day	kg/day	kg/day	kg/day
1	*Alepes djedaba*	79	75	13	0	52
2	*Alepes melanoptera*	28	15	0	0	20
3	*Arius jella*	35	11	2	0	18
4	*Brotula* sp.	12	0	0	0	0
5	*Carangoides armatus*	5	20	0	0	19
6	*Carcharhinus limbatus*	2	15	1	0	12
7	*Cephalopholis formosa*	18	5	0	0	6
8	*Chaetodon decussatus*	0	4	2	0	5
9	*Charybdis natator*	15	11	5	0	11
10	*Chirocentrus dorab*	27	18	7	0	23
11	*Clarias batrachus*	23	32	0	0	26
12	*Dussumieria acuta*	0	25	5	0	37
13	*Epinephelus*	0	12	4	0	7

	malabaricus					
14	*Epinephelus merra*	0	0	0	0	4
15	*Escualosa thoracata*	30	0	0	0	15
16	*Etroplus suratensis*	0	0	0	0	6
17	*Euthynnus affinis*	18	30	3	0	0
18	*Gerres limbatus*	9	25	1	0	12
19	*Hemiramphus far*	19	85	2	0	14
20	*Heniochus acuminatus*	0	45	0	0	18
21	*Leiognathus dussumieri*	12	32	5	0	17
22	*Liza parsia*	22	25	2	0	32
23	*Liza vaigiensis*	4	42	3	0	18
24	*Loligo* sp.	5	25	1	0	13
25	*Lutjanus fulviflamma*	16	15	0	32	29
26	*Lutjanus rivulatus*	0	8	0	25	12
27	*Megalaspis cordyla*	12	5	1	35	48
28	*Mugil* sp.	9	32	2	25	36
29	*Narcine brunnea*	11	25	0	0	28
30	*Nemipterus* sp.	17	42	1	0	37
31	*Nibea maculata*	5	23	0	0	20
32	*Pelates quadrilineatus*	22	25	0	0	18
33	*Platax orbicularis*	31	15	2	0	39
34	*Rastrelliger kanagurta*	312	305	14	0	114
35	*Sardinella* sp.	77	75	6	0	6
36	*Scarus ghobban*	18	22	0	0	18
37	*Scatophagus argus*	4	15	0	0	17
38	*Scomberoides commersonianus*	26	48	1	0	23
39	*Selaroides leptolepis*	45	32	0	0	0
40	*Siganus javus*	12	25	1	0	0
41	*Siganus lineatus*	5	12	0	0	12
42	*Sillago sihama*	14	15	0	0	15
43	*Sphyraena jello*	28	88	0	0	21
44	*Sphyraena* sp.	37	75	4	0	22
45	*Synaptura commersonnii*	53	32	15	0	11
46	*Tenualosa ilisha*	32	25	0	0	6
47	*Thryssa malabarica*	12	15	0	0	0
48	*Trachinocephalus myops*	2	8	1	0	0
49	*Triacanthus biaculeatus*	5	5	1	0	0
50	*Trichonotus* sp.	4	12	1	0	5
51	*Portunus pelagicus*	11	45	2	0	8
52	*Portunus sanguinolentus*	21	25	1	0	6

53	*Scylla serrata*	0	0	0	0	5
54	*Penaeus monodon*	36	125	1	10	53
55	*Penaeus japonicus*	14	32	2	22	12
56	*Metapenaeus* sp.	64	145	8	0	74
57	*Penaeus canaliculatus*	21	42	0	75	15
58	*Penaeus latisulcatus*	11	25	0	15	5

Hand picking of prawns and shell collection

Fishermen use hand picking method to catch the prawns from the brackish water zone (Kosasthalaiyar river, Buckingham canal, Pulicat lake and Ennore creek). Mostly women were involved in hand picking. Similarly they also collect shells from the brackish water zone by hand picking method. The usual fishing time in the brackish water zone extends from morning 6.00 am to forenoon 12.00 am, whereas it extends to 3.00 pm in some days. They usually sell their catch in the road side enroute to Kamaraj Port near Athipattu Pudunagar and some time to the nearby landing centres at Pulicat and Thazhakuppam.

Polychaetes collection

Few fishermen also involved in collection of Polychaetes from the brackish water zone, particularly in the intertidal region in the Kosasthalaiyar river. They involved in collection during the low tide time when most of the intertidal region are exposed above water. The collections of Polychaetes are one of the secondary fishing activities for few fishermen. Both fishermen and fisherwomen are involved in the collection.

Cooli

The main secondary way of income for the local fishermen is through cooli. They are getting fishing related and non-fishing jobs in the nearby area, mostly in aquafarm, salt pan, L & T Ship Building and nearby Thermal Power plants. Mostly they are getting wages on daily basis.

Integrated farming

CIBA (Central Institute of Brackishwater Aquaculture) has provided integrated farming option to few local fishermen to reduce the load in the marine and brackish water ecosystem. They have provided fixed crab cage which was installed in the Kosathaliyar river and cage for poultry breeding. Crab seedling are also provided by CIBA and grown crabs are purchase by CIBA itself.

Summary results and remarks

A total of five coastal villages fall within the study area which are Vairavankuppam, Koraikuppam, Kadalkannikuppam, Kattupalli and Karungali where the fishery survey was conducted. The residents of these fishing villages have fishing as the primary occupation. Most of the fishermen do not have their own boat and are working as crew members others' boats. They fish in the sea, lake, river and canal. The villages do not have proper drinking water supply, transportation, proper medical and health care facilities. Exploitation of fishery resources in the marine and brackish water zones by the fishermen is significant, though the resources are limited. Some of the fishing related activities of the villagers include, fishing in sea and brackish waters, hand picking of prawns, shell collection, polychaetes collection and working as coolies in aqua forms and other agencies. There are about 1534 fishermen live in the study area. The fishermen employ mostly FRP boats fixed with outboard engine. There are about 229 motorized fibre boats are being operated from the study area. Various fishing gears used by the fishermen include thread net, shrimp net, mani valai, kanni valai, visuru valai, crab net, hooks and lines, gill net, ayala valai, velamen valai, kattu valai and pomfret net, of which kanni valai and visuru valai are mainly used for fishing in brackish water area. Fish catch was higher in Koraikuppam, followed by Vairavankuppam and Kattupalli with 1990, 1350 and 1100 kg/day respectively. Among the 58 landed species, *Rastrelliger kanagurta* was the dominantly caught species followed by *Metapenaeus sp.* and *Penaeus monodon* In the case of shell fish, *Portunus pelagicus* and *P. sanguinolentus* were the dominantly landed fishes in this region. Fishermen use hand picking method to catch the prawns from the brackish water zone. Mostly women were involved in hand picking. Few fishermen are also involved in collection of polychaetes from the brackish water zone, particularly in the intertidal region in the Kosasthalaiyar River.

Fishing activities in the study area

Fishing and related activities




Landuse/Land cover pattern

4. COMPARISON BETWEEN BASELINE STUDY (2020) AND PRESENT UPDATE (2022)

In order to a have a clear information about the impact of regular port operation on the nearby ecosystem, comparison was done between the baseline data (2020) and the present data (2022) for the various assessed parameters.

MARINE ZONE UNDERWATER ASSESSMENT

Molluscan communities

Relatively fair assemblage pattern of molluscs was noticed in 2020 and 2022. In 2020, totally 38 species were recorded in the marine zone. The mean density was 8.8 nos/5m^2. *Babylonia spirata* was most dominant species followed by *Babylonia zeylanica, Cerithium columna, Ficus gracilis* and *Agaronia gibbosa*. In 2022, totally 37 species were recorded in the Marine zone. The mean density is 9.66 nos/5m^2. *Babylonia spirata* is most dominant species Agaronia *gibbosa, Cerithium columna, Turritella attenuata* and *Donax scortum* (Fig. 4.1).

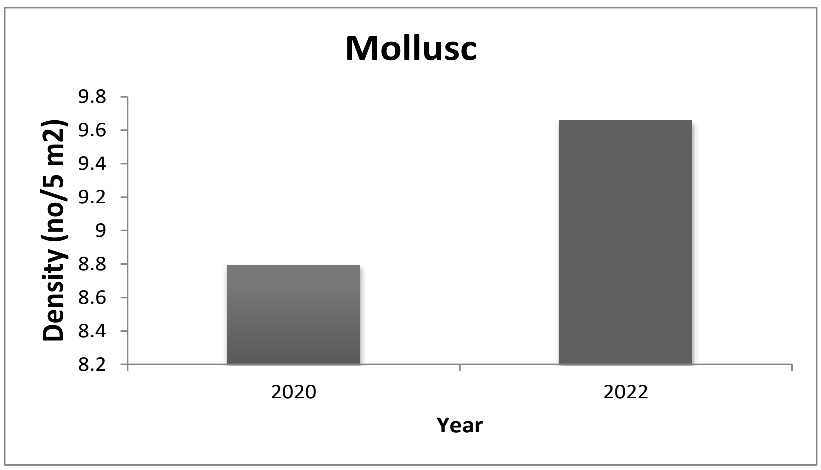


Fig. 4.1: Mollusc density during 2020 and 2022

Soft corals communities

The soft coral communities had relatively low occurrence in 2020 and 2021. In 2020, five species were sighted; *Carijoa* sp., *Virgularia* sp., and *Cavernulina* sp. were the dominant species. The mean density was 0.88 no/5 m^2. Similarly in 2022, five similar species are found during the present survey. *Cavernulina* sp., *Virgularia* sp., and *Carijoa* sp. are the dominant species. The mean density is 1.27 (no/5 m^2) (Fig. 4.2).

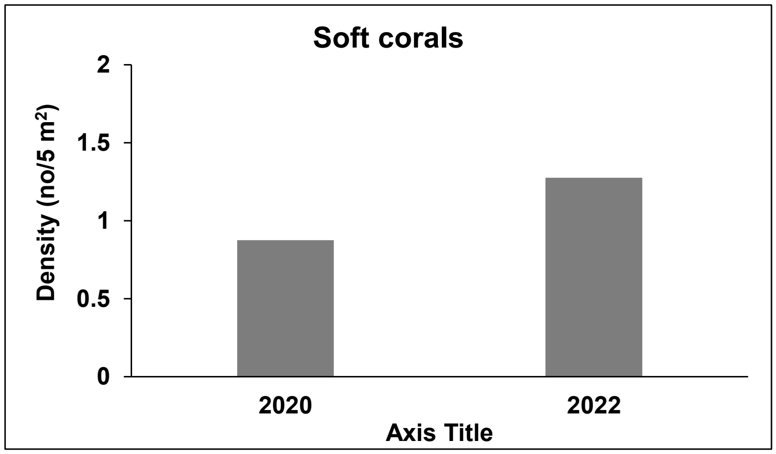


Fig. 4.2: Soft coral density during 2020 and 2022

Sponge communities

The sponge communities had relatively low occurrence in 2020 and 2022. In 2020, ten species were sighted; *Spirastrella* sp., *Chalinula* sp. and *Clathria microciona* were the dominant species. The mean density was 1.80 no/5 m^2. In 2022, twelve species are found during the present survey. *Clathria* sp., *Spirastrella* sp., and *Cliona* sp. are the dominant species. The mean density is 2.35 no/5 m^2 (Fig. 4.3).

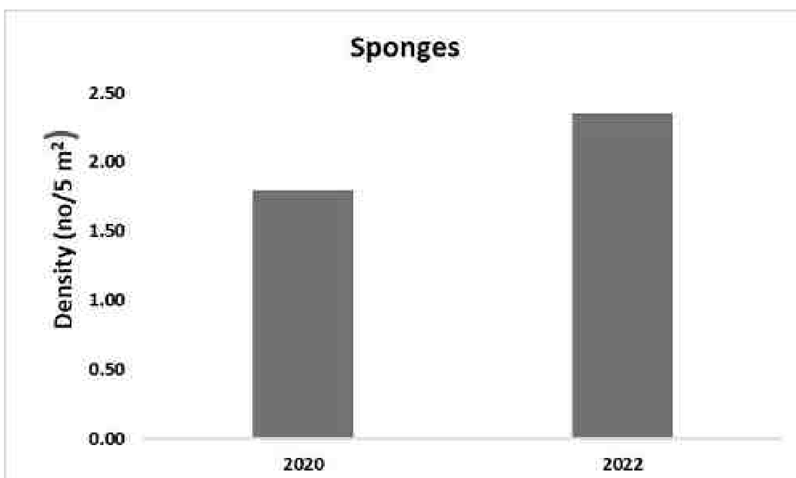


Fig. 4.3: Sponges density during 2020 and 2022

Fish communities

Fish assemblages in terms of species diversity and abundance slightly varied for two assessment periods during 2020 and 2022. Species richness was enumerated as 50 in 2020 and it is 56 in 2022. Mean abundance was 42.82 no/250 m^2 in 2020 and it has slightly increased to 45.64 no/250 m^2 in 2022. In 2022 assessment, six more fish species were observed. In 2020, *Rastrelliger kanagurta, Rhabdosargus sarba, Sphyraena jello, Alepes melanoptera* and *Selaroides leptolepis* were the most abundant fish species, whereas in 2022, *Rastrelliger* *kanagurta, Sardinella* sp., *Sphyraena jello,* and *Selaroides leptolepis* are the most dominant fishes(Fig. 4.4).

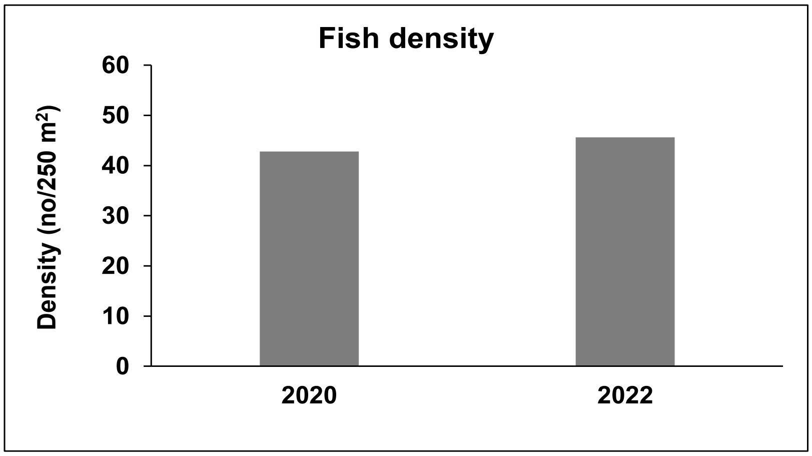


Fig. 4.4: Fish density during 2020 and 2022

Other faunal communities

Similar assemblage pattern of other faunal groups occurs in the study area during 2020 and 2022. *Holothuria* and *Stichodactyla* were sighted during the present survey; it was not observed in 2020. In 2022, mammals were not observed during the survey periods. Sea snakes and sea turtles were not sighted.

MANGROVE HABITAT ASSESSMENT

There is no significant change in mangrove area cover between 2020 and 2022. The total area cover of mangroves was 62 ha during 2020 and it was 62.8 ha during 2022.. Totally three mangrove species were seen during 2020 and 2022, which includes *Avicennia marina, Avicennia* sp. and *Rhizopora mucranata*, of which *Avicennia marina* is the dominant species during both the period of study. No other significant change in density of mangrove and height of the mangroves were observed during 2020 and 2022 respectively. Similarly five types of halophytic plants were also observed in the mangrove areas during 2020 and 2022, which include *Sesuvium portulacastrum, Suaeda monoica, Suaeda* sp.*, Suadea nudifolra Moq.* and *Salicornia brachiate Roxb* (Fig. 4.5).

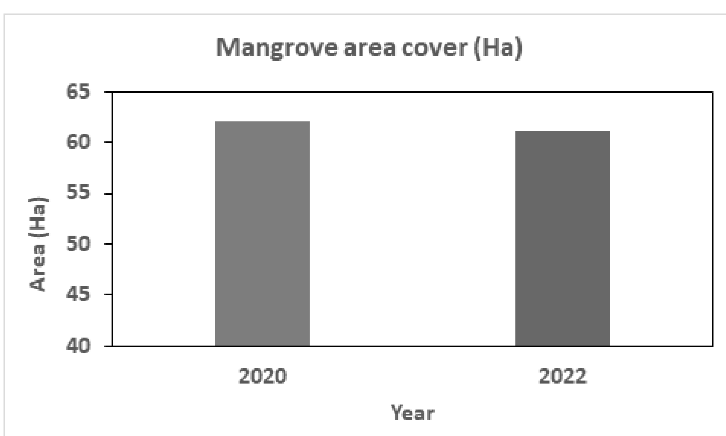


Fig. 4.5: Mangrove area cover for 2020 and 2022 in the Kosasthalaiyar river

COASTAL FLORAL ASSESSMENT

Relatively fair coastal vegetation was observed during both 2020 and 2022 period. During 2020, 36 species of plants were observed, of which 5 were herbs dominated by *Cyperus conglomeratus*, 16 were shrubs dominated by *Calotropis gigantean* and 15 were trees dominated by *Eucalyptus globulus*. The total area cover of coastal vegetation was 274.3 ha, in which *Eucalyptus globulus* was the dominant plant covering an area cover of 92 ha (Fig. 4.6).

During 2022, 41 species of plants were observed, among them 5 are herbs dominated by *Cyperus conglomeratus*, 20 are shrubs dominated by *Ipomoea pes-caprae* and 16 are trees dominated by *Eucalyptus globulus*. The total area cover of coastal vegetation is 282 ha, in which *Eucalyptus globulus* is the dominant plant covering an area cover of 94 ha.

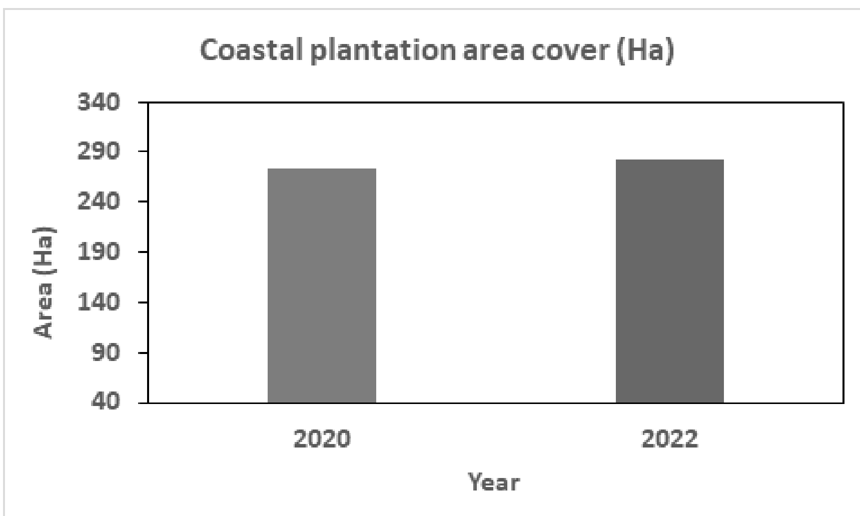


Fig. 4.6: Coastal plantation area cover for 2020 and 2022

SEDIMENT MACRO- AND MEIOFAUNAL COMMUNITIES

The Macrofauna communities in marine zone had relatively more occurrence in 2020 than 2022. In 2020 totally 606 macro benthic faunal individuals were recorded in the Marine zone. The mean density was 75.75nos.0.0256m^2. Polycheates were the most dominant group followed by Others and Gastropods. In 2020 totally 780 benthic meiofauna individuals were recorded in the Marine zone. Mean density was 97.5 nos./10cm^2. Foraminiferans, Nematodes and Ostrocodes were the most dominant groups. In 2022 totally 840 benthic meiofauna individuals were recorded Mean density is 105 nos./10cm^2. Foraminiferan is most dominant group followed by Nematodes and Harpacticoides (Fig. 4.7&8).

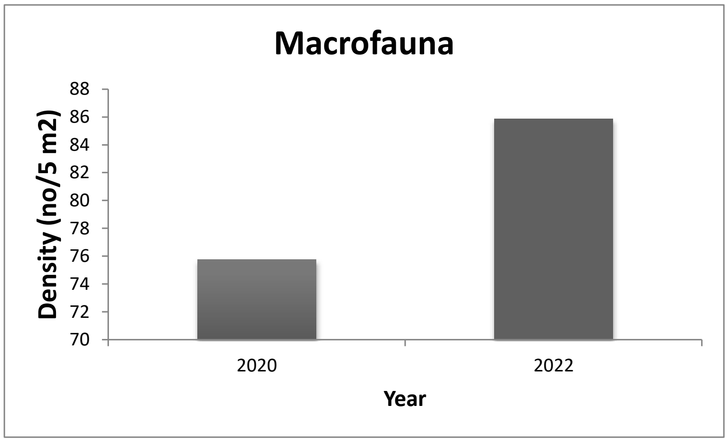


Fig. 4.7: Macrofaunal density in marine zone during 2020 and 2022

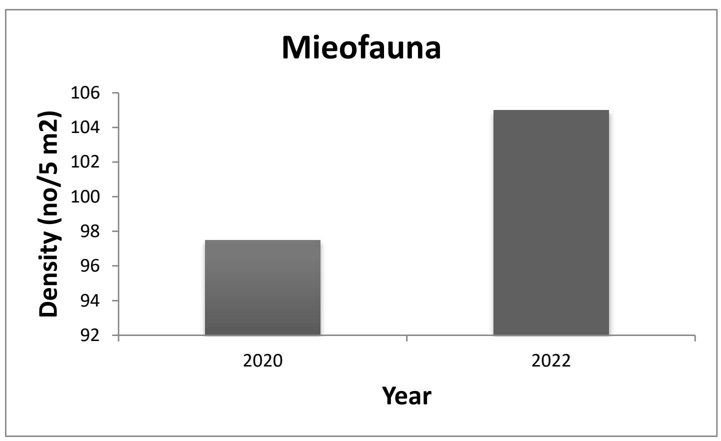


Fig. 4.8: Meiofaunal density in marine zone during 2020 and 2022

In Buckingham Canal, the macrofauna communities had a relatively better occurrence in 2020 than 2022. In 2020, total 314 macro benthic faunal individuals were recorded in the Buckingham Canal. The mean density was 26.16 nos.0.0256m^2. Polychaetes, Amphipods, were the most dominant groups. In 2022, 375 macrobenthic faunal individuals were recorded in the study area. The mean density is 31.16nos.0.0256m^2. Among the groups, Polychaetes, Amphipods are the most dominant groups. Totally 58 benthic meiofauna individuals were recorded in the Buckingham Canal. In 2020 Mean density was 88 nos./10cm^2. Nematodes, Foraminifera, were the most dominant groups. In 2022 Mean density is 100.83 nos./10cm^2. Nematodes and Foraminifera are the most dominant groups (Fig. 4.9&10).

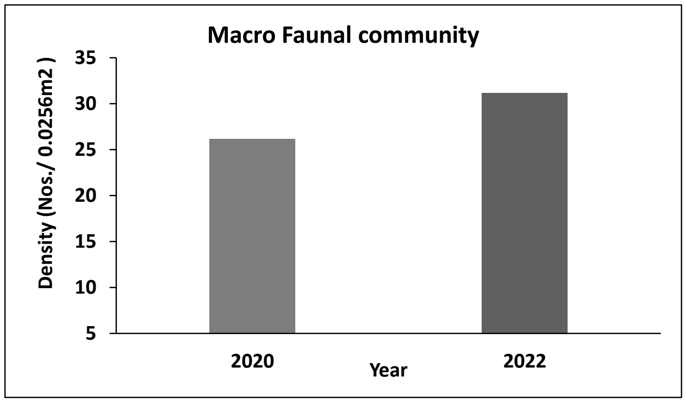


Fig. 4.9: Macrofaunal density in Buckingham canal during 2020 and 2022

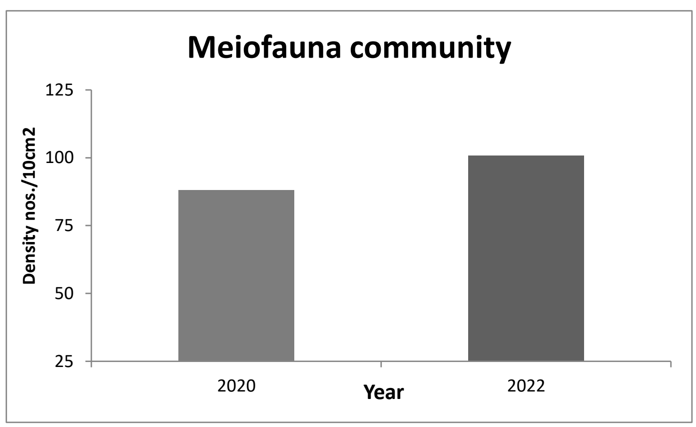


Fig. 4.10: Meiofaunal density in Buckingham canal during 2020 and 2022

The Macrofauna communities in mangrove area had relatively lower occurrence in 2020 than 2022. In 2020 totally 423 macro benthic faunal individuals were recorded in Mangrove zone. The mean density was 38.46 nos.0.0256m^2. Polycheates, Gastropods and Amphipods were the most dominant groups. In 2022 totally 461 macro benthic faunal individuals were recorded in the Mangrove area. The mean density is 41.91nos.0.0256m^2. Polycheates are most dominant group followed by Gastropods and Amphipods. The Meiofauna communities had relatively fair occurrence in both 2020 and 2022. In 2020 totally 1,135 benthic meiofauna individuals were recorded in Mangrove zone. In 2020 Mean density was 103.18 nos./10cm^2. Foraminiferans and Nematodes were the most dominant groups. In 2022 totally 1,217 benthic meiofauna individuals was recorded in Mangrove zone. In 2022 Mean density is 110.64 nos. /10cm^2. Foraminiferans and Nematodes are the most dominant groups (Fig. 4.11&12).

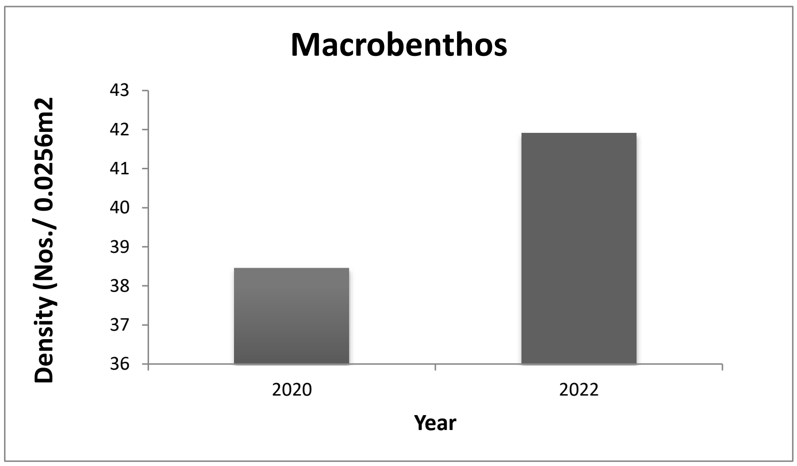


Fig. 4.11: Macrobenthos density in mangroves sediments during 2020 and 2022

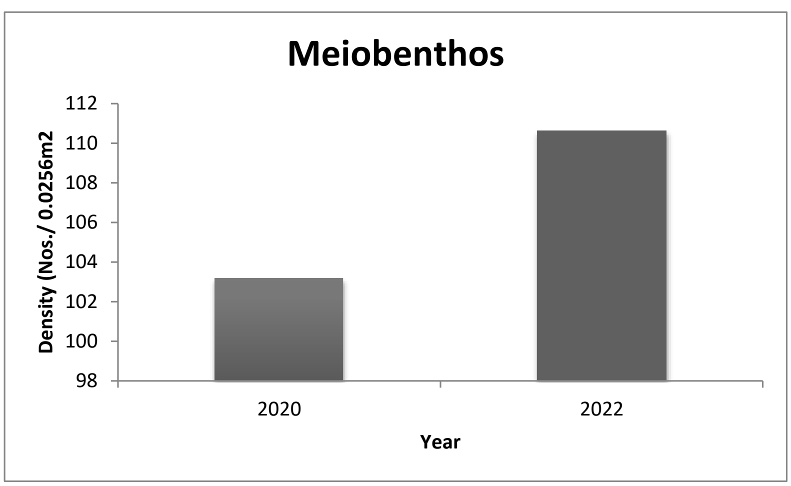


Fig. 4.12: Meiobenthos density in mangroves sediments during 2020 and 2022

In 2020 totally 393 macro benthic faunal individuals were recorded in Pulicat Lake and Ennore Creek area. Mean density was 35.72 nos.0.0256m^2. Polychaetes and Amphipods were the most dominant groups. In 2022 totally 489 macrobenthic faunal individuals were recorded. Mean density is 42 nos.0.0256m^2. Polychaetes and Amphipods are the most dominant groups. In 2020 totally 1062 benthic meiofauna individuals were recorded in the Pulicat Lake and Ennore Creek area. Mean density was 96.54 nos./10cm^2. Foraminifera and Nematodes were the most dominant groups. In 2022 totally 1,272 benthic meiofauna individuals were recorded in the Pulicat Lake and Ennore Creek area. Mean density is 115.63 nos./10cm^2. Foraminifera and Nematodes are the most dominant groups (Fig. 4.13&14).

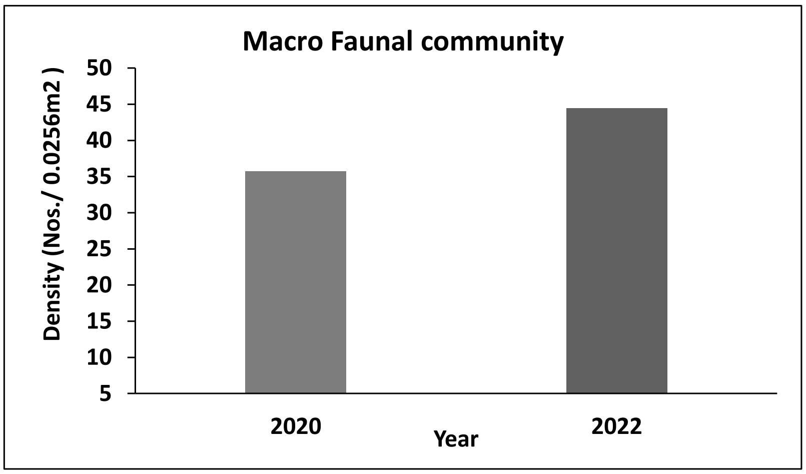


Fig. 4.13: Macrobenthos density in Pulicat lake and Ennore creek sediments during 2020 and 2022

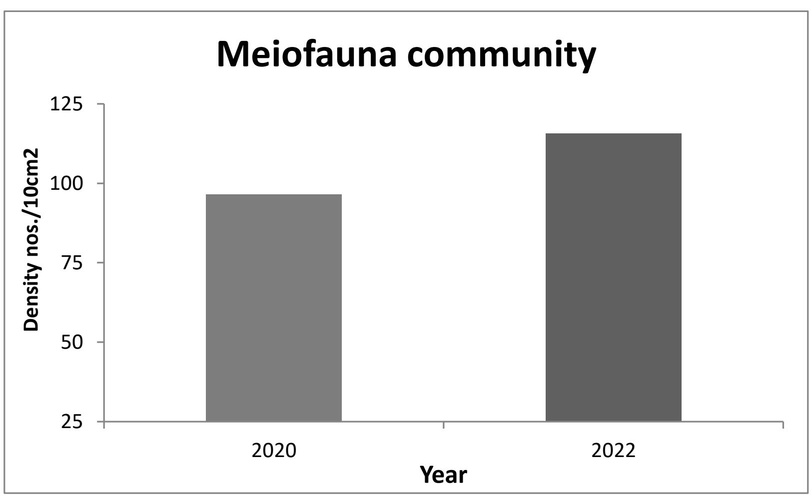


Fig. 4.14: Meiobenthos density in Pulicat lake and Ennore creek sediments during 2020 and 2022

In 2020 totally 370 macro benthic faunal individuals were recorded in Kosathaliyar river. Mean density was 28.46 nos.0.0256m^2. Polychaetes and Amphipods were the most dominant groups. In 2022 totally 451 macrobenthic faunal individuals were recorded. Mean density is 34.69 nos.0.0256m^2. Polychaetes and Amphipods are the most dominant groups. In 2020 totally 1369 benthic meiofauna individuals were recorded in the Kosathaliyar river. Mean density was 105.31 nos./10cm^2. Foraminifera and Nematodes were the most dominant groups. In 2022 totally 1495 benthic meiofauna individuals were recorded in the Kosathaliyar river area. Mean density is 115 nos./10cm^2. Foraminifera and Nematodes are the most dominant groups (Fig. 4.15&16).

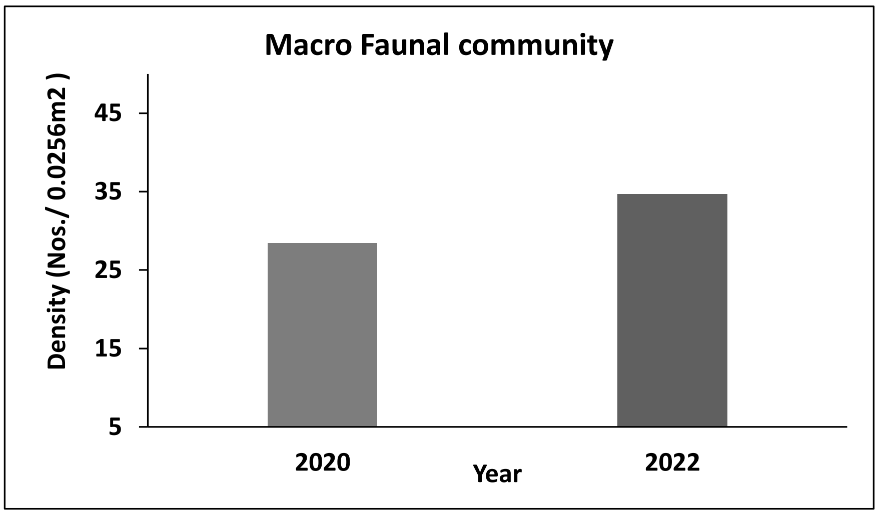


Fig. 4.15: Macrobenthos density in Pulicat lake and Ennore creek sediments during 2020 and 2022

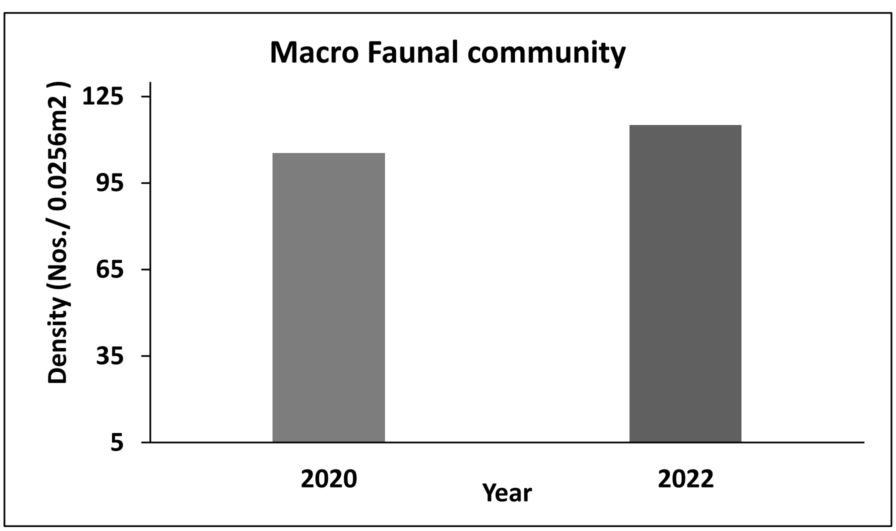


Fig. 4.16: Meiobenthos density in Pulicat lake and Ennore creek sediments during 2020 and 2022

PHYTOPLANKTON AND ZOOPLANKTON COMMUNITY STRUCTURE

No significant change in phytoplankton and zooplankton community structure is observed between 2020 and 2022 period.

In Buckingham Canal, a total of 12 species of Phytoplankton were observed during 2020, whereas in 2022 14 species are found. *Hemidiscus hardmannianus* and *Thalassionema nitzschioides* are the most abundant species in both 2020 and 2022. There is no significant difference in mean density of 2020 and 2022. In Zooplankton, a total of 14 species was observed during 2020, and during 2022 a total of 15 species were observed. Maxillopoda and Hexanauplia are the most abundant classes in both 2020 and 2022. There is no significant difference in mean density observed in 2020 and 2022.

In Ennore Creek, a total of 16 species of Phytoplankton were observed during 2020, whereas in 2022 17 species were observed. *Coscinodiscus* sp. and *Thalassionema nitzschioides* are the most abundant species in both 2020 and 2022. There is no significant difference in mean density observed in 2020 and 2022. In Zooplankton, a total of 7 species were observed during 2020, whereas in 2022, a total of 10 species are found. Maxillopoda are the most abundant class in both 2020 and 2022. There is no significant difference in mean density observed in 2020 and 2022.

In Mangrove waters, a total of 8 species of Phytoplankton were observed during 2020, whereas in 2022 10 species were observed. *Chaetoceros affinis* and *Hemidiscus hardmannianus* are the most abundant species in both 2020 and 2022. There is no significant difference in mean density observed in 2020 and 2022. In zooplankton, a total of 12 species were observed during 2020, whereas in 2022, a total of 14 species were observed. Maxillopoda are the most abundant class in both 2020 and 2022. There is no significant difference in mean density observed in 2020 and 2022.

In Pulicat Lake, a total of 13 species of Phytoplankton were observed during 2020, whereas in 2022 16 species were observed. *Coscinodiscus* sp. and *Pleurosigma* sp. are the most abundant species in both 2020 and 2022. There is a small difference in the mean density observed in 2020 and 2022. In Zooplankton, a total of 8 species were observed during 2020, whereas in 2022, a total of 12 species were observed. Spirotrichea and Maxillopoda are the most abundant class in both 2020 and 2022. There is no significant difference in mean density observed in 2020 and 2022.

In Kosasthalaiyar River, a total of 7 species of Phytoplankton were observed during 2020, whereas in 2022 a total of 10 species were observed. *Hemidiscus hardmannianus and Pleurosigma elongatum* are the most abundant species in both 2020 and 2022. There is no significant difference in mean density observed in 2020 and 2022. In zooplankton, a total of 9 species were observed during 2020, whereas in 2022 a total of 12 species were observed. Maxillopoda and Spirotrichea are the most abundant classes in both 2020 and 2022. There is no significant difference in mean density observed in 2020 and 2022.

In Marine zone, a total of 57 species of phytoplankton were observed during 2020, whereas in 2022 a total of 54 species were observed. *Chaetoceros* sp., and *Hemidiscus hardmannianus* are the most abundant species in both 2020 and 2022. There is no significant difference in mean density observed in 2020 and 2022. In zooplankton, a total of 34 species were observed during 2020, whereas in 2022 a total of 34 species were observed. Maxillopoda and Hexanauplia are the most abundant classes in both 2020 and 2022. There is no significant difference in mean density observed in 2020 and 2022.

Phytoplankton and zooplankton mean density are represented in the figures (Fig. 4.17& 18)

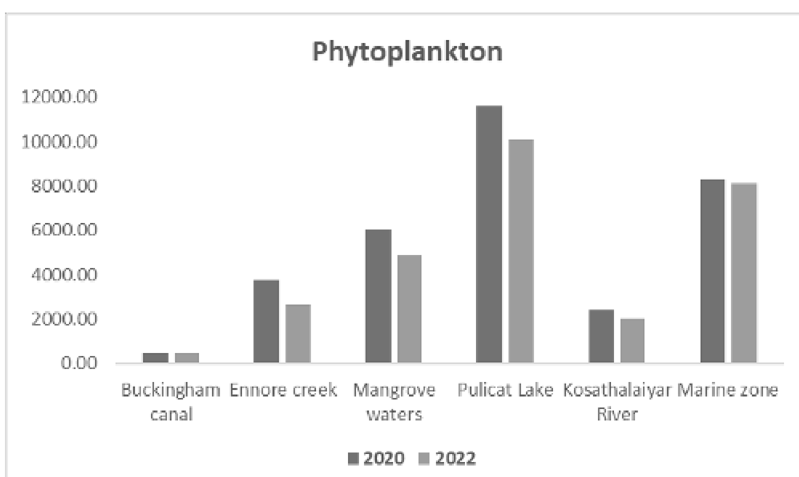


Fig. 4.17: Phytoplankton mean density for 2020 and 2022

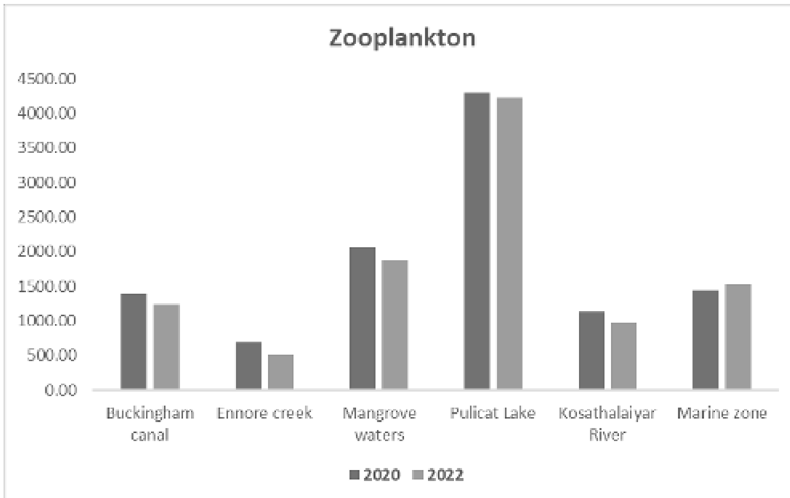


Fig. 4.18: Zooplankton mean density for 2020 and 2022

MICROBIAL PARAMETERS

Microbial parameters are within the optimum levels in the study area, whereas at Ennore Creek it is comparatively higher during the 2020 and 2022. In Ennore Creek, in water samples total viable count show has increased in range from 7.96 $X10^4$ to 8.10 $X10^4$ CFU/ml during 2020 and 2022. In Pulicat Lake, total viable count range decreased from 5.54$X10^4$ to 5.23$X10^4$ CFU/ml during 2020 and 2022. In Kosasthalaiyar River, total viable count decreased from 6.88 $X10^4$ to 6.43 $X10^4$ CFU/ml during 2020 and 2022. In Ennore Creek in sediment samples total viable count increased from 8.63 $X10^5$ to 8.78$X10^5$CFU/g during 2020 and 2022. In mangrove area, total viable count decreased from 6.65 $X10^5$ to 6.24 $X10^5$CFU/g during 2020 and 2022. In marine zone, total viable count decreased from 8.99 $X10^5$ to 8.71 $X10^5$CFU/g during 2020 and 2022. In Ennore Creek, total coliform decreased from 1.95 $X10^4$ to 1.89 $X10^4$CFU/ml during 2020 and 2022. In Pulicat Lake, total coliform decreased from 2.08 $X10^5$ to 2.01 $X10^5$ CFU/g during 2020 and 2022. In Kosasthalaiyar River, total coliform increased from 1.36 X105 to 1.42 X105 CFU/g during 2020 and 2022. In mangrove area, total coliform increased 1.94 $X10^5$ to 2.04 $X10^5$ CFU/g during 2020 and 2022. In Buckingham Canal, total coliform increased from 1.17 $X10^5$ to 1.24 $X10^5$ CFU/g during 2020 and 2022. In marine zone, total coliform increased from 2.27 $X10^5$ to 2.41 $X10^5$ CFU/g during 2020 and 2022. Insignificant changes in total coliform counts were found between two assessment years in the Buchkingham Canal and marine zone. The slight variation could be influenced by several factors responsible, including seasonal, nutrient enrichment from natural sources, and terrestrial runoff from land (Fig 4.198&20).

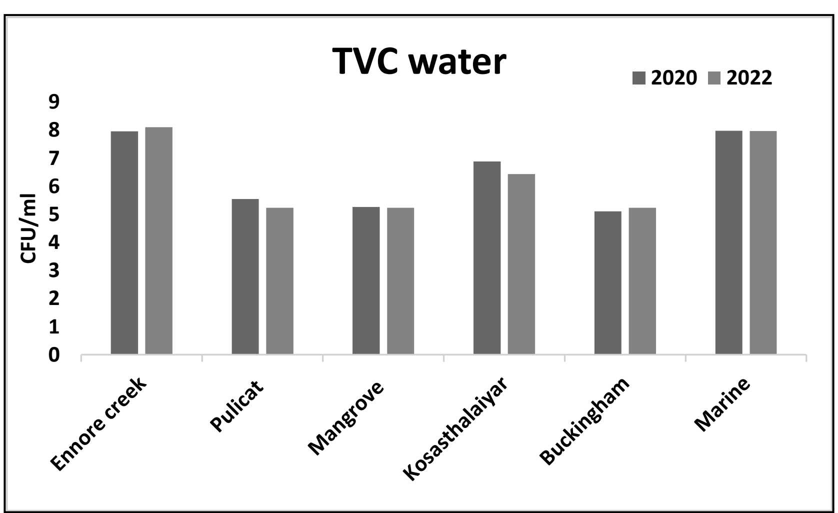


Fig. 4.19: Total viable count variation in water samples between 2020 and 2022

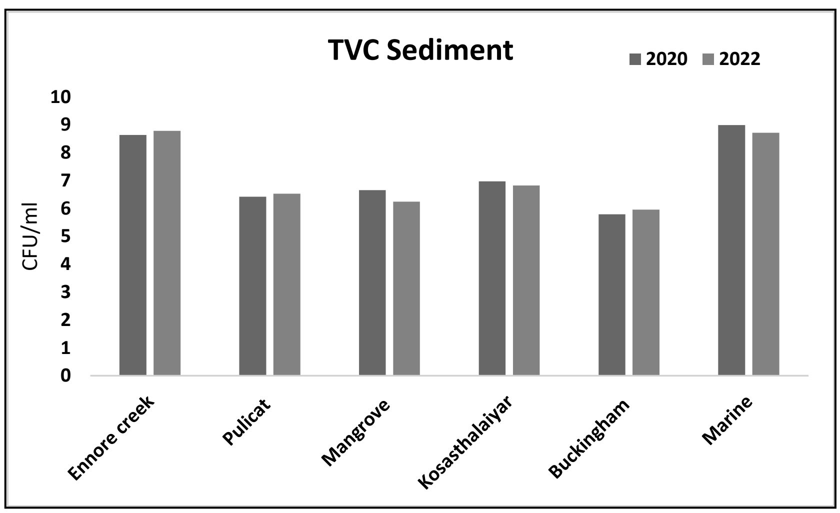


Fig. 4.20: Total viable count variation in sediment samples between 2020 and 2022

BRACKISH AND FRESHWATER ASSOCIATED RESOURCES

The faunal assemblages in the brackish and freshwater include fishes, crustacean, bivalves, gastropods and polychaetes. Similar pattern of faunal assemblage was observed between 2020 and 2022

In Kosasthalaiyar River during 2020, totally 7 species of fishes, 6 species of crabs, 5 species of shrimps, 5 species of bivalves, 12 species of gastropods and polychaetes were observed. During 2022, totally 7 species of fishes, 5 species of crabs, 6 species of shrimps, 5 species of bivalves, 12 species of gastropods and polychaetes were observed.

In the mangrove region, during 2020, 12 species of fishes, 8 species of crabs, 5 species of shrimps, 4 species of bivalves and 22 species of gastropods were observed, whereas during 2022, 11 species of fishes, 8 species of crabs, 6 species of shrimps, 6 species of bivalves and 20 species of gastropods were observed.

In Buckingham Canal, 5 species of fishes, 1 species of crab, 5 species of shrimps, 6 species of bivalves and 6 species of gastropods were recorded during 2020, Whereas during 2022, 5 species of fishes, 2 species of crab, 6 species of shrimps, 5 species of bivalves and 8 species of gastropods were recorded.

In Pulicat Lake, during 2022, totally 9 fish species, 3 crab species, 3 shrimp species, 9 bivalve species, 15 gastropod species along with polychaetes were observed, whereas during 2022, totally 9 fish species, 3 crab species, 6 shrimp species, 7 bivalve species, 13 gastropod species along with polychaetes were observed.

In Ennore Creek, 7 fish species, 3 crab species, 3 shrimp species, 7 bivalve species and 8 gastropod species were observed during 2020, whereas during 2022, 8 fish species, 4 crab species, 6 shrimp species, 6 bivalve species and 14 gastropod species were observed.

ASSESSMNET OF AVIFAUNA AND MAMMALS

Migratory and resident birds were sighted during 2020 and 2022 period. Totally 32 species of birds were sighted during 2020 dominated by *Ardea intermedia, Mycteriya leucocephala, Pelecanus philippensis*, *Tringa glareola* and *Himantopus himantopus*. Whereas during 2022, 37 species of birds were sighted dominted by *Ardea intermedia, Sterna albiforns, Mycteriya leucocephala, Pelecanus philippensis*, *Tringa glareola* and *Himantopus himantopus*.

Terrestial mammals recorded within the study area includes cows, buffaloes, squirrel, field mouse, bat, house rat, dog and hare during 2020. During 2022, cows, buffaloes, squirrel, field mouse, bat, house rat, hare, dog, snake and tree lizards.

FISHERY STATUS

The study area includes 5 coastal villages, of which 4 are fishing villages. They are Vairavankuppam, Koraikuppam, Kadalkannikuppam and Kattupalli, whereas Karungali, situated in between Kattupalli and Kadalkannikuppam, is used by a few fishermen from Kattur region for their fishing activities particularly in the Kosasthalaiyar River. No significant change in the fishery status was observed during 2020 and 2022, except the intervention by CIBA in integrated farming option.

During 2020, the total fish catch was 5906 kg/day in all villages. Fish catch was higher in Koraikuppam, followed by Kattupalli and Vairavankuppam with 1697, 1453 and 1441 kg/day respectively. Totally 58 species of fishes were caught from the region, of which *Rastrelliger kanagurta* was the most landed fish species with 924 kg/day followed by *Alepes* sps. with 326 kg/day and *Sardinella* sp with 237 kg/day. Fishermen also engage in hand-picking of prawns from brackish water zone. A few fishermen are involved in collection of polychaetes.

During 2022, the total fish catch was 4799 kg/day in all villages. Fish catch was higher in Koraikuppam, followed by Vairavankuppam and Kattupalli with 1990, 1350 and 1100 kg/day respectively. Totally 58 species of fishes were caught from the region, of which *Rastrelliger kanagurta* was the most landed fish species with 745 kg/day followed by *Metapenaeus* sp. with 291 kg/day and *Penaeus monodon* with 225 kg/day. Fishermen also involved in hand picking to catch prawns from brackish water zone. Few fishermen engage in collection of polychaetes. CIBA has initiated integrated farming option to few fishermen in the Kosasthaliyar River as an alternate livelihood option in order to reduce the pressure on marine and brackish water ecosystems (Fig 4.21).

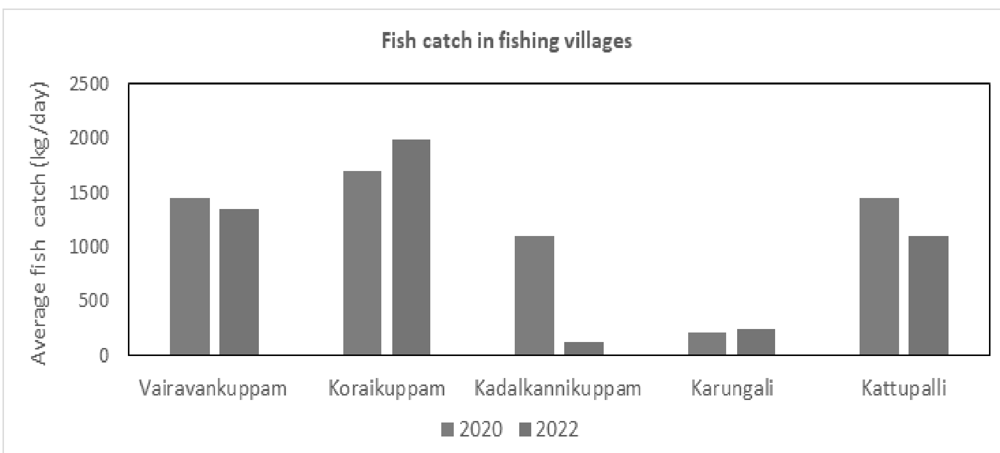


Fig. 4.21: Average fish catch during 2020 and 2022

Land use and land cover pattern

No significant changes in land use and land cover pattern were observed during 2020 and 2022. The land cover in the study area is occupied by vegetation, agriculture, land with shrubs, mangroves, coastal sand, intertidal zone, aqua farms, habitation, salt pans, industries and port area. During 2020, agriculture land dominated with an area cover of 4,700 ha, where paddy was the dominant crop cultivated. Industries and ports cover an approximate area of 2,571 ha. In 2022, agriculture land dominates with an area cover of 4,702 ha, where paddy is the dominant crop cultivated. Industries and ports cover an approximate area of 2,534 ha. The cover of intertidal region from coastal land use map was 666 ha.

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PART - II:

Impact Assessment and Management Plan

Impact Assessment and Management Plan on Environment, Biodiversity and Fishery of the Rivers, Estuary and Sea in and around Kattupalli Port, Chennai, Tamil Nadu

1. Impact Assessment

1.1. Background

Marine Infrastructure Developer Private Limited (MIDPL) has proposed Revised Master Plan for development of Kattupalli Port, which is located in the Tamil Nadu State on the Southeast coast of India. The total proposed quantity of Capital Dredging is 85 Mm^3 and the dredged material will be used for reclamation of an area of 1,145 ha (that includes level-raising). The total proposed reclamation quantity including landfill is estimated at ~138 Mm^3. Apart from the existing Breakwater, two new Breakwaters of total length of 12.10 km are proposed, out of which the new Northern Breakwaters is 9.02 & 1.22 km and the new Southern Breakwater is about 1.86 km. The proposed project is located in Bay of Bengal, which falls within the Indo-Pacific realm, arguably the world's richest region in terms of biodiversity. The fishery resources of Bay of Bengal provide livelihood to thousands of fisher folk living along the coastline immediate to the project site. Further, the proposed project area is in the vicinity of critical marine ecosystems such as mangroves. The area encompasses the sea, river, canal, lake and creek with considerable biodiversity.

Marine biodiversity is very important in terms of ecology and economy. Blue economy has been given priority in recent years. The biodiversity of a marine ecosystem is fragile and suffers when physical, chemical or biological parameters are changed. In view of the ecological and economic benefits of biodiversity, the developmental activities along the coastal belt have to be carried out with utmost care by following all measures of conservation, management and protection. The construction of new ports or extensions of existing ones ought to be undertaken, but at the same time it is important to carry out the developmental activities without damaging the environment, biodiversity and its ecological services. Hence, effective conservation and management plans should be in place to mitigate the impacts of project activities. Monitoring of biological parameters in and around the project site is warranted for any developmental activity. Such monitoring carried before, during and after the developmental activity would help to better manage and minimize the impacts as well as to take appropriate remedial measures through effective mitigation actions. The proposed developmental activities and likely impacts on the biodiversity of Bay of Bengal (marine zone), Kosasthalaiyar River, Buckingham Canal, Ennore Creek and Pulicat Lake are detailed below.

1.2. Major Project Activities

The major activities undertaken during the construction and operation phases that could potentially impact the marine environment include,

A. During Construction Phase

1. Dredging and Reclamation Activity
2. Construction of Breakwater, SBM and Berths
3. Other allied infrastructure development activities close to intertidal and coastal belts, such as land reclamation, backup storage structures, rail and road network
4. Laying of Sub-Sea Pipelines
5. Intake and Outfall Pipelines for Desalination Plan

B. During Operation Phase

1. Maintenance Dredging and Disposal
2. Cargo Handling in the Waterfront & Offshore Berth/Jetty
3. Ship Traffic
4. Discharge from ETP, Desalination Plant and Bilge Water

1.3. Impacts on the environment and biodiversity due to the proposed activities during construction phase

1.3.1. Dredging and Reclamation Activity

1.3.1.1. Impact on benthic organisms

Dredging and reclamation are the key activities in the proposed project and they are expected to cause disturbance to the coastal environment and associated biodiversity. Benthic organisms will suffer the maximum damage as they are directly affected. Dredging for deepening the sea bottom will remove the benthic organisms that live in the area. In the vicinity of the project a total of six macrobenthic groups are observed namely polychaetes, gastropods, bivalves, amphipods, isopods and others, dominated by polychaetes. Meiobenthic groups occurring near the proposed project area include nematodes, foraminifera, cumaceans, harpacticoids, ostracods, and others. Density of molluscs and sponges near the dredging site is about 11 and 1.75 no/5 m^2 respectively; density of macro- and meiobenthic organisms ranges from 88 to 104 no/0.0256 m^2 and from 91 to 149 no/10 cm^2 respectively. Dredging for the proposed layout condition would increase the load of suspended sediments in the nearby water. Sedimentation in the dredged channel would likely be heavy and would also affect all the benthic organisms. Sedimentation caused by dredging could potentially bury the benthic organisms in the nearby region. Owing to the increased sedimentation rate light penetration to the sea floor will be greatly reduced, which will limit the occurrence of benthic organisms.

Dumping of dredged soil is also likely to affect all the benthic organisms in the dumping site apart from causing excessive sedimentation. Changes caused in bathymetry and hydrodynamic conditions could potentially eliminate certain fragile benthic organisms. However, there is no threatened or endangered species of benthic fauna recorded in the project site. The dumping of dredged sediment at the dumping site will decrease the bathymetry there and it will not only harm the benthic organisms but will also increase sedimentation.

1.3.1.2. Impact on plankton and productivity

Dredging and reclamation activities will churn up the bottom sediment and disperse fine particulate matter in the water column and would influence the turbidity and suspended solids. These activities affect the harmony of the marine environment by increasing the suspended sediment concentrations, sediment deposition and turbidity. Besides this direct effect, indirect impacts like changes in circulation pattern and littoral sediment transport are also likely. This will reduce light penetration and consequently suppress photosynthetic efficiency and primary productivity in the water column.

Planktons are primary producers and form the centre of a food web in an aquatic ecosystem. When planktons are affected due to the proposed project activities, the entire food web will be disrupted. The proposed project area has three phytoplankton groups namely diatoms, dinoflagellates and cyanophyceae. Phytoplankton density in the proposed project area ranges between 100 and 42,500 cells/l, whereas zooplankton density ranges between 100 and 5,200 no/m^3. Chlorophyll ‘a’ ranges between 0.33 and 18.49 mg/m3 and chlorophyll ‘b’ ranges between 0.11 and 10.86 mg/m3, while primary productivity ranges between 60.01 and 530.94 $mgCm^{-3}d^{-1}$. The likelihood of changes due to the current patterns caused by the proposed project activities would affect the nutrient movement and plankton density. Nutrients play a vital role in phytoplankton density and diversity, and thus reduced currents would affect the plankton abundance.

1.3.1.3. Impact on fishery resources

Underwater assessment in the proposed project area recorded 56 fish species, dominated by *Rastrelliger kanagurta.* The impact caused to the plankton community and benthic organisms would directly affect the fishery resources. Hence, it is likely that fishery resources in the dredging and reclamation sites will be affected by the proposed activities.

Increased turbidity caused by the dredging and reclamation activities may cause significant changes in fish behaviour, which include avoidance, disorientation, decreased reaction time, increased or decreased predation, increased or decreased feeding activity, and physical injury and even mortality. Noise generated during dredging would force the fishes in the area to move away. Suspended sediment concentration in the dredging and reclamation sites influences the fish availability in the area. Moreover, benthic fishery resources such as shrimps and crabs will be disturbed and dislocated and hence their population is likely to be affected during dredging operations.

1.3.2. Construction of Breakwater, SBM and Berths

1.3.2.1. Impact on benthic organisms

Construction of breakwaters and berths will be done close to the shore and will have the impacts on the near-shore benthic organisms. Intertidal and subtidal benthic organisms will be the primary victims of the proposed construction of breakwater, SBM and berths. Changes in bathymetry around the proposed Port would potentially affect all the benthic macrofauna such as molluscs, and other organisms. Density of molluscs in this area is about 11 no/5 m^2; density of macro- and meiobenthic organisms ranges from 88 to 104 no/0.0256 m^2 and from 91 to 149 no/10 cm^2 respectively. The construction of proposed port facilities will increase the sediment movement and could affect the inter-tidal and sub-tidal benthic organisms. Erosion and accretion are likely on both sides of the proposed port and hence would affect the inter-tidal biodiversity. It is likely that coastal sand and coastal vegetation that occur in the immediate vicinity of the port will likely be affected.

1.3.2.2. Impact on plankton and productivity

The near-shore construction of breakwaters and berths is likely to affect the current pattern and nutrient circulation. This change in the current circulation will affect the flushing of sea water inside the proposed port. Density of phytoplankton was upto 25,200 cells/l in this area, while zooplankton density was 3,610 no/m^3. There is a possibility of wave energy transformation near the construction sites that will also have its impact on plankton and productivity. The likelihood of calm environment inside the proposed port after the construction of berths will impact the nutrient circulation and is likely to affect the plankton communities and associated biodiversity.

1.3.2.3. Impact on mangroves and associated biodiversity

The changes in wave and current pattern to be caused by the construction of breakwaters and births are likely to affect the flushing of water into Ennore Creek and Pulicat Lake. The possible alteration in the flushing is likely to affect the dependant mangroves and associated biodiversity. In the north side of Kattupalli, the distance between the sea and Buckingham Canal is very short (about 1 km), and hence it is likely that shoreline changes caused by the proposed construction of breakwaters and births would destabilize this area causing damages to the nearby mangroves.

1.3.2.4. Impact on fishery resources

The likely changes in current speed caused by the construction of breakwaters and berths inside the proposed and existing Ports would affect the plankton communities and thus the dependent fishery resources. Fish abundance near the existing port is about 3 to 47 no/250 m^2. Impact on phytoplankton abundance due to wave and current Patten changes is likely to affect the primary productivity and zooplankton density, and would consequently affect the fishery resources. Impacts on benthic and pelagic organisms would also eventually affect the fishery resources of the area. Shoreline changes in the vicinity of the proposed project area would affect the benthic organisms and consequently associated fishes will also be affected. A total of five fishing villages fall within the study area, which are Vairavankuppam, Koraikuppam, Kadalkannikuppam, Kattupalli and Karungali. Their catch consists of at least 58 species and among them *Rastrelliger kanagurta* is the most dominant. Any impact on fishery resources would possibly affect their livelihood.

1.3.2.5. Impact on Pulicat Lake

Pulicat Lake is located on the north side of the proposed project area, and it is a biologically rich water body. Though Pulicat Lake is situated considerably far from the proposed project site, it is likely to be affected due to the presumed hydrological changes caused by proposed project activities such as construction of berths and breakwaters. The presumed increase of the sediment load and turbidity may affect pelagic and benthic organisms in the Lake. The Lake is biologically connected with other water bodies such as Bay of Bengal, Kosasthalaiyar River, Buckingham Canal and Ennore Creek. Damage caused on the biodiversity in any of these water bodies would also affect the biodiversity in Pulicat Lake.

1.3.3. Other allied infrastructure development activities close to intertidal and coastal belts, such as land reclamation, backup storage structures, rail and road network

1.3.3.1. Impact on mangroves and associates

In the vicinity of the proposed project area, reasonable extent of mangrove habitat is available due to freshwater supply. Mangroves are seen along the Ennore Creek, Kosasthalaiyar River, Buckingham Canal and Pulicat Lake. Totally three mangrove species are recorded, which are *Avicennia marina, Avicennia* sp. and *Rhizophora mucronata*. Five types of halophytic plants are also observed in the mangrove areas along with other coastal vegetation. Land reclamation works may lead to loss of shores, seabed, flora and fauna within the reclaimed areas. Land reclamation activities such as construction of buildings, rails, roads, bridges, and parking areas for the proposed project can impact the floodplain and may reduce the infiltration of water into the ground. This may hinder the water flow to the sea and is likely to flood the adjacent water bodies during heavy floods and it would affect the mangroves. Blocking of low-lying areas would increase the water flow in the water bodies and it would consequently increase the run-off into the sea causing sedimentation. Moreover, reclamation in the area would cause sedimentation in the water bodies such as Buckingham Canal and Kosasthalaiyar River and it may affect all the benthic and pelagic organisms in the mangrove area. Mangrove associated fishing activities such as hand picking of prawns, shell collection, polychaete collection and other fishing activities is likely to have minimal impact due to the land reclamation activities.
Stockpiling and handling of materials during construction activities have the potential to cause particulate matter pollution in the adjacent mangroves.

1.3.3.2. Impact on avifauna and other animals

The landforms observed in the study area include river, intertidal region, waterlogged area, canal, creek, lake, cultivable land, non-cultivable land, coastal sand and coastal track, and hence the density and diversity of birds are considerably high. At least 37 species of migratory and resident birds were sighted during the study period. The most common birds recorded are *Ardea intermedia, Sterna albifrons, Mycteriya leucocephala, Pelecanus philippensis*, *Tringa glareola* and *Himantopus himantopus*. The increase in the volume of traffics is likely to have an adverse effect on the environment and lead to air pollution, noise pollution and water pollution. The extension and construction of new lanes will affect the land use pattern of the proposed area. Common mammals such as cows, buffaloes, squirrel, field mouse, bat, house rat hare, dog and hare were commonly sighted.

1.3.4. Laying of Sub-Sea Pipelines

The laying of sub-sea pipelines would require minor dredging and hence would affect the benthic organisms that live in the area. A localized sedimentation is very likely and it would affect both benthic and pelagic organisms. When plankton and benthic organisms are affected, it would affect the dependant fishery resources.

1.3.5. Intake and Outfall Pipelines for Desalination Plan

Desalination plant is a reliable source for freshwater, and it is critical to have desalination plant during the proposed project activities to avoid dependence on natural freshwater sources. However, there are many environmental issues associated with the construction and operation of desalination plans. Establishment of pipelines for intake and outfall requires minor dredging, which can cause increased sediment load and turbidity and decreased light penetration. Hence, benthic and pelagic organisms living in the vicinity are likely to be affected.

1.4. Impacts on the environment and biodiversity due to the proposed activities during Operation Phase

1.4.1. Maintenance Dredging and Disposal

Maintenance dredging and disposal to ensure depths will be a major operational activity on a continual basis. Potential turbidity and suspended solids would affect the dredged and disposal areas. The suspension of sediment in the water column is likely during maintenance dredging and disposal and will have their likely impact on benthic and pelagic organisms. Associated fishery resources are also likely to be affected during maintenance dredging and disposal during the operational phase.

1.4.2. Cargo Handling in the Waterfront & Offshore Berth/Jetty

During cargo handling operations in the water front and offshore berth, discharges and emissions are likely. Dry bulk cargoes generally produce a lot of dust which can impact both benthic and pelagic organisms and would consequently affect the fishery resources. Liquid bulks that are handled via pipelines may carry the hazard of static sparks, spillage and emissions, which would also affect the organisms that live in the vicinity.

1.4.3. Ship Traffic

During the operational phase, ship traffic will be very high in the vicinity of the proposed project area and so is likely to cause pollution. The pollution related to ship traffic includes fuel leakage from ships, leaching of antifouling paints, transfer of harmful aquatic organisms, dumping of wastes and oil spills. Apart from these disturbances, air pollution, noise pollution and wave generation would also affect the environment. Further, increased shipping traffic would affect the paths of fishing boats near the proposed project area and would make the area prone to collisions with larger marine animals such as dolphins.

In case of an oil spill inside the port, all the organisms inside the port, starting from plankton to fishes, will be significantly affected. Oil spills outside but adjacent to the port will mostly affect the organisms in the northern side of the port. The impacts of oil spills last long and will have detrimental effects on the benthic and pelagic organisms.

1.4.4. Discharge from ETP, Desalination Plant and Bilge Water

On the intake side of the desalination plants, small organisms such as fish larvae and fingerlings can get sucked into the desalination plant. But the release of brine back into the sea causes more impact than the intake. Brine will be substantially higher in salinity and warmer than normal oceanic water and this condition would make it more difficult for marine life to survive in the immediate vicinity of the discharge. The brine will also have chemicals, and chronic exposure to these chemicals would make the marine organisms accumulate them in the food chain.

If CPCB norms are not followed, the end products of the ETP may contain biodegradable organic substances and micro-organisms, non-biodegradable and toxic substances that can contaminate coastal waters. Sewage sludge is the solid, semisolid, or slurry residual material that is produced as a by-product of wastewater treatment processes. If the sludge is not treated properly it would cause serious environmental problems.

2. Mitigation and Management Plan

2.1. Background

Considering the growing population, increasing demands and the need for coastal developmental activities in particular, construction of new seaports and extension of existing ones are inevitable for economic growth and job opportunity. Equally, managing the environment in its original state is most important and imperative for the sustainability and long term benefits. Any development activity is bound to have some impact on the environment and biodiversity. Activities associated with port development could negatively impact the coastal water quality and natural resources such as mangroves and marine flora and fauna. However effective measures of mitigation and management could help to reduce these negative impacts for sustainable and inclusive development which ensures the health of the marine environment.

This section of the report is aimed to suggest measures for maintaining a healthy biological environment and this would also help to form proper management strategies to conserve the existing biodiversity in and around the proposed project site and to recommend mitigation measures if there is any loss to biodiversity due to project activities. These mitigation measures would help in conserving the biodiversity and protecting the associated marine, brackish and fresh water ecosystems through effective action plan and monitoring. Based on the comprehensive baseline data gathered and the possible impacts on biodiversity predicted, a holistic mitigation and management framework for conserving the marine biodiversity and ecology in the vicinity of the proposed project area are suggested below.

2.2. Baseline Data Creation and Monitoring of Biological Parameters

It is mandatory to collect baseline data on the marine environment in the vicinity of the proposed project area in line with developmental activities. Baseline data have already been collected on water quality parameters, planktonic and benthic (intertidal and subtidal) composition, density, diversity and productivity in the relevant water bodies namely Bay of Bengal, Kosasthalaiyar River, Buckingham Canal, Ennore Creek and Pulicat Lake. This baseline data creation has been done prior to the initiation of construction activities for the proposed project. The baseline data created in the present study will be used for the purpose of monitoring changes during the construction and operational phases by carrying out regular monitoring. On the basis of baseline data, it is essential to have continuous and periodic monitoring of the marine environment in terms of vital parameters which are indicative of the health of the marine environment. Regular monitoring of vital parameters will provide indication of any deviation from the baseline status. This will help the project proponents and managers to take appropriate remedial measures. Thus, this established baseline data on biodiversity in and around the project site will serve to monitor changes throughout the project activities.

2.3. Mitigation and Management Measures during Construction Phase

Mitigation measures during the different phases of the project will be required for activities related to dredging, port infrastructure development and waste discharges. The major impact visualized during the construction phase is related to capital dredging and reclamation. The effects of dredging and reclamation on the marine environment should be evaluated by analyzing the suspended solid loads in the water column, fate and stability of the dredge spoils and general effects of port activity on the marine ecology. As the baseline information is available, it will indicate the changes in water and sediment quality caused by dredging.

It is better to plan the environmentally hostile activities of the construction phase during lean fishing season. To reduce the dispersal of suspended load and siltation, tidal conditions should be considered before the operation. Proper disposal of dredged sediments into the dumping site (including reclamation site) with silt traps should be done to reduce the dispersal of silt and turbidity. A safety exclusion zone around the dredging vessel in accordance with the international standards and best practices should be adopted. Near-shore dredging for berth construction should be carefully done so that dredge spoils, suspended matter and turbid waters do not reach intertidal belts and mangrove areas. Turbidity curtains can be used to minimize sediment transport.

In spite of all these precautionary measures if turbid plumes are observed in the nearby mangrove areas dredging practice should be modified in tune with the tidal condition until no more signs of sedimentation are reported in the subsequent monitoring studies. Rescheduling the dredging operation during that part of the tidal cycle which generates maximum plumes should be done or the pace and intensity of dredging should be sustainably managed.

Impacts arising out of domestic wastewater, sewage, construction related and other anthropogenic waste that are likely to reach the water bodies namely Bay of Bengal, Kosasthalaiyar River, Buckingham Canal, Ennore Creek and Pulicat Lake should be reduced through provision of adequate sanitary facilities and disposal of wastes during construction. Waste oil, garbage and building material rubble should be managed in such a way that they do not reach the water bodies. Provision of adequate drainage should be in place to solve stagnation and subsequent contamination of coastal waters. Site cleanliness and removal of any oil, grease and other spillages to designated pits are mandatory. It is important that construction related activities near intertidal zone are confined within the smallest area possible, which will very much reduce the construction related impacts on the coastal waters. Appropriate stringent monitoring plan *(see Monitoring Protocol section)* should be in place for water bodies such as Bay of Bengal, Kosasthalaiyar River, Buckingham Canal, Ennore Creek and Pulicat Lake, to take all necessary precautionary and remedial measures

2.4. Mitigation and Management Measures during Operational Phase

The following mitigation and management measures are recommended for implementation during the operational phase. Sewage generated from the port operations should be treated in sewage treatment plant and the treated water can be used for other purpose like horticulture and greenbelt development.

The solid waste generated from the port during operational phase should be properly segregated, stored and disposed. All the constructions should be planned in such a way that it does not restrict the prevailing tidal entrance in the mangrove habitats through Pulicat mouth and Ennore mouth. The minor and major oil/chemical spillages should be effectively controlled with appropriate tools and equipments. Critical parameters such as suspended solids, DO, BOD and nutrients should be regularly monitored and compared with baseline study. Use of biocides should be kept at the minimum and their concentration at the outlet should be regularly tested. Comprehensive and easy to implement Standard Operating Procedure (SOP) should be made for each category of cargo in order to avoid oil or chemical spillages. The operating staff at the berth should be trained in such operations and also in handling emergencies. Transfer of bulks to the coal stack yards should only be through closed conveyors. Water sprinkling should be done at stack yards prone to generate wind-blown dust.

2.4.1. Mitigations and Management Measures on Maintenance dredging

Maintenance dredging to ensure depths as required for navigation of vessels will be a major operational activity on a continual basis. The following mitigation and management measures are recommended during port operation. Suitable dredging equipment for fine sediments should be used to minimize the level of turbidity during maintenance dredging operations. If the sediment is contaminated, measures are to be taken in order to limit the lateral movement of turbid water during dredging activity. Appropriate silt curtains should be used to reduce sediment transportation. Dredging activity should not be undertaken during periods of rapid water current and strong trade winds. Establishment of a dredging monitoring *(see Monitoring Protocol section)* and emergency response plan will be useful to monitor the direction of the plume and to monitor for equipment malfunction and accidental dredge spills.

Impacts to the dredge material relocation ground and adjacent areas should be minimised through relocation of the dredge material in such a manner as to uniformly spread it over the relocation ground. Detailed assessment on water quality and biological resources should be carried out to identify the problems at the earliest.

2.4.2. Management of Benthic Organisms and Plankton in the Water Bodies

Fair amount of benthic macrofauna occur in the proposed project area though corals and seagrasses are absent. Soft corals, sponges and molluscs are some of the important benthic macrofauna. Hence, rapid underwater assessment of these fragile organisms should be done at least once in a year during the construction phase and once in two years during operational phase to compare their abundance with baseline information.

The presence of macro- and meiobenthic organisms is also significant in the proposed project area. Hence, permanent monitoring locations should be fixed in all the water bodies including Bay of Bengal, Kosasthalaiyar River, Buckingham Canal, Ennore Creek and Pulicat Lake for regular monitoring. Monthly sample collection and monitoring should be done to understand the changes in benthic biota. If the amount of benthic organisms goes drastically down from the baseline data, necessary remedial measures should be adopted.

Planktonic community and productivity in the vicinity of the proposed project site is moderate. Dredging and reclamation are the major activities that increase water turbidity and suspended load thereby impacting plankton community and productivity. Hence, measures should be taken to reduce the run-off slurry and sediment plume through silt traps and turbidity curtains. As mentioned above, regular and continuous monitoring *(see Monitoring Protocol section)* of plankton density and diversity in permanently fixed locations should be done during the different phases of the proposed project.

2.4.3. Management of Mangroves and Associated Biodiversity

Mangrove habitats occurring along the Ennore Creek, Kosasthalaiyar River, Buckingham Canal and Pulicat Lake are critical for the associated biodiversity and fishery resources. Three mangrove species namely *Avicennia marina*, *Avicennia* sp. and *Rhizophora mucronata* are available in the area along with five halophytic plants. Establishment of facilities for the port is a continuous process and the expansion of infrastructure over the coming years will bring about notable changes in the landscape and seascape in and around the port. Long term human activity of this magnitude will have repercussions on the mangroves, and their conservation and management deserve top priority. Any impact on the mangrove habitats may affect the livelihood of the dependant fishermen. The following measures can be taken to monitor the health of mangroves and associated biodiversity in the proposed project area.

Though there is no direct impact on the existing mangroves, it is the responsibility of the project proponents to take care of the existing nearby mangrove area without any damage. A dedicated action plan should be in place for continuous mangrove monitoring and maintenance *(see Annexure - 1).*

It is important that in any natural resource management effort, stressors acting on the ecosystem are to be identified and removed in order to maintain the ecosystem balance. Hence, regular monitoring of physico-chemical parameters in the mangrove areas should be done to understand the deviation from the baseline due to proposed project activities.

It should be ensured that wastes generated during the construction and operation phases do not in any case enter the mangrove waters. Special attention should be given to chemical and hydrocarbon spillages in the port waters. Immediate measures should be taken to contain spillage and to reduce impact. Oil emergency contingency plan is to be put in place. Waste oil, garbage and building material rubble should be managed in such a way that they do not reach mangroves.

Exhaustive baseline information on mangrove characteristics such as canopy height, sapling, seed, leaf length, etc. has been collected during the baseline study. Based on this baseline information, vegetation structure of mangroves should be studied once in a year. This assessment and the data generated earlier could be used to check short-term and long-term mangrove health.

Mangrove formations in the vicinity of the port should be mapped using GIS and RS once in a year to monitor changes in their physical extent. The base maps will track changes, if any, in the physical extent in subsequent years. These mapping exercises will help monitor changes in the mangrove formations.

As an integral part of mangrove ecosystem, mangrove macrofauna is a reliable indicator of the health status of this ecosystem. Regular monitoring (once in six months) of mangrove macrofaunal abundance, diversity and composition will throw light on the diversity and dynamics of this ecosystem. Comparison of data over the years will reveal the status of mangrove faunal component, which could be linked with overall ecosystem changes.

During the initial induction period, environmental training and awareness imparting should be given to all port related personnel and contractors on the ecological and environmental importance of coastal habitat and the measures necessary to protect and preserve this habitat.

2.4.4. Management of Birds and other fauna

As there are many resident and migratory birds within the proposed project area, ecological monitoring of birds in the vicinity of the project area should be carried out to assess the changes in avifaunal diversity due to the proposed project. Periodical monitoring (once in six months) of birds would identify the positive or negative changes in bird composition of the area.

Endangered marine mammals (dolphins) have also been observed near the project area during the baseline study period and hence proper action plans should be executed to reduce the noise during dredging operations with existing acoustic controls on noise-generating equipment. Arrangements should be made to monitor marine mammals during construction and operational phases particularly during dredging and reclamation period by employing dedicated marine biologists on board in order to avoid accidental deaths of these rare marine species. Any incident of injury or mortality during the project activities should be immediately reported.

2.4.5. Management of Fishery Resources

Many of the project activities likely to have impact on the pelagic and benthic organisms would eventually affect the fishery resources. Turbidity, sedimentation, and pollution of water and air might lead to the migration of fish populations from the proposed project area. Moreover, due to the construction of the proposed breakwaters, there is a likelihood of loss of fishing ground for the fishermen, and deployment of artificial reef structures to enhance fishery resources will compensate that. Deployment of artificial reef structures (Annexure - 2) are comparatively cheaper and easily implementable and would provide substrate that will support marine organisms. Artificial reef modules should be so designed as to enhance biodiversity and fish production, and once built they will last many decades supporting rich faunal components since they provide ideal habitat for them. They have great potential to enhance biodiversity by attracting diverse marine fauna within a short period of time.

Artificial fish habitats would attract not only fishes but also all the benthic organisms, and would create a diverse ecosystem which would provide long-lasting results. The impact of artificial fish habitats should also be studied regularly (covering the four seasons in a year) to assess the enhancement of biodiversity, fish production and socio-economic conditions of the dependent fisher folk

2.4.6. Management of Pulicat Lake and Associated Biodiversity

Pulicat Lake is ecologically sensitive with dynamic ecosystems such as seagrasses and mangroves. Due to the likely impact on the biodiversity of Pulicat Lake, permanent monitoring sites should be fixed for monthly sample collection and analysis of physical, chemical and biological parameters.

Fishing for livelihood is significant in the Pulicat Lake. Shell fishes such as shrimps and crabs in the Lake are the major economic contributors to the income of the fishermen. Sea ranching (Annexure - 3) of cultured fingerlings of these shrimps and crabs would provide sustainable fishery yield to the fishermen.

2.4.7. Management of Desalination and ETP Discharges

Wastes produced during the construction of desalination plant should be carefully removed from the marine environment to the landfill site. Monitoring of benthic and pelagic organisms during the construction phase is critical to identify the changes immediately. Assessment of seawater quality during and after the installation is imperative. Proper monitoring of the quality of marine water and sediment should be in place during construction phase which involves dredging for laying intake and outfall pipes. During the operational phase, to avoid impacts from high salinity, the desalination plant effluent should be pre-diluted and dispersal of the discharge plume should be enhanced by installing a diffuser system. Negative impacts from chemicals should be minimized by treatment before discharge by substitution of hazardous substances, and by implementing alternative treatment options. To minimize the impingement and entrainment of marine organisms a combination of differently meshed screens and a low intake velocity should be considered. Regular monitoring of seawater quality and assessment on marine organisms in the vicinity of the intake and outfall sites should be done monthly to understand the changes and adopt management actions.

The treated effluent should be regularly checked for water quality according to the norms of CPCB. Water quality in the outfall area should be regularly monitored to identify the changes. Usage of well treated effluents for agriculture and horticulture purposes can be considered. The sludge should be properly treated, which involves a combination of thickening, digestion, and dewatering processes according to the norms. In any case, the sludge should not be dumped into the sea. The final destination of treated and dewatered sludge is earth and so it should be buried underground in a sanitary landfill as per the norms of CPCB. It may also be used on agricultural land to take advantage of its value as a soil conditioner and fertilizer after due analysis.

2.4.8. Management of Ship Traffic Impacts

Discharges of all kinds of wastes should be regulated and a proper disposal system should be in place. Proper training should be given to the staff on salvage, marine firefighting, and spill prevention and preparedness for reducing the risk of occurrence of an incident and, if an incident occurs, for appropriately responding to prevent further damage or to remove oil spilled in the marine environment. Speed restrictions can greatly reduce impacts and risks related to animal injuries and accidents with fishing boats.

3. Monitoring Protocol

The proposed project area is in the vicinity of critically important marine ecosystems such as mangroves, creeks and river and marine zone. The coastal area between Ennore and Pulicat has been covered in the assessment, which includes coastal wetlands, inland region, Ennore Creek, Pulicat Lake, Kosasthalaiyar River, Buckingham Canal and Bay of Bengal. The project area has a reasonable extent of mangrove habitat as freshwater supply is available. Mangroves are seen along the Ennore Creek, Kosasthalaiyar River, Buckingham Canal and Pulicat Lake. Significant level of fishing activities happens in these water bodies. Apart from mangroves, other coastal vegetation and paddy fields also occur in the vicinity of the proposed project site. The marine zone namely Bay of Bengal falls within the Indo-Pacific realm, arguably the world's richest region in terms of biodiversity. The fishery resources of Bay of Bengal provide livelihood to thousands of fisher folk living along the immediate coastline from the project site. Another important ecosystem near the proposed project site is Pulicat Lake, which is about 7 km away. The seagrass ecosystem and associated biodiversity in the Lake provide livelihood to thousands of people who live near it. Considering the importance of project area from the ecological, biological and social perspectives, comprehensive monitoring protocol should be in place to take appropriate and timely management and remedial actions during the construction and operation phases of the project. It is also important that the project proponents should take up livelihood and conservation initiatives like deployment of Multipurpose Artificial Fish Habitats (Artificial Reefs) for the enhancement of biodiversity and fish production, and regular sea ranching of cultured fingerlings of shrimps and crabs.

3.1. Construction Phase

Comprehensive and regular monitoring during the construction phase is crucial to manage the environmental impacts and to protect the environmental health and biodiversity. Ocean is dynamic and disturbances for short period would disappear. However, if the disturbances persist for long, particularly dredging and reclamation, they would make considerable impact on the environment in the absence of proper monitoring of the activities. The systematic monitoring would help to understand the status of environmental health during the construction period and accordingly the management and remedial action could be taken up. In the case of coastal wetlands, inland region, Ennore Creek, Pulicat Lake, Kosasthalaiyar River, Buckingham Canal, the area is sheltered and hence constant monitoring of environmental parameters should be in place to take effective management and remedial actions in the face of any adverse impacts.

Figures 1 to 3 give details of the project area and the suggested monitoring locations during construction phase.

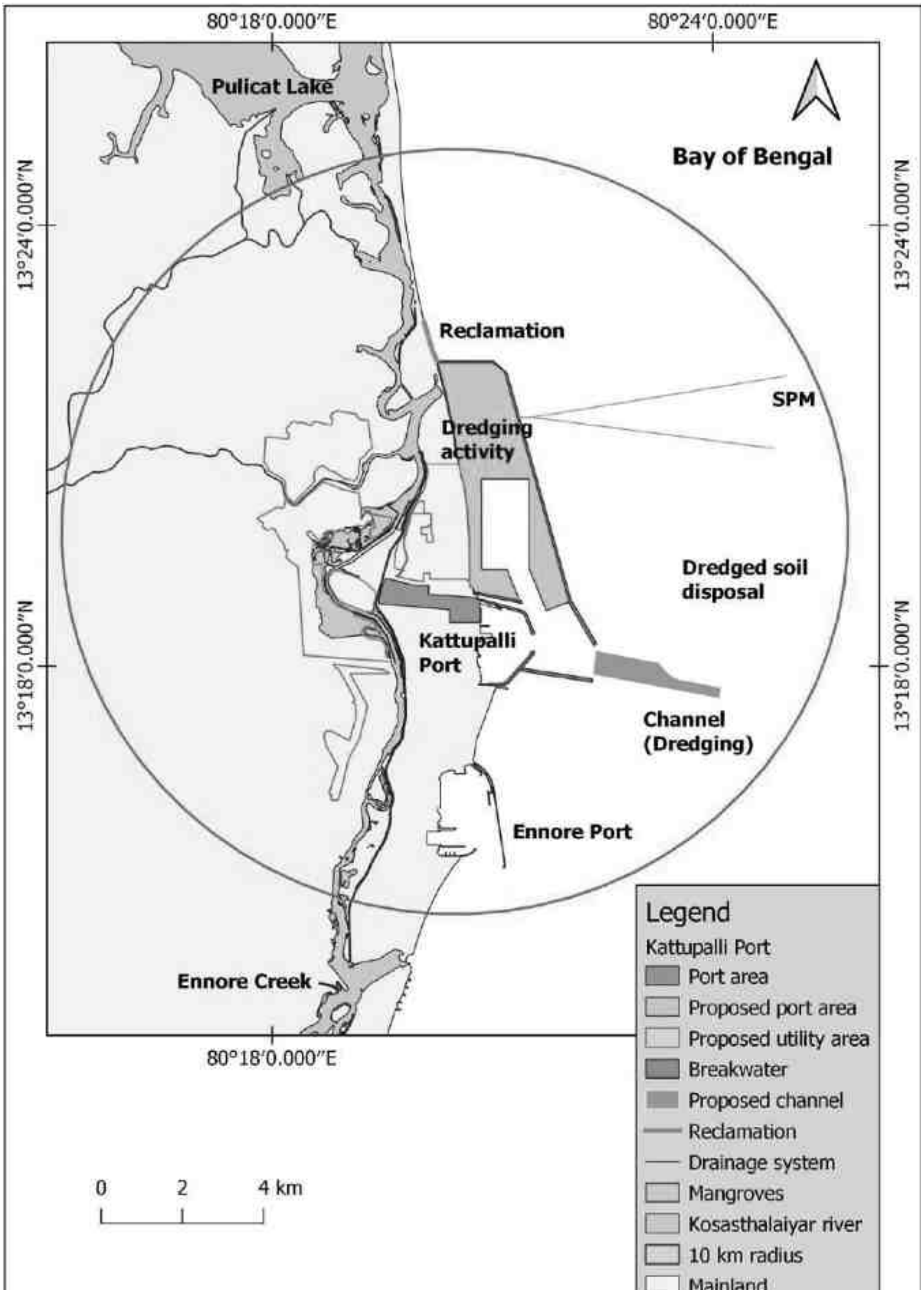
80°18′0.000″E
80°24′0.000″E
Pulicat Lake
Bay of Bengal
13°24′0.000″N
Reclamation
SPM
Dredging activity
Dredged soil disposal
Kattupalli Port
13°18′0.000″N
Channel (Dredging)
Ennore Port
Ennore Creek
Legend
Kattupalli Port
Port area
Proposed port area
Proposed utility area
Breakwater
Proposed channel
Reclamation
Drainage system
Mangroves
Kosasthalaiyar river
10 km radius
Mainland
0
2
4 km

Fig. 1: Map showing the project activities

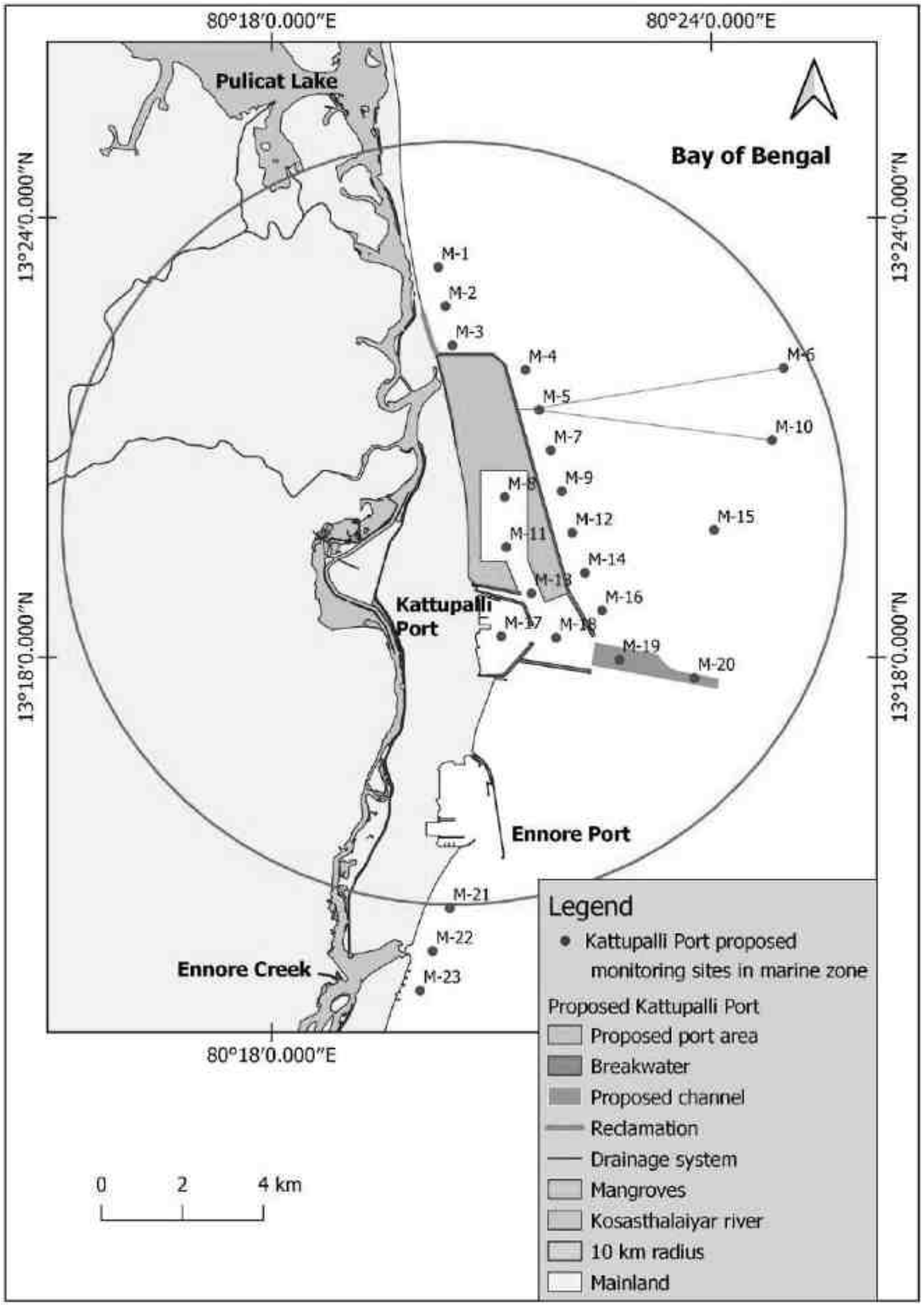

Fig.2: Map showing the monitoring locations in the marine zone during construction phase

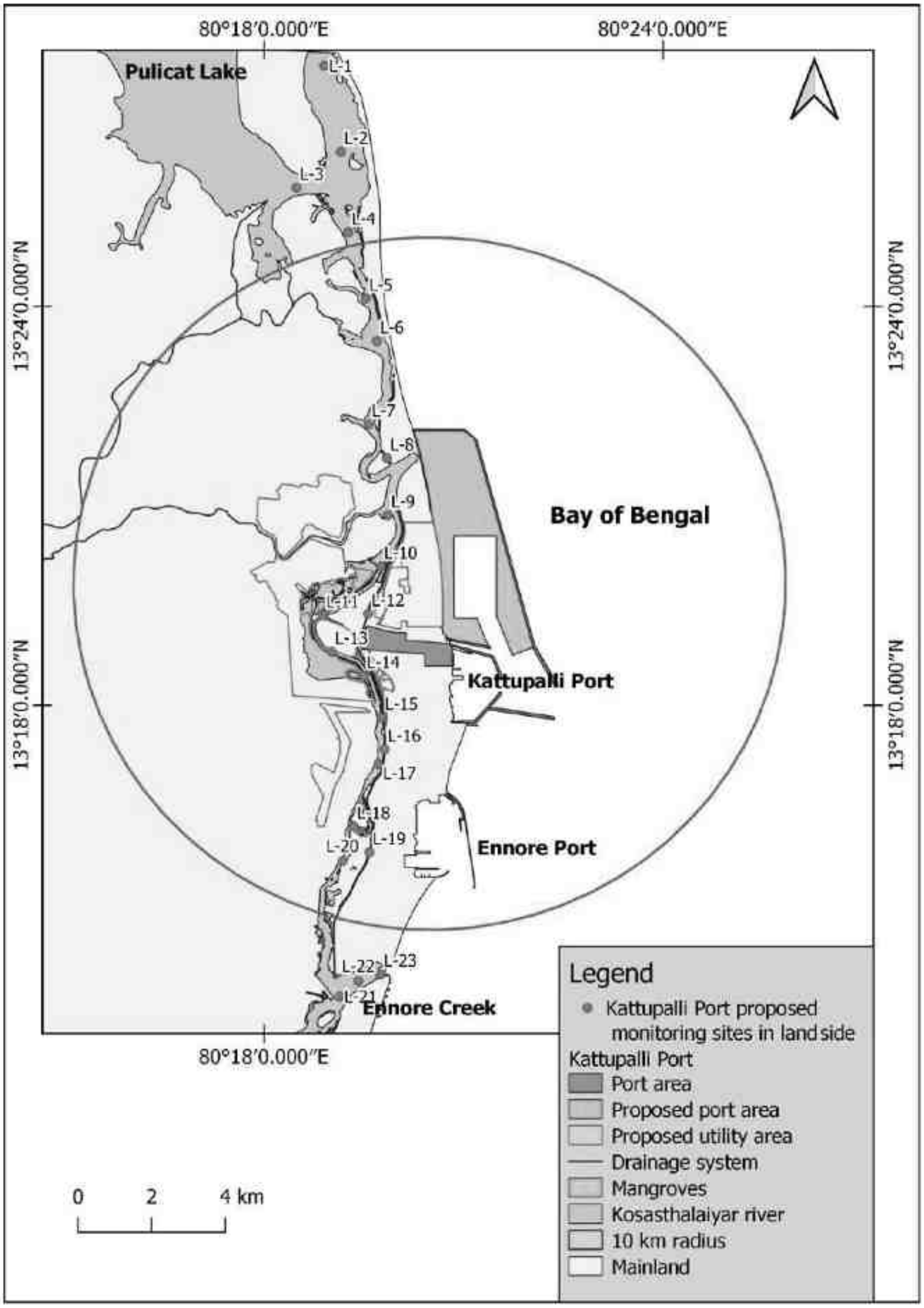

Fig.3: Map showing the monitoring locations in the land side covering coastal wetlands, inland region, Ennore Creek, Pulicat Lake, Kosasthalaiyar River, Buckingham Canal during construction phase

Proposed Monitoring Locations (Water and Sediment Sampling) in accordance with Project Activities during Construction Phase

MARINE ZONE (23 Monitoring Locations)

I- North of Proposed Reclamation Area (North of Kattupalli Port)

Total sampling numbers -3 (M-1 to M-3)
Sampling distance
Perpendicular to coast – 0.5 km
Along the coast – 1 km

II - Proposed Berth (Dredging & Reclamation)

Inside the berth

Total sampling numbers – 5 (M-8, 11, 13, 17 & 18)
Sampling distance – approximately 1km from the coast
Along the coast – 1.25 km
One sample in the centre of the existing Kattupalli port

Outside the berth

Total sampling numbers – 7 (M-4, 5, 7, 9, 12, 14 & 16)
Sampling distance
Perpendicular to berth – 0.5 km
Along the berth - 1km

III - Desalination (Outfall and Intake)

(The outfall and intake sites are located near the proposed berth where sampling sites are fixed)

IV- SPM (SPM1& SPM2)

Total sampling numbers - 2 (M-6 & M-10)
Sampling distance –approximately 8 km from the shore and the distance between the samples are 2 km.

V - Dredging soil disposal

Total sampling numbers - 1 (M-15)
Sampling distance – 6 km from the coast.

VI - Dredging channel

Total sampling numbers - 2 (M-19 & 20)
Sampling distance – 3.5 km and 4.5m from the shore.

VII - Sediment deposition

Total sampling numbers - 3 (M-21 to M-23)
Sampling distance
Perpendicular to coast – 0.5 km
Along the coast – 1 km

LAND SIDE (23 Monitoring Locations)

Pulicat Lake

Total sampling numbers – 4 (L-1 to L-4)

Kosathalaiyar River

Total sampling numbers – 7 (L-5, 6,7, 10, 13, 17&20)

Buchingham Canal

Total sampling numbers – 4 (L-8, 12, 16& 19)

Ennore Creek

Total sampling numbers – 3 (L-21 to L-23)

Mangroves

Total sampling numbers – 5 (L- 9, 11, 14,15, 18)

Table 1 give details of components, parameters to be monitored, locations and monitoring frequency during construction phase.

Table 1: Details of monitoring components, parameters to be monitored, locations and monitoring frequency during construction phase

Sl. No.	Components	Parameters to be Monitored	Locations	Monitoring frequency
I - Marine Zone				
1.	Marine Water Quality	Physical properties: Temperature, Salinity, pH, Electrical Conductivity (EC), Turbidity, Total Suspended Solids (TSS), Total Dissolved Solids(TDS), Visibility Chemical Properties Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Ammonia, Nitrite, Nitrate, Total Nitrogen, Inorganic Phosphate, Total Phosphate, Silicate, Petroleum Hydrocarbon (PHC) Heavy metals: Copper, Ferrous, Nickel, Mercury, Magnesium, Chromium, Arsenic, Lead, Zinc, Cobalt Bacteriological parameters: Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count Marine Biology **Pigment Parameters:** Chlorophyll –a, Phaeo-pigments, Total biomass **Phytoplankton:** Primary Productivity, Population Density, Percentage Composition, Diversity Indices **Zooplankton:** Population Density, Percentage Composition, Diversity Indices	23 (Surface and bottom) covering all project activities such as Dredging, Reclamation, desalination plant activities, and SPM.	***Monthly*** *(However, the parameters like Chlorophyll content, TSS, TDS, salinity, turbidity, oil and grease, DO, BOD and COD should be monitored* ***fortnightly*** *in 15 locations (M-1 to M-3), (M-8, 11, 13, 17 & 18) and (M-4, 5, 7, 9, 12, 14 &16) during dredging and reclamation period.*
2.	Marine Sediment Quality	Physical & Chemical properties: Soil pH, Soil Texture (Sand, Silt, Clay), Organic Matter, Total Nitrogen, Total Phosphate, Petroleum Hydrocarbon (PHC)	23 locations covering all project activities such as Dredging, Reclamation,	**Monthly** *(However, the*

		<u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Manganese, Chromium, Arsenic, Lead, Zinc, Cobalt, Cadmium, Selenium <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Marine Biology</u> **Macro-benthos:** Population Density, Percentage Composition, Diversity Indices **Meio-benthos:** Population Density, Percentage Composition, Diversity Indices	desalination plant activities, and oil spill.	*parameters like organic matter, organic carbon, alkalinity, sediment texture, oil and grease should be monitored* ***fortnightly*** *in 15 locations (M-1 to M-3), (M-8, 11, 13, 17 & 18) and (M-4, 5, 7, 9, 12, 14 &16) during dredging and reclamation period.*
3.	Fish Population Monitoring	Diversity and Abundance	Randomly selected 6 sites around the project area (dredging and reclamation sites)	**Monthly**
4.	Rapid underwater biodiversity Assessment	Diversity and Abundance	Marine Zone (in line with baseline data)	**Yearly**
II – Pulicat Lake				
1.	Water Quality	<u>Physical properties:</u> Temperature, Salinity, pH, Electrical Conductivity (EC), Turbidity, Total Suspended Solids (TSS), Total Dissolved Solids(TDS), Visibility <u>Chemical Properties</u> Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Ammonia, Nitrite, Nitrate, Total Nitrogen, Inorganic Phosphate, Total Phosphate, Silicate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u>	4 Locations (Surface and bottom)	**Monthly**

		Copper, Ferrous, Nickel, Mercury, Magnesium, Chromium, Arsenic, Lead, Zinc, Cobalt <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Biological parameters</u> **Pigment Parameters:** Chlorophyll –a, Phaeo-pigments, Total biomass **Phytoplankton:** Primary Productivity, Population Density, Percentage Composition, Diversity Indices **Zooplankton:** Population Density, Percentage Composition, Diversity Indices		
2.	Sediment Quality	<u>Physical & Chemical properties:</u> Soil pH, Soil Texture (Sand, Silt, Clay), Organic Matter, Total Nitrogen, Total Phosphate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Manganese, Chromium, Arsenic, Lead, Zinc, Cobalt, Cadmium, Selenium <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Marine Biology</u> **Macro-benthos:** Population Density, Percentage Composition, Diversity Indices **Meio-benthos:** Population Density, Percentage Composition, Diversity Indices	4 Locations.	**Monthly**
4.	Fish Population Monitoring	Diversity and Abundance	2 sites around the sampling locations	**Quarterly**
III - Kosasthalaiyar River				
1.	Water Quality	<u>Physical properties:</u> Temperature, Salinity, pH, Electrical Conductivity (EC), Turbidity, Total	7 Locations (Surface and bottom)	**Quarterly**

		Suspended Solids (TSS), Total Dissolved Solids(TDS), Visibility Chemical Properties Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Ammonia, Nitrite, Nitrate, Total Nitrogen, Inorganic Phosphate, Total Phosphate, Silicate, Petroleum Hydrocarbon (PHC) Heavy metals: Copper, Ferrous, Nickel, Mercury, Magnesium, Chromium, Arsenic, Lead, Zinc, Cobalt Bacteriological parameters: Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count Biological parameters **Pigment Parameters:** Chlorophyll –a, Phaeo-pigments, Total biomass **Phytoplankton:** Primary Productivity, Population Density, Percentage Composition, Diversity Indices **Zooplankton:** Population Density, Percentage Composition, Diversity Indices		
2.	Sediment Quality	Physical & Chemical properties: Soil pH, Soil Texture (Sand, Silt, Clay), Organic Matter, Total Nitrogen, Total Phosphate, Petroleum Hydrocarbon (PHC) Heavy metals: Copper, Ferrous, Nickel, Mercury, Manganese, Chromium, Arsenic, Lead, Zinc, Cobalt, Cadmium, Selenium Bacteriological parameters: Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count Biological parameters **Macro-benthos:** Population Density, Percentage Composition, Diversity Indices **Meio-benthos:** Population Density, Percentage Composition, Diversity Indices	7 Locations.	**Quarterly**

IV - Buckingham Canal				
1.	Water Quality	Physical properties: Temperature, Salinity, pH, Electrical Conductivity (EC), Turbidity, Total Suspended Solids (TSS), Total Dissolved Solids(TDS), Visibility Chemical Properties Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Ammonia, Nitrite, Nitrate, Total Nitrogen, Inorganic Phosphate, Total Phosphate, Silicate, Petroleum Hydrocarbon (PHC) Heavy metals: Copper, Ferrous, Nickel, Mercury, Magnesium, Chromium, Arsenic, Lead, Zinc, Cobalt Bacteriological parameters: Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count Biological parameters **Pigment Parameters:** Chlorophyll –a, Phaeo-pigments, Total biomass **Phytoplankton:** Primary Productivity, Population Density, Percentage Composition, Diversity Indices **Zooplankton:** Population Density, Percentage Composition, Diversity Indices	4 Locations (Surface and bottom)	**Quarterly**
2.	Sediment Quality	Physical & Chemical properties: Soil pH, Soil Texture (Sand, Silt, Clay), Organic Matter, Total Nitrogen, Total Phosphate, Petroleum Hydrocarbon (PHC) Heavy metals: Copper, Ferrous, Nickel, Mercury, Manganese, Chromium, Arsenic, Lead, Zinc, Cobalt, Cadmium, Selenium Bacteriological parameters: Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count Biological parameters **Macro-benthos:** Population Density, Percentage Composition, Diversity Indices	4 Locations.	**Quarterly**

		Meio-benthos: Population Density, Percentage Composition, Diversity Indices		
V. Ennore Creek				
1.	Water Quality	<u>Physical properties:</u> Temperature, Salinity, pH, Electrical Conductivity (EC), Turbidity, Total Suspended Solids (TSS), Total Dissolved Solids(TDS), Visibility <u>Chemical Properties</u> Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Ammonia, Nitrite, Nitrate, Total Nitrogen, Inorganic Phosphate, Total Phosphate, Silicate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Magnesium, Chromium, Arsenic, Lead, Zinc, Cobalt <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Biological parameters</u> **Pigment Parameters:** Chlorophyll –a, Phaeo-pigments, Total biomass **Phytoplankton:** Primary Productivity, Population Density, Percentage Composition, Diversity Indices **Zooplankton:** Population Density, Percentage Composition, Diversity Indices	3 Locations (Surface and bottom)	**Monthly**
2.	Sediment Quality	<u>Physical & Chemical properties:</u> Soil pH, Soil Texture (Sand, Silt, Clay), Organic Matter, Total Nitrogen, Total Phosphate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Manganese, Chromium, Arsenic, Lead, Zinc, Cobalt, Cadmium, Selenium <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Biological parameters</u>	3 Locations.	**Monthly**

		Macro-benthos: Population Density, Percentage Composition, Diversity Indices **Meio-benthos:** Population Density, Percentage Composition, Diversity Indices		
VI - Mangroves				
1.	Water Quality	<u>Physical properties:</u> Temperature, Salinity, pH, Electrical Conductivity (EC), Turbidity, Total Suspended Solids (TSS), Total Dissolved Solids(TDS), Visibility <u>Chemical Properties</u> Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Ammonia, Nitrite, Nitrate, Total Nitrogen, Inorganic Phosphate, Total Phosphate, Silicate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Magnesium, Chromium, Arsenic, Lead, Zinc, Cobalt <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Biological parameters</u> **Pigment Parameters:** Chlorophyll –a, Phaeo-pigments, Total biomass **Phytoplankton:** Primary Productivity, Population Density, Percentage Composition, Diversity Indices **Zooplankton:** Population Density, Percentage Composition, Diversity Indices	5 Locations	**Monthly**
2.	Sediment Quality	<u>Physical & Chemical properties:</u> Soil pH, Soil Texture (Sand, Silt, Clay), Organic Matter, Total Nitrogen, Total Phosphate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Manganese, Chromium, Arsenic, Lead, Zinc, Cobalt, Cadmium, Selenium <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa,*	5 Locations.	**Monthly**

		Streptococcus faecalis, Shigella count, *Salmonella* count Biological parameters **Macro-benthos:** Population Density, Percentage Composition, Diversity Indices **Meio-benthos:** Population Density, Percentage Composition, Diversity Indices		
3.	Mangrove Area Monitoring	• Species composition and vegetation structure • Density, height, growth and canopy • Associated fauna and flora. • Numbers, species composition, size and structure of fish populations. • Juvenile fishes, especially target species. • Threats (sedimentation) etc. • Avifauna (Diversity and abundance)	5 sites	**Half Yearly**
VII – Others (Turtles, Mammals etc.)				
1.	Others – Turtles, Mammals etc	Presence of Turtles, Mammals etc. in the study area. Diversity and abundance; Action to rescue them if seen in activity area	(Around the project/operation site)	Marine Biologists onboard should monitor during dredging and reclamation period

3.2. Operational Phase

The activities of the project during the operational phase have to be regularly monitored in a holistic manner in order to manage and protect the health of environment and biodiversity. It is important to closely monitor the sites of reclamation, sites of sediment disposal, and sediment deposition to record any changes in and depletion of environmental quality. The concrete structures are to be monitored to record any sedimentation and also to know if organisms are attached to them. The number of monitoring locations in the marine zone is the same as that during the construction phase in order to collect continuous data so as to monitor the health status and to take appropriate conservation and management measures, wherever required. Similarly, in the land side covering coastal wetlands, inland region, Ennore Creek, Pulicat Lake, Kosasthalaiyar River, and Buckingham Canal, the number of sampling locations are similar to the number during the construction phase, which would help to take effective management and remedial actions, in case of any adverse impacts.

Figures 4 & 5 give details of the suggested monitoring locations during operational phase.

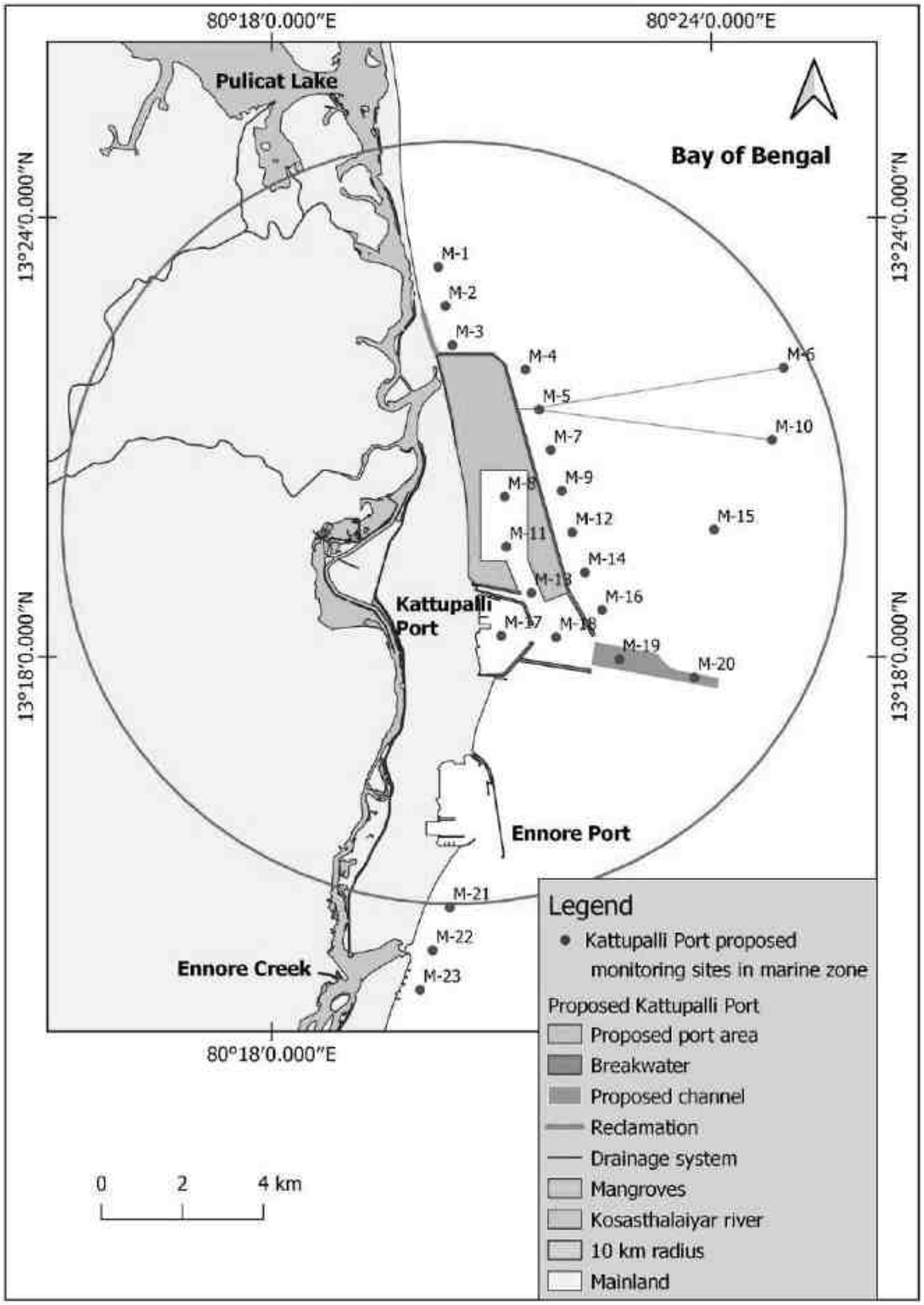

Fig.4: Map showing the monitoring locations in the marine zone during operational phase

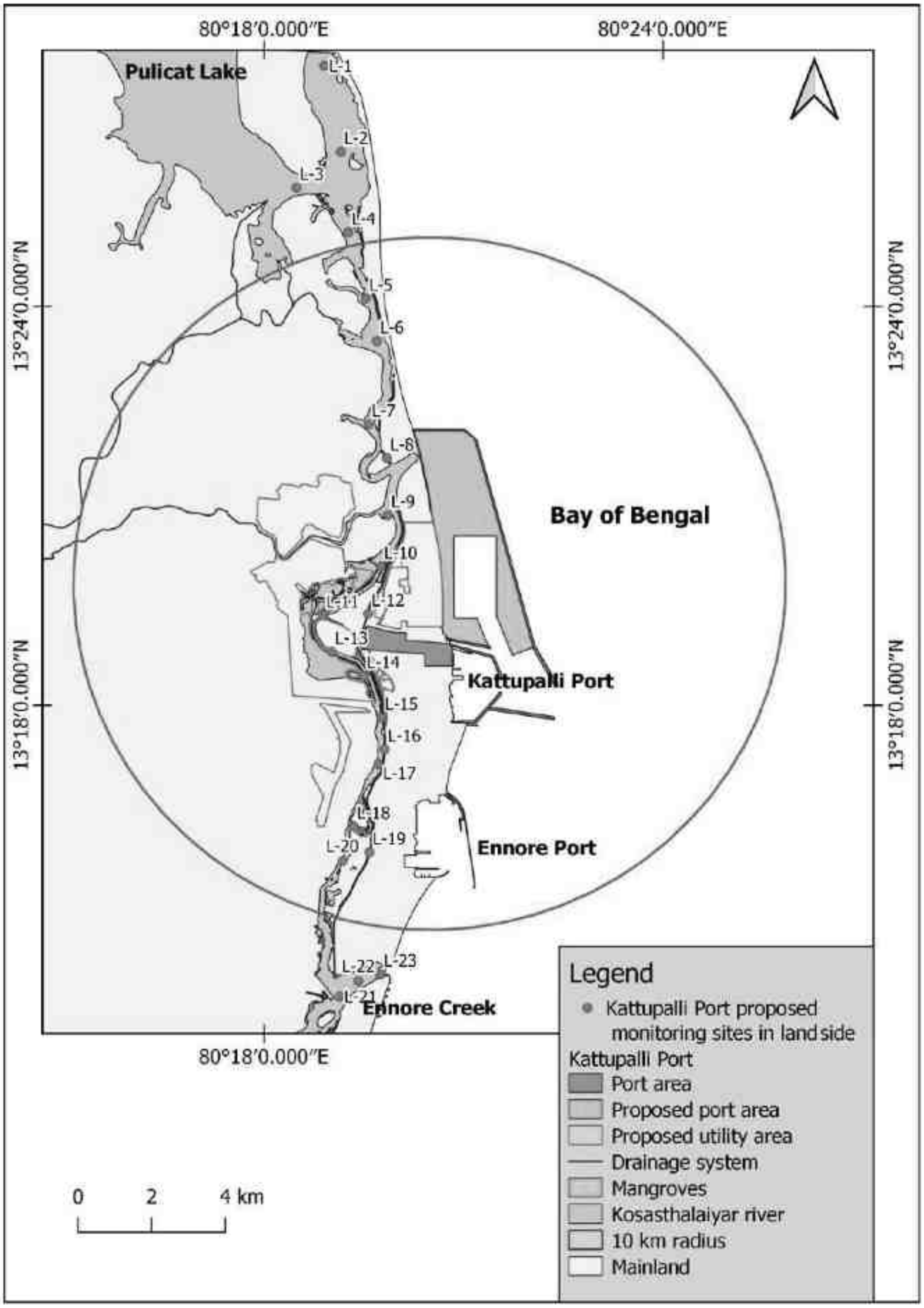

Fig.5: Map showing the monitoring locations in the land side covering coastal wetlands, inland region, Ennore Creek, Pulicat Lake, Kosasthalaiyar River, Buckingham Canal during operational phase

Proposed Monitoring Locations (Water and Sediment Sampling) in accordance with Project Activities during Operational Phase

MARINE ZONE (23 Monitoring Locations)

I- North of Proposed Reclamation Area (North of Kattupalli Port)

Total sampling numbers -3 (M-1 to M-3)

Sampling distance

Perpendicular to coast – 0.5 km

Along the coast – 1 km

II - Proposed Berth

Inside the berth

Total sampling numbers – 5 (M-8, 11, 13, 17 & 18)

Sampling distance – approximately 1km from the coast

Along the coast – 1.25 km

One sample in the centre of the existing Kattupalli port

Outside the berth

Total sampling numbers – 7 (M-4, 5, 7, 9, 12, 14 & 16)

Sampling distance

Perpendicular to berth – 0.5 km

Along the berth - 1km

III - Desalination (Outfall and Intake)

(The outfall and intake sites are located near the proposed berth where sampling sites are fixed)

IV- SPM (SPM1& SPM2)

Total sampling numbers - 2 (M-6 & M-10)

Sampling distance –approximately 8 km from the shore and the distance between the samples are 2 km.

V - Dredging soil disposal

Total sampling numbers - 1 (M-15)

Sampling distance – 6 km from the coast.

VI - Dredging channel

Total sampling numbers - 2 (M-19 & 20)

Sampling distance – 3.5 km and 4.5m from the shore.

VII - Sediment deposition

Total sampling numbers - 3 (M-21 to M-23)

Sampling distance

Perpendicular to coast – 0.5 km

Along the coast – 1 km

LAND SIDE (23 Monitoring Locations)

Pulicat Lake

Total sampling numbers – 4 (L-1 to L-4)

Kosathalaiyar River

Total sampling numbers – 7 (L-5, 6,7, 10, 13, 17&20)

Buchingham Canal

Total sampling numbers – 4 (L-8, 12, 16& 19)

Ennore Creek

Total sampling numbers – 3 (L-21 to L-23)

Mangroves

Total sampling numbers – 5 (L- 9, 11, 14,15, 18)

Table 2 give details of components, parameters to be monitored, locations and monitoring frequency during operational phase.

Table 2: Details of monitoring components, parameters to be monitored, locations and monitoring frequency during operational phase

Sl. No.	Components	Parameters to be Monitored	Locations	Monitoring frequency
I - Marine Zone				
1.	Marine Water Quality	<u>Physical properties:</u> Temperature, Salinity, pH, Electrical Conductivity (EC), Turbidity, Total Suspended Solids (TSS), Total Dissolved Solids(TDS), Visibility <u>Chemical Properties</u> Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Ammonia, Nitrite, Nitrate, Total Nitrogen, Inorganic Phosphate, Total Phosphate, Silicate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Magnesium, Chromium, Arsenic, Lead, Zinc, Cobalt <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Marine Biology</u> **Pigment Parameters:** Chlorophyll –a, Phaeo-pigments, Total biomass **Phytoplankton:** Primary Productivity, Population Density, Percentage Composition, Diversity Indices **Zooplankton:** Population Density, Percentage Composition, Diversity Indices	23 locations	**Monthly**
2.	Marine Sediment Quality	<u>Physical & Chemical properties:</u> Soil pH, Soil Texture (Sand, Silt, Clay), Organic Matter, Total Nitrogen, Total Phosphate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Manganese, Chromium, Arsenic, Lead, Zinc, Cobalt, Cadmium, Selenium <u>Bacteriological parameters:</u>	23 locations	**Monthly**

		Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Marine Biology</u> **Macro-benthos:** Population Density, Percentage Composition, Diversity Indices **Meio-benthos:** Population Density, Percentage Composition, Diversity Indices		
3.	Fish Population Monitoring	Diversity and Abundance	Randomly selected 6 sites around the project area (new berth and reclaimed area)	**Quarterly**
4.	Rapid underwater biodiversity Assessment	Diversity and Abundance	Marine Zone (in line with baseline data)	**Once in two years**
II – Pulicat Lake				
1.	Water Quality	<u>Physical properties:</u> Temperature, Salinity, pH, Electrical Conductivity (EC), Turbidity, Total Suspended Solids (TSS), Total Dissolved Solids(TDS), Visibility <u>Chemical Properties</u> Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Ammonia, Nitrite, Nitrate, Total Nitrogen, Inorganic Phosphate, Total Phosphate, Silicate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Magnesium, Chromium, Arsenic, Lead, Zinc, Cobalt <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Biological parameters</u> **Pigment Parameters:** Chlorophyll –a, Phaeo-pigments, Total biomass	4 Locations (Surface and bottom)	**Quarterly**

		Phytoplankton: Primary Productivity, Population Density, Percentage Composition, Diversity Indices **Zooplankton:** Population Density, Percentage Composition, Diversity Indices		
2.	Sediment Quality	<u>Physical & Chemical properties:</u> Soil pH, Soil Texture (Sand, Silt, Clay), Organic Matter, Total Nitrogen, Total Phosphate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Manganese, Chromium, Arsenic, Lead, Zinc, Cobalt, Cadmium, Selenium <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Marine Biology</u> **Macro-benthos:** Population Density, Percentage Composition, Diversity Indices **Meio-benthos:** Population Density, Percentage Composition, Diversity Indices	4 Locations.	**Quarterly**
4.	Fish Population Monitoring	Diversity and Abundance	2 sites around the sampling locations	**Quarterly**
III - Kosasthalaiyar River				
1.	Water Quality	<u>Physical properties:</u> Temperature, Salinity, pH, Electrical Conductivity (EC), Turbidity, Total Suspended Solids (TSS), Total Dissolved Solids(TDS), Visibility <u>Chemical Properties</u> Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Ammonia, Nitrite, Nitrate, Total Nitrogen, Inorganic Phosphate, Total Phosphate, Silicate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Magnesium, Chromium, Arsenic, Lead, Zinc, Cobalt <u>Bacteriological parameters:</u>	7 Locations (Surface and bottom)	**Quarterly**

		Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count Biological parameters **Pigment Parameters:** Chlorophyll –a, Phaeo-pigments, Total biomass **Phytoplankton:** Primary Productivity, Population Density, Percentage Composition, Diversity Indices **Zooplankton:** Population Density, Percentage Composition, Diversity Indices		
2.	Sediment Quality	Physical & Chemical properties: Soil pH, Soil Texture (Sand, Silt, Clay), Organic Matter, Total Nitrogen, Total Phosphate, Petroleum Hydrocarbon (PHC) Heavy metals: Copper, Ferrous, Nickel, Mercury, Manganese, Chromium, Arsenic, Lead, Zinc, Cobalt, Cadmium, Selenium Bacteriological parameters: Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count Biological parameters **Macro-benthos:** Population Density, Percentage Composition, Diversity Indices **Meio-benthos:** Population Density, Percentage Composition, Diversity Indices	7 Locations.	**Quarterly**
IV - Buckingham Canal				
1.	Water Quality	Physical properties: Temperature, Salinity, pH, Electrical Conductivity (EC), Turbidity, Total Suspended Solids (TSS), Total Dissolved Solids(TDS), Visibility Chemical Properties Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Ammonia, Nitrite, Nitrate, Total Nitrogen, Inorganic Phosphate, Total Phosphate, Silicate, Petroleum Hydrocarbon (PHC) Heavy metals:	4 Locations (Surface and bottom)	**Quarterly**

		Copper, Ferrous, Nickel, Mercury, Magnesium, Chromium, Arsenic, Lead, Zinc, Cobalt Bacteriological parameters: Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count Biological parameters **Pigment Parameters:** Chlorophyll –a, Phaeo-pigments, Total biomass **Phytoplankton:** Primary Productivity, Population Density, Percentage Composition, Diversity Indices **Zooplankton:** Population Density, Percentage Composition, Diversity Indices		
2.	Sediment Quality	Physical & Chemical properties: Soil pH, Soil Texture (Sand, Silt, Clay), Organic Matter, Total Nitrogen, Total Phosphate, Petroleum Hydrocarbon (PHC) Heavy metals: Copper, Ferrous, Nickel, Mercury, Manganese, Chromium, Arsenic, Lead, Zinc, Cobalt, Cadmium, Selenium Bacteriological parameters: Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count Biological parameters **Macro-benthos:** Population Density, Percentage Composition, Diversity Indices **Meio-benthos:** Population Density, Percentage Composition, Diversity Indices	4 Locations.	**Quarterly**
V. Ennore Creek				
1.	Water Quality	Physical properties: Temperature, Salinity, pH, Electrical Conductivity (EC), Turbidity, Total Suspended Solids (TSS), Total Dissolved Solids(TDS), Visibility Chemical Properties Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Ammonia, Nitrite, Nitrate, Total Nitrogen, Inorganic Phosphate, Total Phosphate,	3 Locations (Surface and bottom)	**Quarterly**

		Silicate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Magnesium, Chromium, Arsenic, Lead, Zinc, Cobalt <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Biological parameters</u> **Pigment Parameters:** Chlorophyll –a, Phaeo-pigments, Total biomass **Phytoplankton:** Primary Productivity, Population Density, Percentage Composition, Diversity Indices **Zooplankton:** Population Density, Percentage Composition, Diversity Indices		
2.	Sediment Quality	<u>Physical & Chemical properties:</u> Soil pH, Soil Texture (Sand, Silt, Clay), Organic Matter, Total Nitrogen, Total Phosphate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Manganese, Chromium, Arsenic, Lead, Zinc, Cobalt, Cadmium, Selenium <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Biological parameters</u> **Macro-benthos:** Population Density, Percentage Composition, Diversity Indices **Meio-benthos:** Population Density, Percentage Composition, Diversity Indices	3 Locations.	**Quarterly**
VI - Mangroves				
1.	Water Quality	<u>Physical properties:</u> Temperature, Salinity, pH, Electrical Conductivity (EC), Turbidity, Total Suspended Solids (TSS), Total Dissolved Solids(TDS), Visibility <u>Chemical Properties</u>	5 Locations	**Quarterly**

		Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Ammonia, Nitrite, Nitrate, Total Nitrogen, Inorganic Phosphate, Total Phosphate, Silicate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Magnesium, Chromium, Arsenic, Lead, Zinc, Cobalt <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Biological parameters</u> **Pigment Parameters:** Chlorophyll –a, Phaeo-pigments, Total biomass **Phytoplankton:** Primary Productivity, Population Density, Percentage Composition, Diversity Indices **Zooplankton:** Population Density, Percentage Composition, Diversity Indices		
2.	Sediment Quality	<u>Physical & Chemical properties:</u> Soil pH, Soil Texture (Sand, Silt, Clay), Organic Matter, Total Nitrogen, Total Phosphate, Petroleum Hydrocarbon (PHC) <u>Heavy metals:</u> Copper, Ferrous, Nickel, Mercury, Manganese, Chromium, Arsenic, Lead, Zinc, Cobalt, Cadmium, Selenium <u>Bacteriological parameters:</u> Total Viable Count, Total Coliform, Faecal Coliform, *Escherichia coli, Vibrio cholera, Vibrio parahaemolyticus, Pseudomonas aeruginosa, Streptococcus faecalis, Shigella* count, *Salmonella* count <u>Biological parameters</u> **Macro-benthos:** Population Density, Percentage Composition, Diversity Indices **Meio-benthos:** Population Density, Percentage Composition, Diversity Indices	5 Locations.	**Quarterly**
3.	Mangrove Area Monitoring & Avifauna	• Species composition and vegetation structure • Density, height, growth and canopy • Associated fauna and flora.	5 sites	**Yearly**

		• Numbers, species composition, size and structure of fish populations. • Juvenile fishes, especially target species. • Threats (sedimentation) etc. • Avifauna (Diversity and abundance)		
VII – Others (Turtles, Mammals etc)				
1.	Others (Turtles, Mammals etc)	Presence of Turtles, Mammals etc. in the study area. Diversity and abundance; Action to rescue them if seen in activity area	(Around the project/operation site)	Marine Biologists should monitor during maintenance dredging & disposal and ship navigation routes near the project site
VII1 – Monitoring concrete structures outside the new berths for biodiversity & sedimentation				
1.	Concrete structures outside the newly constructed berths	Biodiversity: Epifauna, Fish Population	In and around concrete structures outside the newly constructed berths	**Quarterly**

Annexure - 1: Mangrove Management Plan (during construction & Operational Phases)

4.1. Existing mangrove resources in the vicinity of the proposed project area

Mangroves are dynamic marine ecosystems that offer food and shelter to a wide range of ecologically and economically important marine species. The proposed project area is endowed with water bodies of different salinities, suitable for mangrove growth. Mangroves are frequently seen in Ennore Creek, Kosasthalaiyar River (connecting Ennore Creek and Pulicat Lake), mouth of the Buckingham Canal and Pulicat Lake. Mangroves are seen as patches and lines. Small to larger patches of mangroves are seen on the intertidal region present inside and on the banks of the river. Similarly, sparse distributions of mangroves also occur along the banks of the river at many locations. Mangroves are also seen at a few locations along the mouth of Buckingham Canal, where it meets the Kosasthalaiyar River. Halophytic plants are also seen in association with mangroves. Well-grown healthy mangrove vegetation is seen in most of the patches, whereas stunted and degraded mangroves are also seen in a few patches where flushing of water is limited. Mangrove cover is more extensive in the south-to-central part of the Kosasthalaiyar River, whereas in the northern part mangrove cover is scanty.

The three species of mangroves observed in the study area are *Avicennia marina*, *Avicennia* sp. and *Rhizophora mucronata* dominated by *Avicennia marina*. The density of mangrove vegetation near the proposed project site ranges between 1.5 and 12 plants per 5 square meters. Stem circumference of mangrove trees ranges between 4 and 72 cm near the project area. Mangrove seeds and saplings are extensively available in the area. Five types of halophytic plants are also observed near the project area dominated by *Suaeda monoica* and *Sesuvium portulacastrum*. In the mangrove ecosystem near the proposed project area, twelve species of fishes, eight species of crabs, five species of shrimp, four species of bivalves and 22 species of gastropods are recorded. Significant level of fishing happens in the mangrove area near the proposed project site and provides livelihood to hundreds of fishermen who live in the vicinity.

4.2. Impact on mangroves due to the project activities

Construction of buildings, roads, bridges, parking areas includes reclamation of low-lying areas which are natural flood plains. Land reclamation activities during the constructional phase are likely to impact the mangroves. These activities may hinder the flow of water into sea during floods and it may reduce the floodplain area cover and may reduce the infiltration of water into the ground. Potential reduction in low-lying areas may hinder the water flow to the sea and may flood the adjacent water bodies during heavy floods and the flood water may take its course via the channels and is likely to impact the banks of water bodies during a flood and the mangroves. Likely increase in the water may consequently increase the run-off into the sea causing sedimentation. Moreover, reclamation in the area would cause sedimentation in the water bodies such as Buckingham Canal and Kosasthalaiyar River and it may affect all the benthic and pelagic organisms.

4.3. Management of mangroves

4.3.1. Coastal communities and mangroves

In spite of no ownership rights to mangrove or its resources, coastal village communities near the proposed project area have considerable independence over the manner in which they use them. Different types of fishing activities take place in the mangroves occurring in the vicinity of the proposed project area. The communities have been using the mangroves sustainably for hundreds of years and hence they have a deep understanding of mangrove ecology and utilization. Coastal communities have also knowledge about mangrove degradation due to different factors. Hence, coastal communities will remain a key stakeholder in management initiatives, which will include schemes to appreciate and reward community conservation management. The local communities should be educated on conservation of mangrove habitats. Their capacity in mangrove conservation and management should be strengthened.

4.3.2. Management of indirect impacts

4.3.2.1. Altered Tidal Flushing

There is a likelihood of changes in tidal flushing into the mangrove habitats due to the proposed project activities. Some small intertidal channels may have disrupted flows while other channels may have comparatively faster flow. The causeway should be designed to maintain adequate tidal flow for the support of healthy mangrove habitat. Engineering design of the infrastructure facility should ensure the tidal flushing from the water bodies through appropriate provision.

4.3.2.2. Slippage of Fill

There is a possibility of earth fill used during the construction of the infrastructure facility to slip down slope and spread out to the mangrove area, and this may bury mangrove pneumatophores. Hence, construction workers should be trained to work carefully not to allow the slippage of fill into mangrove areas. Engineering measures to manage and/or prevent slippage of fill, as much as practicable, include the use of rock armouring to contain fill to the base of the channel crossing and stabilize earth fill as it is placed.

4.3.2.3. Dust Deposition

Dust generated during the construction and operational phases of the proposed project could result in the deposition of dust on surrounding mangroves. Dust deposition on mangroves and other vegetation can block photosynthetic processes and growth. Proper dust management plan should be in place to avoid any increased dust concentrations. The following measures will be useful in reducing dust deposition:

- Watering of unsealed roads, exposed surfaces, active construction areas and stockpiles
- Use of environmentally safe dust suppressants
- Restriction of vehicle movements and vehicle speeds to reduce dust emissions
- General housekeeping practices to manage waste materials within the construction site that may generate dust
- Awareness programs to ensure that all persons onsite are aware of the need to minimize dust emissions
- Reporting of any community complaints regarding dust levels.

4.3.2.4. Mangrove associated biodiversity

Accumulation of dust on mangrove leaves adjacent to the proposed development may impact organisms inhabiting mangrove canopies. Indirectly, the proposed development may also impact the avifauna through noise disturbance during construction and operational phases of the project. Impacts on mangrove associated organisms will primarily be managed by reducing the impacts to mangroves. Management of indirect impacts on mangrove avifauna will be by restricting direct habitat loss to the defined project footprint.

4.3.2.5. Mangrove monitoring

Monitoring to assist in the management of potential impacts on mangrove vegetation associations will include,

- Mangrove mapping
- Mangrove health surveys
- Monitoring of any sediment accumulation and turbidity within mangrove vegetation associations
- Assessment of water and sediment quality in the vicinity of the infrastructure development area

4.3.2.6. Mangrove mapping

Satellite images and field surveys should be used to map the distribution and coverage of mangrove vegetation situated near the proposed project area. Mangrove mapping should be done prior to the commencement of the project to provide current information on mangrove distribution and at project milestones including the completion of clearing activities and through the operational phase. Mangrove distribution and cover should be compared to the baseline data to confirm that the negative impact does not exceed the approved limits.

4.3.2.7. Mangrove health surveys

Mangrove health surveys should be undertaken once in a year to detect the negative impacts as soon as possible. Mangrove health monitoring will consist of regular visual assessments to determine mangrove condition. Mangrove monitoring sites should be established before the construction activities begin. The number and location of these sites should be fixed based on the baseline survey. Parameters such as number of species, number of trees, number of dead limbs, number of stems per tree, stem diameters, health status of trees, height of trees and foliage density should be collected during health surveys. A change in mangrove health leading to increased yellowing, wilting and dead leaves at any monitoring site should be shared and discussed with the stakeholders for proper action. The health survey should use the available results of the mangrove mapping and sedimentation monitoring to determine if the decline in mangrove health is directly related to the infrastructure development of the proposed project activities.

4.3.2.8. Turbidity and Sedimentation

Turbidity and sedimentation should be monitored in the mangrove area to provide an early warning of any potential changes due to the proposed project activities. Monitoring of sedimentation and turbidity should be done at the same monitoring sites used in the mangrove health surveys.

4.3.2.9. Assessment of water and sediment quality

Regular sample collection and monitoring of water and sediment quality parameters from permanent monitoring sites will be of utmost importance to understand the deviations from the baseline. It will enable the managers to take corrective action if a parameter goes higher or lower than the permissible limits.

Table 3 gives details of mangrove survey and monitoring protocol

Table 4: Mangrove survey and monitoring protocol

Assessment	Periodicity
Mangrove health surveys (Natural & Rehabilitated Mangroves) Mangrove diversity Number of trees present Number of dead limbs Number of stems per tree Stem diameters Health status of trees	Annual

Height of trees Foliage density	
Mangrove mapping	Annual

Annexure - 2: Multipurpose Artificial Fish Habitats for the enhancement of biodiversity, fish production, and sustained livelihood (during construction and operational phases)

In marine ecosystems Artificial Fish Habitats (AFH) serve multiple purposes, the most important of which are biodiversity and fisheries enhancement and coastal protection. Worldwide, artificial fish habitats are also used for several other purposes like improvement of recreational and commercial fisheries (increase of fish production and creation of new fishing grounds), control of inshore trawling, restoration of degraded habitats, control of beach erosion, provision of spawning areas, creation of recreational diving sites and climate change adaptation. AFHs act as fish habitats to enhance fishery production, and help to stop migration of fishes due to climate change, and thereby sustain the livelihood of the dependent fisher folk.

The proposed AFH deployment activity has the following purposes:

- to increase fish production through the development of Artificial Fish Habitats,
- to help fisher folk have a sustained fish catch throughout the year,
- to enhance the daily income of poor fishermen and improve socio-economic conditions,
- to enrich the marine biodiversity,
- to assess the impact of AFHs on the socio-economic aspects,
- to study the adaptive benefits of climate change impacts on both the fishermen community and the environment

Purpose

To compensate the fishery loss to the fishermen of the nearby coastal villages.

AFH deployment sites

Adequate AFH modules need to be deployed, covering considerable extent of fishing grounds at every 1 km outside the proposed project area in Bay of Bengal. It is suggested to deploy such AFHs in 15 sites in the first phase before the start of operational phase. The deployment of artificial fish habitats (artificial reefs) should start parallel to Ennore and should be done upto to Pulicat at every 1 km parallel to the shore. Artificial fish habitats would attract not only fishes but also all the benthic organisms, and would create a diverse ecosystem which would provide long-lasting results.

Impact Assessment

The impact of artificial fish habitats should also be studied regularly (covering the four seasons in a year) to assess the enhancement of biodiversity, fish production and socio-economic conditions of the dependent fisher folk

Annexure - 3: Sea ranching of commercially important organisms in Pulicat Lake (during operational phase)

Commercial fishing by small scale fishermen is practiced to a significant degree in Pulicat Lake as it is the second largest brackish water lake in India. Important catch includes shrimps and crabs. On account of the likely impact on these commercially important fishery resources due to the proposed project activities, eco-friendly and sustainable measures leading to livelihood enhancement may be considered. To compensate the loss, fingerlings of cultured shell fishes can be ranched in this brackish water Lake. Release of fingerlings would certainly help the fishermen to get good catch sustainably for a long time. Ranching of *Penaeus* spp., *Portunus* spp. and *Scylla serrata* would provide much economic benefits to the fishermen.

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