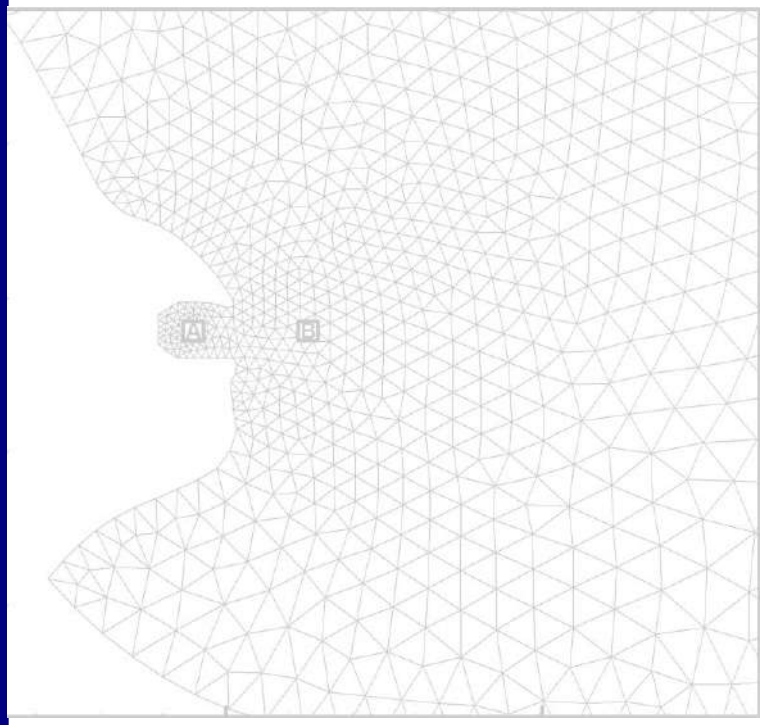
DETAILED PROJECT REPORT FOR RECLAMATION WORK FOR THE DEVELOPMENT OF LAND FOR INDUSTRIAL ACTIVITIES AT PARADIP



Interim Report

Marine EIA Report

Client

Dredging Corporation of India Limited

Consultants

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1 PROJECT BACKGROUND

Indian Oil reaches precious petroleum fuels to every nook and corner of the country through its network of over 60,000 plus customer touch-points, surmounting the challenges of tough terrain, climate, and accessibility. The marketing network is bolstered by 70.05 MMTPA of Refining Capacity and more than 17,000 KM of cross-country pipelines. Moreover, Indian Oil R&D Centre at Faridabad, one of Asia's finest in downstream petroleum R&D, offers a competitive advantage to the Corporation through world-class technology process solutions and innovative products. Indian Oil R&D has also been instrumental in pioneering path-breaking research to leverage the potential of Hydrogen and other cleaner fuels for the sustainable progress of the nation.

Paradip Refinery, was commissioned in 2016, is situated in Paradip, Jagatsinghpur district in the State of Odisha. Situated on the Eastern Coast this Refinery caters to the petroleum products demand and is strategically located for export of petroleum products to South-East Asian countries. This refinery is spread over approximately 3,345 acres of land and is situated approximately 5 km southwest from the Paradip Port.

Paradip Refinery is Indian Oil's first refinery with a single Atmospheric Column for processing 15.0 Million Metric Tonnes Per Annum. The crude receipt is by 3 nos. Single Point Mooring (SPM) is located around 30 km inside the sea to facilitate Crude delivery by VLCC. The refinery is designed to process 100% High Sulphur Crude and TAN of 0.5.

Several first-time technological features has been installed at Paradip Refinery including Flue Gas Desulphurization facilities for firing high Sulphur Vacuum Residue & Vapor Recovery system from jetty loading to meet the stringent emission norms of SOx and Volatile organic emissions despite processing heavy high Sulphur Crude. The refinery is in a synergic partnership with the environment as this is a zero effluent discharge refinery with strictly monitored and controlled stack emissions that are uplinked on real-time basis to the server of Central Pollution Control Board.

The refinery consists of an Alkylation unit to produce octane-rich low-benzene MS blend components. The refinery configuration also consists of "INDMAX" unit that is indigenous IOCL technology. It is capable of producing a high yield of LPG and propylene. The refinery can produce various petroleum products like gasoline, diesel, kerosene, and aviation turbine fuel, Propylene, Sulphur, and Petroleum Coke. The refinery is also designed to produce total Premium Quality Gasoline variants for export. Major units are AVU, Coker, CCRU, VGO Hydro-treater, Sulfur Recovery unit, Diesel hydro-treater, and Sulphuric Acid Regeneration Unit (SARU).

On the petrochemical front, Paradip produces various grades of PP from its Polypropylene unit. To expand IOCL's petrochemical footprint ERU (Ethylene Recovery Unit) and MEG (Mono Ethylene Glycol) unit were installed.

Figure 1 Aerial view of IOCL Paradip Plant

Indian Oil Corporation Limited (IOCL) has planned to establish a Petrochemical Complex at Paradip. The proposed site for the project is at Pratappur as shown in Figure 2.

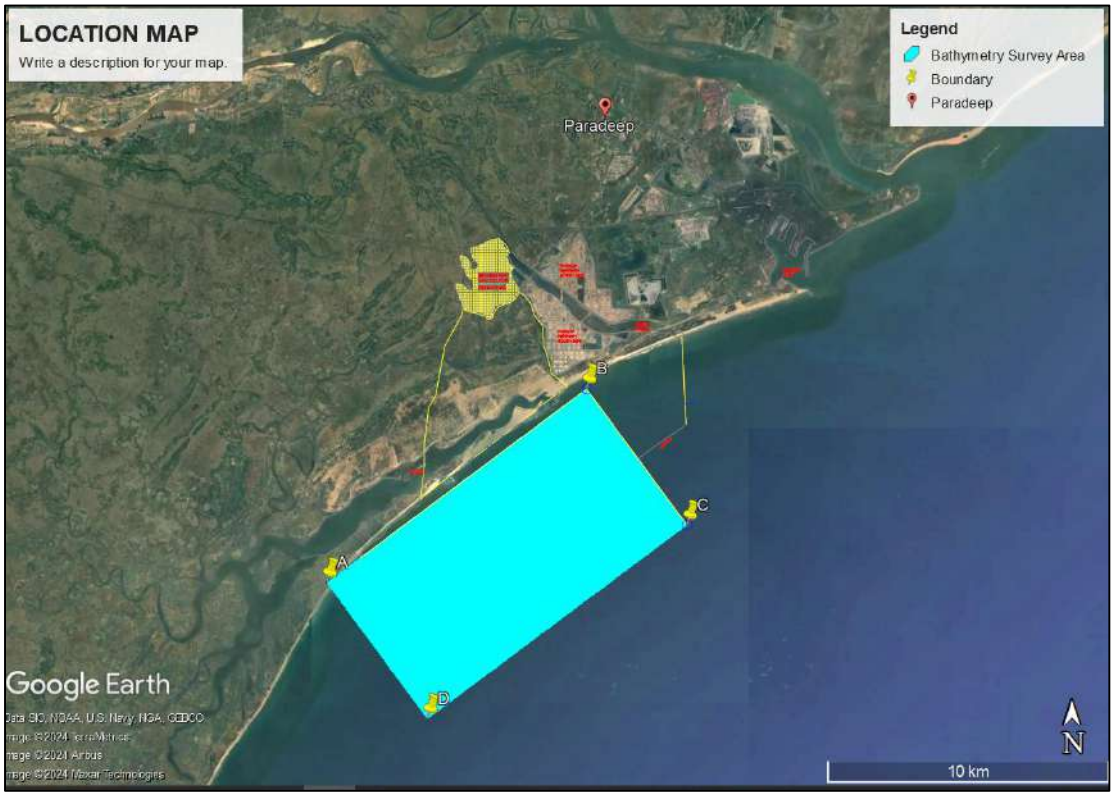

Figure 2 Location Map of the site

The identified land site spread over 780 acres, requires to be filled up to an approximate height of +2.50m in order to match with the existing ground level inside the Paradip refinery, IOCL, and the material required for filling is estimated at 10 Million Cubic meters. Hence, IOCL had approached Odisha Industrial Infrastructure Development Corporation, an organization under the Government of Odisha, for extending assistance to scout the fill materials from the adjacent sea, and in turn, IDCO had nominated Dredging Corporation of India, Limited (DCIL) for dredging at a suitable location in the sea and transporting the dredged materials for the purpose of reclamation in the low lying area allotted to IOCL. Prior to carrying out the dredging and reclamation work, it is necessary to select suitable borrow areas and pipeline routes, bathymetry and topographic surveys, geotechnical and geophysical investigations, as well as environmental studies such as EIA and EMP for the marine environment. A "Detailed Project Report" (DPR) needs to be prepared after the site investigations to obtain statutory clearances, if any, NOC from the concerned departments of the State Government of Odisha and the Government of India.

Considering the expertise available with National Technology Centre for Ports, Waterways, and Coasts (NTCPWC) of the Indian Institute of Technology Madras (IITM) for carrying out similar

type of studies and preparation of the detailed project reports (DPR), DCIL had awarded the work of Preparation of DPR for Reclamation work for the development of land for Industrial Activites at Paradip vide work order no DCl/IWD/NTCPWC/2023/02 dated 15.12.2023.

1.1 OBJECTIVE AND SCOPE OF THE STUDY

1.1.1 The main objectives of the study is to prepare DPR for the Dredging and Reclamation work for the Development of Land for Industrial Activities at Paradip.

1.1.2 The Scope of the study in preparation of DPR inter-alia covers

- To carry out the bathymetry survey at the proposed, borrow area of 6kmx11.5km at 100m line intervals.
- To carry out the Sub-bottom profiler survey at the proposed, borrow area of 6kmx11.5km at 200m line interval.
- To carryout topographic survey between the boundary to the edge of the proposed borrow area for selection of suitable pipeline routes and to assess the gradient from the borrow area to reclamation area (30sqkms).

- To carry out the geotechnical investigation at the proposed 24 marine boreholes in the borrow area of about 6km x 11.5km to assess the suitability of ill material for the reclamation area and to assess the required quantity.
- To prepare the Detailed Project Report (DPR) inter-alia covering;
  a. Identification of borrow areas based on the suitability of soil.
  b. Selection of suitable pipeline route.
  c. Total estimate fill quantity
  d. Methodology of Dredging and Reclamation
  e. Pre and Post-impacts of dredging and reclamation and mitigation measures.
- To complete the entire requisite to fill the form-1 application to the state Environmental Impact Assessment Authority (SEIMAA) for obtaining TOR.
- To prepare EIA/EMP reports as per SEIMAA and MoEF for obtaining environmental clearances from the concerned authority.
- To prepare the CRZ map reflecting the HTL/LTL line for the proposed project site.
- Presentation before SEIMAA or in front of statutory/regulatory body for getting NOC clearances.
- To assist the client in obtaining NOC from the state pollution control board.
- To conduct numerical modeling including hydrodynamic modeling and sediment transport model.

The present report pertains to the following objective Based on the primary data and also appending with secondary data, the Comprehensive Marine Environmental Impact Assessment (CMEIA) has been prepared to meet the following objectives:

a) To collect baseline data on the physico-chemical and biological characteristics of the prevailing marine environment.
b) To study the biodiversity potential of proposed project sites.

In this regard, the Center for Advanced Studies in Marine Biology at Annamalai University, a reputed Marine Institute in India, has been appointed to undertake a comprehensive Marine Environmental Impact Assessment (EIA) study within the designated borrows area.

2 MARINE EIA STUDY

To carry out the Marine EIA study, an extensive survey was made at 21 distinct stations (3 intertidal; 18 estuary and coastal stations) from January 26th to 29th January, 2024. The survey spanned across, strategically positioned at intervals ranging from 4 to 6.5 kilometers (shortest) and 12 to 15 kilometers (longest) from the proposed project site encompassing the Mahanadi River and the coastal waters of Paradeep, Odisha. This comprehensive assessment entails analyses of various parameters such as water quality, sediment attributes, and the biodiversity of biological communities, including plankton, benthos, microbes, and other ecologically sensitive flora and fauna, if any. The latitude and longitude co-ordinates of these sampling stations are detailed in Fig. 1 and also in Table 1.

Figure 3 Map showing the sampling stations in Estuary and Paradeep coastal waters

Table 1. SAMPLING STATIONS AND THEIR GEOGRAPHICAL COORDINATES

Station ID	Sampling Region	Latitude	Longitude
PES-1	Mahanadi Estuary	20°17'41.79"N	6°41'45.45"E
PES-2		20°17'34.69"N	86°42'24.90"E
PES-3		20°17'32.83"N	86°43'13.57"E

Station ID	Sampling Region	Latitude	Longitude
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PPS-5		20°15'33.97"N	86°40'58.39"E
PPS-6		20°14'57.52"N	86°41'01.49"E
PMS-7	Paradeep Offshore	20°13'04.78"N	86°36'14.95"E
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PMS-10		20°10'29.83"N	86°36'14.92"E
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PMS-14		20°10'34.64"N	86°34'25.30"E
PMS-15		20°09'36.85"N	86°35'13.72"E
PMS-16		20°09'05.40"N	86°33'59.52"E
PMS-17		20°09'52.76"N	86°33'20.67"E
PMS-18		20°10'33.75"N	86°32'46.27"E
PIS-19	Intertidal Region	20°12'09.41"N	86°33'12.50"E
PIS-20		20°12'44.22"N	86°34'22.94"E
PIS-21		20°08'53.12"N	86°34'23.71"E

(Footnote: PES-Paradeep Mahanadi Estuary Station; PPS–Paradeep Port Station; PMS–Paradeep Coastal Station; PIS-Paradeep Intertidal Station)

Overall report for Marine EIA study including results and discusisons has been attached as Appendix 1. However, the conclusion is summarized hereunder.

In the present survey, which lasted for four days, the physico-chemical and biological parameters were analyzed both in the water and sediment samples from predetermined (3 intertidal and 18 coastal stations) locations of Mahanadi estuary and Paradeep coastal waters. As such, the physico-chemical parameters did not show much variation barring a few parameters which showed only marginal variations. The results of various parameters are summarized below:

The diversity indices calculated for the plankton and benthic data in the present study showed undisturbed nature of the environment since diversity values of plankton and benthos were more than 2.5 as has been stated by the Marine ecologist Sanders (1968). The macro benthic conservative species Armandia sp., Glycera longipinnis, Goniada emerita, Spiochaetopterus costarum, Nereis sp. were predominantly occurred in the Mahanadi river Paradeep coastal waters which reflect the stable nature of the ecosystem.

Further, the results of physico-chemical and biological parameters indicated that the water is well oxygenated and nutrients are adequate supporting fairly good plankton population, the base in the food chain. Not only is that, the metal concentration in coastal water and sediment samples indicates that it is well within the ERM (Effective Range Median) values (Long et al., 1995) which means there is no possibilities of heavy metal contamination in the region.

In short, the results of marine ecological survey made during 26th to 29th January 2024 Mahanadi estuary and Paradeep coastal waters and careful perusal of the available information suggested that the water quality parameters are within the safe level and did not indicate any alarming impact on the existing biological components. The analysis on other ecologically sensitive organisms reflected the patchy occurrence of a few groups especially seaweeds from the nearby regions. The discharges occurring from the proposed facility will result in only marginal impacts on biota but such impacts are confined to a limited period since most of the marine organisms are capable of recouping themselves quickly to its original form and thus there will not be any pronounced change to the biotic community. Further, the present marine survey was done only short period, continuous monitoring is also needed even after commissioning of this proposed facility with a view to ascertain the temporal variations in the physico – chemical and biological components of this environment, if any.

for NTCPWC, IITM

[Prof K. Murali]

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MARINE BIODIVERSITY SURVEY FOR SITE DEVELOPMENT FOR IDCO INDUSTRIAL ESTATE AT PARADEEP, ODISHA

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MARINE BIODIVERSITY SURVEY FOR SITE DEVELOPMENT FOR IDCO INDUSTRIAL ESTATE AT PARADEEP, ODISHA

1. Preamble

Paradeep Port, located in Odisha on the eastern coast of India, serves as a crucial maritime gateway for trade in the eastern and central regions. Boasting modern infrastructure including deep-water berths, cargo handling equipment, and container terminals, it handles diverse cargo such as iron ore, coal, fertilizers, petroleum products, and containers. Through continuous modernization efforts, the port enhances its efficiency to meet evolving trade demands, contributing significantly to regional and national economic growth. Moreover, cognizant of its ecological footprint, Paradeep Port is proactive in embracing environmental stewardship, employing measures to mitigate its impact on the surrounding ecosystem while advancing sustainability objectives. Dredging sediment from oceanic sources for sand extraction represents a prevalent practice in coastal regions, notably observed in port facilities like Paradeep. This process entails the removal of sediments, encompassing sand, silt, and mud, from aquatic substrates such as rivers, lakes, or oceans. Dedicated machinery, known as dredgers or dredging vessels, is employed for this task, facilitating efficient extraction operations. Following dredging, sand is typically conveyed through pipelines or retained onboard dredging vessels for transportation to designated disposal sites. The repurposing of dredged sand commonly serves various ends, including beach replenishment endeavors, construction endeavors, or restoration initiatives targeting erosion-affected locales. Regulatory frameworks govern dredging endeavors to ensure minimal environmental ramifications. Environmental impact assessments form a pivotal component, scrutinizing potential repercussions on marine ecosystems, water quality, and adjacent habitats. Implementation of mitigation strategies, such as

sedimentation control mechanisms and comprehensive monitoring protocols, serves to address and alleviate adverse impacts stemming from dredging activities.

The Odisha Industrial Infrastructure Development Corporation (IDCO) serves as the nodal agency for providing land to large projects in Odisha, including the development of a Petroleum, Chemical, and Petrochemical Investment Region (PCPIR) at Paradip spanning over 70,214 acres in Jagatsinghpur and Kendrapara Districts, with Indian Oil Corporation (IOCL) as the anchor tenant. IDCO has acquired and handed over 3,300 acres to IOCL for the existing Paradip Refinery and has secured 780 acres in Pratapapur & Fatepur villages in Jagatsinghpur District, which requires raising by +2.5 m. IOCL requires approximately 10 million cubic meters of sand for this elevation. IDCO has engaged Dredging Corporation of India (DCI), Visakhapatnam for identifying a suitable Barrow Area in nearby Bay of Bengal near Paradip Port. DCI has engaged National Technology Centre for Ports, Waterways & Coasts (NTCPWC), Indian Institute of Technology-Madras, Chennai for carrying out the required Surveys & Studies. The Team of Experts has identified a Borrow Area of 11.5 (parallel to the Coastline) x 6 km (distance from Coastline) in the Sea for carrying out the Dredging of Sea Bed and transporting the Dredged Materials to the Site through pipeline. The Site is located at as distance of 4.0-6.5 km (shortest) & 12.0-15.0 km (longest) from the identified Dredging Area. The sea bed can be dredged to 1.0-1.5 m depth and pumped to the Site through temporary Pipelines. Furthermore, IDCO assumes the responsibility of procuring all requisite statutory endorsements.

In this regard, the Center for Advanced Studies in Marine Biology at Annamalai University has been tasked to undertake a comprehensive Marine Environmental Impact Assessment (EIA) study within the designated borrows area. To carry out the task, an extensive survey was made at 21 distinct stations (3 intertidal; 18 estuary and coastal stations) from January 26th to 29th January, 2024. The survey spanned across, strategically positioned at intervals ranging from 4 to 6.5 kilometers (shortest) and 12 to 15 kilometers (longest) from the proposed project site encompassing the Mahanadi River and the coastal waters of Paradeep,

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2. Objectives of the study

Based on the primary data and also appending with secondary data, the Comprehensive Marine Environmental Impact Assessment (CMEIA) has been prepared to meet the following objectives:

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Fig. 1. Map showing the sampling stations in Estuary and Paradeep coastal waters

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RESEARCH TEAM

3. MATERIALS AND METHODS

3.1. Water and Sediment Sampling

3.1.1 Water samples

The water samples were collected from the selected stations considering tidal influences, discharge and non-discharge points. Subsurface water samples were collected at a depth 0.5 meter using Niskin water sampler. For accurate measurements of the *in situ* properties and composition of seawater proper sampling is of utmost importance. It is essential to ensure that the sampling is contamination free and all the samples are appropriately sub-sampled and preserved to avoid/minimize changes in the water composition during storage. After sampling, adequate care was taken for measurements of hydrographic, chemical and biological properties of sea water in coastal and near-shore waters. Adequate samples were collected for duplicate and repeat analysis.

Prior to sampling, the sampler and sampling bottles were acid washed with 1N HCl in the laboratory. Sample bottles were rinsed thoroughly with the water sample and after that samples were collected. Water samples were collected using Teflon coated Niskin samplers (avoid any form of metal contact with samples). The prioritized individual sub sampling order was planned for the following parameters as given below: (i) for dissolved gases and pH, (ii) for nutrients and physical parameters, (iii) trace metals, (iv) Chlorophyll and (v) bacteria.

For dissolved oxygen, the samples were fixed by employing Winkler's reagent on board vessel itself and after fixing the samples were kept in shade until analysis. Temperature and pH were measured immediately after collection. Water samples were stored in an ice box for transportation. Samples for trace metal analysis were collected in acid-washed and pre-cleaned high density polyethylene (HDPE) bottles. Disposable, clean gloves were used while sampling and handling samples for trace metals. All samples were kept in a cool condition away from light

to avoid evaporation. All samples (for trace metals) were filtered immediately using 0.22 µM pore size filter paper and acidify the pH till 2 by adding SUPRAPURE NITRIC ACID and stored in metal free plastic bags till analysis, so as to avoid contamination.

3.2. Sediment samples

Sediment samples were stored in metal free plastic bags for trace metals analysis and in aluminium foils for analysis of organic matter. These samples were kept in a cool condition and brought in ice boxes. Further, it was dried in an electric oven at low temperatures (about 60 degrees C) in clean glass petri-dishes for the above analysis.

3.2.1 Collection of Sediment Samples (Grabs and Corer)

Van Veen grab with a sampling area of 0.1 m^2 was employed as a standard sediment sampler, since it is (i) an efficient sampler for the range of soft surface sediments encountered in the near shore area, (ii) reliable and simple to operate and (iii) widely applied, which allows data comparison with other marine areas. Grab is equipped with hinged inspection ports. The biting depth of grabs can vary with sediment conditions. Weights coated with Teflon were added to adjust according to the sediment conditions.

3.3 Preservation and processing of samples

Storage and Preservation of Samples: It is understood that the concentration of dissolved constituent is bound to change with time, due to the biological activity of the microorganisms present in the seawater. Trace quantity are vulnerable to adsorption/desorption process, therefore, they were analysed immediately. Where immediate analysis is not possible, the recommended method include freezing the samples is in -80°C. A quick note for sample collection and preservation procedures is given below:

Temperature, Salinity and pH analysis

The physical parameters such as temperature, salinity and pH were measured *in-situ* in the field. The subsurface temperature was measured with a mercury thermometer (± 0.02°C accuracy) and the pH was measured by a calibrated pH pen (pH ep-3 model). Salinity was estimated using a Hand Refractometer (Atago, Japan). Water samples collected for dissolved oxygen estimation were transferred carefully to BOD bottles. The DO was immediately fixed and brought to the laboratory for further analysis.

Preservation and Laboratory Analysis

After collection, the water samples were immediately cooled to 4°C and then brought to the laboratory in an insulated icebox. In the laboratory, water samples were filtered through Whatman GF/C filter paper and analysed for organic matter and other nutrients. Unfiltered samples were used for the estimation of total nitrogen and total phosphorus. All the analyses were carried out by adopting standard procedures. Briefly, the methodology for each analysis is given below:

Nitrate and Nitrite

The nitrate and nitrite content of samples were analysed by following the methods described by Strickland and Parsons (1972). The nitrite was estimated from highly coloured azo dye formed by the addition of N (1-Napthyl) ethylene diamine di hydro-chloride and sulfanilamide into the solution was then measured at 543 nm in a spectrophotometer. The same procedure was followed for the estimation of nitrate. For this, nitrate was reduced to nitrite by passing the sample through copper coated cadmium column. The values are expressed in µmol of Nitrogen/l

Inorganic Phosphate

The single solution mixed reagent procedure developed by Murphy and Riley (1962) was followed for the estimation of dissolved inorganic phosphate levels in water sample. This involves the conversion of phosphate into phosphomolybdic acid, which was then reduced to molybdenum blue colour complexes and then the intensity of colour was measured at 882 nm in a spectrophotometer. The calculated values are expressed in µmol of Phosphorus/l.

Total Phosphorus

The Total Phosphate in samples was estimated by adopting the method described by Menzel and Corwin (1964). This procedure involves the conversion of organically bound phosphate into inorganic phosphate by wet oxidation of samples with potassium persulphate in an autoclave for 30 min at 15 lbs pressure. The converted inorganic phosphate was then estimated by using the method described by Murphy and Riley (1962). The subtraction of original dissolved inorganic phosphate from total phosphate yielded the organic phosphate in the water sample. The calculated value is expressed in µmol of Phosphorus/l.

Reactive Silicate

The reactive silicate content of water was estimated by following the method of Strickland and Parsons (1972). In this method, the intensity of blue colour formed by silico-molybdate complex was measured in a spectrophotometer at 810 nm and the calculated values are expressed in µmol of Silica/l

Total Petroleum Hydrocarbon

The total petroleum hydrocarbon analysis of water and sediment sample was done by the methods suggested by Laboratory Analytical Work Instruction, 2011.

3.4. Sediment Analysis

For the analysis of textural composition and pH, the air-dried sediment samples were used as such. For all other analyses of organic matter, sediment samples were ground to fine powder and dried in an oven at 110°C to constant weight for an hour.

Total Organic Carbon

The estimation of total organic carbon in sediment was performed by adopting the method of El Wakeel and Riley (1956). The procedure involves chromic acid digestion and subsequent titration against ferrous ammonium sulphate solution in the presence of 1-10 Ferrous phenonthroline indicator. The values calculated are expressed in mg C/g of sediment.

Heavy Metal Analysis in Water and Sediment Samples

Seawater samples were collected in pre-cleaned polypropylene bottles with 10% nitric acid and Milli-Q water and acidified till pH ~1.6 using HNO_3 for further metal detection by using ICP-MS (Søndergaard *et al*., 2015). Sediment samples were collected with the aid of cleaned and dried Teflon/stainless steel coated Peterson grab. Sediment samples were transferred from the grab to cleaned polyethylene containers using cleaned plastics scoops. The samples were stored in frozen condition for further analysis. The preserved sediment subsamples were dried at 110°C to constant weight for estimation of metals. Dry powdered sediment was gently heated and digested with Hydrofluoric acid whereby Silica volatizes as Silicon tetra-fluoride. This is followed by treatment with Nitric acid and Per-chloric acid to destroy the organic matter. The residue after evaporation of acids was dissolved in 0.1 N HCl and desired metals were determined by Atomic Absorption Spectrophotometry (AAS).

Sediment texture

The percentage composition of sand, silt and clay was worked out by the pipette method as proposed by Krumbein and Pettijohn (1938) and the values are plotted in soil trigon.

Statistical analysis - Principal Component Analysis (PCA)

PCA is a powerful tool that attempts to explain the variance of a large dataset of inter-correlated variables with a smaller set of independent variables (Simeonov *et al*., 2003). PCA technique extracts the eigenvalues and eigenvectors from the covariance matrix of original variables. PCA is designed to transform the original variables into new, uncorrelated variables (axes), called the principal components, which are linear combinations of the original variables (Shrestha and Kazama, 2007). It reduces the dimensionality of the data set by explaining the co-relation amongst a large number of variables in terms of a smaller number of underlying factors, without losing much information (Vega *et al*., 1998; Alberto *et al*., 2001). This routine was adopted using the statistical programme PRIMER (Ver. 7.0) with a view to ascertain the relationship among the environmental entities studied in various stations of Mundra coastal waters (Clarke and Warwick, 2001).

3.5. Bacteriological Methods

3.5.1. Collection of 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. 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 polyethylene bags. All the samples were brought to the laboratory in

portable icebox soon after collection and bacteriological analyses were carried out in the laboratory immediately, with necessary dilution.

3.5.2. Enumeration of Total Viable Counts:

TVC was enumerated by adopting the spread plate method using Zobell's Marine Agar medium (EA123, Hi-Media, Mumbai). The samples (water and sediment) were diluted using the sterile sea water and 0.1 ml of the diluted sample was pippeted into the petriplates containing Zobell's Marine Agar and it was spread using a 'L' shaped glass spreader. The plates after inoculation were incubated in an inverted position at a temperature of 28+2°C for 24to 48 h. The colonies were counted and the population density expressed as Colony Forming Unit (CFU) per ml or g of the sample. The bacterial colonies were picked up from the pertidishes and re-streaked in appropriate nutrient agar plates thrice before a pure culture was established in agar slants.

3.5.3. Enumeration of Total Coliforms:

Macconkey agar with 0.15% bile salt, crystal violet and NaCl has been recommended in accordance with USP/Nfxi (1) for the detection, isolation and enumeration of coliforms and intestinal pathogens in water, dairy products, pharmaceutical preparations, etc. The agar weighing 51.5 g in 1000 ml distilled water was heated up to the boiling point to dissolve the medium completely and sterilized by autoclaving at 15 lbs pressure (121°C) for 15 min. suitably diluted samples were inoculated in the petriplates containing medium and were incubated for 48 h. After incubation, the colonies of *E. coli* appeared with pink colour.

M-FC agar is employed for detection and enumeration Faecal Coliforms by the membrane filter technique 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. Finally, the medium was poured into small 60mm plates. Samples filtered by Millipore apparatus using 0.45µm Whatman filter papers were impregnated in the petriplates. After 48 h of incubation, the colonies of *E. coli* appeared with blue colour.

3.6. Chlorophyll `a':

The samples were filtered through Whatman GF/C filter papers and the chlorophyll was extracted into 90% acetone. The resulting collared acetone extract was measured in a Spectrophotometer at different wavelengths and the same acetone extracts were acidified and measured for the phaeo-pigments. The detailed methodology as described in APHA manual (1989) was followed.

3.7. Phytoplankton:

Phytoplankton samples were collected from the surface waters of the study area by towing a plankton net (mouth diameter 0.5 m) made of bolting silk (mesh size 20 micron) for half an hour. These samples were preserved in 5% neutralized formalin and used for qualitative analysis. For the quantitative analysis of phytoplankton, the settling method as described by Sukhanovo (1978) was adopted. Numerical plankton analysis was carried out using Utermohl's inverted plankton microscope.

Phytoplankton species was identified using the standard works of Hustedt (1930-1966), Venkataraman (1939), Cupp (1943), Subramanian (1946), Prescott (1954), Desikachary (1959 and 1987), Hendey (1964), Steidinger and Williams (1970) and Taylor (1976) and Anand *et al.* (1986).

3.8. Zooplankton:

Zooplankton samples were collected from the surface waters of the study areas by horizontal towing of plankton net with mouth diameter of 0.35 m, made of bolting silk (No. 70 mesh size 200 µm) for half an hour. After collection, the samples were preserved in 5 - 7% neutralized formalin and used for quantitative analysis. The zooplankton collected were identified to the species level using the classical works of Dakin and Colefax (1940), Davis (1955), Kasthurirangan (1963) and Wickstead (1965) and Damodara Naidu (1981). For the quantitative analysis of zooplankton, a known quantity of water (100l) was filtered through a bag net (0.33 mm mesh size) and filtrate was made up to 1 litre in a wide mouthed bottle and then enumerated using Utermohl's inverted plankton microscope. The plankton density is expressed as number of organisms/m^3.

3.9. Benthic Community:

Macrofauna

Three replicate samples were collected by using van-Veen grab, which was found to take a sample covering an area of 0.1m^2 and this grab is designed to take large samples from the soft bottom. The benthic sample collection was done following the standard method of Mackie (1994). After collection, the sediment samples were emptied in to a plastic tray and the larger organisms were immediately taken, remaining samples were gently sieved through 0.5mm mesh. The organisms retained by the sieve were preserved with 5-7% of formalin and stained with 0.1% Rose Bengal stain for greater visibility during sorting and species identification. After a day, the sorted macro benthic organisms were counted and identified to species level under a stereomicroscope (EISCO Stereo Binocular Microscope) by consulting the standard works of Fauvel (1953), Day (1967) for polychaetes; Lyla *et al*. (1999) for amphipods; Rajagopal *et al*. (1998) for gastropods; Shanmugam *et al*. (1997) & Fernando and Fernando (2002) for bivalves;

Barnes (1980) and Lyla *et al*. (1999) for crustaceans and Subba Rao *et al.* (1991) and Ramakrishna (2003) for molluscs.

Meiofauna

Sediment subsamples (~100 g) for meiofaunal analysis were collected from each haul and placed in labeled plastic bags, immediately fixed in 4% buffered formalin in distilled water, and brought to the laboratory. The sediments were washed with tap water through a set of 0.5 mm and 0.063 mm sieves. The sediment retained on the 0.063 mm sieve was decanted to extract meiofauna following the methodology of Higgins & Thiel (1988). Sorting of metazoan meiofauna (nematodes, harpacticoids, and ostracodes) from sediment was done by flotation and decantation using a sieve with 0.040 mm mesh size; the efficiency of this technique has been reported as 95% by various researchers (Somerfield & Warwick, 1994; Danovaro *et al*., 2004; Giere, 2009). The organisms retained on the sieve were placed into Petri dishes for sorting and preserved in 70% ethyl alcohol with 5% glycerol (Tolhurst *et al*., 2010). A few drops of Rose Bengal (1 g/l) were also added to this solution to facilitate the counting process. For the separation of foraminifera, sediment subsamples were fixed with 5% buffered formalin and stained with Rose Bengal. In the laboratory, sediment samples were washed with tap water through a 0.063 mm sieve and then dried (Walton, 1952).

Subsequently, the sorted meiobenthic organisms were counted and identified to species level under a stereomicroscope (EISCO Stereo Binocular Microscope) by consulting the standard works of Loeblich & Tappan (2015), Mohan *et al*. (2013) and Murugananthan *et al*. (2017) for foraminifera; Chitwood (1958), Lambshead (2004), De Ley *et al*. (2005), Poinar (2008), Vovlas *et al*. (2011), and Ahmed *et al*. (2015) for nematodes; Brouwers *et al*. (2000), Tanaka (2008), and Yasuhara *et al*. (2014) for ostracods; and Huys & Boxshall (1991), Wells

(2007), and Yeom & Lee (2020) for harpacticoids. The numerical abundance of the meiofauna was expressed in individuals per 10 cm^2 (Fernando *et al*., 1983).

3.11. Statistical Analysis

Cluster Analysis

As done for environmental parameters, the classification method, Cluster analysis was done to find out the similarities between the samples/ stations/regions. The most commonly used clustering technique is the hierarchical agglomerative method. The results of this are represented by a tree diagram or dendrogram with the x- axis representing the full set of samples and the y-axis defining the similarity level at which the samples or groups are fused. Bray – Curtis coefficient (Bray and Curtis 1957) was used to produce the dendrogram.

MDS (non - metric Multi-Dimensional Scaling)

This method was proposed by Shepard (1962) and Kruskal (1964). To confirm the clustering pattern, this was used to find out the similarities (or dissimilarities) between each pair of entities to produce a 'map', which would ideally show the interrelationships of all.

BIO-ENV procedure

In the present study, to ascertain the relationship between biological and environmental variables, the BIO-ENV procedure (Clarke and Ainsworth, 1993) was employed. The basic principle behind this is to measure the agreement between the rank correlations of the biological (Bray-Curtis similarity) and environmental (Euclidean distance) matrices. A weighted Spearman rank correlation coefficient ($\rho\omega$) was used to determine the harmonic rank correlation between the biological matrix and all possible combinations of the environmental variables.

VIEWS OF SAMPLING AREA

Paradeep fishing harbor and fish landing center

Proposed M/s. JSW Utkal Steel Limited

Mangrove Zone

Mahanadi River mouth

Proposed Site Development for IDCO Industrial Estate at Paradeep

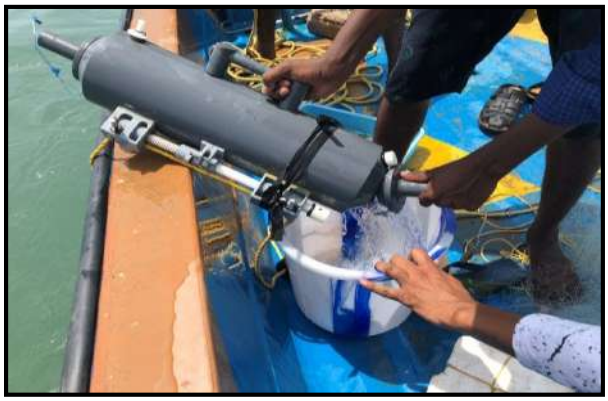
RESEARCH PERSONNEL IN ACTION

Locating sampling points by using GPS

In-situ Temperature measurement by using Thermometer

Water pH measurement by using pH pen

Salinity measurement by using Refractometer



Sub-surface water sample collection by using Niskin water sampler

Sediment sample collected by using Van Veen Grab

Plankton sample collection by using Bongo net

Vertical transparency measurement by using Secchi disc

DO estimation by following Winkler's method

Sieve retains-benthic samples

Water analysis using (UV – 1900 UV – VS Spectrophotometry)

Light microscope used for identification (KL-300LED Carl Zeiss microscope)

3. OBSERVATION REPORT

4.1. Water Quality

Depth

The depth in the study area varied between 3.5 and 19.5m, with maximum was at PMS-15 and minimum at PES-1 (Fig. 2).

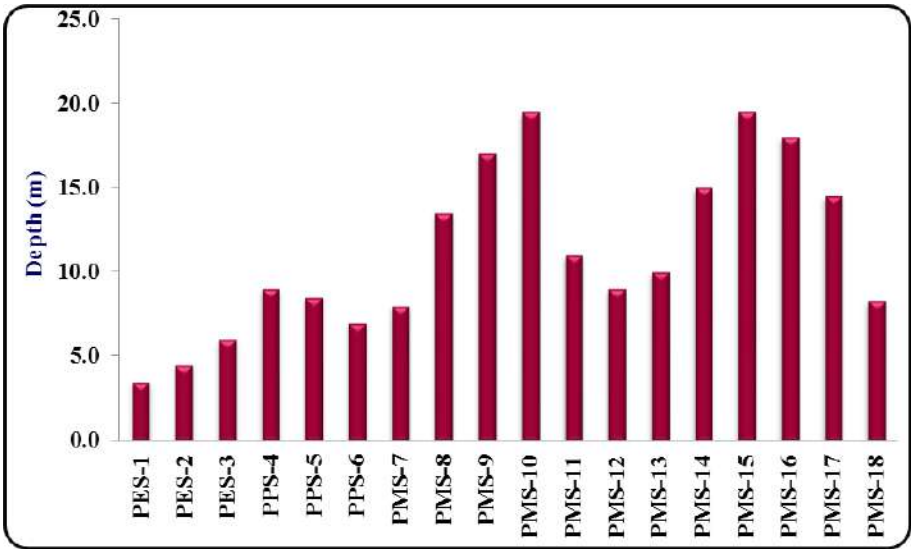


Fig. 2. Depth values recorded at various stations of Estuary and Paradeep coastal waters

Water Temperature

The water temperature fluctuated from 27.5 to 32.0°C. The minimum value was recorded at PES-2 and maximum was recorded at PMS-12 (Fig. 3).

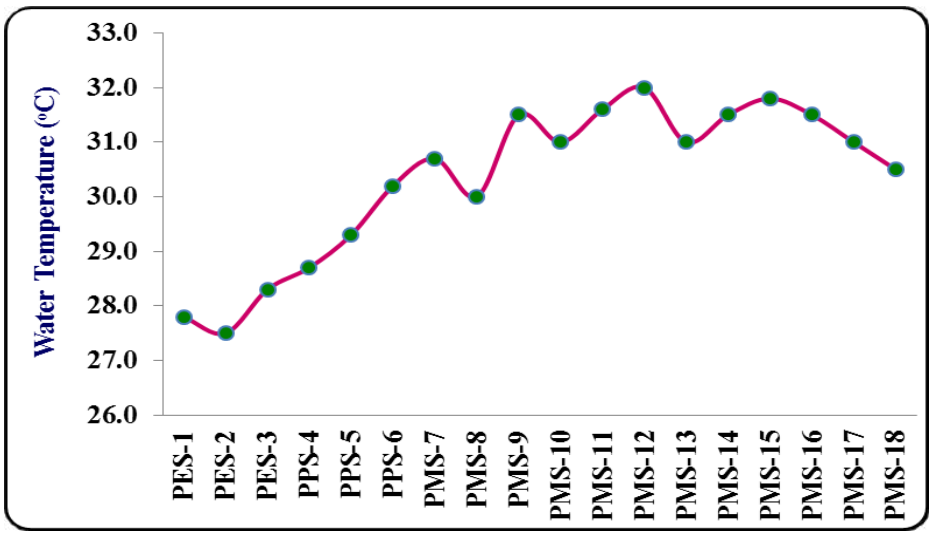


Fig. 3. Water temperature values recorded at various stations of Estuary and Paradeep coastal waters

Salinity

The water salinity varied from 27.0 to 35.3ppt. The salinity was found to be lower at PES-1 and higher value at PMS-15 (Fig. 4).

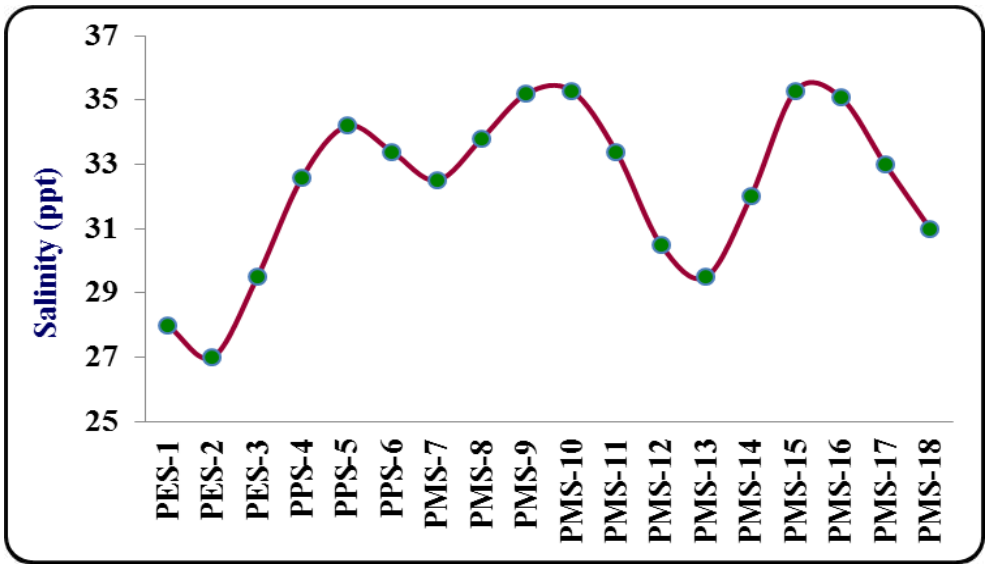


Fig. 4. Salinity level recorded at various stations in Estuary and Paradeep coastal waters

Water pH

The water pH varied between 7.81 and 8.41 with minimum value was recorded at PES-1 andmaximum value was recorded at PMS-10 (Fig. 5).

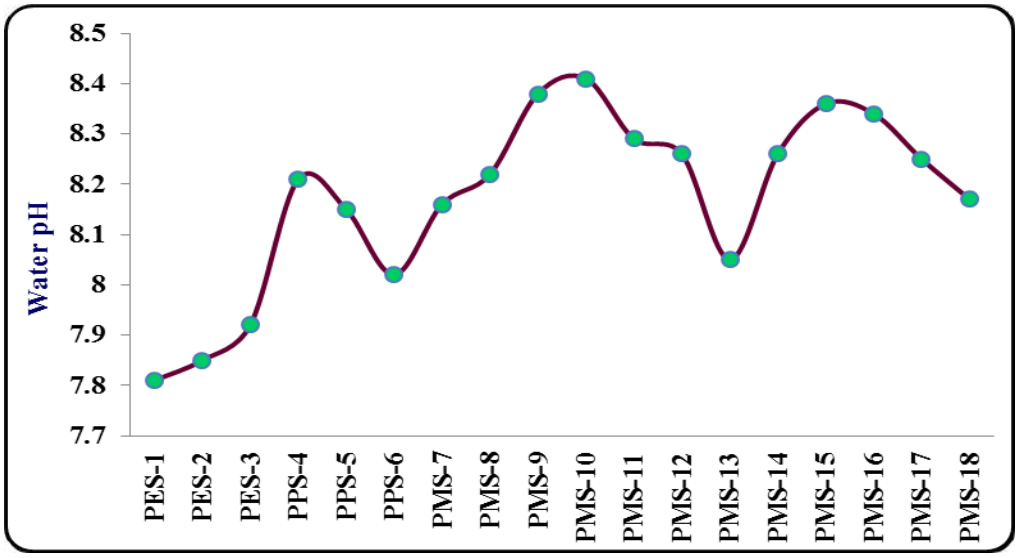


Fig. 5. Water pH level recorded at various stations of Estuary and Paradeep coastal waters

Dissolved Oxygen

The Dissolved Oxygen level in the water varied between 3.41 and 5.69 mg/l. The lower value was recorded at PPS-5 and the higher value at PMS-13 (Fig. 6).

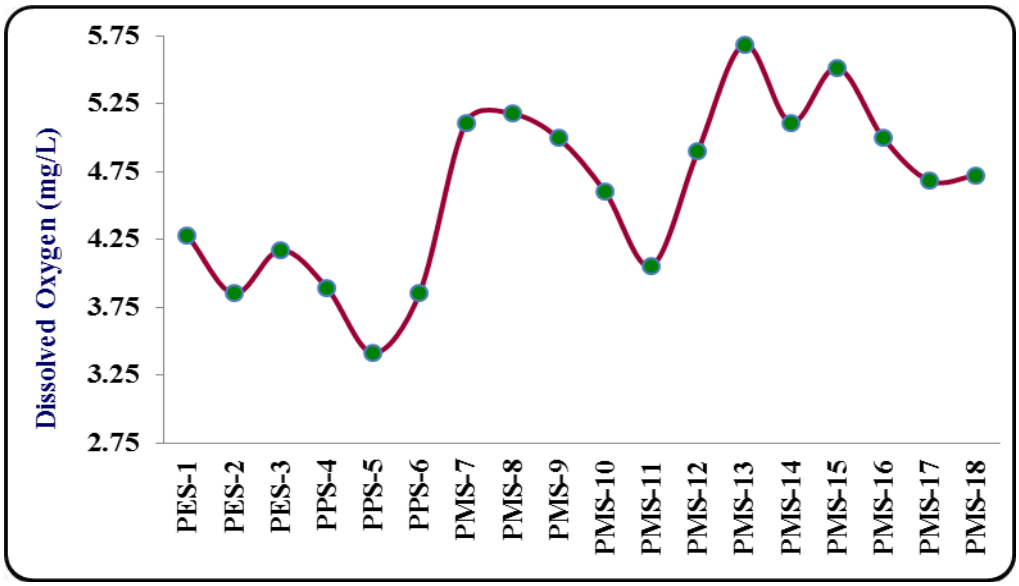


Fig. 6. Dissolved oxygen level recorded at various stations of Estuary and Paradeep coastal waters

Biological Oxygen Demand

The BOD values varied between 1.36 and 2.51mg/l with minimum at PMS-10 and the maximum value was recorded at PPS-5 (Fig. 7).

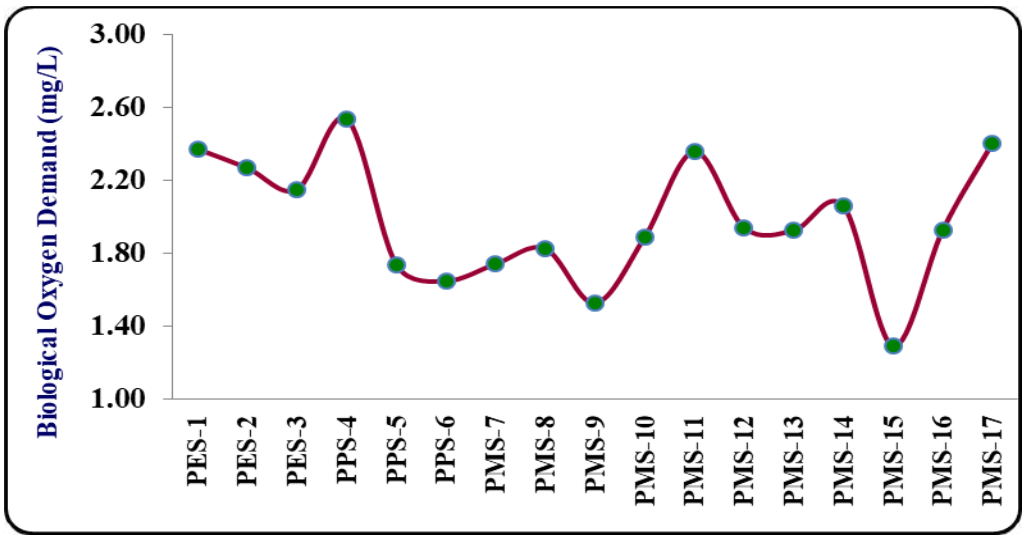


Fig. 7. Biological oxygen demand values recorded at various stations of Estuary and Paradeep coastal waters

Total Suspended Solids (TSS)

The Total Suspended solids values ranged between 60.60 and 122.32ppm. The minimum value was recorded at PMS-11 and the maximum was recorded at PMS-5 (Fig. 8).

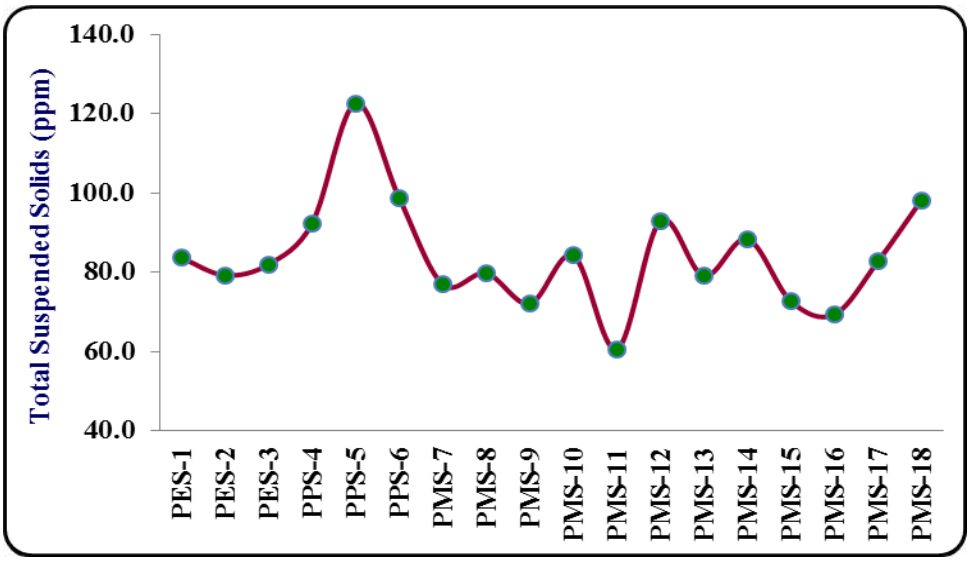


Fig. 8. Total suspended solids values recorded at various stations of Estuary and Paradeep coastal waters

Turbidity

The turbidity values were between 4.1 and 6.6NTU. The minimum level was recorded at PMS-10 and the maximum level at PPS-5 (Fig. 9).

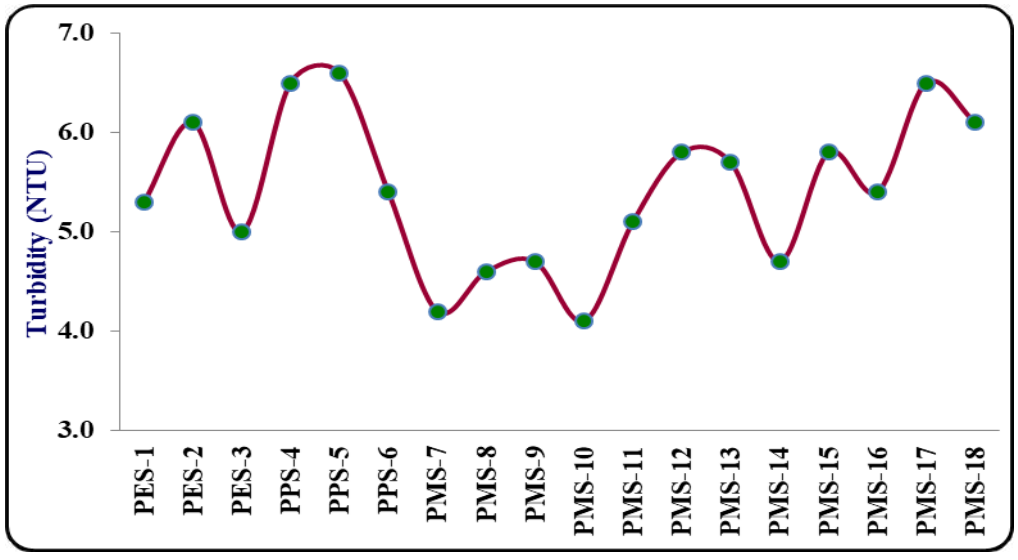


Fig. 9. Turbidity values recorded at various stations of Estuary and Paradeep coastal waters

4. 1. 1. Water Nutrients

The life supporting processes in the sea requires an array of inorganic substances, of which, the role of nitrogen, phosphorus and silicon are considered to be very vital in marine ecosystem. Among the nitrogenous compounds, nitrite, nitrate and ammonia are the major constituents, which play a key role in the growth and proliferation of phytoplankton. Accordingly, the results of various parameters recorded in various stations of the study area are given below:

Nitrite

The nitrite level varied from 0.94 to 2.17µmol/l with maximum at PES-1 and minimum at PMS-11 (Fig. 10).

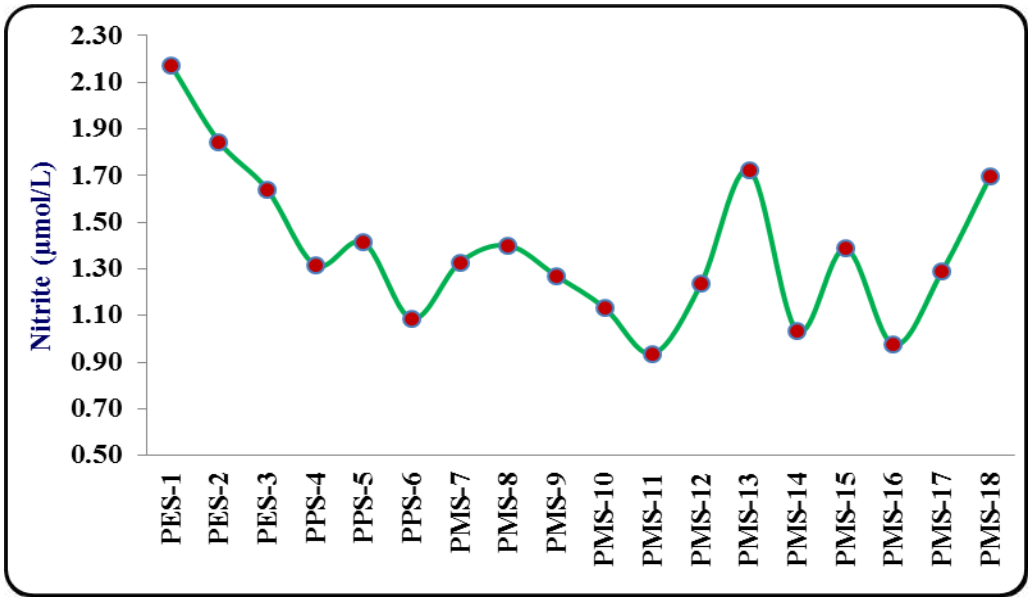


Fig. 10. Nitrite level recorded at various stations of Estuary and Paradeep coastal waters

Nitrate

Nitrate concentration ranged between 2.65 and 4.18µmol/l with minimum at PMS-10 andmaximum at PES-1 (Fig. 11).

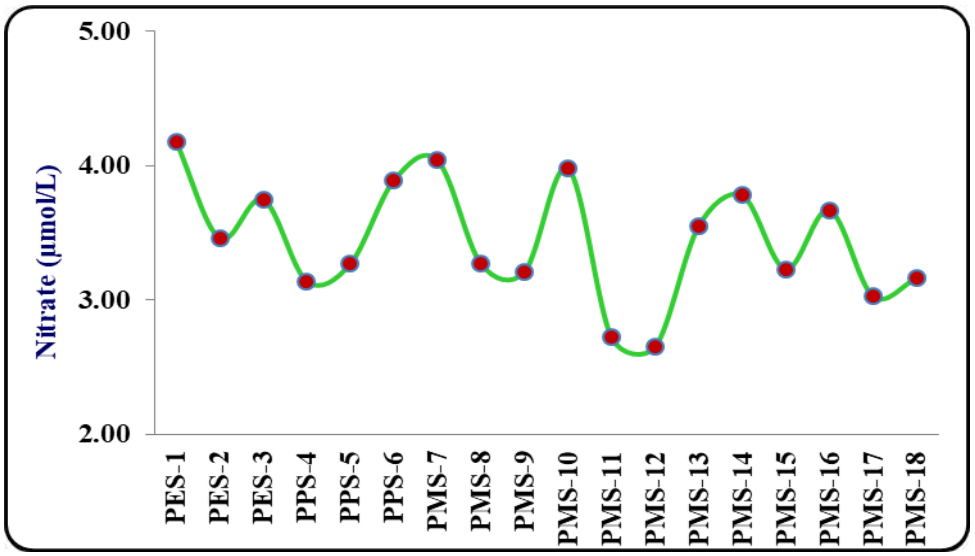


Fig. 11. Nitrate concentration recorded at various stations of Estuary and Paradeep coastal waters

Total Nitrogen

The Total nitrogen values ranged from 13.52 to 19.42µmol/l. The minimum value was recorded at PMS-9 and the maximum value at PPS-5 (Fig. 12).

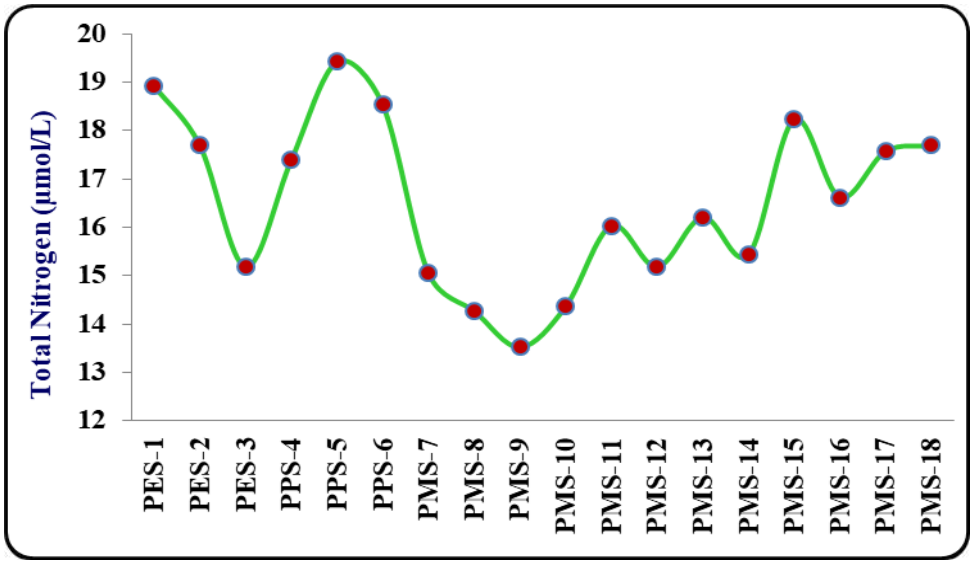


Fig. 12. Total nitrogen values recorded at various stations of Estuary and Paradeep coastal waters

Ammonical Nitrogen

The ammonia concentration varied from 0.08 to 0.23µmol/l. The maximum concentration (0.23µmol/l) was recorded at PES-2 and minimum (0.08µmol/l) at PMS-15 (Fig. 13).

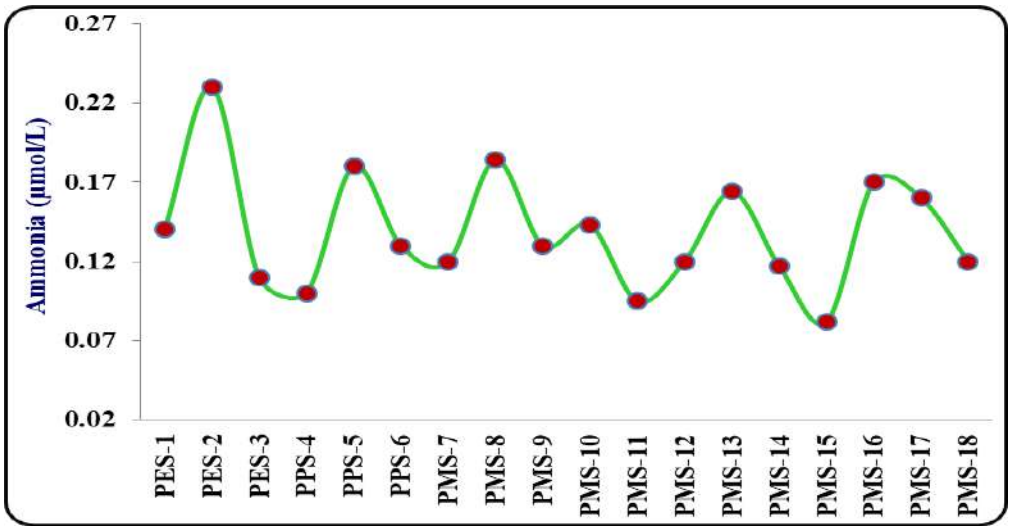


Fig. 13. Ammonical nitrogen concentration recorded at various stations of Estuary and Paradeep coastal waters

Inorganic Phosphate

The inorganic phosphate values ranged between 0.48 and 0.99µmol/l with maximum value at PES-2 and minimum at PMS-14 (Fig. 14).

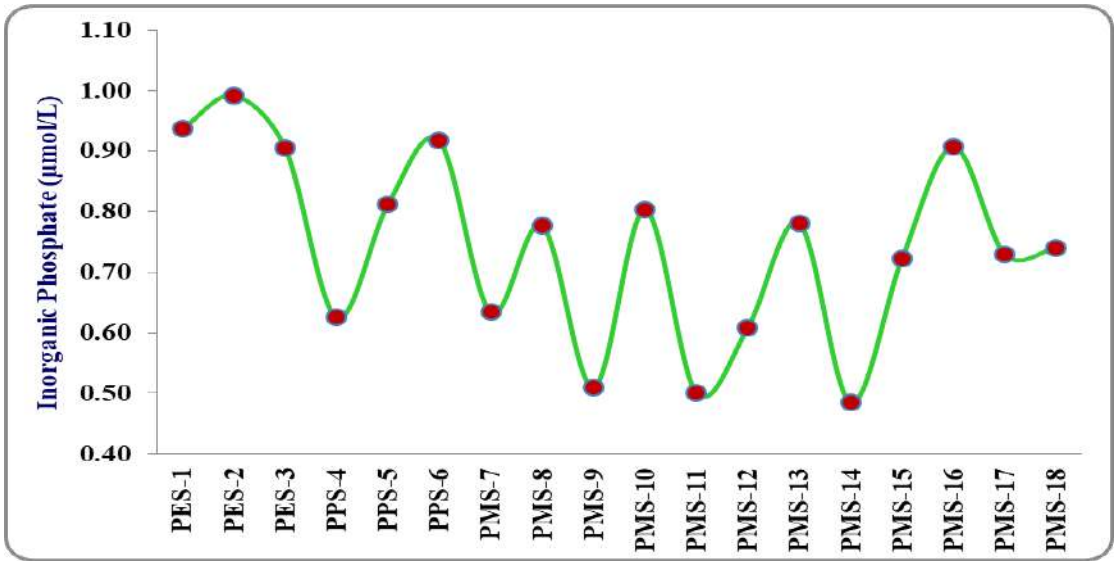


Fig. 14. Inorganic phosphate concentration recorded at various stations of Estuary and Paradeep coastal waters

Total Phosphorus

The Total phosphorous values ranged from 1.01 to 2.83µmol/l with minimum value were atPPS-5 and the maximum value at PMS-13 (Fig. 15).

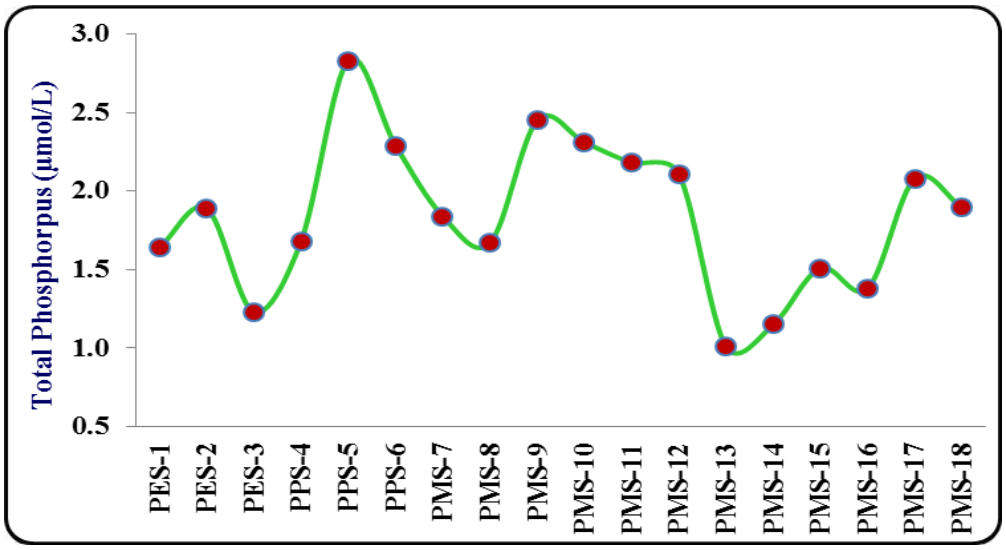


Fig. 15. Total phosphorous values recorded at various stations of Estuary and Paradeep coastal waters

Reactive Silicate

The silicate values ranged between 25.34 and 58.25µmol/l with minimum was recoded PES-2 and the maximum values were recorded at PMS-16 (Fig. 16).

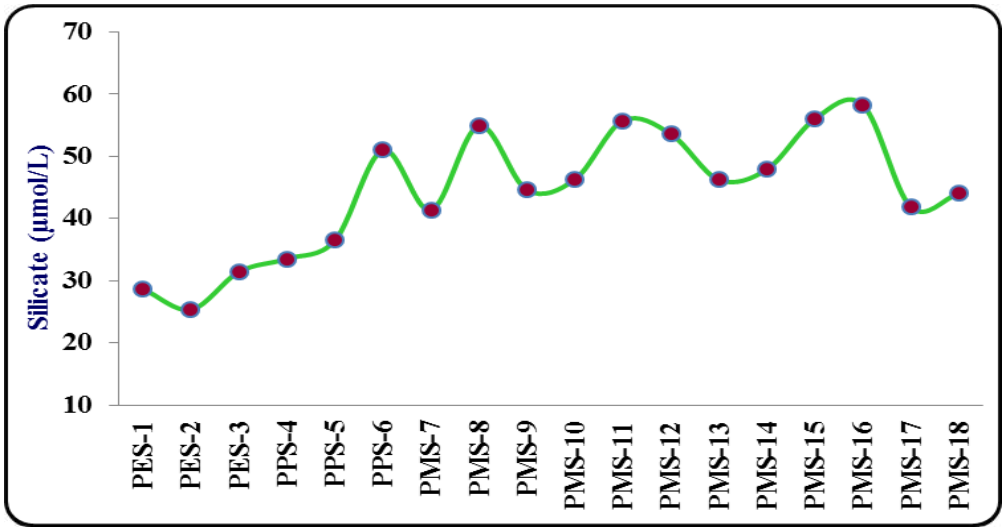


Fig. 16. Reactive silicate level recorded at various stations of Estuary and Paradeep coastal waters

Particulate organic Carbon

The particulate organic carbon level ranged between 77.30 and 139.20µgC/l with minimum (77.30µgC/l) was at PMS-15 and maximum (139.20µgC/l) at PPS-5 (Fig. 17).

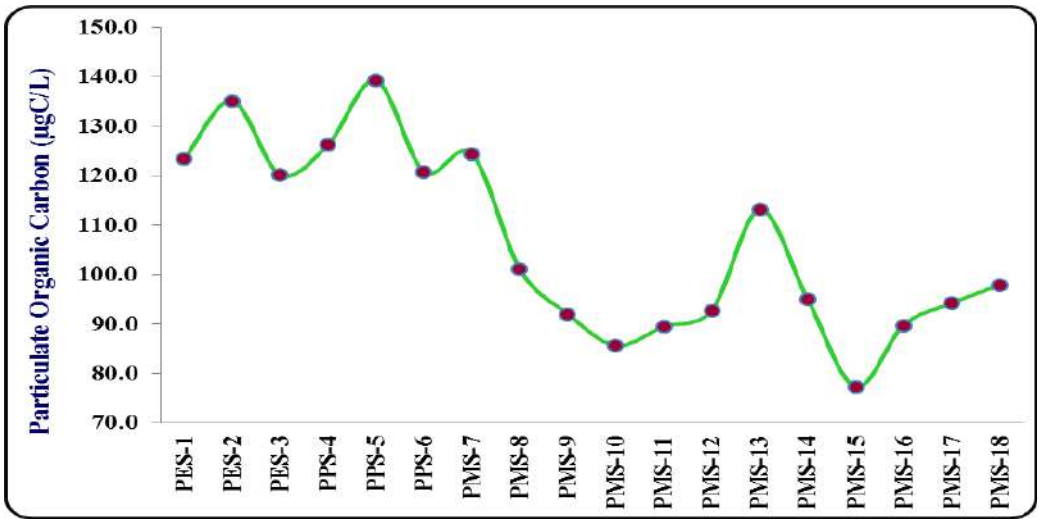


Fig. 17. Particulate organic carbon level recorded at various stations of Estuary and Paradeep coastal waters

Petroleum hydrocarbons

PHC level in water fluctuated from 0.104 and 0.372µg/l. The maximum value was recorded atPPS-5 and the minimum was recorded at PMS-10 (Fig. 18).

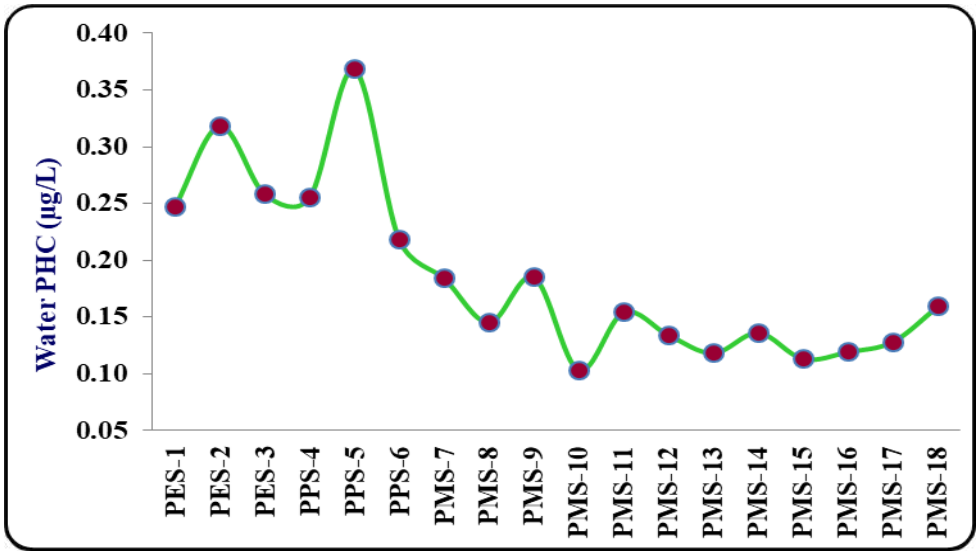


Fig. 18. Petroleum hydrocarbons concentration recorded at various stations of Estuary and Paradeep coastal waters

4. 1. 2. Heavy Metals in water

Iron

The iron level varied from 11.03 to 19.31µg/L (Fig. 19). The maximum was recorded atPPS-4 and the minimum was recorded at PMS-15.

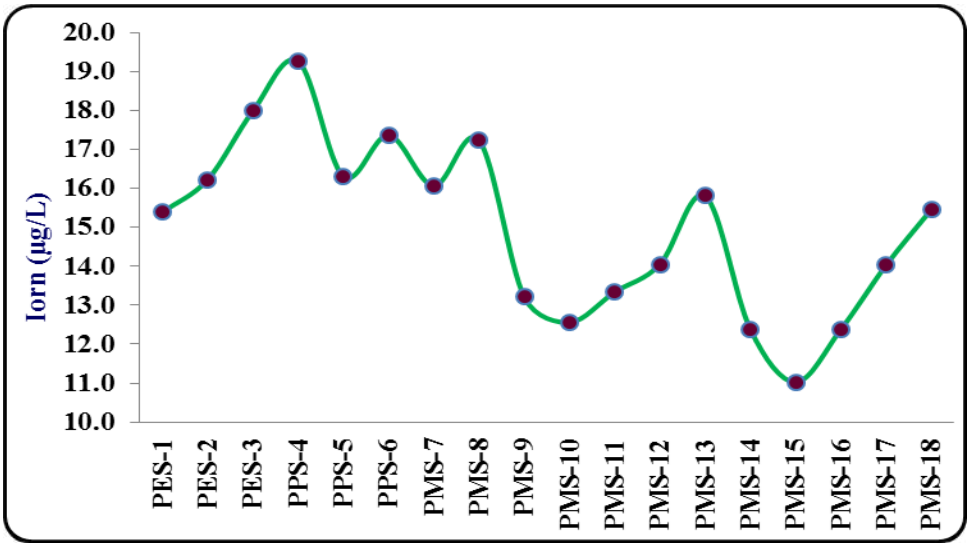


Fig. 19. Iron level recorded at various stations of estuary and Paradeep coastal waters

Zinc

The zinc level varied from 12.97 to 25.74µg/L (Fig. 20). The maximum was recorded at PES-1 and the minimum were recorded at PMS-15.

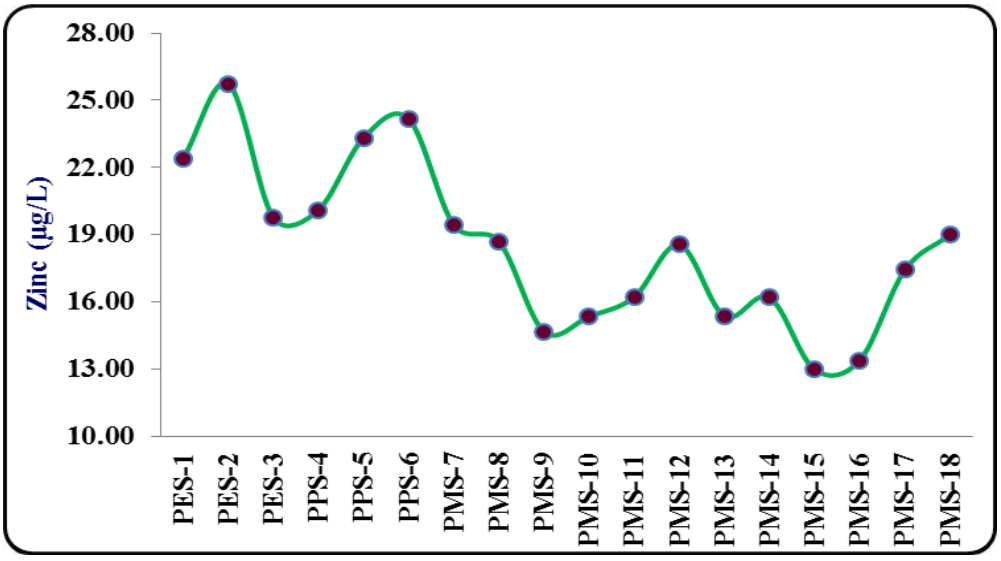


Fig. 20. Zinc level recorded at various stations of Estuary and Paradeep coastal waters

Manganese

The Manganese concentration varied from 15.43 to 44.30µg/L (Fig. 21). The maximum was recorded PES-2 and the minimum was recorded at PMS-15.

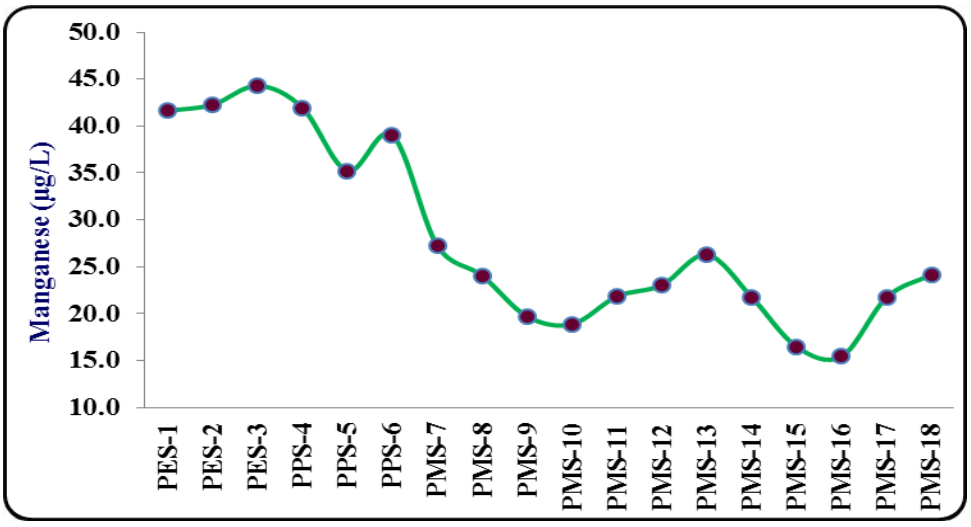


Fig. 21. Manganese concentration recorded at various stations of Estuary and Paradeep coastal waters

Cadmium

The Cadmium concentration varied from 1.33 to 2.86µg/L (Fig. 22). The maximum was recorded at PPS-5 and the minimum was recorded at PMS-11.

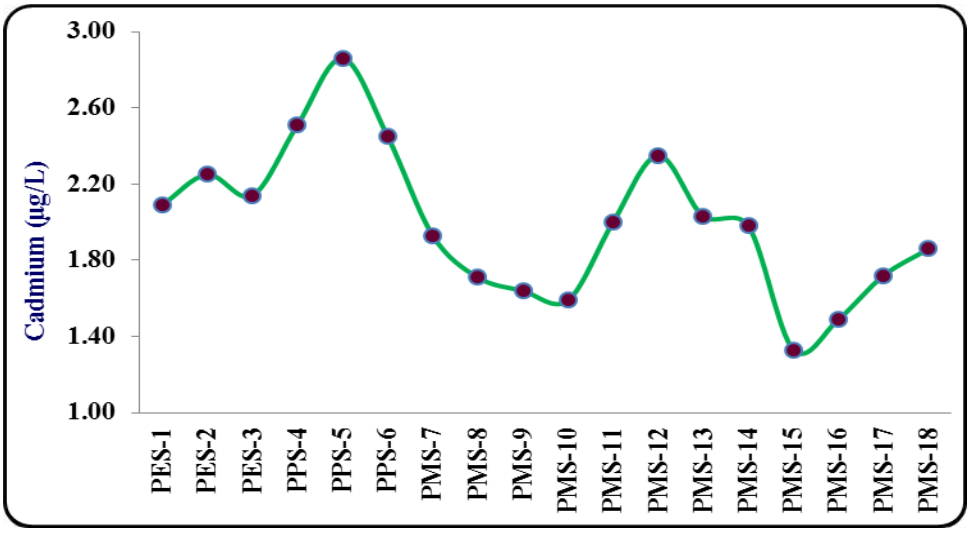


Fig. 22. Cadmium concentration recorded at various stations of Estuary and Paradeep coastal waters

Nickel

The Nickel level varied from 1.47 to 2 . 3 4 µg/L (Fig. 23). The maximum level was recorded at PES-2 and the minimum was recorded at PMS-10.

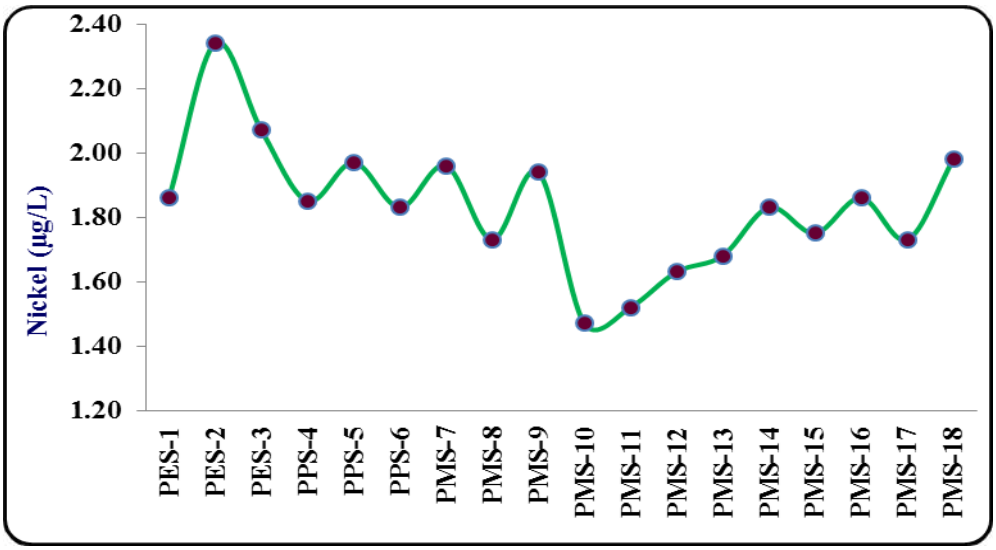


Fig. 23. Nickel level recorded at various stations of Estuary and Paradeep coastal waters

Chromium

The chromium level varied from 1.04 to 1.85µg/L (Fig. 24). The maximum value was recorded at PPS-5 and the minimum was recorded at PMS-10.

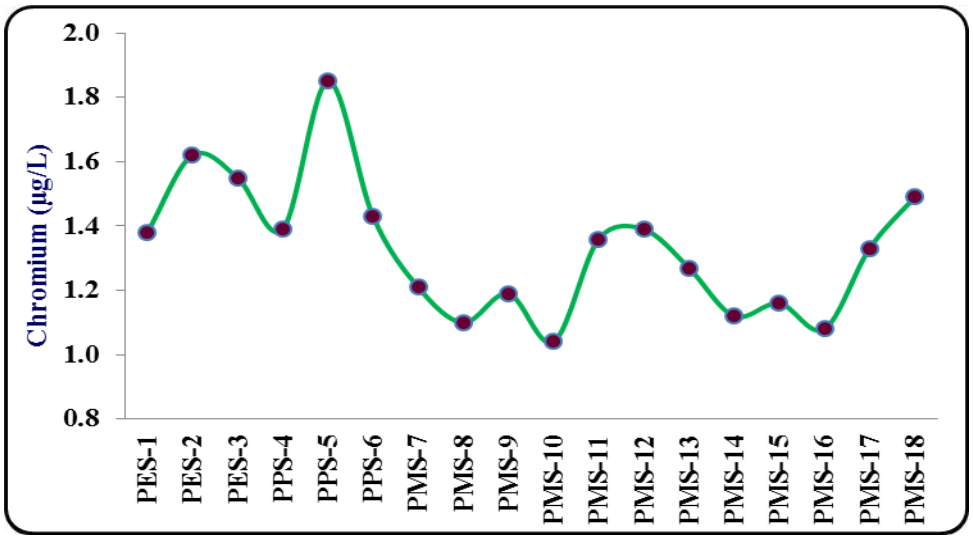


Fig. 24. Chromium level recorded at various stations at Estuary and Paradeep coastal waters

Lead

The Lead concentration ranged from 1.10 to 3.51µg/L (Fig. 25) with maximum value was recorded at PPS-5 and the minimum was recorded at PMS-15 during this survey.

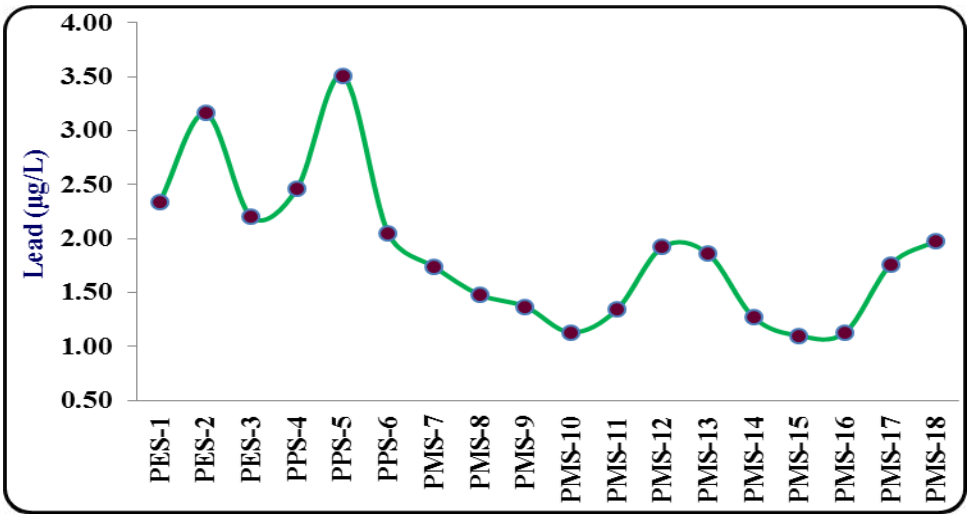


Fig. 25. Lead concentration recorded at various stations of Estuary and Paradeep coastal waters

Copper

The copper concentration varied from 3.36 to 7.38µg/L (Fig. 26). The maximum was recorded at PPS-5 and the minimum was recorded at PMS-9 during this survey.

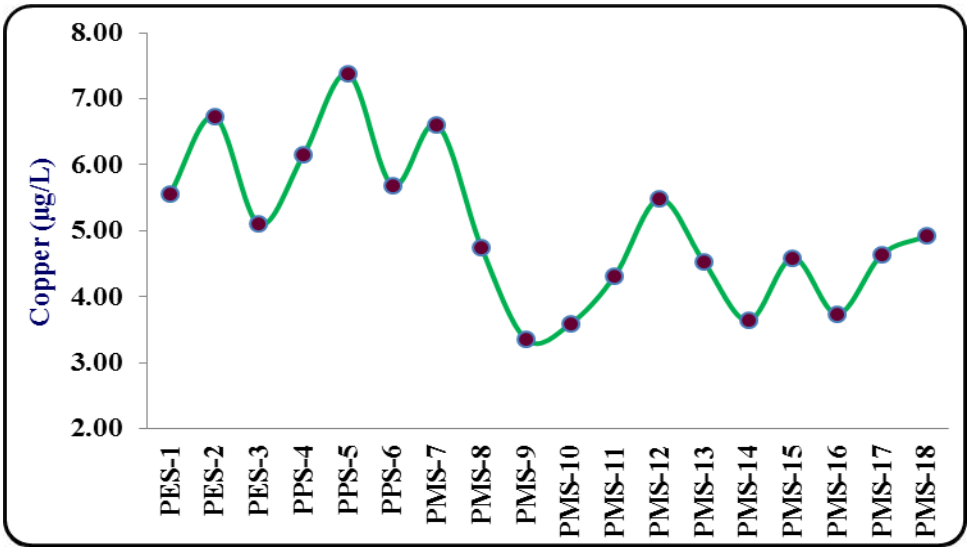


Fig. 26. Copper concentration recorded at various stations of Estuary and Paradeep coastal waters

Mercury

The mercury level varied from 0.22 to 0.41µg/L (Fig. 27). The maximum value was recorded at PPS-5 and the minimum was recorded at PMS-15 during this survey.

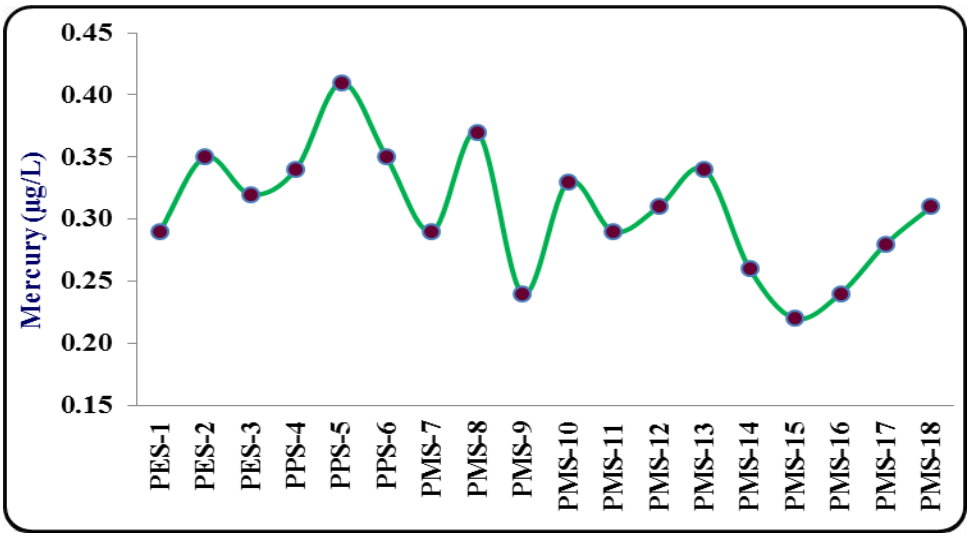


Fig. 27. Mercury level recorded at various stations at Estuary and Paradeep coastal waters

4. 2. Sediment Characteristics

Sediment pH

The maximum value (8.49) of soil pH was recorded at PMS-10 and minimum of 7.93 at PES-1 (Fig. 28).

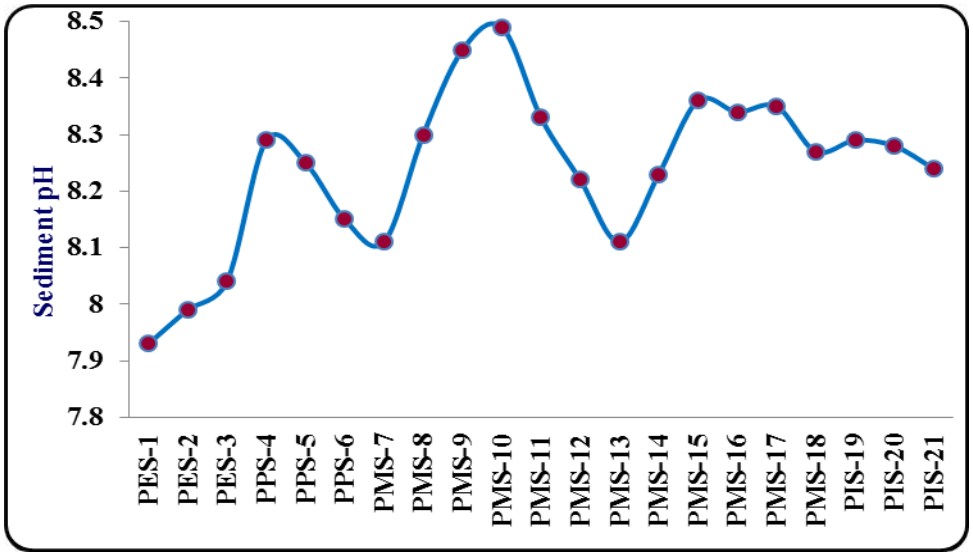


Fig. 28. Soil pH values recorded at various stations of Estuary and Paradeep coastal waters

Soil Texture

The sand content varied from 4.29 to 84.40 % with maximum value was at PIS-21 and the minimum at PPS-4; maximum Silt content (47.58%) was found at PES-1 and minimum (10.40%) at TIS-21 and the maximum Clay content (74.08%) was found at PES-2 and minimum(2.40%) at PIS-19 (Fig. 29).

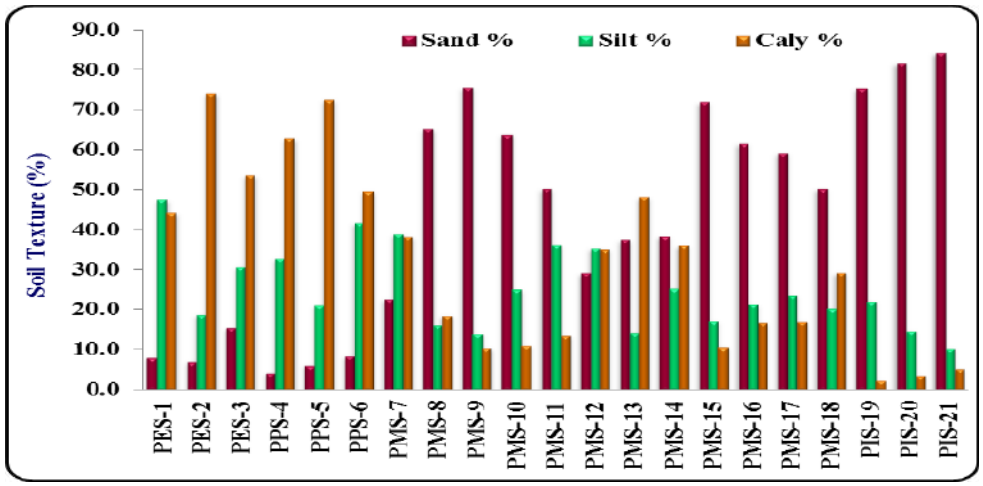


Fig. 29. Variations in soil texture recorded in various stations of Estuary and Paradeep coastal waters

Total organic Carbon

The total organic carbon ranged between 2.24 and 10.97mgC/g. The maximum level(10.97mgC/g) was found at PES-2 and minimum (4.62mgC/g) at PIS-21 (Fig. 30).

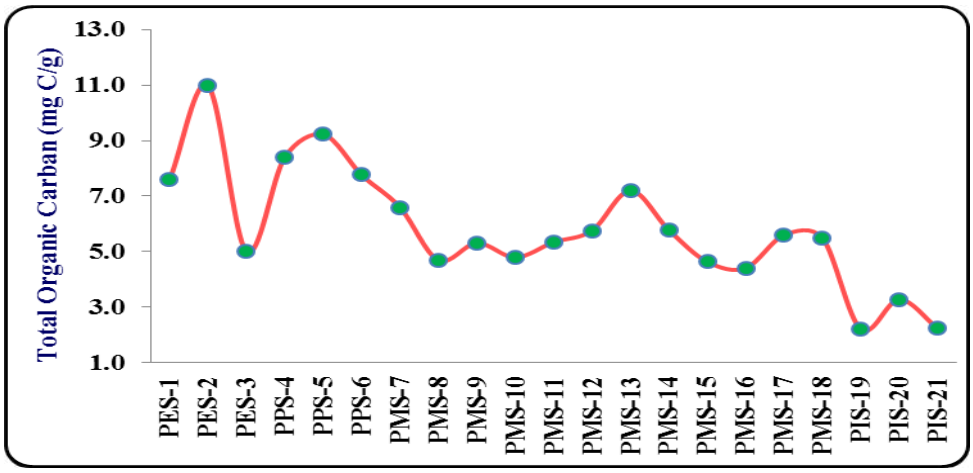


Fig. 30. Total organic carbon values recorded in various stations of Estuary and Paradeep coastal waters

Sediment PHC

The Sediment PHC level varied from 0.065 to 0.581µg/g (Fig. 31). The maximum level was recorded at PPS-5 and the minimum was recorded at PIS-20 during this survey.

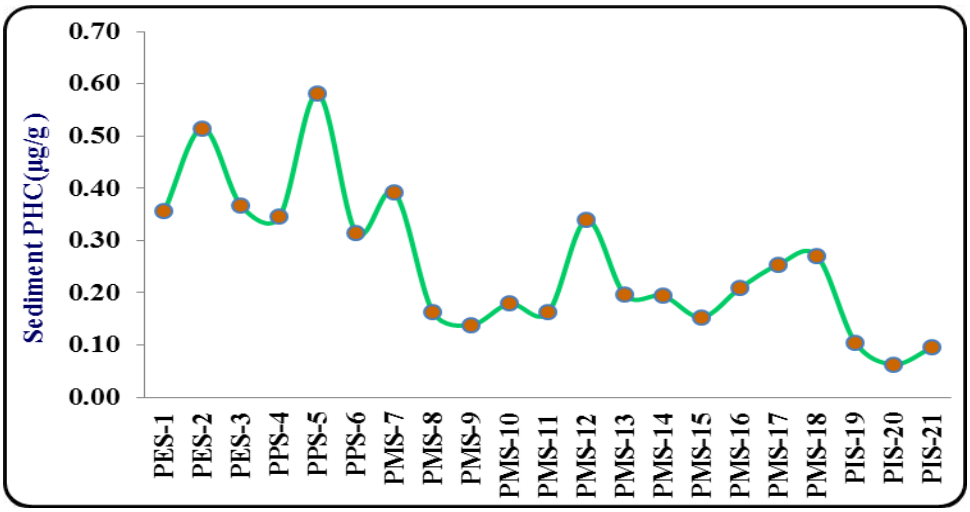


Fig. 31. Sediment PHC level recorded at various stations at Estuary and Paradeep coastal waters

4. 2. 1. Heavy Metals in sediments

Iron

The Iron level varied from 1128.90 to 1820.10µg/g (Fig. 32). The maximum was recorded at TES-2 and the minimum was recorded at PMS-9.

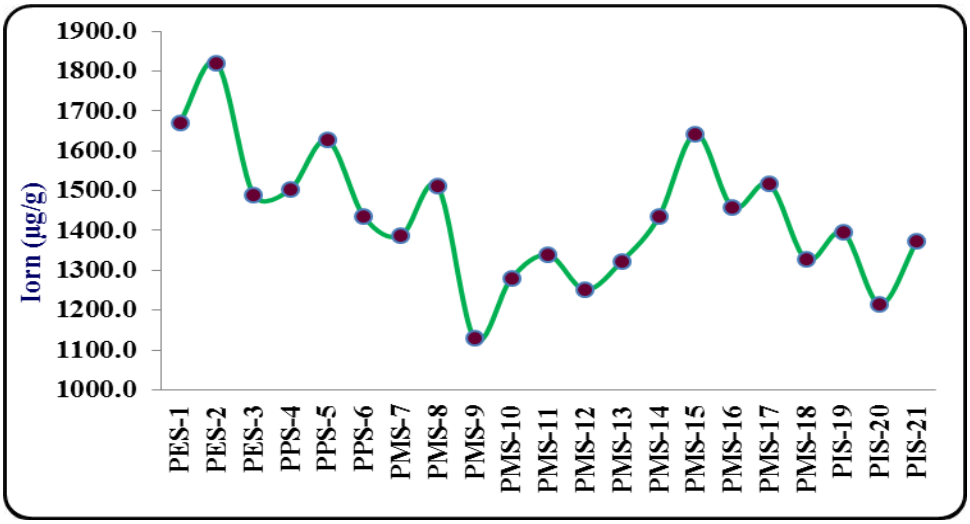


Fig. 32. Iron level recorded in various stations Estuary and Paradeep coastal waters

Zinc

Zinc concentration varied from 10.10 to 18.90µg/g (Fig. 33). The maximum level was recorded at PPS-5 and the minimum was recorded at PMS-11.

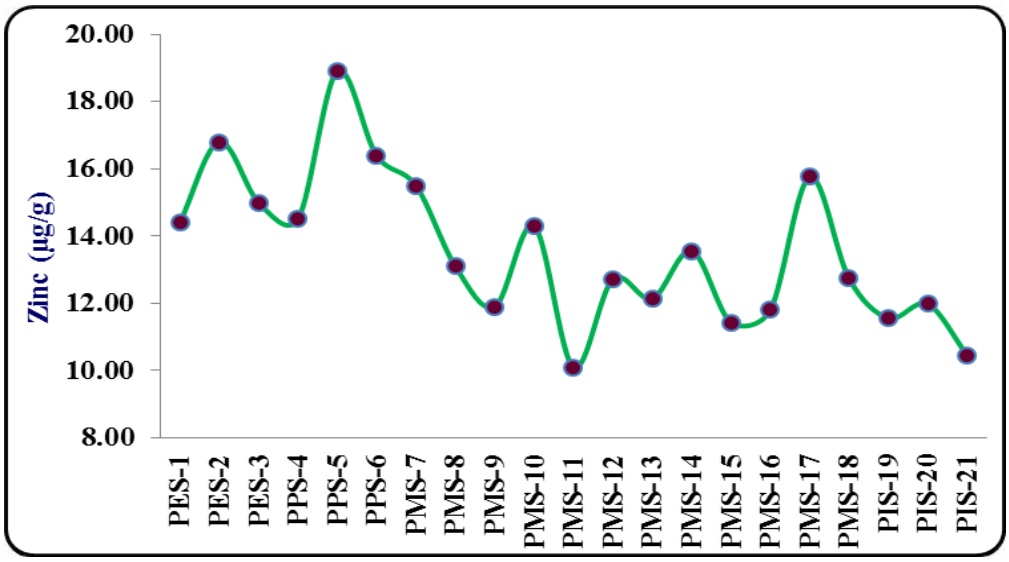


Fig. 33. Zinc concentration recorded at various stations of Estuary and Paradeep coastal waters

Manganese

The Manganese level varied from 19.80 to 61.80µg/g (Fig. 34). The maximum level was recorded at PPS-5 and the minimum was recorded at PIS-20.

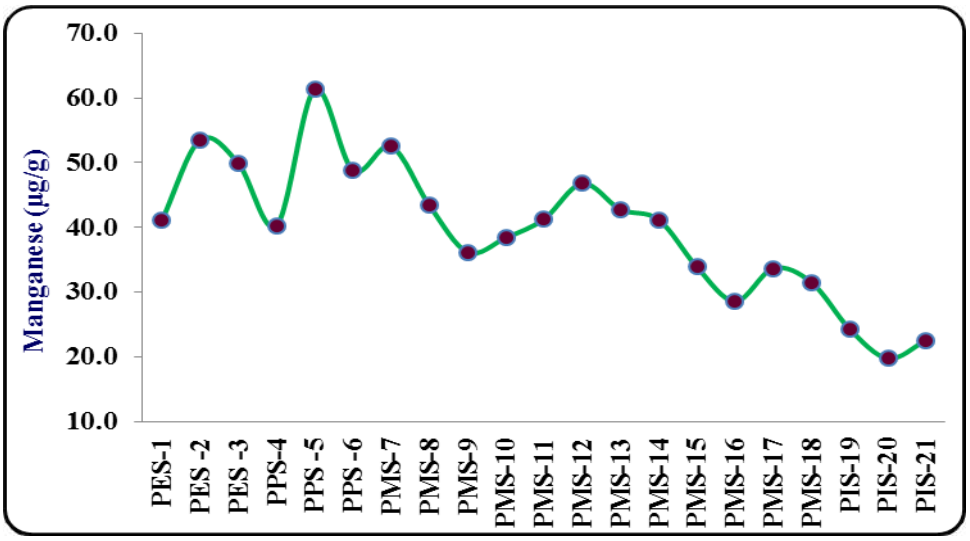


Fig. 34. Manganese level recorded at various stations of Estuary and Paradeep coastal waters

Cadmium

The Cadmium level varied from 1.02 to 2.36µg/g (Fig. 35). The maximum level was recorded at PPS-5 and the minimum was recorded at PMS-10.

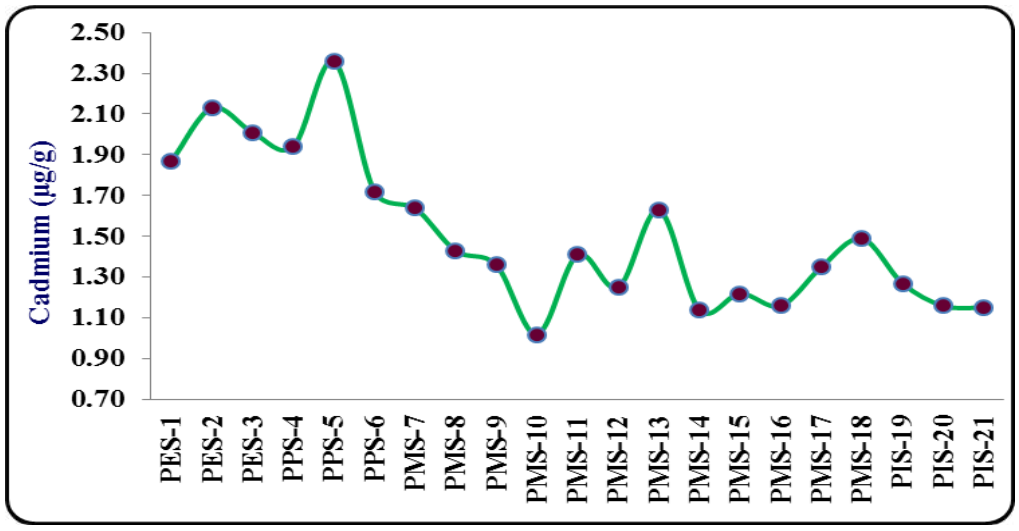


Fig. 35. Cadmium level recorded at various stations of Estuary and Paradeep coastal waters

Nickel

The nickel concentration varied from 1.65 to 4.54µg/g (Fig. 36). The maximum was recorded at PPS-6 and the minimum was recorded at PIS-200.

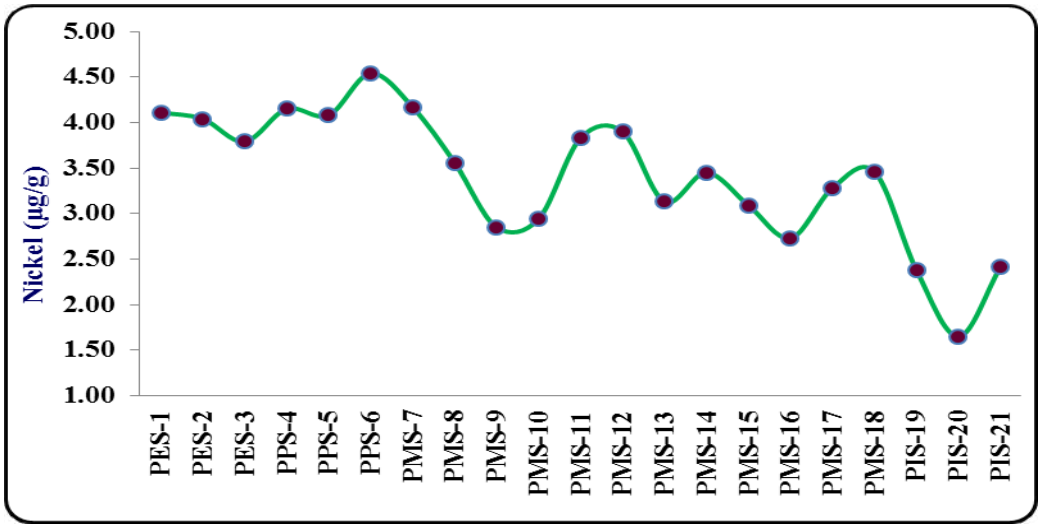


Fig. 36. Nickel concentration recorded at various stations of Estuary and Paradeep coastal waters

Chromium

The Chromium level varied from 4.23 to 10.37µg/g (Fig. 37) with the maximum wasrecorded at PES-2 and the minimum was recorded at PMS-16.

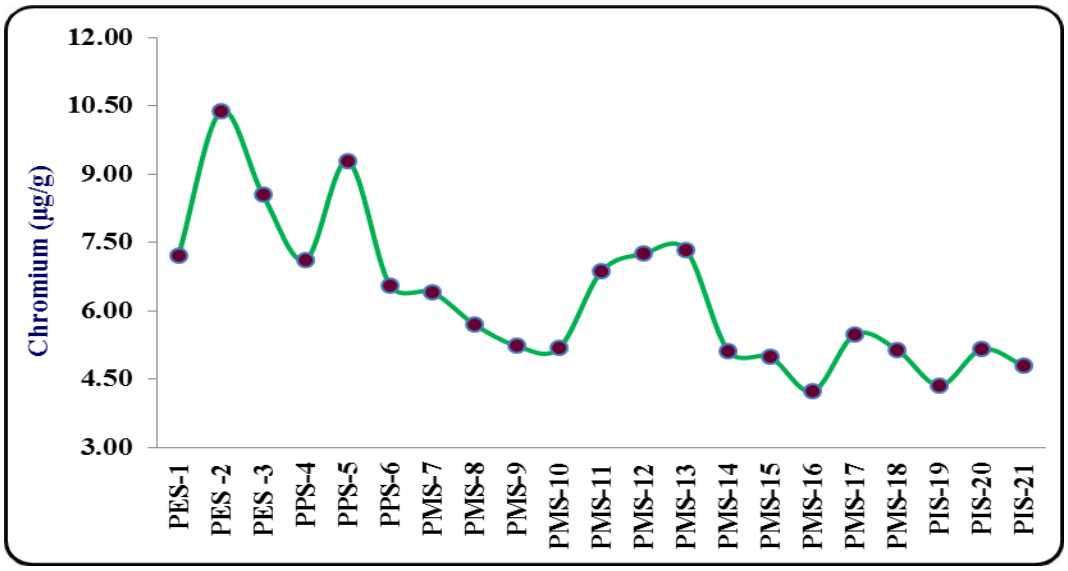


Fig. 37. Chromium level recorded at various stations of Estuary and Paradeep coastal waters

Lead

The lead concentration varied from 3.96 to 7.04µg/g (Fig. 38). The maximum value was recorded at PES-2 and the minimum was recorded at PMS-9.

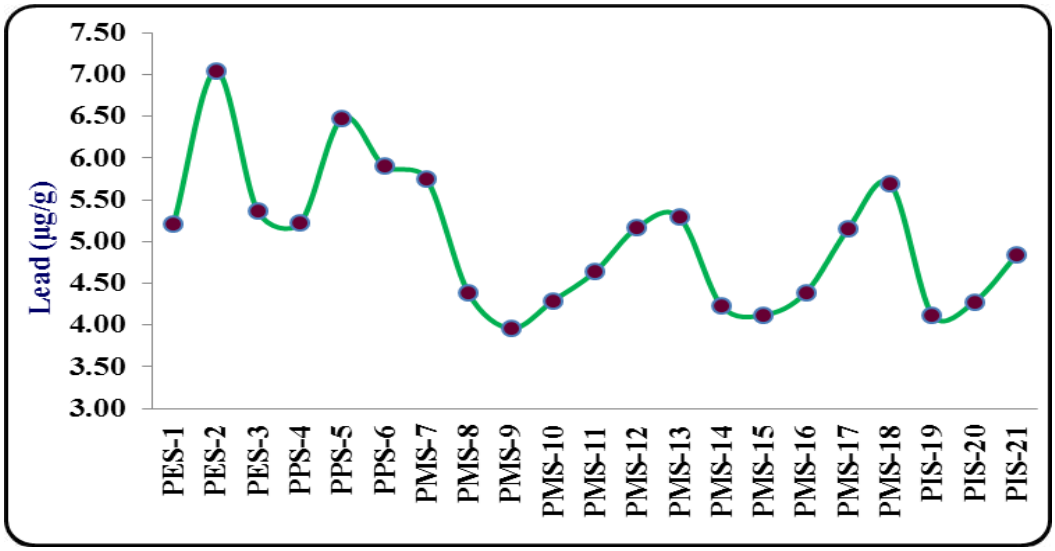


Fig. 38. Lead concentration recorded in various stations of Estuary and Paradeep coastal waters

Copper

The copper level varied from 4 .41 to 9.17µg/g (Fig. 39). The maximum value was recorded at PES-2 and the minimum was recorded at PMS-15.

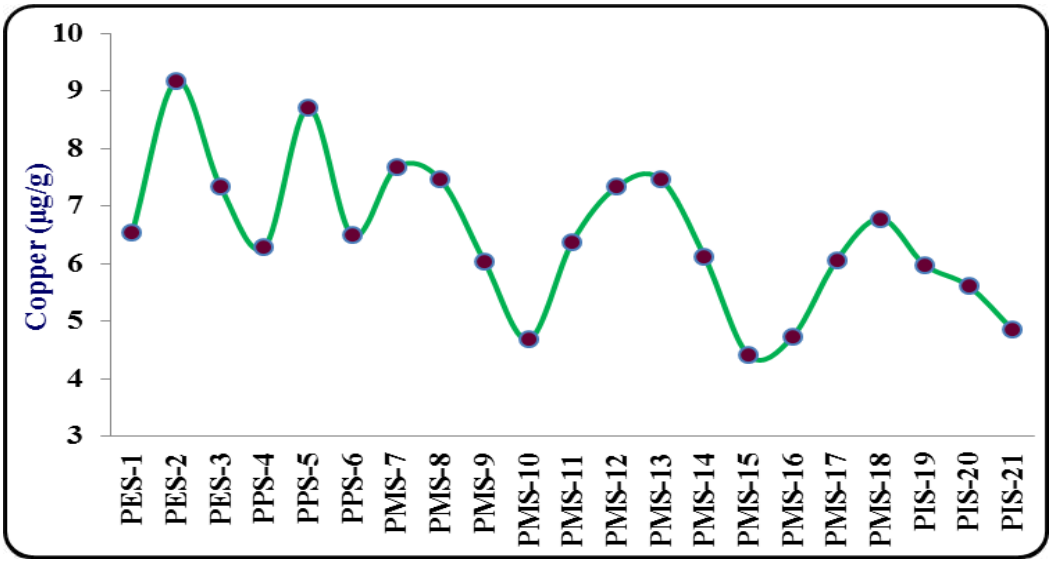


Fig. 39. Copper level recorded in various stations of Estuary and Paradeep coastal waters

Mercury

The mercury concentration varied from 0.32 to 0.76µg/g (Fig. 40). The maximum was recorded at PPS-6 and the minimum was recorded at PMS-16.

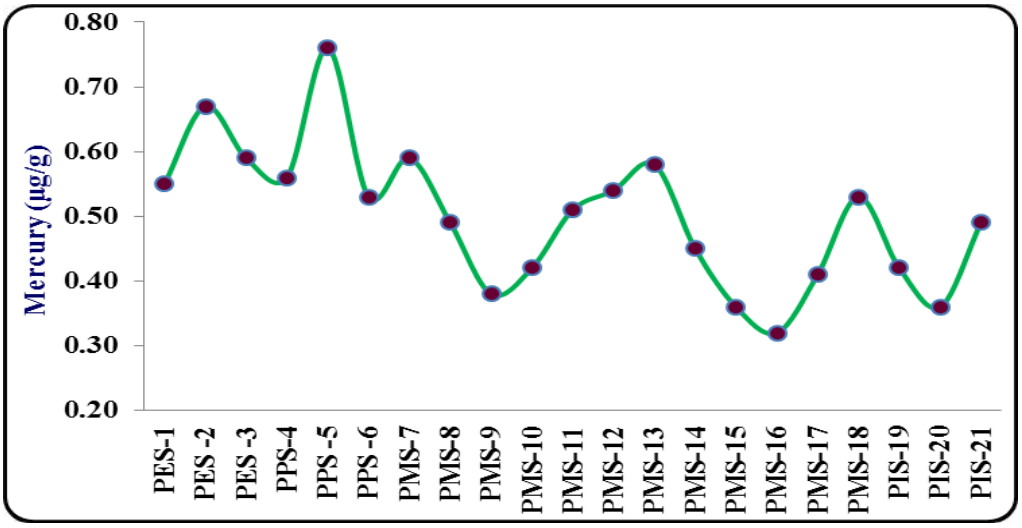


Fig. 40. Mercury concentration recorded in various stations of Estuary and Paradeep coastal waters

Principle Component Analysis (PCA)

The data on physico-chemical parameters collected in water samples were subjected to Principle component analysis to set a well-defined relation between the environmental parameters against the surveyed stations (Fig. 41). The PCA plot drawn indicated that water parameters such as Temperature, DO, Salinity, pH, TN, TP, SiO3, POC, W.PHC, Cu, TOC, Mn, Fe, Pb sand and Cr had significant correlation with the surveyed stations. Looking at the nature of correlation, the parameters such as Temperature, DO, salinity, pH, TN, TP, SiO3, Chl-a, TOC, clay, sand, Fe and Mn got correlated with stations PMS-7, PMS-8, PMS-9, PMS-10, PMS-11, PMS-12, PMS-14, and PMS-16 while the rest of the parameters showed strong correlation with stations PMS-13, PES-1, PES-2, PES-3, PPS-4, PPS-6 and PPS-5.

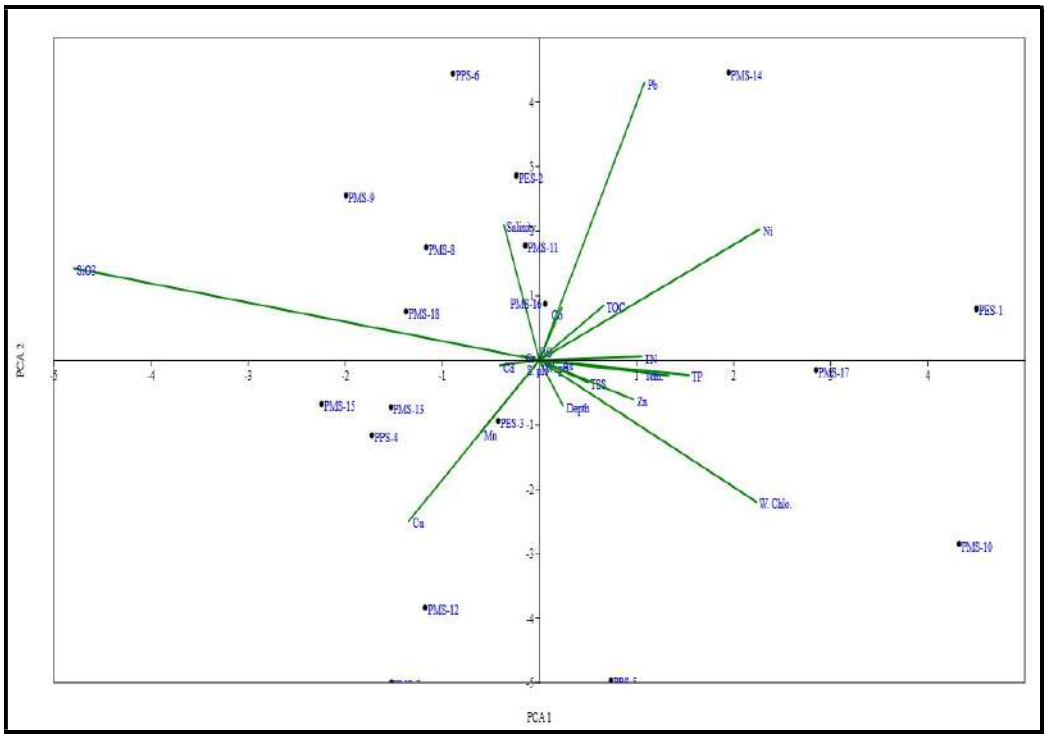


Fig. 41. Principal Component Analysis plot drawn for the correlation between various environmental variables and stations of Estuary and Paradeep coastal waters

4.3. MICROBIOLOGY

4. 3. 1. Water sample

The total viable count in water samples ranged from 11 $x10^3$ to 37 $x10^2$ CFU/ml. The maximum count was found at PES-2 and the minimum count was found at PMS-15. The Total coliform count in the samples varied from $11x10^4$ to $29x10^3$ CFU/ml with the high colony count at PES-3 and the low count at PMS-9. The *E. coli* count ranged from $10x10^2$ to $36x10^1$ CFU/ml with a maximum value at PPS-5 and the minimum value at PMS-13. The *Faecal coliform* was found to vary from $11x10^3$ to $38x10^4$ CFU/ml with higher value at PES-2 and the lower value at PMS-15. The *Pseudomonas aeurginosa* count ranged from $07x10^2$ to $17x10^3$ CFU/ml with maximum value at PPS-5 and the minimum value at PMS-15. The *Streptococcus faecalis* count ranged from $06x10^2$ to $26x10^1$ CFU/ml. The higher values were recorded at PES-1 and the lower values were recorded at PMS-14. The *Shigella* count varied from $06x10^2$ to $28x10^2$ CFU/ml with a higher value at PES-3 and the lower value at PMS-11. The *Salmonella* colony count variedfrom $07x10^3$ to $17x10^3$CFU/ml with the higher value at PES-2 and the lower value at PMS-15. The *Vibrio cholera* colony count was found to fluctuate from $05x10^2$ to $20x10^4$CFU/ml. The higher colony count was observed at PES-2 and the lower count was recorded at PMS-10. *Vibrio parahaemolyticus* colony count varied from $09x10^3$ to $17x10^4$ CFU/ml with the maximum value at PPS-5 and minimum value at PMS-18 (Table 2).

Table 2. Bacterial populations recorded in water sample at Estuary and Paradeep coastal waters

Station ID	FC	TVC	TC	EC	VC	VP	PA	SF	SH	SL
PES-1	37 x10^4	31 x10^4	19 x10^4	26 x10^2	12 x10^3	16 x10^3	10 x10^4	26 x10^1	11 x10^3	15 x10^3
PES-2	38 x10^4	35 x10^3	23 x10^4	33 x10^1	20 x10^4	15 x10^3	17 x10^3	14 x10^4	15 x10^3	17 x10^3
PES-3	36 x10^4	33 x10^3	29 x10^4	27 x10^1	14 x10^4	14 x10^3	05 x10^3	15 x10^3	28 x10^2	13 x10^2
PPS-4	33 x10^4	28 x10^3	08 x10^2	28 x10^1	16 x10^3	15 x10^4	13 x10^4	12 x10^4	14 x10^3	11 x10^3
PPS-5	30 x10^3	37 x10^2	21 x10^3	36 x10^1	17 x10^3	17 x10^4	12 x10^3	12 x10^3	21 x10^2	10 x10^3
PPS-6	30 x10^3	24 x10^3	18 x10^4	30 x10^1	14 x10^4	16 x10^3	12 x10^4	11 x10^4	17 x10^3	16 x10^3
PMS-7	31 x10^4	21 x10^3	20 x10^4	14 x10^1	18 x10^4	16 x10^4	15 x10^4	17 x10^4	23 x10^3	13 x10^3
PMS-8	27 x10^4	23 x10^2	13 x10^3	20 x10^1	14 x10^4	12 x10^4	13 x10^4	10 x10^4	19 x10^3	09 x10^3
PMS-9	29 x10^4	16 x10^3	10 x10^3	21 x10^2	07 x10^2	12 x10^3	10 x10^2	11 x10^4	09 x10^2	11 x10^2
PMS-10	32 x10^3	11 x10^3	15 x10^3	19 x10^1	05 x10^2	12 x10^4	09 x10^2	15 x10^4	19 x10^3	13 x10^3
PMS-11	14 x10^4	21 x10^4	21 x10^3	12 x10^2	16 x10^1	13 x10^2	11 x10^4	12 x10^2	06 x10^2	08 x10^2
PMS-12	12 x10^4	18 x10^4	18 x10^4	13 x10^2	10 x10^4	11 x10^2	10 x10^4	10 x10^2	08 x10^2	13 x10^2
PMS-13	18 x10^4	19 x10^4	21 x10^4	10 x10^2	07 x10^3	10 x10^2	11 x10^2	08 x10^2	11 x10^2	11 x10^2
PMS-14	13 x10^4	15 x10^4	19 x10^3	15 x10^2	10 x10^2	10 x10^2	13 x10^3	06 x10^2	08 x10^2	09 x10^2
PMS-15	11 x10^3	16 x10^4	12 x10^3	13 x10^5	06 x10^2	12 x10^3	07 x10^2	10 x10^2	09 x10^3	07 x10^3
PMS-16	15 x10^3	10 x10^4	11 x10^4	16 x10^5	09 x10^3	10 x10^3	08 x10^2	09 x10^3	10 x10^3	08 x10^3
PMS-17	19 x10^3	14 x10^4	15 x10^4	17 x10^4	12 x10^2	11 x10^3	09 x10^3	11 x10^3	09 x10^3	10 x10^3
PMS-18	13 x10^3	12 x10^5	17 x10^4	11 x10^3	13 x10^4	09 x10^3	10 x10^4	08 x10^3	08 x10^3	09 x10^3

4. 3. 2. Sediment sample

With respect to sediment samples, the total viable count in sediment samples ranged from $16x10^2$ to $40x10^4$ CFU/g. The maximum was found at PES-1 and the minimum value was found at PMS-16. The Total coliform count was found to vary from $16x10^3$ to $39x10^4$ CFU/g with the higher value at PPS-5 and the lower value at PMS-15. The *E. coli* count ranged from $15x10^3$ to $40x10^5$CFU/g with the higher value at PES-3 and the lower value at PIS-20. The *Faecal coliform* count in the samples varied from $15x10^3$ to $38x10^5$ CFU/g with the higher colony count at PES-3 and the lower count at PMS-10. *Pseudomonas aeurginosa* counts ranged from 10 $x10^4$ to 18 $x10^5$ CFU/g with the maximum at PMS-17 and the minimum at TMS-15. The *Streptococcus faecalis* count ranged from $10x10^4$ to $25x10^5$ CFU/g. The higher value was recorded at PES-2 and the lower value was recorded at PMS-12. The *Shigella* counts varied from $12x10^4$ to $19x10^4$ CFU/g with the higher value at PES-1 and lower value at PMS-16. *Salmonella* colony counts varied from $11x10^2$ to $26x10^4$ CFU/g with the maximum value at PPS-5 and the minimum value at PMS-11. *Vibrio parahaemolyticus* colony count varied from $10x10^5$ to $22x10^4$ CFU/g. The higher value was found at PPS-5 and the lower value at PMS-16. The other species *Vibrio cholerae* colony was found to range from $13x10^4$ to $33x10^3$ CFU/g with the maximum colony count at PPS-5 and the minimum count was observed at PMS-15 (Table 3).

Table 3. Bacterial populations recorded in sediment sample at Estuary and Paradeep coastal waters

Station ID	FC	TVC	TC	EC	VC	VP	PA	SF	SH	SL
PES-1	32 x10^5	40 x10^4	31 x10^4	32 x10^4	25 x10^3	19 x10^3	14 x10^3	24 x10^4	19 x10^4	24 x10^4
PES-2	45 x10^5	36 x10^4	32 x10^5	35 x10^5	27 x10^3	19 x10^4	16 x10^3	25 x10^5	18 x10^5	22 x10^3
PES-3	38 x10^5	23 x10^4	36 x10^4	40 x10^5	23 x10^3	21 x10^3	17 x10^3	21 x10^4	15 x10^3	25 x10^4
PPS-4	20 x10^5	24 x10^4	37 x10^4	36 x10^5	15 x10^3	15 x10^3	12 x10^3	18 x10^4	16 x10^3	25 x10^3
PPS-5	37 x10^4	28 x10^4	39 x10^4	39 x10^4	33 x10^3	22 x10^4	14 x10^4	11 x10^4	18 x10^4	26 x10^4
PPS-6	17 x10^5	23 x10^5	27 x10^5	33 x10^5	15 x10^4	13 x10^4	13 x10^4	11 x10^2	14 x10^4	13 x10^4
PMS-7	18 x10^4	27 x10^5	22 x10^4	34 x10^5	18 x10^4	15 x10^4	12 x10^4	13 x10^4	12 x10^4	16 x10^3
PMS-8	21 x10^4	23 x10^4	19 x10^5	31 x10^3	14 x10^4	17 x10^4	12 x10^4	12 x10^4	15 x10^4	12 x10^3
PMS-9	17 x10^3	21 x10^4	24 x10^5	29 x10^3	11 x10^2	13 x10^4	13 x10^4	15 x10^4	10 x10^3	15 x10^4
PMS-10	15 x10^3	19 x10^5	22 x10^4	21 x10^4	12 x10^2	12 x10^5	12 x10^5	13 x10^4	09 x10^3	12 x10^4
PMS-11	18 x10^4	33 x10^5	22 x10^3	19 x10^4	13 x10^5	11 x10^2	12 x10^3	12 x10^2	14 x10^4	11 x10^2
PMS-12	20 x10^4	39 x10^3	19 x10^3	21 x10^3	16 x10^2	13 x10^2	12 x10^3	10 x10^4	13 x10^3	13 x10^2
PMS-13	29 x10^4	31 x10^4	20 x10^3	23 x10^3	21 x10^5	15 x10^5	15 x10^4	14 x10^5	16 x10^3	23 x10^4
PMS-14	21 x10^5	32 x10^4	21 x10^4	24 x10^5	27 x10^5	18 x10^4	13 x10^4	12 x10^3	13 x10^4	21 x10^4
PMS-15	19 x10^5	18 x10^2	16 x10^3	20 x10^5	13 x10^4	16 x10^5	10 x10^4	11 x10^3	14 x10^5	12 x10^4
PMS-16	20 x10^5	16 x10^2	18 x10^3	21 x10^5	14 x10^4	10 x10^5	12 x10^5	15 x10^3	12 x10^4	17 x10^4
PMS-17	22 x10^5	20 x10^4	25 x10^5	26 x10^5	20 x10^5	14 x10^5	18 x10^5	13 x10^3	14 x10^5	14 x10^4
PMS-18	19 x10^5	25 x10^4	32 x10^3	25 x10^3	24 x10^4	13 x10^4	16 x10^5	19 x10^5	16 x10^4	15 x10^4
PIS-19	21 x10^5	26 x10^5	26 x10^3	18 x10^3	20 x10^3	15 x10^4	16 x10^4	16 x10^4	14 x10^4	12 x10^3
PIS-20	19 x10^4	28 x10^5	25 x10^3	15 x10^3	16 x10^5	14 x10^5	17 x10^5	19 x10^4	15 x10^5	15 x10^3
PIS-21	26 x10^4	20 x10^4	24 x10^4	17 x10^3	20 x10^5	17 x10^5	16 x10^2	21 x10^5	16 x10^4	22 x10^2

4.4 Pigments concentration

Chlorophyll –a (mg/m^3), Phaeopigments (mg/m^3) and Total biomass (ml/100m^3)

In the present study, the chlorophyll '*a*' in water sample varied from 0.886 to 1.956 mg/m^3, with maximum at PMS-15 and minimum at PES-2. The Phaeopigments content varied from 0.538 to 0.971 mg/m^3 with maximum was at PMS-15 and the minimum was observed at PES-2. The Total biomass values varied from 2.106 to 4.615 ml/100m^3, with maximum at PMS-9 and minimum at PPS-4 (Table 4).

Table 4. Chlorophyll *a*, Phaeopigments and total biomass recorded in Mahanadi estuary and Paradeep coastal waters

Stations	Chlorophyll 'a' (mg/m^3)	Phaeopigments (mg/m^3)	Total biomass (ml/100m^3)
PES-1	0.976	0.673	2.845
PES-2	0.886	0.538	2.963
PES-3	1.168	0.794	3.236
PPS-4	1.059	0.775	2.106
PPS-5	1.032	0.652	3.728
PPS-6	1.692	0.782	2.634
PMS-7	1.863	0.815	2.587
PMS-8	1.577	0.784	3.501
PMS-9	1.485	0.769	4.615
PMS-10	1.073	0.913	4.014
PMS-11	0.951	0.831	2.845
PMS-12	1.945	0.752	2.963
PMS-13	1.593	0.868	3.236
PMS-14	0.981	0.775	3.006
PMS-15	1.956	0.971	3.728
PMS-16	1.153	0.844	2.634
PMS-17	1.367	0.884	2.587
PMS-18	0.984	0.766	3.501

Primary productivity

The primary productivity was measured using the dark and light reaction method. The values ranged from 116.37 to 157.06mgCm^{-3}d^{-1}. The maximum value was recorded at PMS-15 and minimum value at PES-2 (Fig. 42).

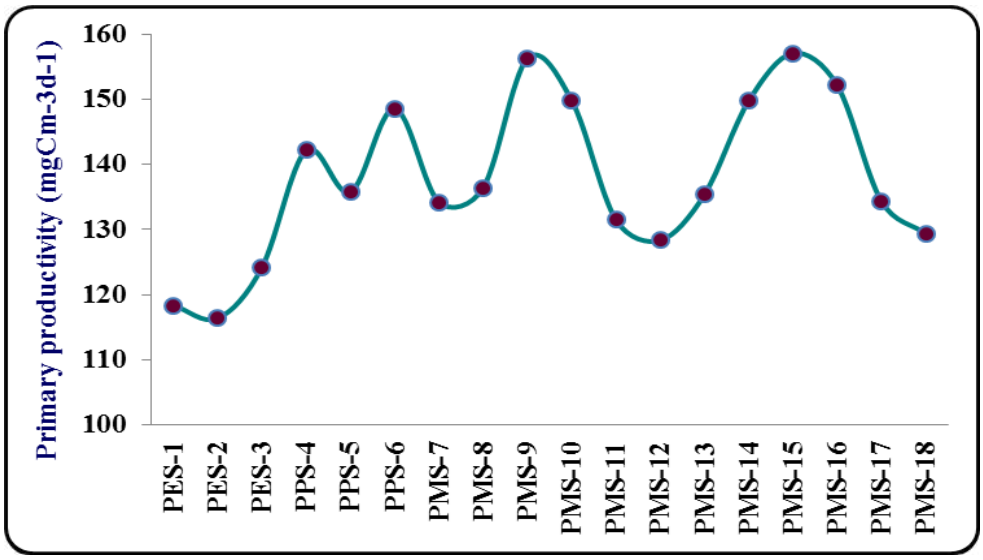


Fig. 42. Primary productivity values recorded at various stations of Estuary and Paradeep coastal waters

PLANKTON

4.4.1 Phytoplankton

In the present study, as many as 49 phytoplankton species belonging to three major groups namely Bacillariophyceae (Diatom), Dinophyceae (Dinoflagellates) and Cyanophyceae (Cyanobacteria) were recorded in Thiruvottiyurkuppam coastal area. Of these, Bacillariophyceae were found to be the dominant group with 36 species, Dinophyceae formed next group with 10 species and Cyanophyceae with three species.

Among the Bacillariophyceae, *Skeletonema costatum, Cylindrotheca closterium* and *Odentella sinensis* was observed highly dominated in all the stations and followed by *Asterionella glacialis Chaetoceros curvisetus, Rhizosolenia alata* and *Triceratium reticulatum* also were found in all sampling sites except station second (PMS-10) in Mahanadi estuary and

Paradeep coastal waters. The Dinophyceae, (*Dinophysis caudate, Protocentrum micans* and *Pyrophagus stenii*) and Cyanophyceae (*Trichodesmium erythraeum, Merimopedia glauca*) similarly were recorded in all the twelve sampling sites. Among the various species, *Bacteriastrum comosum, Gramatophora marina, Gyrosigma balticum, Leptocylindrus danicus, Navicula hennedyii, Nitzschia longissima, Odentella mobilensis, Pseudonitzschia inflatula, Plonktonella sol, Rhizosolenia alata, Rhizosolenia styliformis, Thalassiosira punticera, Thalassiothrix frauenfeldii, Ceratium furca, Ceratium extensum, Ceratium macroceros, Ceratium tripos, Ditylum brightwellii, Triceratium favus, Protocentrum micans* and *Pyrophagus stenii* were the most abundant forms. The distribution and abundance of phytoplankton varied considerably following seasonal environmental fluctuations.

Population density

Density of phytoplankton varied from 6,915 to 11,228 Cells/l with maximum was at PMS-10 and minimum at PES-2 (Fig. 43).

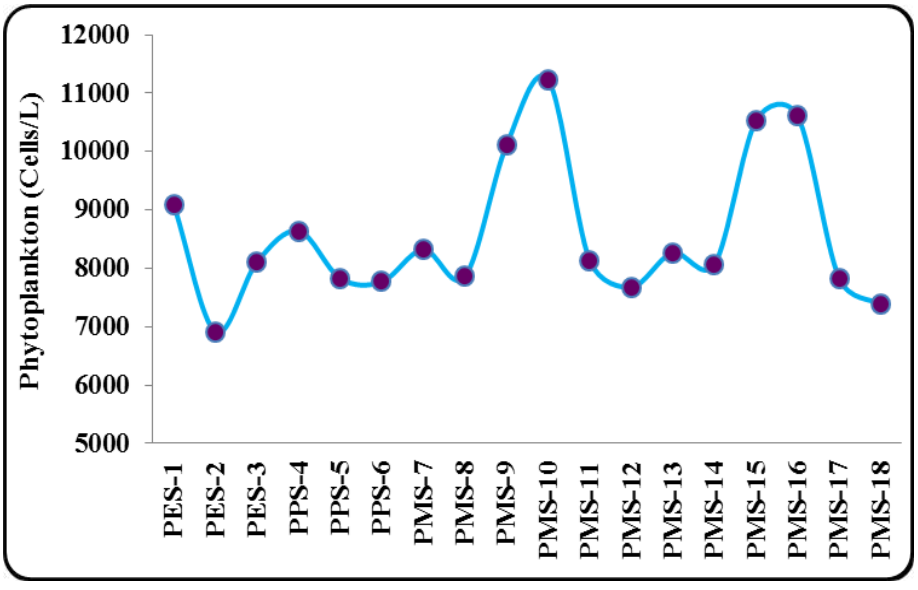


Fig. 43. Population density of Phytoplankton in various stations of Mahanadi estuary and Paradeep coastal waters

Percentage composition

When the results of percentage composition of phytoplankton were looked at, (Bacillariophyceae) Diatoms constituted the maximum with 73% of the total followed by (Dinophyceae) Dinoflagellates with 21% and Blue Green Algae (Cyanophyceae) with 6% of the total (Fig. 44).

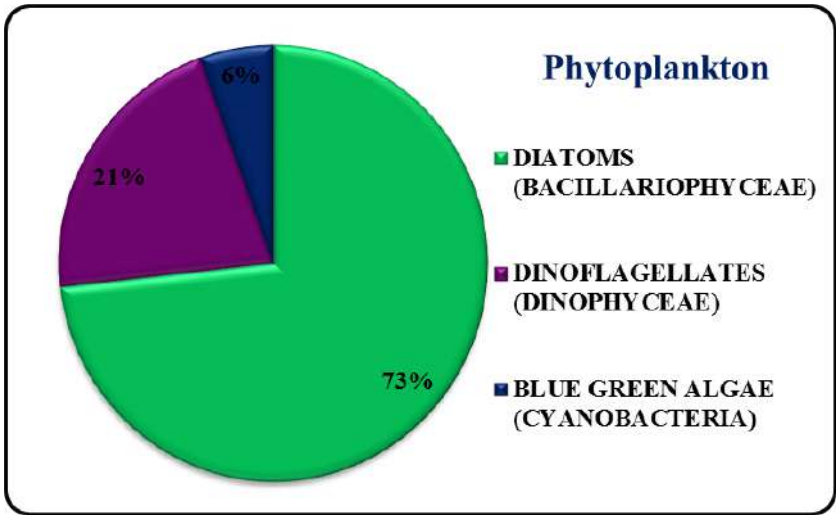


Fig. 44. Percentage composition of Phytoplankton in various stations of Mahanadi estuary and Paradeep coastal waters

Diversity indices

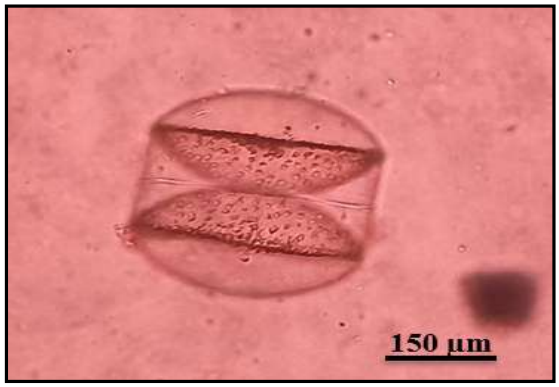
The phytoplankton species diversity (H') varied from 2.365 to 3.811 with maximum value was at PMS-10 and minimum at PES-2. The species richness (d) ranged between 4.528 and 6.879 with maximum was at PPS-5 and minimum at PMS-15. The species evenness varied from 0.545 to 0.924 with maximum value was at PMS-15 and minimum at PES-2 (Table-5).

Table 5. Diversity indices; Shannon diversity (H'); Margalef richness (d) and Pielou's evenness (J') calculated for Phytoplankton in Mahanadi estuary and Paradeep coastal waters

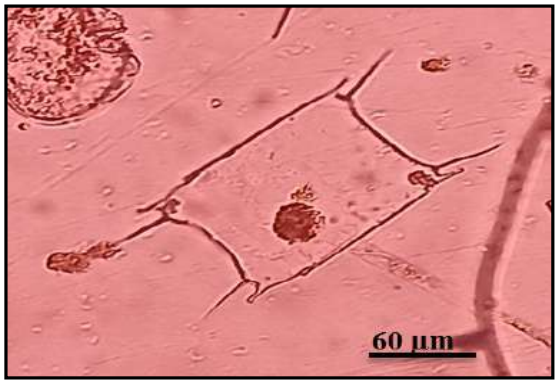
Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
PES-1	2.494	5.967	0.594
PES-2	2.365	6.011	0.545
PES-3	2.788	6.815	0.615

PPS-4	2.592	5.916	0.629
PPS-5	3.122	6.879	0.634
PPS-6	3.193	5.754	0.74
PMS-7	3.252	5.035	0.728
PMS-8	2.983	5.634	0.605
PMS-9	3.436	5.653	0.814
PMS-10	3.811	4.691	0.623
PMS-11	3.176	5.361	0.631
PMS-12	2.855	5.848	0.672
PMS-13	3.011	5.583	0.594
PMS-14	2.988	6.233	0.770
PMS-15	3.149	4.528	0.924
PMS-16	3.326	6.824	0.623
PMS-17	3.271	5.328	0.791
PMS-18	3.388	5.811	0.734

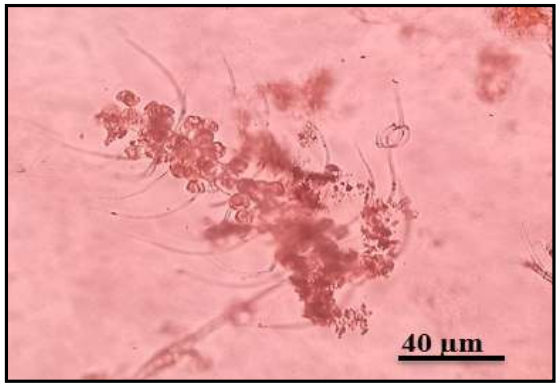
PLATE -I COMMON SPECIES OF PHYTOPLANKTON



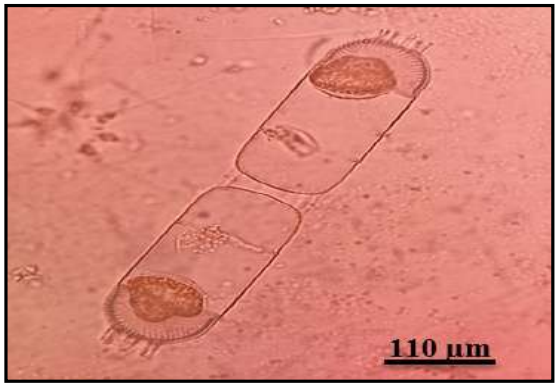
Coscinodiscus granii



Odontella mobiliensis

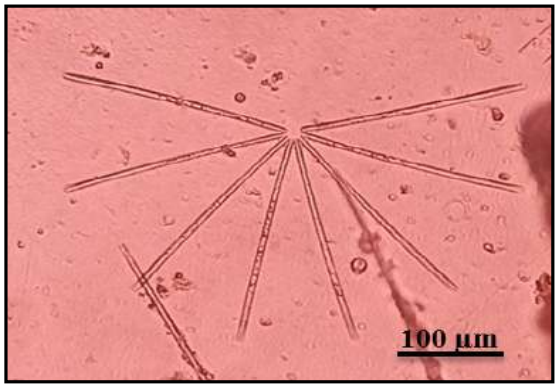


Chaetoceros coarctatus

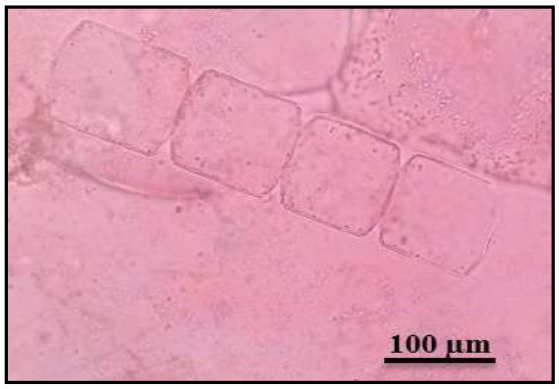


Stephanopyxis palmeriana

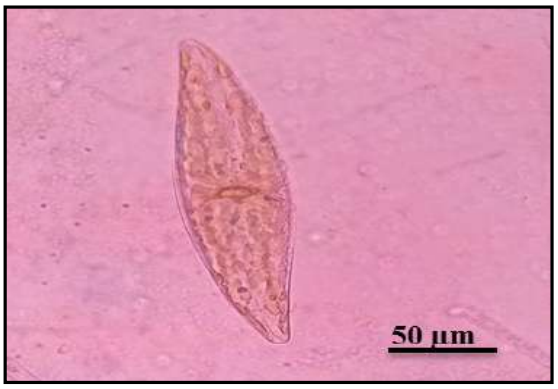
Gyrosigma sp.



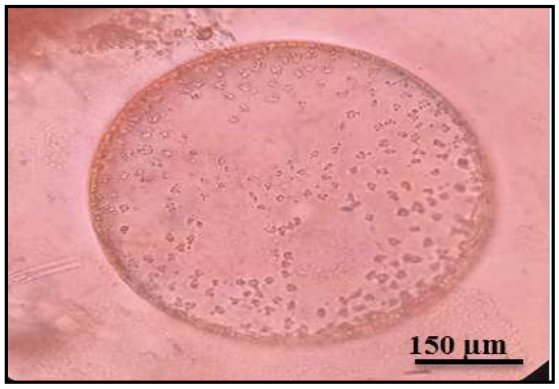
Thalassionema nitzschioides



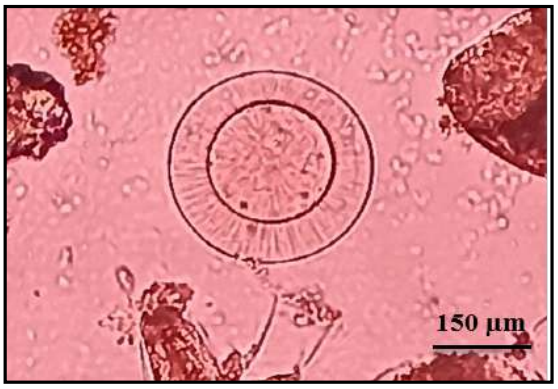
Lauderia annulata



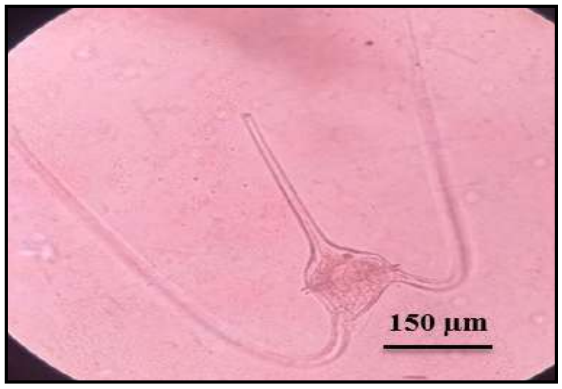
Pleurosigma normanii



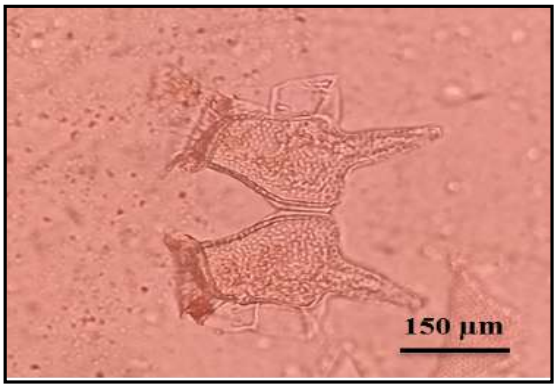
Coscinodiscus centralis



Planktoniella sol



Ceratium macroceros



Dinophysis caudata

Zooplankton

During the survey, 6 groups of macro zooplankton namely, Calanoid copepod, Cyclopoid copepod, Harpacticoid copepod, Oligotrichea, Foraminifera and Other Crustacean forms and 4 groups of micro zooplankton namely, Mollusca, Chaetognatha, Decapoda and Annelida were recorded. In them, Calanoid Copepod was found to be the dominant group with 13 species. Cyclopoid copepod and Harpacticoid copepod came as next dominant group with 6 species each. The Spirotrichea, Protozoans and Other Crustacean forms were observed with 4 species from each group, Rotatoria and Larvacean were observed with 2 species, Mollusca, Cladocera, Decapoda and Annelida were recorded 1 species from each division of total zooplankton abundance.

The common Calanoid copepod, Cyclopoid copepod, Harpacticoid copepod, Spirotricha, Foraminifera and Other Crustacean species are; *Acartia danae, Acartia erythraea, Acartia spinicauda, Acrocalanus gibber, Acrocalanus gracilis, Centropages furcatus, Nannocalanus minor, Paracalanus parvus, Pseudodiaptomus serricaudatus, Temora turbinate, Clytmnestra scutellata, Euterpina acutifrons, Corycaeus danae, Corycaeus catus, Oithona rigida, Oithona similis, Oncaea venusta, Favella brevis, Favella philipiensis, Tintinnopsis tocantinensis, Globigernia bulloides* and *Globigernia opima* were found during this survey. Mollusca, Cladocera, Decapoda and Annelida species such as *Daphina* sp., *Lucifer hanseni,* Bivalve veliger, Barnacle nauplii, Crustacean nauplii, Copepod nauplii, Gastropod veliger and Polychaete larvae showed consistency in their occurrence in the samples collected in various stations.

Population density

The zooplankton density varied from 4888 to 6680Nos/m^3 with maximum at PMS-15 and minimum at PES-2 (Fig. 45).

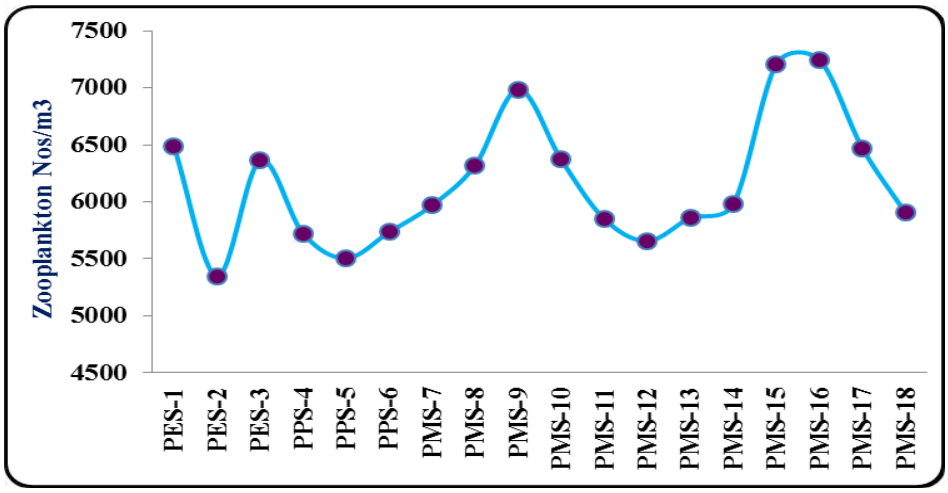


Fig. 45. Population density of zooplankton recorded in various stations of Estuary and Paradeep coastal waters

Percentage composition

Calanoid copepod emerged as the dominant group by constituting 29% and followed by Cyclopoid copepod with 16%, Harpacticoid copepod with 12%, Protozoa with 10%, and Spirotrichea and Other Crustacean forms with 9% each and with 6%, Rotatoria with 4%, and Annelida with 3% each, Mollusca Larvacean, Decapoda and Hydroida with 2% the total percentage composition (Fig. 46).

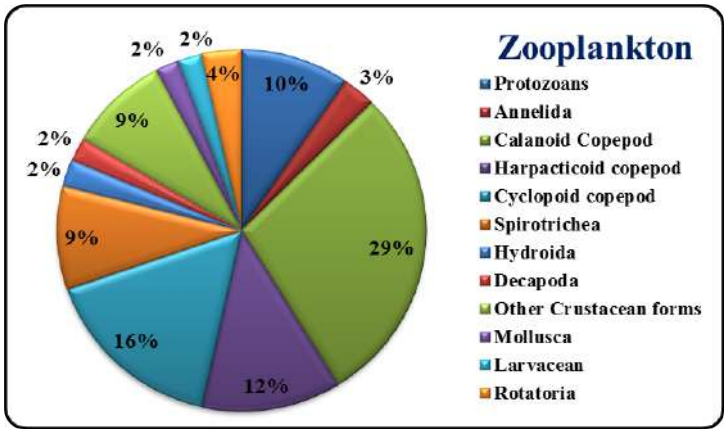


Fig. 46. Percentage composition of Zooplankton in various stations of Mahanadi estuary and Paradeep coastal waters

Diversity Indices

As done for phytoplankton, the zooplankton species diversity (H') varied from 2.592 to 3.846 with maximum was in PMS-16 and minimum in PPS-5. The species richness (d) ranged between 4.873 and 7.186 with maximum in PES-2 and minimum in PMS-9. The species evenness varied from 0.645 to 0.941 with the maximum in PMS-10 and minimum in PES-2 (Table 6).

Table 6. Diversity indices, Shannon diversity (H'); Margalef richness (d) and Pielou's evenness (J') calculated for zooplankton in Estuary and Paradeep coastal waters

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
PES-1	2.301	6.296	0.968
PES-2	2.492	6.512	0.645
PES-3	2.526	6.615	0.689
PPS-4	2.702	5.843	0.893
PPS-5	3.136	5.624	0.792
PPS-6	2.989	5.861	0.892
PMS-7	3.252	5.690	0.749
PMS-8	2.947	5.096	0.874
PMS-9	3.423	4.934	0.939
PMS-10	3.350	5.142	0.941
PMS-11	2.919	6.265	0.786
PMS-12	2.899	6.169	0.890
PMS-13	2.626	5.645	0.697
PMS-14	2.738	5.684	0.652
PMS-15	2.989	5.596	0.779
PMS-16	3.846	5.273	0.737
PMS-17	3.763	5.758	0.759
PMS-18	3.224	5.308	0.816

Cluster analysis

The abundance data of phytoplankton and zooplankton were amalgamated and subjected to classification and ordination methods. The resulting dendrogram revealed that the stations coastal regions PMS-6, PMS-7, PMS-8, PMS-9, PMS-10, PMS-11, PMS-12 PMS-13 PMS-14 PMS-15, PMS-16, PMS-17 and PMS-18 were forming a cluster based on the species composition and abundance. Similarly, the stations within the estuarine and Port regions PES-1, PES-2, PES-3, PPS-4, PPS-5 and PPS-6 also formed separate cluster (Fig. 47). This fact was further confirmed through MDS, which was also revealed same pattern of groupings as observed in cluster analysis. The stress value (0.25), which is overlying on the top-right corner ofthe MDS plot, was also found to be low signifying the good ordination pattern of the samples (Fig. 48).

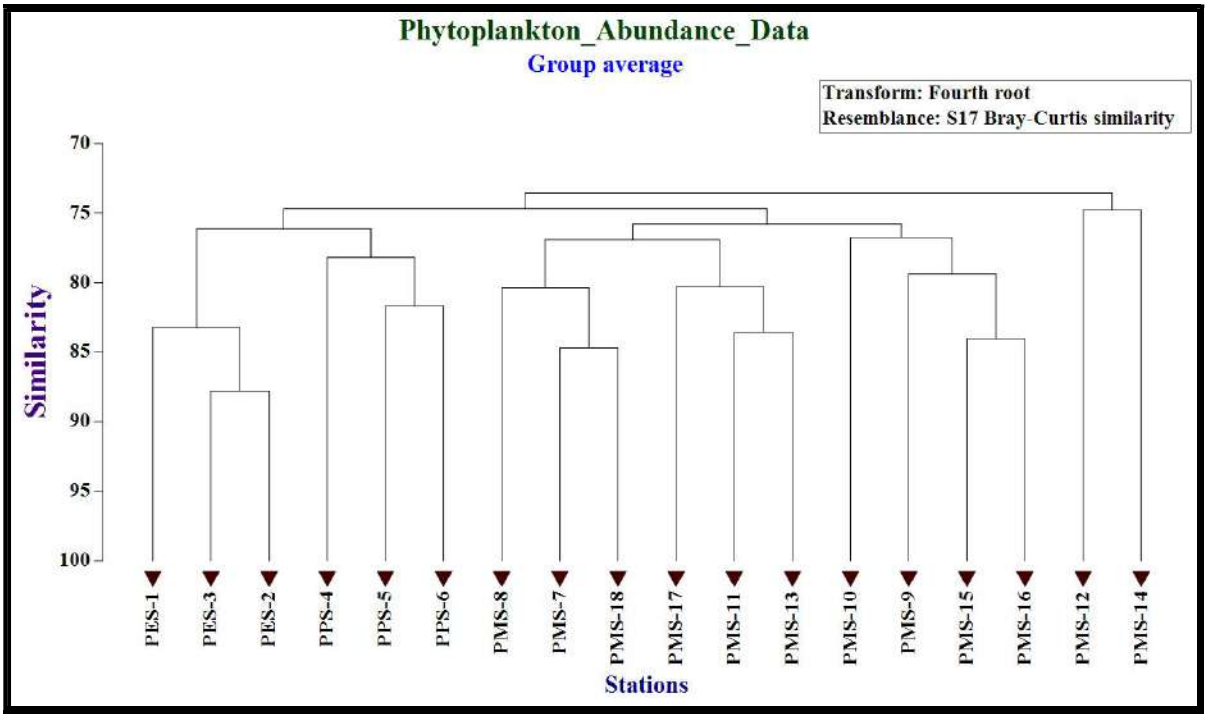


Fig. 47. Dendrogram for the Plankton abundance data collected from Estuary and Paradeep coastal waters

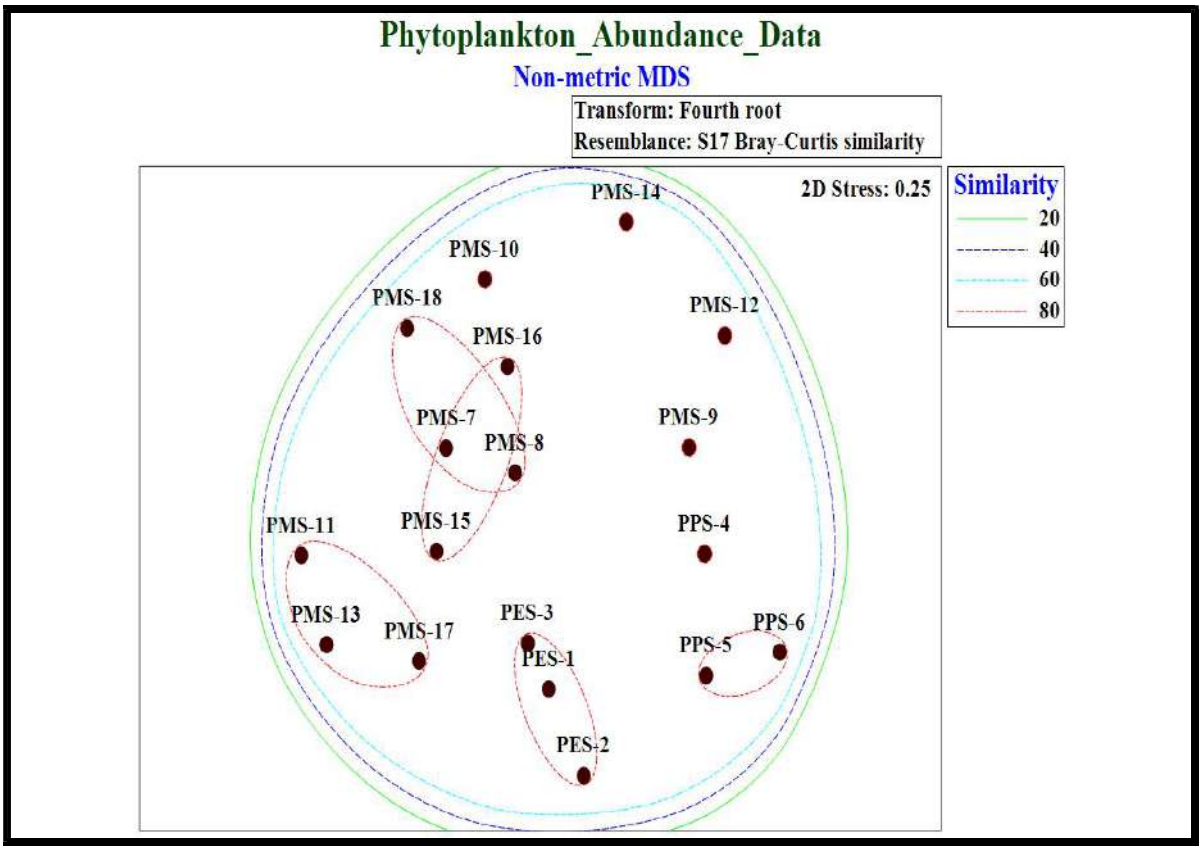


Fig. 48. MDS drawn for the Plankton abundance in various stations of Estuary and Paradeep coastal waters

BIO-ENV (Biota-Environment matching)

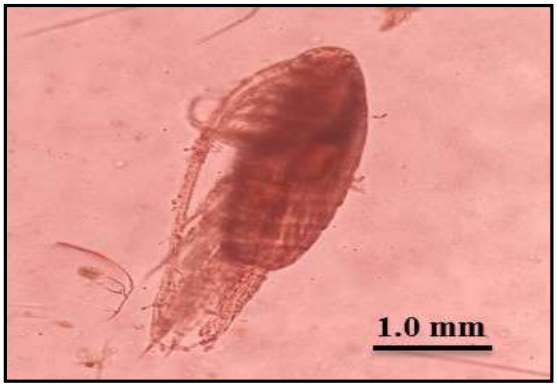
The BIO-ENV procedure was adopted to measure the agreement between the rank correlations of the biological (Bray-Curtis similarity) and environmental (Euclidean distance) matrices. To achieve this, thirteen environmental variables (Primary productivity, Total nitrogen, Nitrite, Nitrate, Dissolved oxygen, Salinity, Temperature Chlorophyll 'a', Silicate, Inorganic phosphate, Total phosphate, ammonia, pH and Temperature) were allowed to match the biota. The results of best combinations are given in Table 7. In this case, the Temperature, Salinity, Dissolved Oxygen, W. pH, Total phosphate, Total Nitrogen, Chlorophyll 'a', Silicate, Primary productivity and Total biomass were featured as the major variables explaining the best match ($p\omega$= 0.915) with plankton (both phytoplankton and zooplankton) distributions. The other

parameters such as W. pH, Total Nitrogen, Total phosphate, Silicate, Salinity, Chlorophyll 'a', Dissolved Oxygen and Primary productivity (pω = 894) which also got manifested in the next best variable combinations in determining the plankton distribution in Mahanadi estuary and Paradeep coastal waters

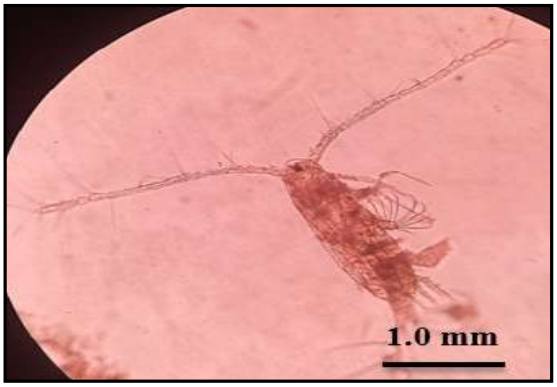
Table-7. Harmonic rank correlations (pω) between plankton (both phytoplankton and zooplankton) abundance against environmental variables in Estuary and Paradeep coastal waters

No. of variables	Best variable combinations	Correlation (pω)
10	Temperature – Salinity – Dissolved Oxygen – W. pH – Total phosphate – Total Nitrogen –Chlorophyll 'a' – Silicate – Primary productivity –Totalbiomass	0.938
8	W. pH – Total Nitrogen – Total phosphate – Silicate – Salinity – Chlorophyll 'a' –Dissolved Oxygen – Primary productivity	0.894
8	Salinity – Dissolvedoxygen– Total Nitrogen – Chlorophyll 'a'– Total phosphate – Silicate – Total biomass – Primary productivity	0.853
6	Primary productivity – Chlorophyll 'a' – Total Nitrogen –Total Phosphate – Silicate – Dissolved Oxygen – Total Biomass	0.811
6	Dissolved Oxygen – Total Nitrogen – Primary productivity – Chlorophyll 'a' – Total biomass - Salinity	0.775

PLATE-II COMMON SPECIES OF ZOOPLANKTON



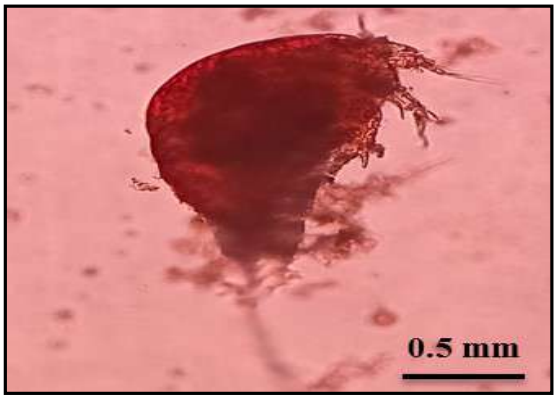
Paracalanus parvus



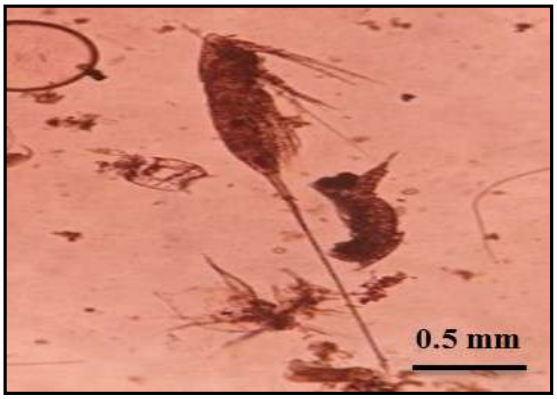
Acartia danae

Corycaeus catus

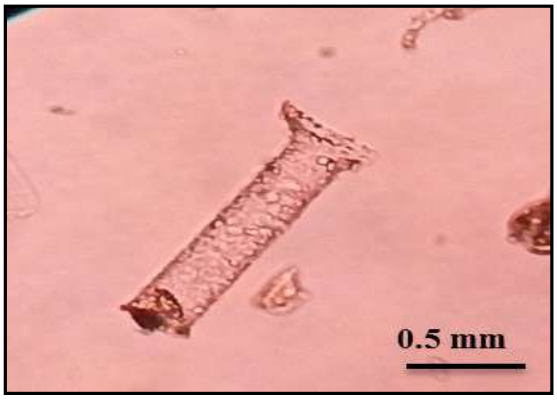
Copepod nauplii



Metis jousseaumei

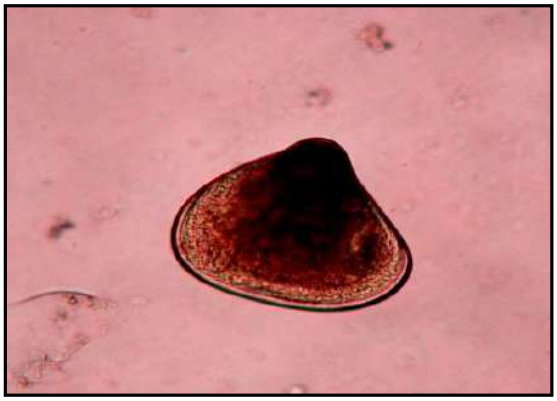


Microsetella sp



Tintinnopsis tubulosa

Oithona rigida



Bivalve veliger

Lucifer hanseni

Globigerina rubescense

Globigerina rubescense

4.6. Benthos

4.6.1. Macro-benthos

During the present investigation, four groups of benthic organisms namely Polychaetes, Bivalves, Gastropods and Crustaceans were recorded in various stations in Mahanadi estuary and Paradeep coastal waters. Among them, polychaetes constituted the dominant group followed by bivalves, gastropods and Crustaceans. Altogether, 45 species of macro fauna were recorded from the surveyed stations. Of these, polychaetes topped the list with 26 species. Bivalves were found to be the next dominant group in the order of abundance with 8 species. Gastropods and Crustaceans came next in the order with 8 and 4 species respectively of the total benthic organisms collected during the present study.

Among the polychaetes*, Aramantia intermedia, Ancistrolysis robusta, Capitella capitella, Cossura coasta, Etone siphodonta, Eunice siciliensis, Glycera unicornis, Goniada emerita, Minuspio cirriferra, Nephtys dibranchis, Notomastus aberans, Pista brevibranchiata, Poecilochaetes serpens, Polydontes melanonlus, Prionospio cirrifera, Prionospio cirrobranchiata, Prionospio japonica, Prionospio pinnata, Scoloplos johnstoneri* and *Terebelides stroemi* were found to be the most commonly occurring species in the samples collected in Mahanadi estuary and Paradeep coastal waters.. Coming to bivalves *Anadara rhombea*, Bivalve veliger, *Donax incarnatus, Gafrarium tumidum, Meretrix meretrix, Siliqua radiata, Sunettta meroe*, and in Gastropods, *Cerithedia cingulata, Drillia sacra,* Gastropods veliger*, Turritella dublicata, Turritella attenuata* and *Umbonium vestiarium* and in Crustaceans, *Amphithoe romondi* and *Crab larvae* were found to be the common species in the collection.

Population density

The population density varied from 875 to 2575 No m^{-2} with maximum was at PMS-10 and minimum was PIS-21 (Fig. 49).

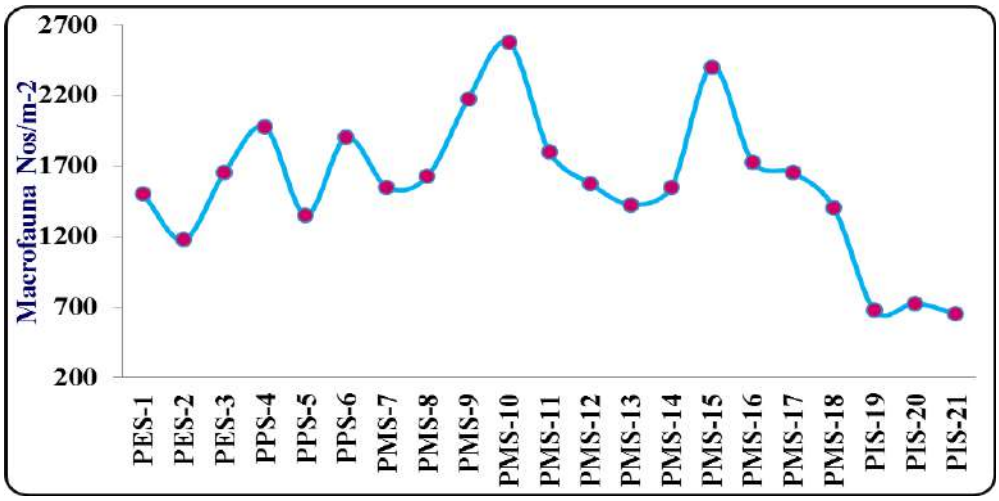


Fig. 49. Population density of Macro benthos in various stations of Estuary and Paradeep coastal waters

Percentage composition

When the results of percentage composition of benthic fauna were viewed, polychaetes constituted the maximum with 63% to the total benthic organisms. Bivalves, Gastropods and Crustaceans contributed to 17%, 10% and 10% respectively to the total benthic faunal community (Fig. 50).

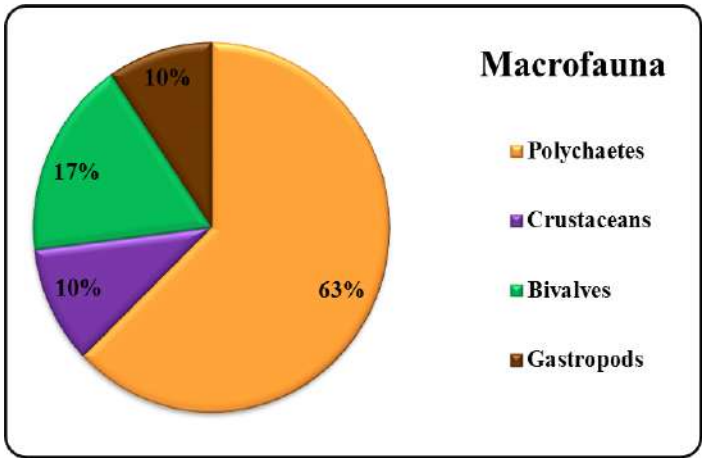


Fig. 50. Percentage composition of macro benthos in various stations of Mahanadi estuary and Paradeep coastal waters

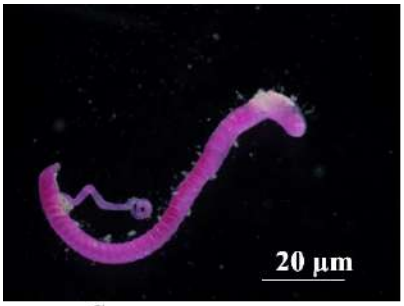
Diversity Indices:

The macro-benthic species diversity (H') varied from 2.355 to 3.627 with maximum was in PMS-10 and minimum in PIS-20. The species richness (d) ranged between 4.223 and 7.845 with maximum in PES-2 and minimum in PMS-16. The species evenness varied from 0.521 to 0.973 with the maximum in PMS-10 and minimum in PES-2 (Table 8).

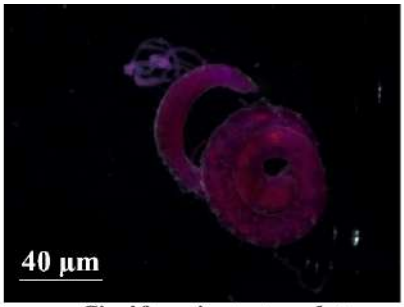
Table 8. Diversity indices Shannon diversity (H'); Margalef richness (d) and Pielou's evenness (J') calculated for macro benthos in Mahanadi estuary and Paradeep coastal waters

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
PES-1	2.461	6.248	0.544
PES-2	2.529	7.845	0.521
PES-3	2.416	6.771	0.54
PPS-4	2.385	6.689	0.522
PPS-5	3.004	5.68	0.672
PPS-6	3.048	6.264	0.659
PMS-7	3.12	6.537	0.758
PMS-8	3.164	5.725	0.885
PMS-9	3.581	4.856	0.964
PMS-10	3.627	4.697	0.973
PMS-11	3.055	5.284	0.661
PMS-12	2.923	5.737	0.64
PMS-13	3.268	4.613	0.66
PMS-14	2.943	5.639	0.868
PMS-15	2.868	4.759	0.851
PMS-16	2.549	4.223	0.662
PMS-17	2.713	4.719	0.85
PMS-18	2.675	5.683	0.648
PIS-19	2.402	5.035	0.721
PIS-20	2.355	5.475	0.735
PIS-21	2.541	4.605	0.767

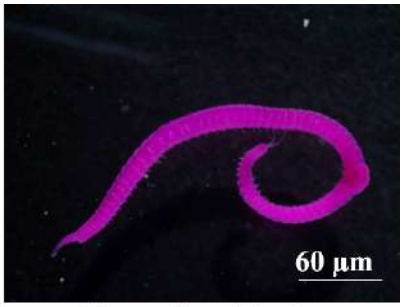
PLATE-III MACRO BENTHOS
POLYCHAETES



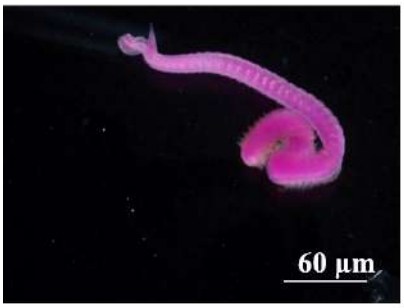
Cossura sp.



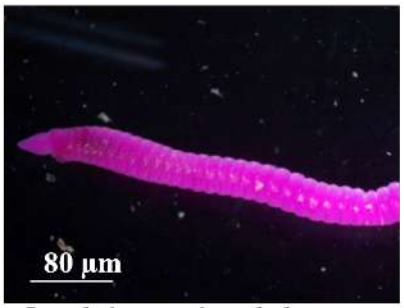
Cirriformia tentaculata



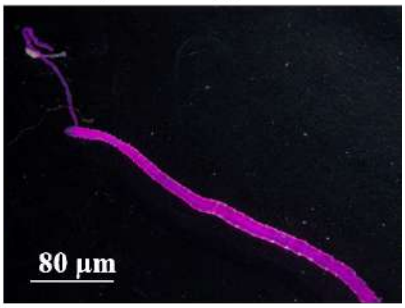
Glycera longipinnis



Goniada sp.

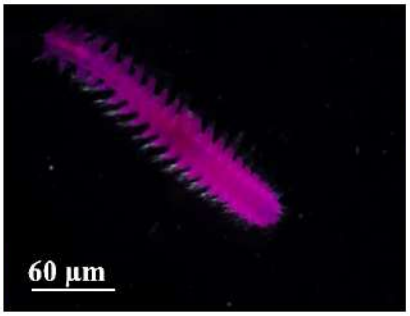


Lumbriconereis polydesma

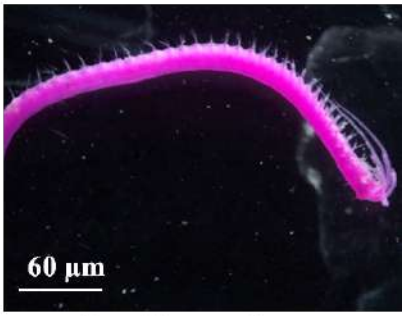


Magelona sp.

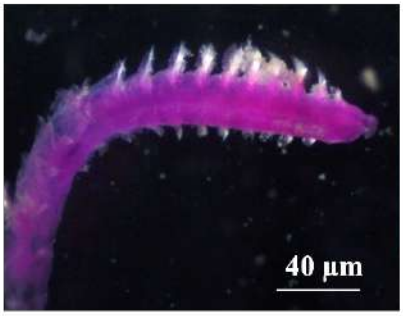
Eunice sp.



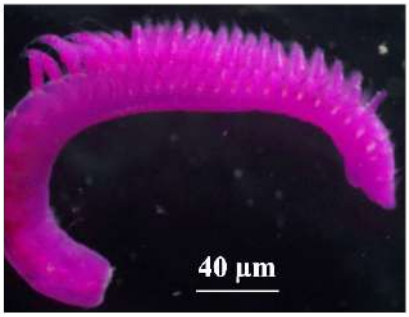
Nephthys polybranchia



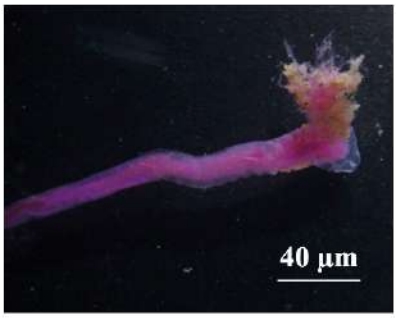
Onuphis eremita



Prionospio pinnata



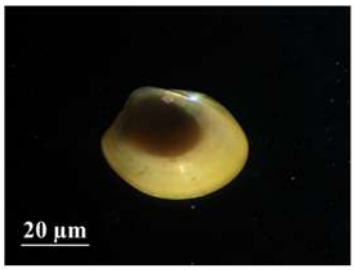
Scoloplos sp.



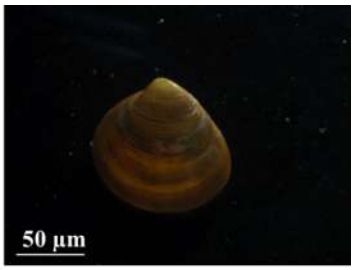
Terebellides stroemii

BIVALVES

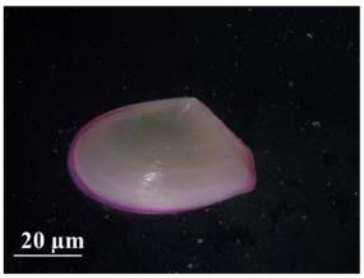
Donax scortum



Meretrix casta



Meretrix meretrix

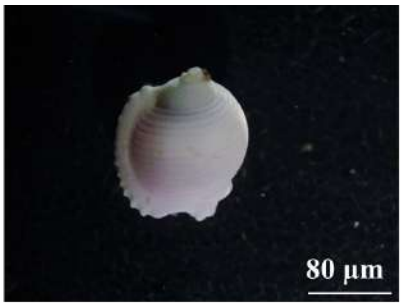


Tellina angulata

GASTROPODS

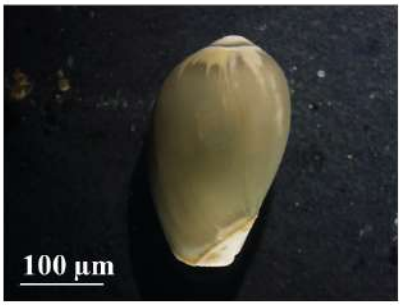
Nassarius stolatus

Neverita didyma



Tonna sulcosa

Umbonium vestiarium



Volvarina angustata

4.6.2. Meio-benthos:

In the present study, as many as 40 species belonging to four groups of Meio-benthic organisms namely Foraminiferans, Nematodes, Ostracodes and Harpacticoids were recorded. Among them, Foraminiferans topped the list with 22 species. Nematodes were found to be the next dominant group in the order of abundance with 8 species and Ostracodes and Harpacticoids came next with 6 and 4 species.

Among the foraminiferans, *Ammonia beccarii, Ammonia tepida, Ammodiscus intermedius, Bolivina limbata, Cornuspira foliacea, Discorbinella montereyensis, Elphidium texanum, Globorotalia hirsute, Lagena lacunata, Lagena semistriata, Neouvigerina hispida, Nonion grateloupi, Orbulina universa, Orbitolites adunca, Pararotalia ozawai, Pseudononion japonicum, Quinqueloculina granulocostata, Rosalina globularis, Rosalina orbicularis, Spirillina lateseptata, Spiroloculina excavata, Sorites marginalis, Triloculina tricarinata* and *Trochammina adaperta* were found commonly in various stations. With respect to nematodes, *Astomonema jenneri, Daptonema conicum, Draconema cephalatum, Neochromadora craspedota, Halalaimus filum, Theristus acer* and *Oxystomina clavicauda* were found to be the common species in the samples collected in various stations. The Ostracodes species such as *Basslerites liebaui, Bairdoppilata scaura, Keijella reticulate, Neocytherideis senescens, Candona candida, Eucythere argus* and *Stenocypris major* and in Harpacticoids, *Paramesochra dubia, Canuella perplexa, Euterpina acutifrons, Cylindropsyllus laevis* and *Laophonte thoracica* were found to be common species in the surveyed stations.

Population density

The population density of Meio-benthic fauna varied from 108 to 310 Nos.10cm^{-2} with maximum was recorded at PMS-10 and minimum at PIS-20 (Fig. 51).

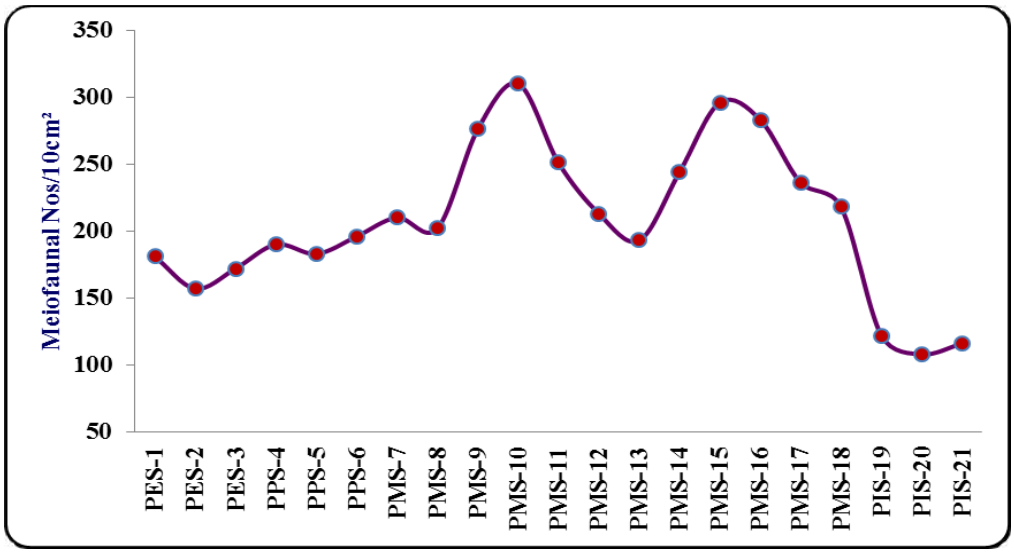


Fig. 51. Population density of Meio-fauna recorded in various stations of Mahanadi estuary and Paradeep coastal waters

Percentage composition:

The results of percentage composition of Meio-fauna revealed that Foraminiferans constituted maximum with 62% of the total Meio-benthic organisms. Nematodes, Ostracodes and Harpacticoids contributed with 16%, 15% and 7% respectively to the total Meio-benthic samples collected (Fig. 52).

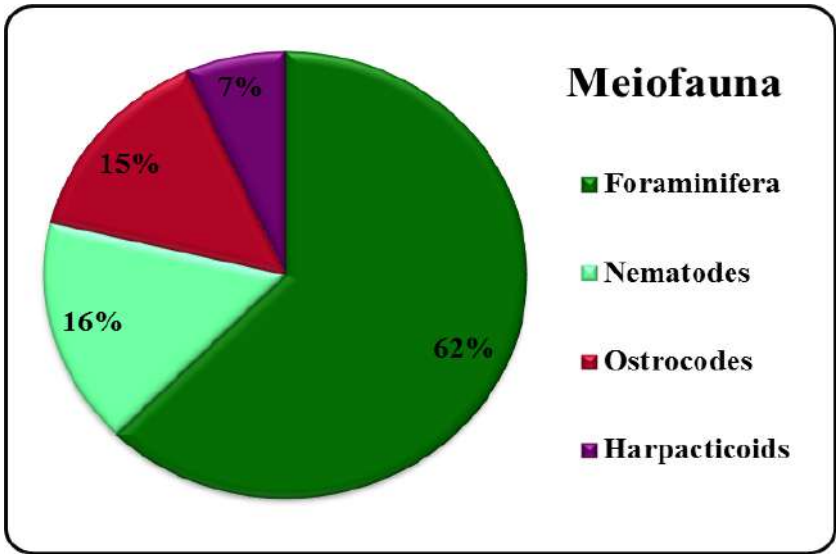


Fig. 52. Percentage composition of Meio-benthos in various stations of Mahanadi estuary and Paradeep coastal waters

Diversity Indices

The Meio-benthic species diversity (H') varied from 2.327 to 3.628 with maximum was in PMS-10 and minimum in PES-2 and similarly the species richness (d) ranged between 4.392 and 7.975 with maximum in PPS-5 and minimum in PIS-21. The species evenness varied from 0.579 to 0.914 with the maximum in PMS-14 and minimum in PES-2 (Table 9).

Table 9. Diversity indices Shannon diversity (H'); Margalef richness (d) and Pielou's evenness (J') calculated for Meio-benthos in Mahanadi estuary and Paradeep coastal waters

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
PES-1	2.52	6.415	0.586
PES-2	2.327	6.634	0.579
PES-3	2.575	7.172	0.583
PPS-4	2.471	7.765	0.591
PPS-5	2.972	7.975	0.685
PPS-6	3.064	6.695	0.650
PMS-7	3.112	6.71	0.677
PMS-8	3.304	5.719	0.612
PMS-9	3.537	4.849	0.746
PMS-10	3.628	4.943	0.766
PMS-11	2.873	6.196	0.695
PMS-12	2.694	6.304	0.853
PMS-13	2.982	5.872	0.865
PMS-14	2.863	6.153	0.914
PMS-15	3.011	5.057	0.726
PMS-16	2.928	4.895	0.805
PMS-17	2.941	4.829	0.718
PMS-18	3.279	5.679	0.874
PIS-19	3.265	4.567	0.583
PIS-20	3.398	4.723	0.715
PIS-21	3.478	4.392	0.744

Cluster analysis

To find out the similarity/dissimilarity between stations, as done for plankton data, the benthic faunal abundance data (macrofauna and meiofauna) were amalgamated and subjected to classification and ordination methods. The resulting dendrogram revealed that the stations stations coastal regions PMS-6, PMS-7, PMS-8, PMS-9, PMS-10, PMS-11, PMS-12 PMS-13 PMS-14 PMS-15, PMS-16, PMS-17 and PMS-18 were forming cluster separately based on the species composition and abundance. Similarly, the stations estuarine, Intertidal and Port regions PES-1, PES-2, PES-3, PPS-4, PPS-5, PPS-6, PIS-19, PIS-20 and PIS-21 also formed separate cluster (Fig. 53). This fact was further confirmed through MDS, which was also revealed the same pattern of groupings as observed in cluster analysis. The stress value (0.19), which is overlying on the top-right cornerof the MDS plot, was also found to be low signifying the good ordination pattern of the samples (Fig. 54).

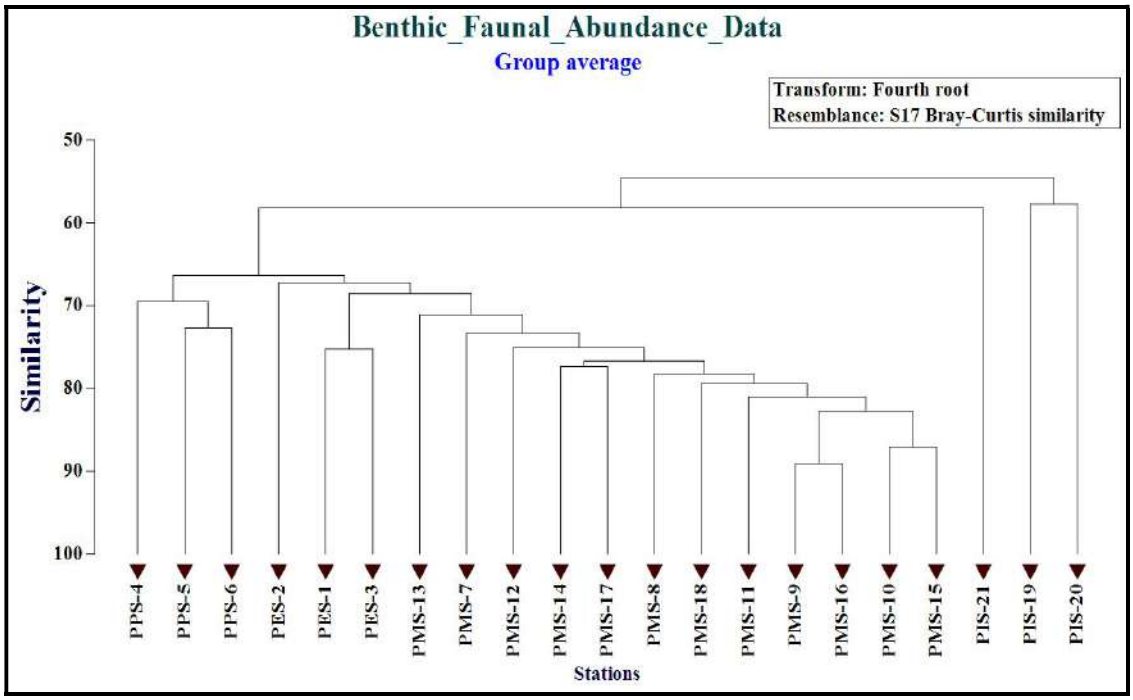


Fig. 53. Dendrogram for the benthic faunal abundance data collected in Mahanadi estuary and Paradeep coastal waters

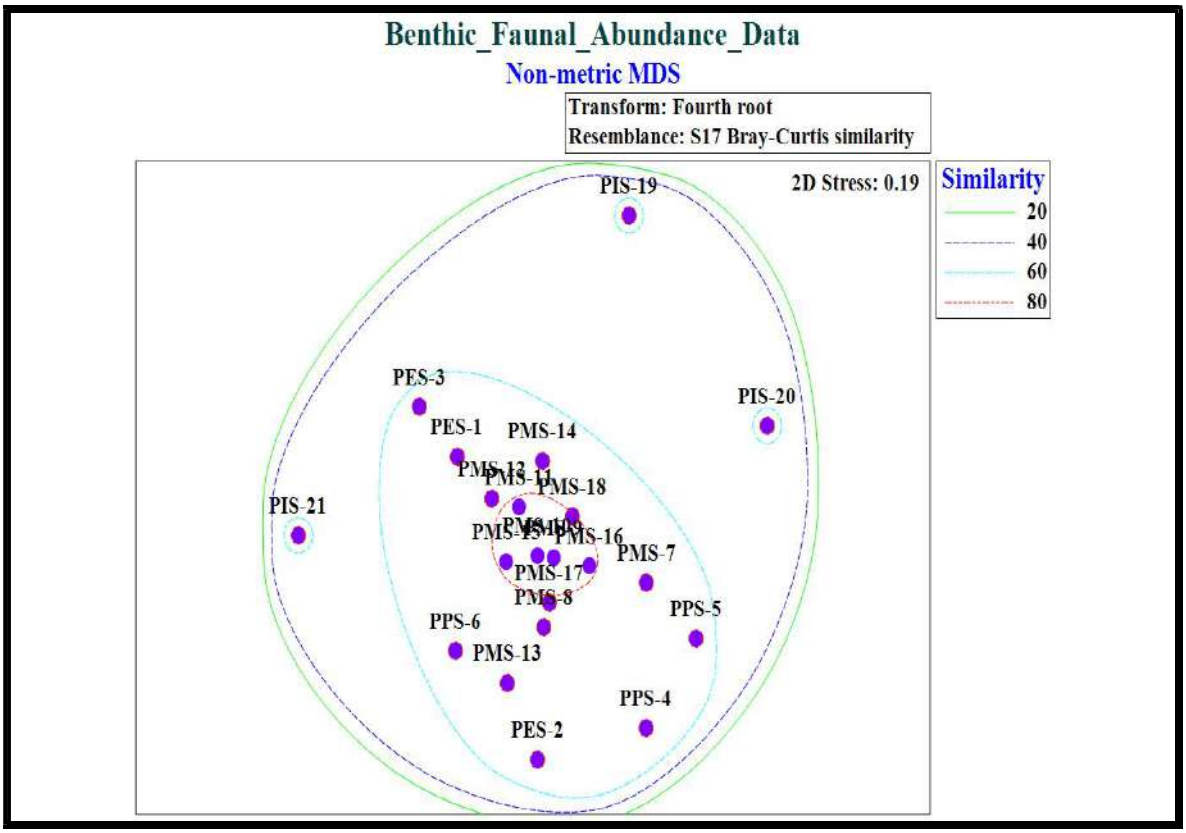


Fig. 54. MDS drawn for the benthic faunal abundance in various Mahanadi estuary and Paradeep coastal waters

BIO-ENV (Biota-Environment matching)

As done for plankton data, the BIO-ENV matching was employed to measure the rank correlations of the benthic faunal abundance (Bray-Curtis similarity) and environmental (Euclidean distance) matrices as well. For this, eleven environmental variables (Temperature, Salinity, W. pH, Silt, Sand, Clay, DO, TOC, S. pH, Evenness, Richness and Diversity) were allowed to match the biota. The results revealed that, a combination of eight environmental parameters ($p\omega = 0.948$) namely Salinity, Dissolved Oxygen, S. pH, Sand, Diversity, Evenness, Clay and TOC gotmanifested as best match in determining benthic faunal distribution followed by Salinity, S. pH, Dissolved Oxygen, Clay, TOC, Sand, Diversity and Evenness ($p\omega = 0.891$)

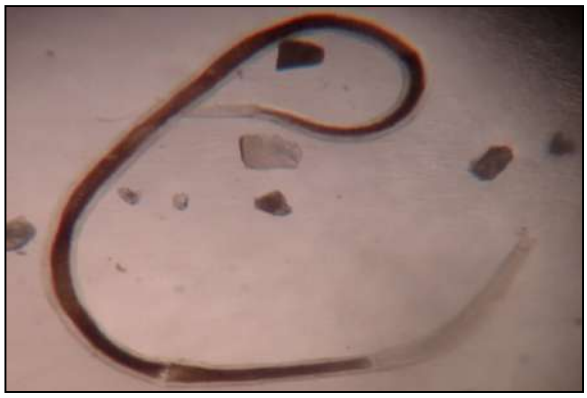
which also got manifested as second best variable combinations, in determining the faunal distribution in the Mahanadi estuary and Paradeep coastal waters (Table 10).

Table 10. Harmonic rank correlations (pω) between benthic faunal (both Macro-benthos and Meio-benthos) abundance against environmental variables in Mahanadi estuary and Paradeep coastal waters

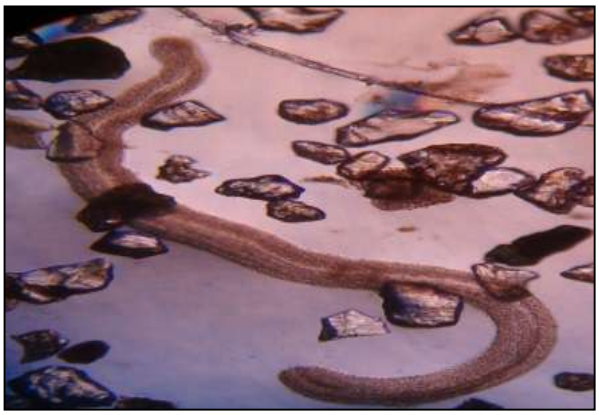
No. of variables	Best variable combinations	Correlation (pω)
8	Salinity – Dissolved Oxygen – S. pH – Sand – Diversity – Evenness – Clay – TOC	0.948
8	Salinity – S. pH – Dissolved Oxygen – Clay – TOC – Sand – Diversity – Evenness	0.891
7	Dissolved Oxygen – W. pH – Salinity – Sand – TOC – Diversity – Evenness	0.825
7	Salinity – W. pH – Dissolved Oxygen – Clay – TOC – Sand – S. pH	0.794
6	Salinity – Dissolved Oxygen – Clay – TOC – Evenness – Diversity	0.768

PLATE-IV MEIO-BENTHOS
NEMATODES

Halalaimus filum



Oxystomina clavicauda



Neochromadora craspedota

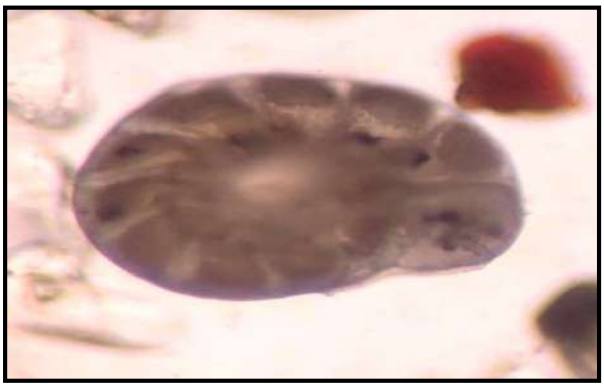
Daptonema conicum

Epsilonema steiner

Desmodora cambelli

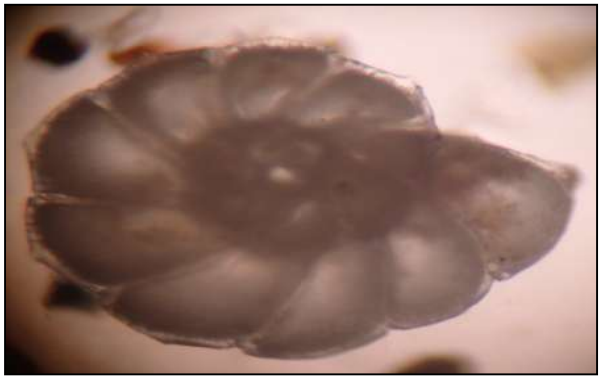
FORAMINIFERANS

Spiroloculina excavata

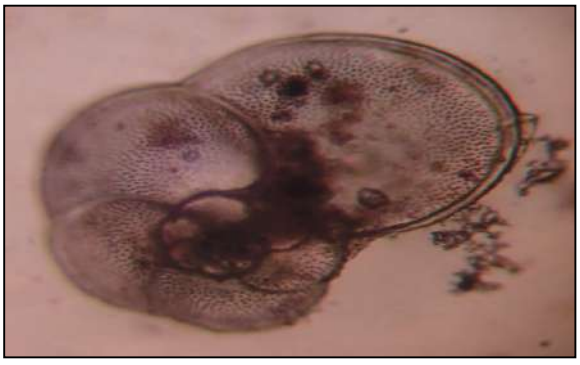


Ammonia tepida

Nonion depressulus



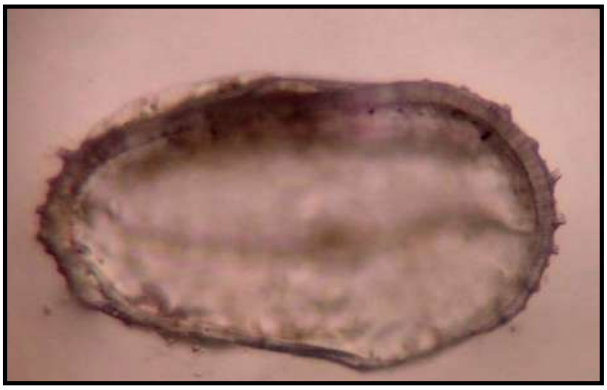
A. beccarii



Rosalina globularis

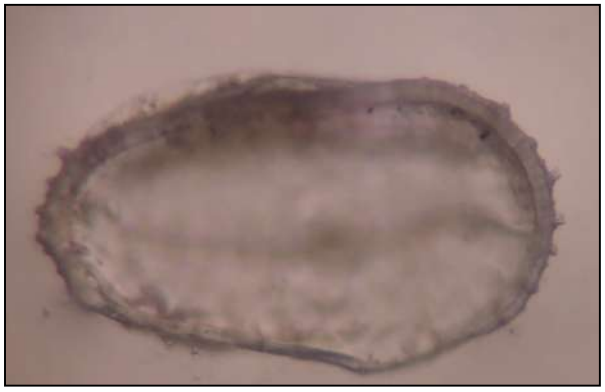
Miliolinella subrotunda

OSTRACODES



Parastenocypris canaliculata

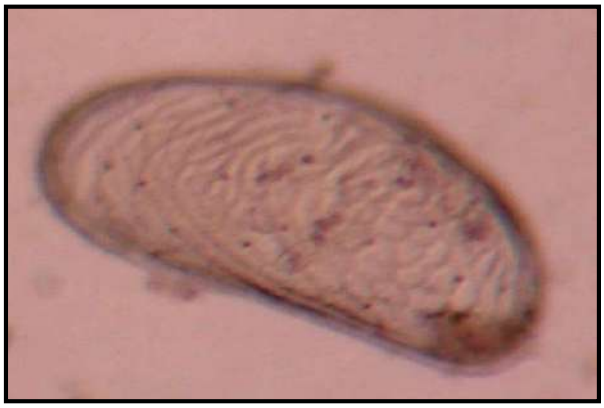
Stigmatocythere indica



***Echinocythereis* sp.**

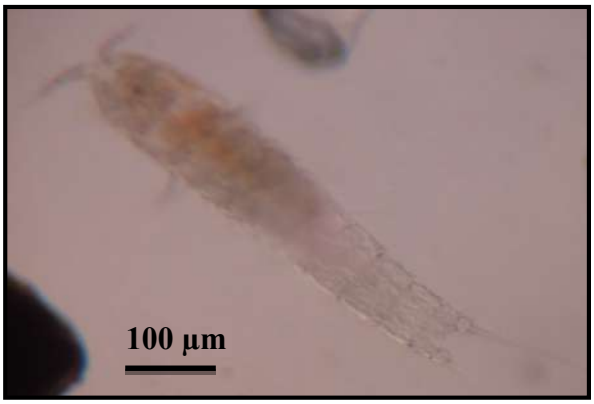
Keijella reticulata

Microcytherura nigrescens



Cytheronorph fuscata

HARPACTICOIDS



Laophonte thoracica

Harpacticus chelifer

Other Ecologically Sensitive Fauna and Flora

Mangroves

In Paradeep, the mangroves are best tidal forest and fall in arid regions and semi-arid regions where evapo-transpiration and mean annual rainfall decide quality of the vegetation. Climatic conditions in this region are not very favorable for the development of the tidal forests of outstanding quality, hence only few species of mangroves grow this coast. A patchy occurrence of mangroves species such as *Avicennia marina*, *Rhizophora stylosa, Rhizophora mucronata,* were observed, that is away from the project site.

Corals

No coral or any associated reef has been reported along the surveyed stations of the project region.

Turtles

The Odisha coast sustains the largest congregation of olive ridley turtles, and is among the only three mass nesting grounds of the world; this phenomenon of mass nesting is called the Arribada-a Spanish term for mass arrival. Turtles, such as *Chelonia mydas*, *Eretmochelys imbricata* and *Dermochelys coriacea* have also been sighted off the shores of Odisha. However, only olive ridley has been reported to nest in the Paradeep coast, Odisha (Kar and Bhaskar, 1982; Kar, 1988, Dash and Kar, 1990; Pandav *et al*. 1997). During this survey, no organized nesting

area was observed but the local residents advocated that Olive Ridley Sea turtles (*Lepidochelys olivacea*) nests are observed oddly between December-March. The lesser incidence of turtle nesting in the surveyed area may be due to the fact that the inter-tidal area is dominated by muddy substratum besides scanty occurrence of mangroves.

Other Endangered Species

The other endangered species like Sea horse, Indian otter, Salt water crocodile and etc., were not sighted during the survey.

Avifauna

In the project region, a few common bird species were recorded. They are Black-headed Ibis, Black-necked Stork, Lesser Sand Plover and Indian Roller.

Seaweeds and sea grass

A patchy occurrence of the following seaweed and seagrass species found near the surveyed stations: *Gracilaria verrucosa, Cladophora sericea* and *Gelidium divaricatum.*

Fisheries

Dasyatis zugei, Arius arius, Plicofollis tenuispinis, Caranx para, Decapterus russelli, Scomberoides lysan, Scomberoides tala, Lepturacanthus savala, Nemipterus bipunctatus, Secutor insidiator, Sillago sihama, Leiognathus equulus and Rastrelliger kanagurta. The other common species were Liza macrolepis, Mugil cephalus, Polynemus tetradactylus, Thryssa hamiltonii, Lepturacanthus savala, Parapenaeopsis stylifera, Penaeus monodon, P. merguiensis, Metapenaeus monoceros, M. brevicorins, Portunus pelagicus, Portunus sanguinolentus, Charybdis sp., Podophthalmus sp. and *Charybdis cruciate* were the commonly recorded fishes. Crustacean resources like prawns, lobsters & crabs formed an important commercial catch for the local fishing community.

COMMERCIALLY IMPORTANT FISHES

Mene maculate

Platax orbicularis

Rhabdosargus sarba

Xanthichthys ringens

Lates calcarifer

Trachinotus blochii

5. SUMMARY AND CONCLUSION

In the present survey, which lasted for four days, the physico-chemical and biological parameters were analyzed both in the water and sediment samples from predetermined (3 intertidal and 18 coastal stations) locations of Mahanadi estuary and Paradeep coastal waters. As such, the physico-chemical parameters did not show much variation barring a few parameters which showed only marginal variations. The results of various parameters are summarized below:

The surface water temperature varied from 27.5 to 32.0°C. The salinity varied from 27.0 to 35.3PPT. Hydrogen ion concentrations in surface waters remained alkaline and the maximum value of 8.41 was recorded at PMS-10. The observations made on the key physical factors such as TSS and turbidity was within the safe level. The turbidity ranged between 4.1 and 6.6NTU. The TSS values fluctuated from 60.60 and 122.60ppm. The maximum TSS and turbidity values were at PPS-5 and minimum at PMS-11. The variation noticed between the stations is only marginal, which might be due to seasonal, geographical location and tidal influence.

The range of ecologically sensitive chemical parameters such as Dissolved Oxygen, BOD, nutrients were also at the optimal concentration conforming to the seasonal trend. The oxygen level fluctuated from 3.41 and 5.69mg/l, with the maximum DO level was recorded at PMS-13 and the minimum was recorded at PPS-5. The DO concentration remained fairly well within the prescribed limit of water quality. The BOD level was found to be ranged from 1.37 and 2.50mg/l with the maximum BOD was observed at PPS-5 during this survey.

In the present investigation, the ammonical nitrogen concentration ranged between 0.08 and 0.23µmol/l. The concentration of nitrite fluctuated from 0.94 to 2.17 µmol/l. The nitrate values ranged from 2.65 to 4.18µmol/l and the total nitrogen varied between 13.52 to

19.42µmol/l. The inorganic phosphate ranged from 0.48 and 0.99µmol/l. The observed total phosphorus values ranged between 1.01 to 2.83µmol/l. The silicate concentration ranged from 25.34 and 58.25µmol/l. The particulate organic carbon values ranged from 77.30 and 139.21µgC/l respectively.

In the present survey, Petroleum Hydrocarbons in water varied between 0.16 and 0.37µg/l. with higher concentration was at station PPS-5. The total organic carbon content varied from 2.14 and 10.97mgC/g with the maximum was at PES-2 and minimum at PIS-21. The present survey showed that the Petroleum hydrocarbon relatively higher in sediment than the water and the values ranged from 0.113 to 0.584µg/g. The maximum was recorded at PPS-5 and the minimum was recorded at PIS-20 during this survey

The level of metal concentrations recorded in the present study is comparatively lesser than the earlier reports from the study area except for Iron. The sediment Iron concentration was found to be higher (1128.90 to 1820.10µg/g) compared to iron concentration in water (11.07 to 19.30µg/L). The maximum was recorded at PES-2 and the minimum was recorded at PMS-15. In general, areas experiencing high shipping and boating operations are usually to record higher Iron concentration. The concentration in coastal sediment samples indicates that it is well within the ERM (Effective Range Median) which mean there are no possibilities of Heavy metal contamination in the region.

The sand, silt and clay fraction at each station along with their textural classification indicated that the Sand and Clay percentage was higher during this survey.

Principal Component Analysis (PCA) is considered to be effective as they can reveal information from data sets containing larger amounts of variance, simultaneously considering the inter-relationships of several influential variables. Further, this method also allows us to analyze

patterns in biotic data and to relate biotic patterns to spatio-temporal environmental variables (Field *et al*., 1987). It is understood that environmental factors can modify, support or augment each other by acting independently or in tandem as has been stated by Kinne (1964).

The PCA plot drawn for the physico-chemical parameters collected in water samples were subjected to Principle component analysis to set a well-defined relation between the environmental parameters against the surveyed stations. The PCA plot drawn indicated that water parameters such as Temperature, DO, Salinity, pH, TN, TP, SiO3, POC, W.PHC, Cu, TOC, Mn, Fe, Pb sand and Cr had significant correlation with the surveyed stations. Looking at the nature of correlation, the parameters such as Temperature, DO, salinity, pH, TN, TP, SiO3, Chl-a, TOC, clay, sand, Fe and Mn got correlated with stations PMS-7, PMS-8, PMS-9, PMS-10, PMS-11, PMS-12, PMS-14, and PMS-16 while the rest of the parameters showed strong correlation with stations PMS-13, PES-1, PES-2, PES-3, PPS-4, PPS-6 and PPS-5 significantly correlated with other parameters. Similar combinations of parameters with stations were also obtained earlier from Chennai coast by Mohanty *et al.* (2014).

The microbial population showed typical seasonal trend in water and sediment samples during this survey. The maximum colony count was observed in sediment when compared to the water samples.

In the present study, the chlorophyll '*a*' in water sample varied from 0.886 to 1.956 mg/m^3, with maximum at PMS-15 and minimum at PES-2. The Phaeopigments content varied from 0.538 to 0.971 mg/m^3 with maximum was at PMS-15 and the minimum was observed at PES-2. The Total biomass values varied from 2.106 to 4.615 ml/100m^3, with maximum at PMS-9 and minimum at PPS-4. The primary productivity was measured using the dark and light reaction

method. The values ranged from 116.37 to 157.06mgCm-3d-1. The maximum value was recorded at PMS-15 and minimum value at PES-2.

Density of phytoplankton varied from 6,915 to 11,228 Cells/l with maximum was at PMS-10 and minimum at PES-2. In the present study, as many as 49 phytoplankton species belonging to three major groups namely Bacillariophyceae (Diatom), Dinophyceae (Dinoflagellates) and Cyanophyceae (Cyanobacteria) were recorded in Thiruvottiyurkuppam coastal area. Of these, Bacillariophyceae were found to be the dominant group with 36 species, Dinophyceae formed next group with 10 species and Cyanophyceae with three species.

The phytoplankton species diversity (H') varied from 2.365 to 3.811 with maximum at PMS-10 and minimum at PES-2. The species richness (d) ranged between 4.528 and 6.879 with maximum at PPS-5 and minimum at PMS-15. The species evenness varied from 0.545 to 0.924 with the maximum at PMS-15 and minimum at PES-2.

The zooplankton density varied from 4888 to 6680Nos/m^3 with maximum at PMS-15 and minimum at PES-2. During the survey, 6 groups of macro zooplankton namely, Calanoid copepod, Cyclopoid copepod, Harpacticoid copepod, Oligotrichea, Foraminifera and Other Crustacean forms and 4 groups of micro zooplankton namely, Mollusca, Chaetognatha, Decapoda and Annelida were recorded. In them, Calanoid Copepod was found to be the dominant group with 13 species. Cyclopoid copepod and Harpacticoid copepod came as next dominant group with 6 species each. The Spirotrichea, Protozoans and Other Crustacean forms were observed with 4 species from each group, Rotatoria and Larvacean were observed with 2 species, Mollusca, Cladocera, Decapoda and Annelida were recorded 1 species from each division of total zooplankton abundance.

As done for phytoplankton, the zooplankton species diversity (H') varied from 2.592 to 3.846 with maximum in PMS-16 and minimum in PPS-5. The species richness (d) ranged between 4.873 and 7.186 with maximum in PES-2 and minimum in PMS-9. The species evenness varied from 0.645 to 0.941 with the maximum in PMS-10 and minimum in PES-2.

The abundance data of phytoplankton and zooplankton were amalgamated and subjected to classification and ordination methods. The resulting dendrogram revealed that the stations coastal regions PMS-6, PMS-7, PMS-8, PMS-9, PMS-10, PMS-11, PMS-12 PMS-13 PMS-14 PMS-15, PMS-16, PMS-17 and PMS-18 were forming a cluster based on the species composition and abundance. Similarly, the stations within the estuarine and Port regions PES-1, PES-2, PES-3, PPS-4, PPS-5 and PPS-6 also formed separate cluster. This fact was further confirmed through MDS, which was also revealed same pattern of groupings as observed in cluster analysis. The grouping of stations might be based on the variation in species composition in nearshore and off-shore besides fluctuations in environmental variables between the stations as evidenced by Sahu *et al.* (2010); Robin *et al.* (2013) from Chennai coastal waters; Janakiraman et al. (2013); Baliarsingh et al. (2014) and Srichandan et al. (2015) from east coast of India.

The BIO-ENV results indicated that the parameters such as Temperature, Salinity, Dissolved Oxygen, W. pH, Total phosphate, Total Nitrogen, Chlorophyll 'a', Silicate, Primary productivity and Total biomass were featured as the major variables explaining the best match ($p\omega$= 0.915) with plankton (both phytoplankton and zooplankton) distributions. The other parameters such as W. pH, Total Nitrogen, Total phosphate, Silicate, Salinity, Chlorophyll 'a', Dissolved Oxygen and Primary productivity ($p\omega$ = 894) which also got manifested in the next best variable combinations in determining the plankton distribution in Mahanadi estuary and

Paradeep coastal waters. This view point agrees well with the earlier works as they have pointed out that these parameters are the most important factor in determining the distribution of phytoplankton and zooplankton abundance in estuarine environments (Juggins, 1992; Hassan *et al*., 2007).

With respect to benthos, the population density varied from 875 to 2575 No m-2 with maximum was at PMS-10 and minimum at PIS-21. During the present investigation, four groups of benthic organisms namely Polychaetes, Bivalves, Gastropods and Crustaceans of organisms were recorded in various stations in Mahanadi estuary and Paradeep coastal waters. Among them, polychaetes constituted the dominant group followed by bivalves, gastropods and Crustaceans. Altogether, 45 species of macro fauna were recorded from the surveyed stations. Of these, polychaetes topped the list with 26 species. Bivalves were found to be the next dominant group in the order of abundance with 8 species. Gastropods and Crustaceans came next in the order with 8 and 4 species of the total benthic organisms collected during the present study.

The macro-benthic species diversity (H') varied from 2.355 to 3.627 with maximum was in PMS-10 and minimum in PIS-20. The species richness (d) ranged between 4.223 and 7.845 with maximum in PES-2 and minimum in PMS-16. The species evenness varied from 0.521 to 0.973 with the maximum in PMS-10 and minimum in PES-2.

Regarding meiobenthic organisms, the population density of Meio-benthic fauna varied from 108 to 310 Nos.10cm-2 with maximum was recorded at PMS-10 and minimum at PIS-20. In the present study, as many as 40 species belonging to four groups of Meio-benthic organisms namely Foraminiferans, Nematodes, Ostracodes and Harpacticoids were recorded. Among them, Foraminiferans topped the list with 22 species. Nematodes were found to be the next dominant

group in the order of abundance with 8 species and Ostracodes and Harpacticoids came next with 6 and 4 species.

The Meio-benthic species diversity (H') varied from 2.327 to 3.628 with maximum was in PMS-10 and minimum in PES-2 and similarly the species richness (d) ranged between 4.392 and 7.975 with maximum in PPS-5 and minimum in PIS-21. The species evenness varied from 0.579 to 0.914 with the maximum in PMS-14 and minimum in PES-2.

The resulting dendrogram revealed that the stations coastal regions PMS-6, PMS-7, PMS-8, PMS-9, PMS-10, PMS-11, PMS-12 PMS-13 PMS-14 PMS-15, PMS-16, PMS-17 and PMS-18 were forming cluster separately based on the species composition and abundance. Similarly, the stations estuarine, Intertidal and Port regions PES-1, PES-2, PES-3, PPS-4, PPS-5, PPS-6, PIS-19, PIS-20 and PIS-21 also formed separate cluster. This fact was further confirmed through MDS, which was also revealed the same pattern of groupings as observed in cluster analysis. The stress value (0.19), which is overlying on the top-right corner of the MDS plot, was also found to be low signifying the good ordination pattern of the samples. Similar groupings in intertidal and inshore waters were reported earlier by various researchers (Ajmal Khan *et al*. 2005; Tolhurst and Chapman, 2007 and Martins *et al*., 2016).

The BIO-ENV matching indicated that the combination of eight environmental parameters ($p\omega = 0.948$) namely Salinity, Dissolved Oxygen, S. pH, Sand, Diversity, Evenness, Clay and TOC got manifested as best match in determining benthic faunal distribution followed by Salinity, S. pH, Dissolved Oxygen, Clay, TOC, Sand, Diversity and Evenness ($p\omega = 0.891$) which also got manifested as second best variable combinations, in determining the faunal distribution in the Mahanadi estuary and Paradeep coastal waters. True to its sense, in a study

made by Murugesan (2002), Muthuvelu (2013) and Sivaraj (2014) reported the similar combinations of environmental variables influencing the macro-benthic and meio-benthic faunal distribution.

With respect to ecologically sensitive groups, the presence of patchy stunted mangrove, *Avicennia marina, Avicennia alba Rhizophora mucronata,* were observed in the nearby regions. No coral or any associated reef has been reported along the surveyed stations of the project region. During this survey, no organized nesting area was observed but the local residents advocated that Olive Ridley Sea turtles (*Lepidochelys olivacea*) nests are observed oddly between December-March. The lesser incidence of turtle nesting in the surveyed area may be due to the fact that the inter-tidal area is dominated by muddy substratum besides scanty occurrence of mangroves.

In the project region, a few common bird species were recorded. They are Black-headed Ibis, Blue Rock Pigeon, Lesser Sand Plover and Indian Roller.

The proposed area was found to have very poor coastal floral growth, as the sandy/muddy substratum is associated with relatively high turbidity which does not support the species. The survey conducted indicated the presence of Seaweed species such as *Gracilaria verrucosa, Cladophora sericea and Gelidium divaricatum.* Observations made on fish landing center, revelaed 44 species of fin fishes, prawns, *Squilla*, crab, other crustaceans, and cephalopods. *Dasyatis zugei, Arius arius, Plicofollis tenuispinis, Caranx para, Decapterus russelli, Scomberoides lysan, Scomberoides tala, Lepturacanthus savala, Nemipterus bipunctatus, Secutor insidiator, Sillago sihama, Carcharhinus macloti, Stolephorus commersonii, Cynoglossus arel, Synaptura albomaculata, Pseudorhombus elevatus, Himantura uarnak, Lagocephalus lunaris, Triacanthus biaculeatus, Leiognathus equulus* and *Rastrelliger*

kanagurta. The other common species were *Liza macrolepis, Mugil cephalus, Polynemus tetradactylus, Thryssa hamiltonii, Lepturacanthus savala, Parapenaeopsis stylifera, Penaeus monodon, P. merguiensis, Metapenaeus monoceros, M. brevicorins, Portunus pelagicus, Portunus sanguinolentus, Charybdis* sp.*, Podophthalmus* sp. and *Charybdis cruciate* were the commonly recorded fishes.

Further, the diversity indices calculated for the plankton and benthic data in the present study showed undisturbed nature of the environment since diversity values of plankton and benthos were more than 2.5 as has been stated by the Marine ecologist Sanders (1968). The macro benthic conservative species *Armandia* sp., *Glycera longipinnis, Goniada emerita, Spiochaetopterus costarum, Nereis* sp. were predominantly occurred in the Mahanadi river Paradeep coastal waters which reflect the stable nature of the ecosystem.

Further, the results of physico-chemical and biological parameters indicated that the water is well oxygenated and nutrients are adequate supporting fairly good plankton population, the base in the food chain. Not only is that, the metal concentration in coastal water and sediment samples indicates that it is well within the ERM (Effective Range Median) values (Long *et al*., 1995) which means there is no possibilities of heavy metal contamination in the region.

In short, the results of marine ecological survey made during 26th to 29th January 2024 Mahanadi estuary and Paradeep coastal waters and careful perusal of the available information suggested that the water quality parameters are within the safe level and did not indicate any alarming impact on the existing biological components. The analysis on other ecologically sensitive organisms reflected the patchy occurrence of a few groups especially seaweeds from the nearby regions. The discharges occurring from the proposed facility will result in only marginal impacts on biota but such impacts are confined to a limited period since most of the

marine organisms are capable of recouping themselves quickly to its original form and thus there will not be any pronounced change to the biotic community. Further, the present marine survey was done only short period, continuous monitoring is also needed even after commissioning of this proposed facility with a view to ascertain the temporal variations in the physico – chemical and biological components of this environment, if any.