BEFORE THE NATIONAL GREEN TRIBUNAL

SOUTHERN ZONE, CHENNAI

Original Application No. 08 of 2024 (SZ)

In the matter of:

Meenava Thanthai K.R. Selvaraj Kumar,
Meenavar Nala Sangam, Rep.,by its President,
M.R.Thiyagarajan. … Applicant(s)

Versus

State of Tamil Nadu,
Through its Chief Secretary,
Chennai and Ors. …Respondent(s)

REPORT FILED BY 6TH RESPONDENT –
DEPARTMENT OF FISHERIES AND FISHERMEN WELFARE
(ANNEXURES)

INDEX

(**Note**: The page numbers are at the right corner of every page)

Through

Dr. D. Shanmuganathan

Standing Counsel of Tamil Nadu

National Green Tribunal

Southern Zone, Chennai

DATE:02.02.2025

ANNEXURE 1

TAMIL NADU BIODIVERSITY BOARD

(A statutory, autonomous & regulatory body of the Government of Tamil Nadu)

Tel: 044-22782730 Email: secy.tnbb@tn.gov.in

From,

Dr. Sudhanshu Gupta, IFS.,
Principal Chief Conservator of Forests
(HoD) and Secretary (FAC),
Tamil Nadu Biodiversity Board,
TBGP Campus, II Floor
Velachery-Tambaram Main Road,
Nanmangalam, Chennai-600 100.

To,

Dr.K.Saravanakumar, B.E.,
Executive Engineer,
Fishing Harbout Project Division,
Chennai -35.

Sir,

Ref. No. TNBB/799/2023/B1, Dated: 05.06.2024

Sub: TNBB – Fisheries and Fishermen Welfare – Construction of Tuna Fishing Harbour at Thiruvottriyur kuppam in Thiruvallur District – Conducting Detailed marine biodiversity management plan – Remarks attended – Report – reg.

Ref:
1. Your letter No. DB/D1/C.25(1)/2021 Dated: 17.07.2023
2. This Office Ref. No. TNBB/799/2023/B1, Dated: 25.08.2023
3. Your letter No. DB/D1/C.25(1)/2021 Dated: 10.05.2024

******

With reference to the mentioned letter 3rd cited, I am to inform that Marine Biodiversity Survey for Tuna Fishing Harbour at Thiruvottriyur Kuppam, in Thiruvallur District is approved with the observation that the local Biodiversity Management Committee (BMC) may be involved in implementation of the management plan. It is observed in the comprehensive report communicated vide reference 3rd cited above that the present marine rapid survey was done for three seasons, however, it is recommended that a long-term intensive survey may please be continued even after commissioning of the proposed structure, to pin point the changes in the biotic community arising out of proposed project may please be communicated to this office in due course.

Yours faithfully,

5/6/24

Secretary, Tamil Nadu Biodiversity Board.

ANNEXURE 2

MARINE BIODIVERSITY SURVEY FOR TUNA FISHING HARBOUR THIRUVOTTRIYUR KUPPAM, THIRUVALLUR DISTRICT, CHENNAI, TAMIL NADU

Research Team

Dr. P. Murugesan
Associate Professor & Principal Investigator
Annamalai University

Research Scholars

Dr. V. Bharathidasan

Dr. K. Manimaran

Dr. R. Punniyamoorthy

Mr. P. Chandrasekaran

Mr. S. Mariyappan

Ms. Sasmita Swain

Centre of Advanced Study in Marine Biology
Faculty of Marine Sciences
Annamalai University
Parangipettai - 608 502

March 2023

Dr. P. MURUGESAN, M.Sc.,Ph.D.,
ASSOCIATE PROFESSOR
C.A.S. in Marine Biology
Faculty of Marine Sciences
Annamalai University
Parangipettai - 608 502
Tamil Nadu India

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March 2023

CONTENTS

MARINE BIODIVERSITY SURVEY FOR TUNA FISHING HARBOUR THIRUVOTTRIYUR KUPPAM, THIRUVALLUR DISTRICT, CHENNAI, TAMILNADU

1. Introduction

The coastal area, adjoining the north of the Chennai Port has been adversely affected by continued erosion due to the development of the port. Since several developmental activities such as advent of industries, improvement of fisheries, etc. a groyne field was constructed stretching from Royapuram to northwards and the sea wall stretch of about 10 km length lying parallel to Ennore High Road to combat the erosion problems. A proposal was further made to expand existing groynes to form a fishing harbor. Accordingly, the Fisheries Department, Govt. of Tamilnadu requested the Department of Ocean Engineering, IIT Madras to revise/revive the proposed layout and perform numerical model studies to validate the same. Therefore, the layout was revised and subjected to tranquility and shoreline evolution studies. Thiruvallur District is historically known for its fishery resources and community living and presently it has a fishermen population of around 50,000 in the stretch of 25 Km that includes North Chennai. The project location is historically known for fishery resources and a strong fishermen settlement and more precisely, with a fishery harbor at about 3.5Km south as a landmark facility of Chennai since long time.

The proposed Tuna Fishing Harbour is a flag ship project of Government of Tamil Nadu which intended to create exclusive facilities to enhance Tuna catching and processing the same to add value to benefit the fishing community of the project location, Thiruvottriyur Kuppam, Chennai. The proposed fishing harbour facility is intended principally to ease out the congested Chennai Fishing Harbour as it is overflowing with more traffic and fishing activities. At times, there is an acute shortage of space to anchor the boats inside the harbour. The proposed Harbour location is about 3.5Km North from the Chennai Fishing Harbour which will provide location advantage and flexibility in harbour operation and fishing activities. Accordingly, the Department of Fisheries was mandated to enhance the harbour facilities. The project is much needed to improve the socio economic status of the local fishing community of more than a lakh in the North Chennai Zone of Tamil Nadu.

The project location is historically used by the local fishermen community and only in the recent past the coastline got eroded and it was then provided with groynes which were subsequently extended as a field with 13 numbers of groynes. It is evident that the project shoreline of about 10km stretch has been stabilized and with sand by passing over groynes over the years, the beach line has been restored and now, the project coastline is showing features of stabilization with accretion of sand and restored shoreline. The proposed harbour, as it is very close to Chennai Fishing Harbour, will serve as an extended harbour facility of it and intended to promote Tuna catching & processing. At present, from the Chennai Fishing Harbour, there are about 300 boats are operating exclusively to venture deep into the Bay of Bengal to catch tuna and bring in about 1,000 tonnes every month. Under these circumstances, the project proponent has been mandated to study marine biodiversity potential of the project site by a reputed Institute/University.

Justifiably, the task was entrusted to the Centre of Advanced Study (CAS) in Marine Biology of Annamalai University, Tamilnadu, who is the pioneer in Marine Sciences, to carry out Marine Ecological feasibility survey. Accordingly, the Experts from CAS in Marine Biology, Annamalai University carried out a detailed Marine Biodiversity survey including under water SCUBA survey during 23rd to 25th February 2023 at Thiruvottiyur kuppam coastal waters, Thiruvallur District, Chennai, Tamilnadu. During this survey, water, sediment and biological samples (plankton, benthos, microbiological and other ecologically important flora and fauna) were collected from 12 different stations from the proposed sites. The latitude and longitude of the sampling stations are given in Table 1 and also in Map (Fig.1).

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:

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

Table 1. Sampling stations and their geographical Co-Ordinates

S. No.	Stations Code	Latitude	Longitude
1.	TGS-1	13°9'58.80"N	80°18'39.15"E
2.	TGS-2	13°9'52.98"N	80°18'35.17"E
3.	TGS-3	13°9'41.92"N	80°18'36.69"E
4.	TGS-4	13°9'48.90"N	80°18'42.45"E
5.	TGS-5	13°9'55.34"N	80°18'44.32"E
6.	TMS-6	13°10'3.92"N	80°18'42.96"E
7.	TMS-7	13°9'58.41"N	80°18'53.14"E
8.	TMS-8	13°9'50.30"N	80°18'50.41"E
9.	TMS-9	13°9'50.09"N	80°19'20.13"E
10.	TMS-10	13°9'38.59"N	80°18'54.27"E
11.	TMS-11	13°9'31.19"N	80°18'41.43"E
12.	TMS-12	13°9'34.84"N	80°18'31.45"E

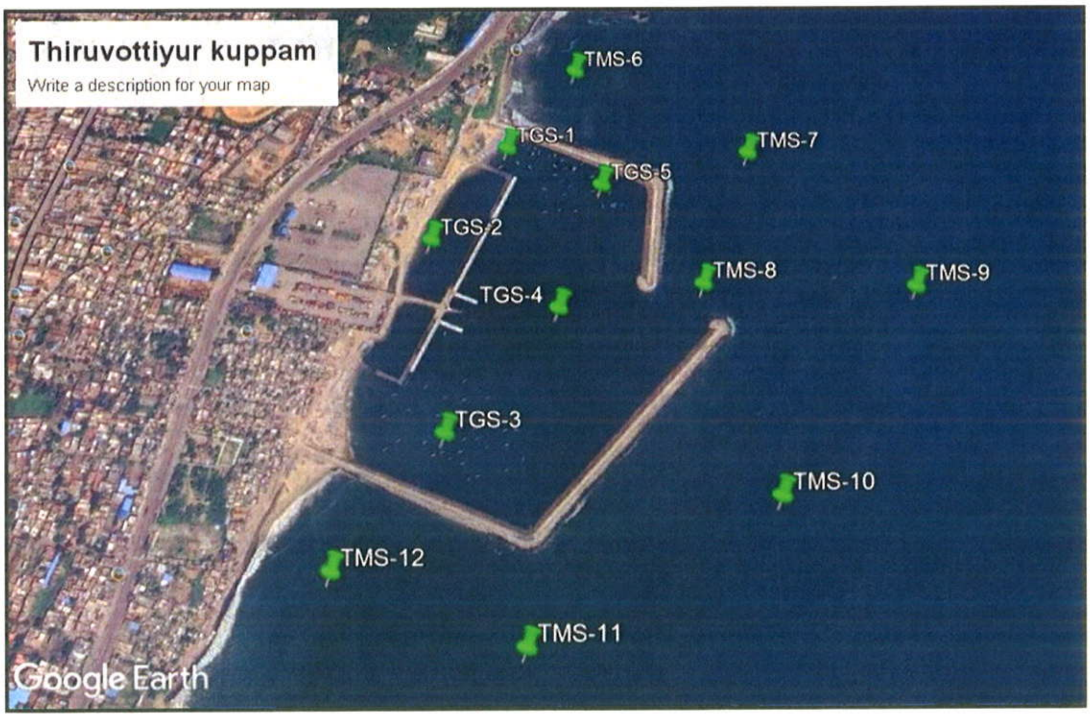


Fig. 1. Map showing the stations in Thiruvottiyur kuppam coastal waters

RESEARCH TEAM

3. MATERIALS AND METHODS

3.1. Water and Sediment Sampling

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.

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.

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.

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 analyzed 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.

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.

4. 2. Microbiology methods

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.

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.

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. 3. Pigments concentration

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. 4. Plankton community

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).

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. 5. 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 Muruganantham *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. 6. 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).

Cluster Analysis

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)

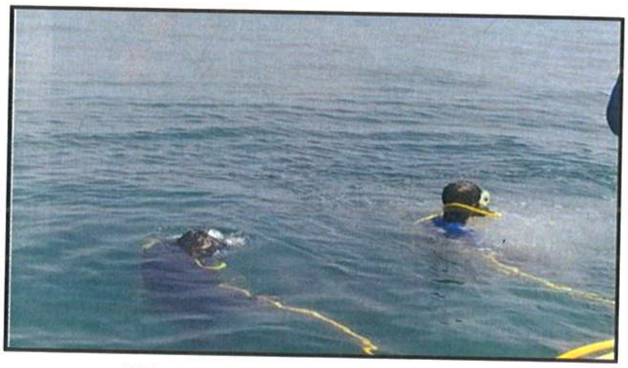
This method was proposed by Shepard (1962) and Kruskal (1964). To confirm the clustering pattern, this was used to find out the similarities (or dissimilarities) between each pair of entities to produce a 'map', which would ideally show the interrelationships of all.

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 AND ACTIVITIES

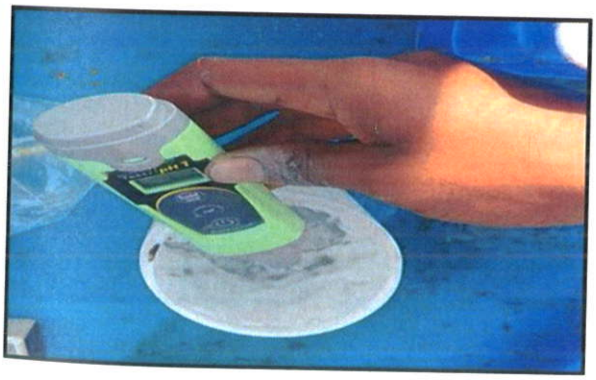
Near Thiruvottriyur Kuppam
Fishing Harbor



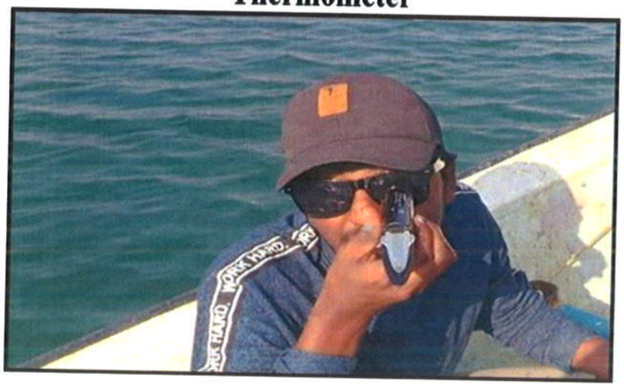
Biological sample collection by
SUBA diving method

Locating sampling points by using GPS

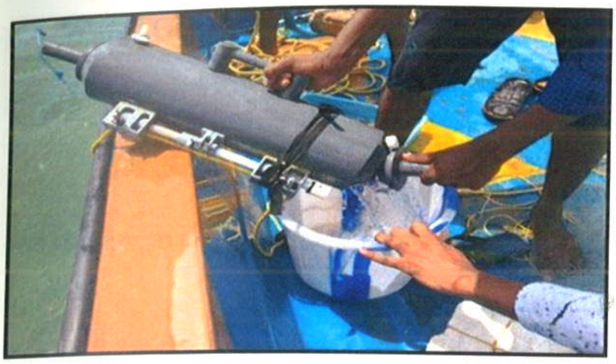
Temperature measurement by using
Thermometer



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 plankton net

Sieve retains-benthic samples

DO estimation by following Winkler's method

Vertical transparency measurement by using Secchi disc

4. OBSERVATION REPORT

4.1. Water Quality

Depth

The depth in the study area varied between 0.8 and 12.5m, with maximum at TMS-10 and minimum at TGS-1 (Fig. 2).

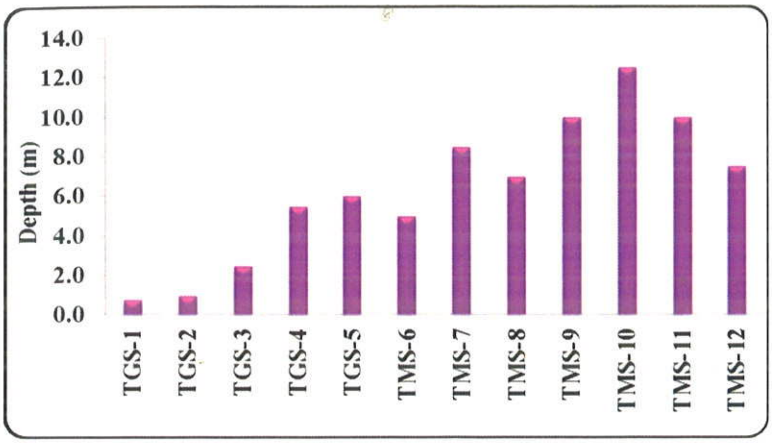


Fig. 2. Depth values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Water Temperature

The water temperature fluctuated from 27.2 to 29.5°C. The minimum value was recorded at TGS-1 and maximum was recorded at TMS-12 (Fig. 3).

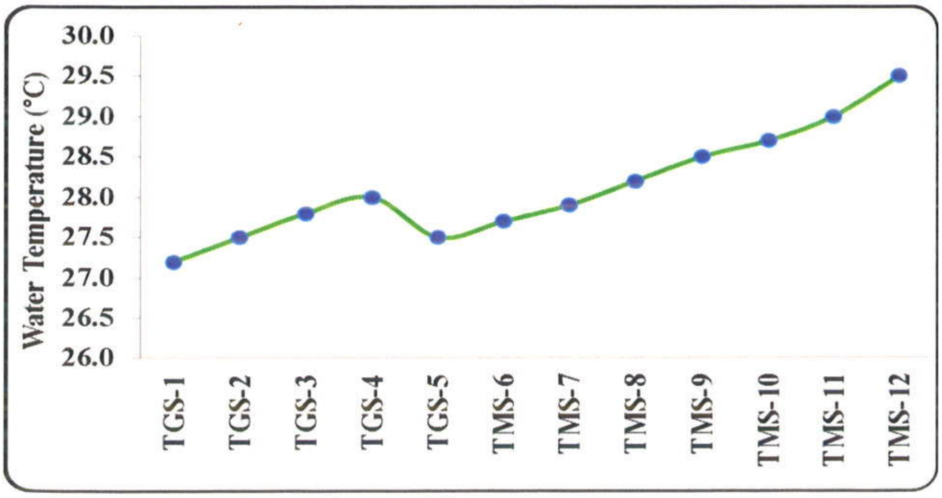


Fig. 3. Water temperature values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Salinity

The water salinity varied from 33.5 to 35.5PSU. The salinity was found to be lower at TGS-2 and higher value at TMS-10 (Fig. 4).

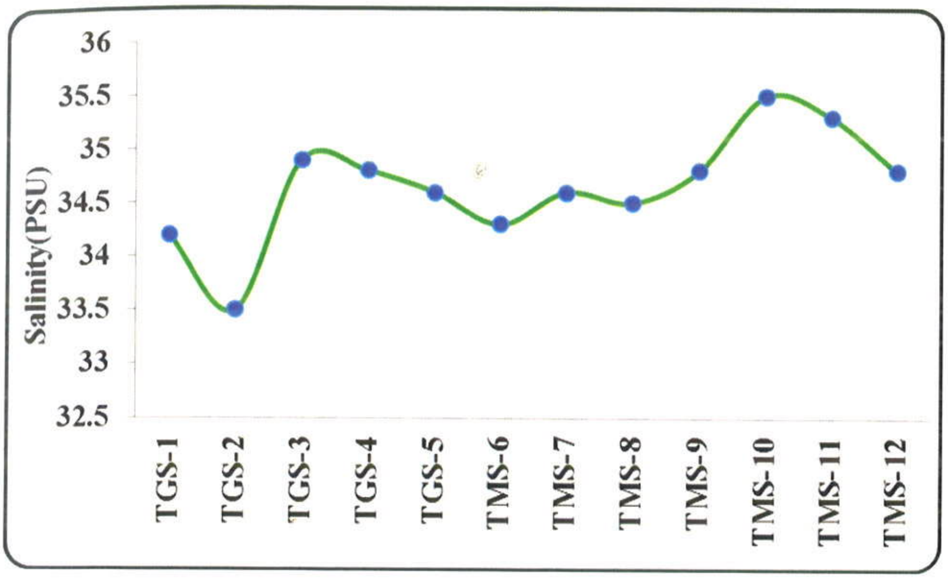


Fig. 4. Salinity level recorded at various stations in Tiruvottiyur Kuppam coastal waters

Water pH

The water pH varied between 7.7 and 8.3 with minimum value was recorded at TGS-2 and maximum value was recorded at TMS-10 (Fig. 5).

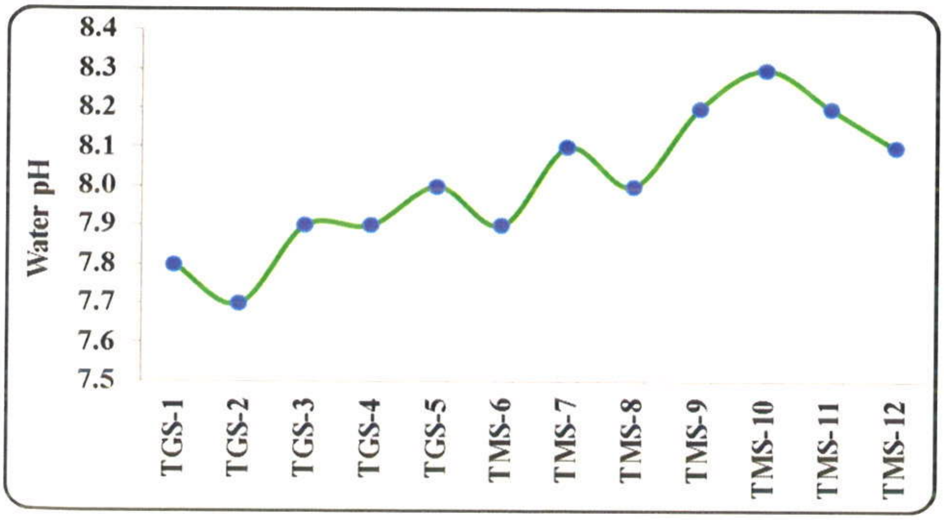


Fig. 5. Water pH level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Dissolved Oxygen

The Dissolved Oxygen level in the water varied between 4.495 and 6.265 mg/l. The lower value was recorded at TGS-2 and the higher value at TMS-10 (Fig. 8).

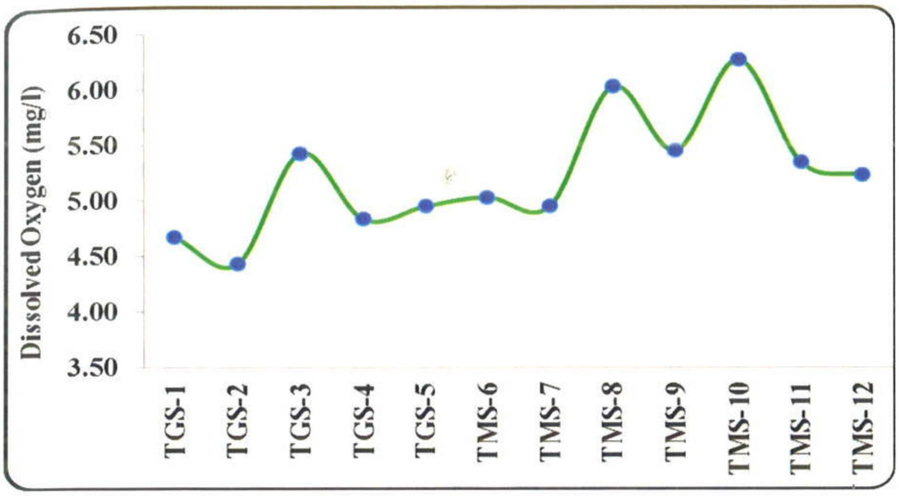


Fig. 8. Dissolved oxygen level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Biological Oxygen Demand

The BOD values varied between 1.03 and 2.38mg/l with minimum at TMS-11 and the maximum value was recorded at TGS-2 (Fig. 9).

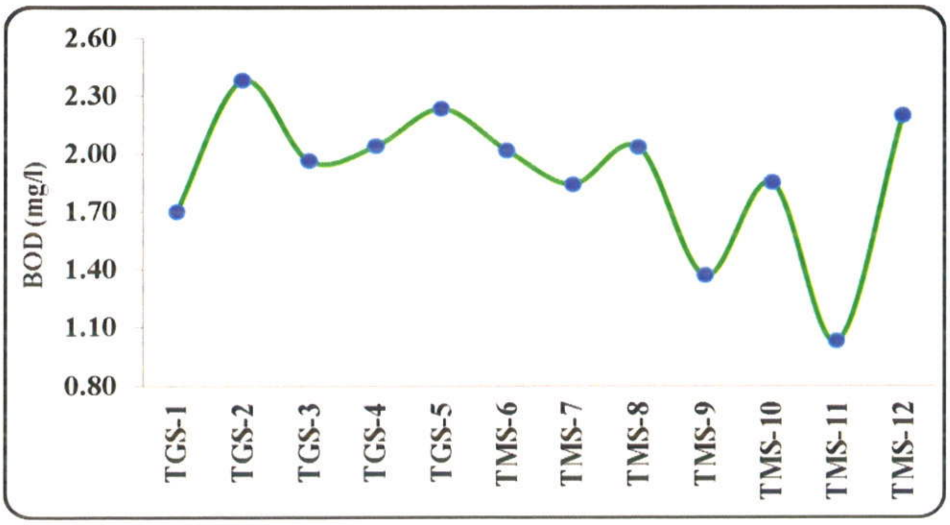


Fig. 9. Biological oxygen demand values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Total Suspended Solids (TSS)

The Total Suspended solids values ranged between 71.20 and 135.20ppm. The minimum value was recorded at TMS-9 and the maximum was recorded at TGS-2 (Fig. 6).

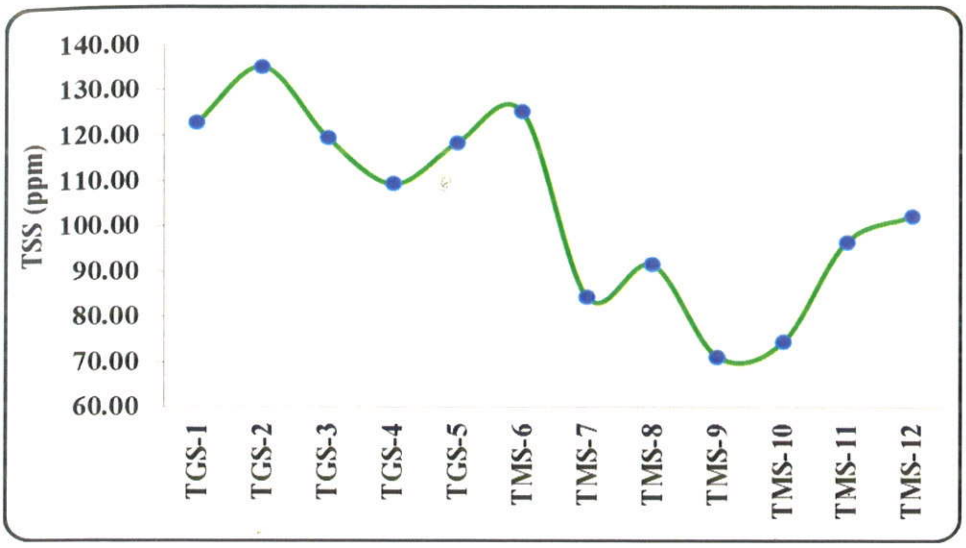


Fig. 6. Total suspended solids values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Turbidity

The turbidity values were between 3.8 and 8.4NTU. The minimum level was recorded at TMS-9 and the maximum level at TGS-2 (Fig. 7).

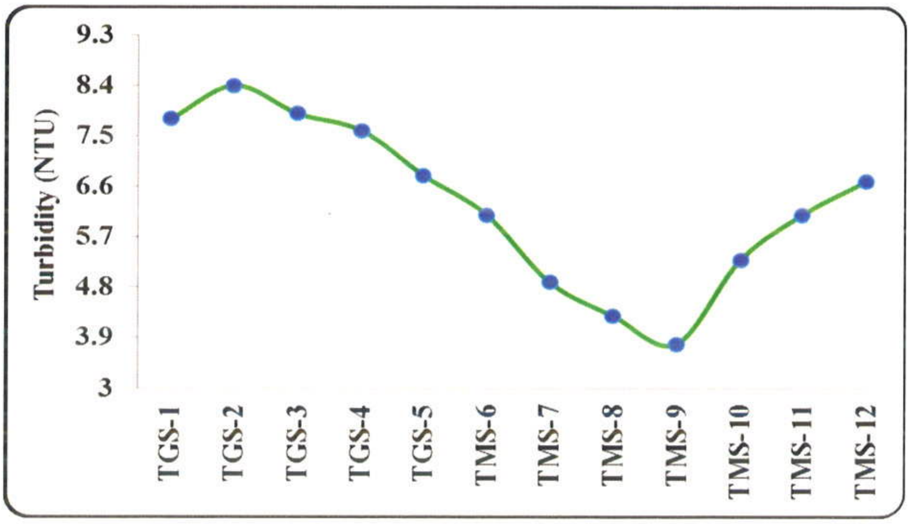


Fig. 7. Turbidity values recorded at various stations of Tiruvottiyur Kuppam coastal waters

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 0.86 to 2.82µmol/l with maximum at TGS-2 and minimum at TMS-9 (Fig. 10).

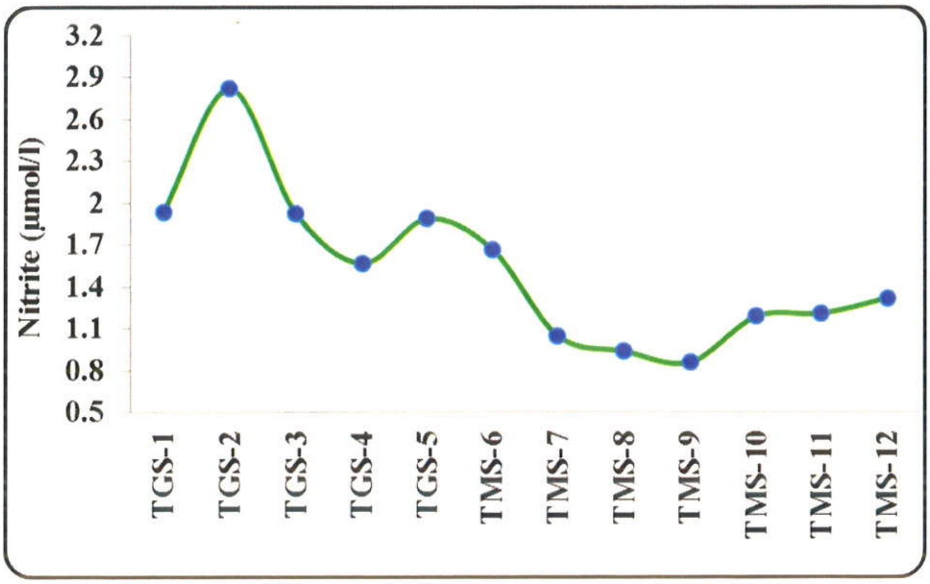


Fig. 10. Nitrite level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Nitrate

Nitrate concentration ranged between 2.10 and 3.75μmol/l with minimum at TMS-9 and maximum at TGS-2 (Fig. 11).

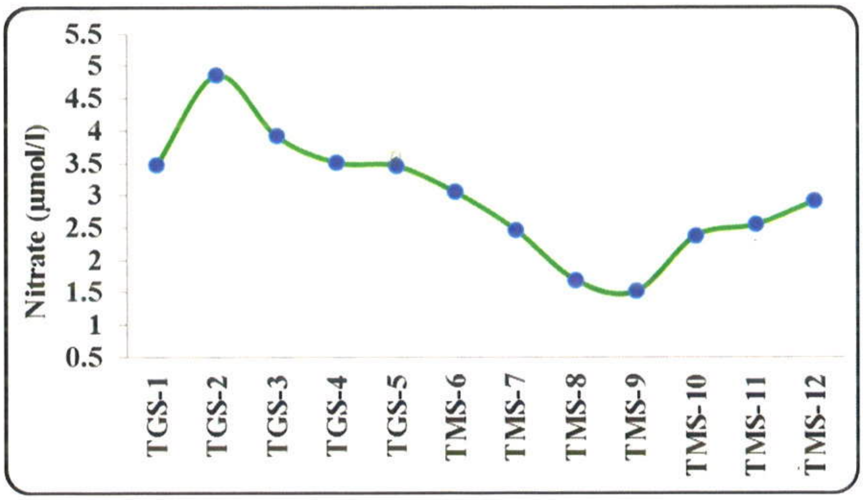


Fig. 11. Nitrate concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Total Nitrogen

The Total nitrogen values ranged from 13.14 to 19.41μmol/l. The minimum value was recorded at TMS-8 and the maximum value at TGS-3 (Fig. 12).

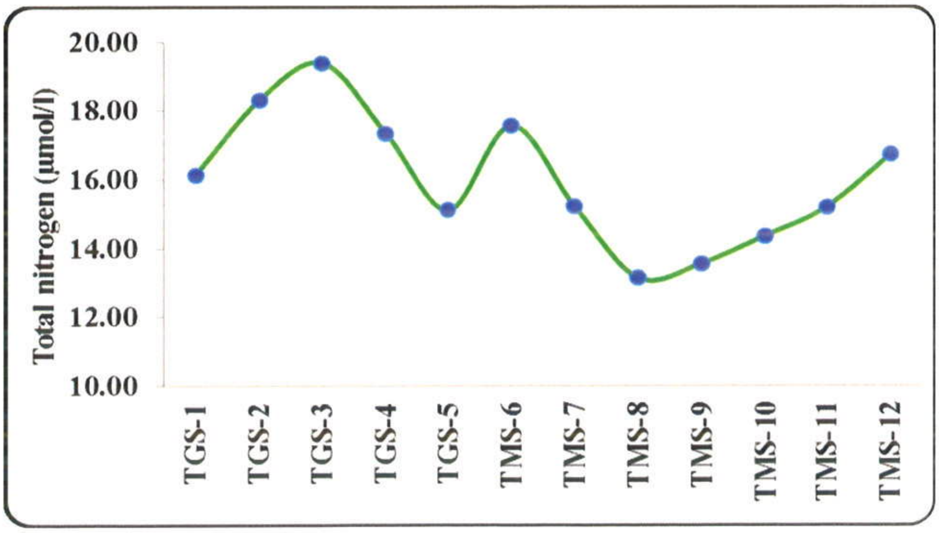


Fig. 12. Total nitrogen values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Ammonical Nitrogen

The ammonia concentration varied from 0.31 to 0.97μmol/l. The maximum concentration (0.97μmol/l) was recorded at TGS-2 and minimum (0.31μmol/l) at TMS-8 (Fig. 13).

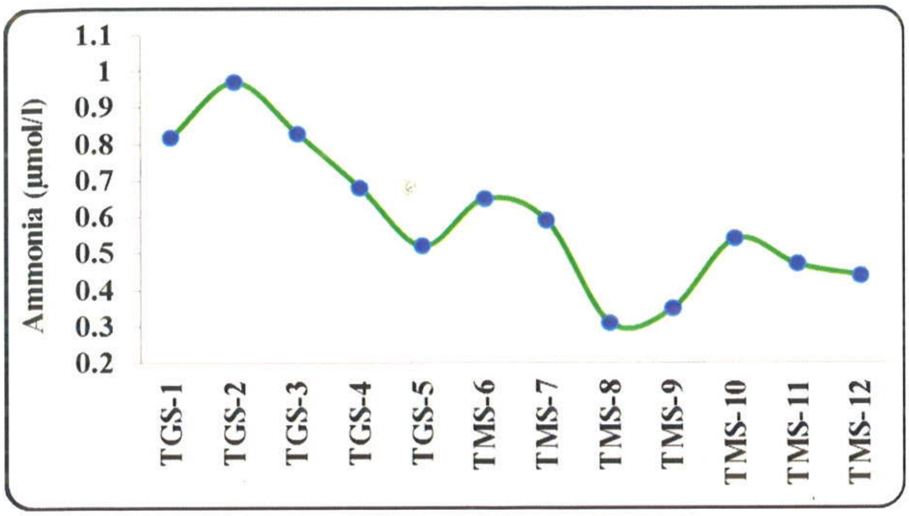


Fig. 13. Ammonical nitrogen concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Inorganic Phosphate

The inorganic phosphate values ranged between 0.49 and 0.68μmol/l with maximum at TGS-4 and minimum at TMS-8 (Fig. 14).

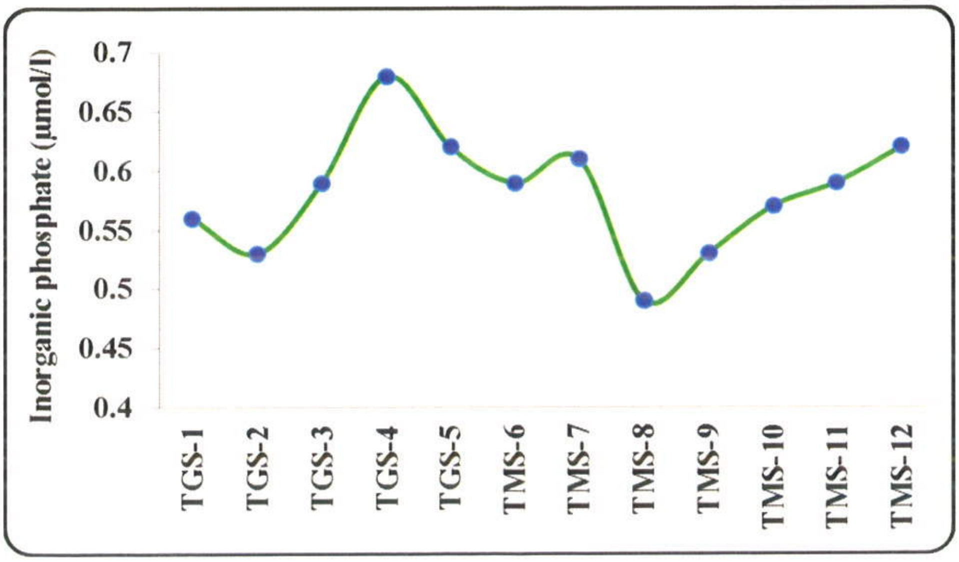


Fig. 14. Inorganic phosphate concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Total Phosphorus

The Total phosphorous values ranged from 1.68 to 3.14μmol/l with minimum value at TMS-9 and the maximum value at TGS-3 (Fig. 15).

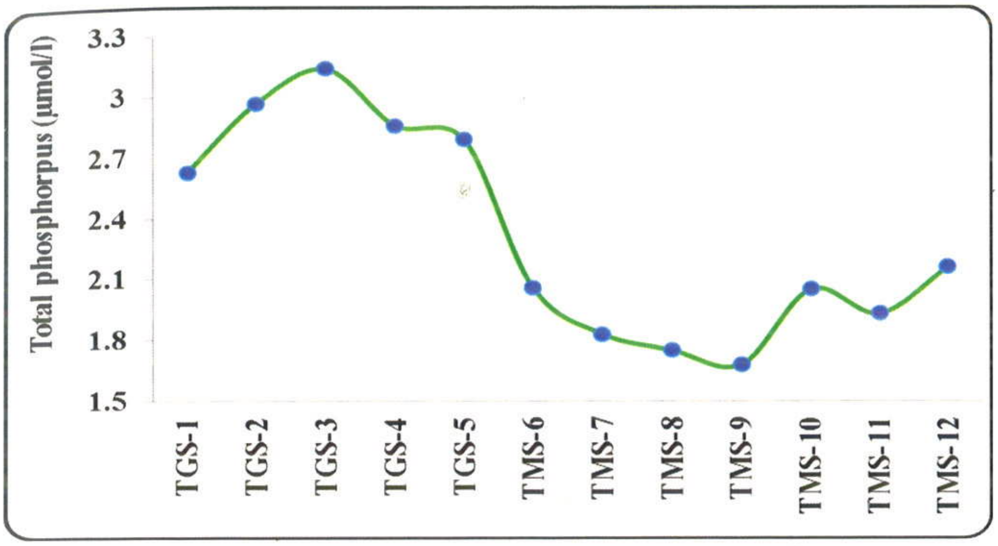


Fig. 15. Total phosphorous values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Reactive Silicate

The silicate values ranged between 62.55 and 82.46μmol/l with minimum was recoded TMS-9 and the maximum values were recorded at TGS-4 (Fig. 16).

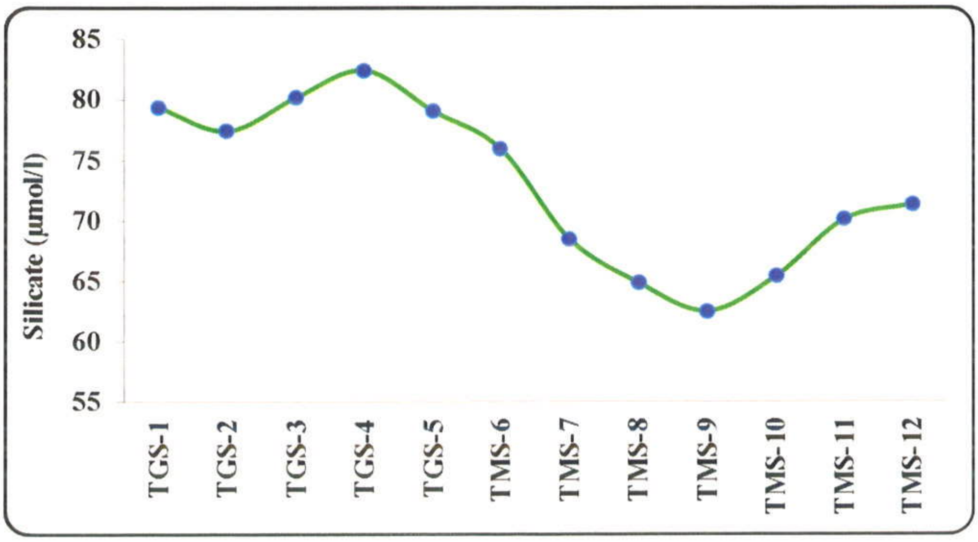


Fig. 16. Reactive silicate level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Particulate organic Carbon

The particulate organic carbon level ranged between 74.37 and 125.45µgC/l with minimum (74.37µgC/l) at TMS-9 and maximum (125.45µgC/l) at TGS-3 (Fig. 17).

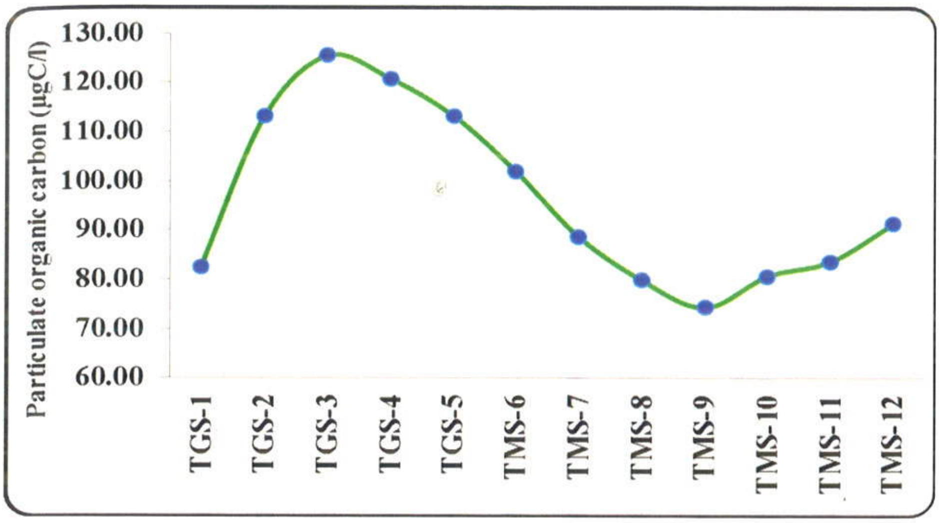


Fig. 17. Particulate organic carbon level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Petroleum hydrocarbons

PHC level in water fluctuated from 0.306 and 0.498µg/l. The maximum was recorded at TGS-2 and the minimum was recorded at TMS-9 (Fig. 18).

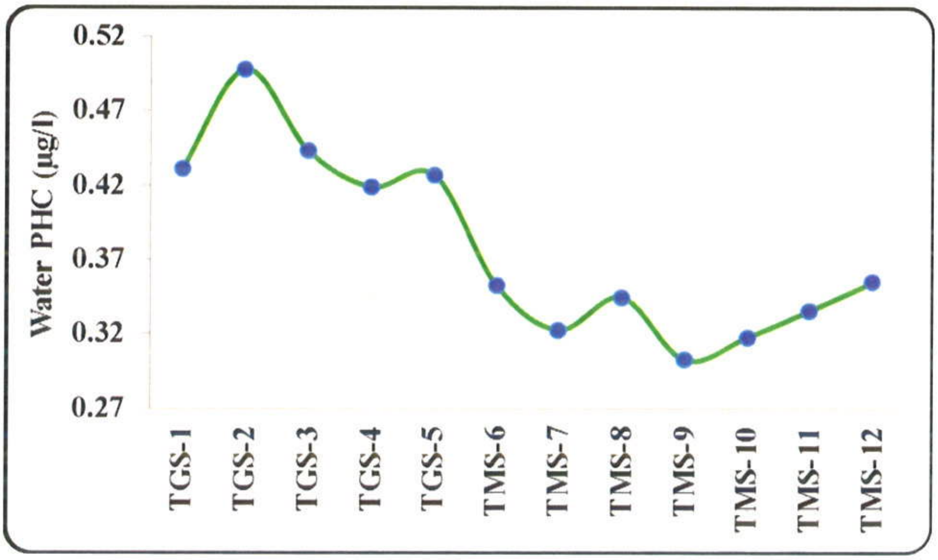


Fig. 18. Petroleum hydrocarbons concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

4. 1. 2. Heavy Metals in water

Iron

The iron level varied from 9.97 to 16.58µg/L (Fig. 19). The maximum was recorded at TGS-3 and the minimum was recorded at TMS-9.

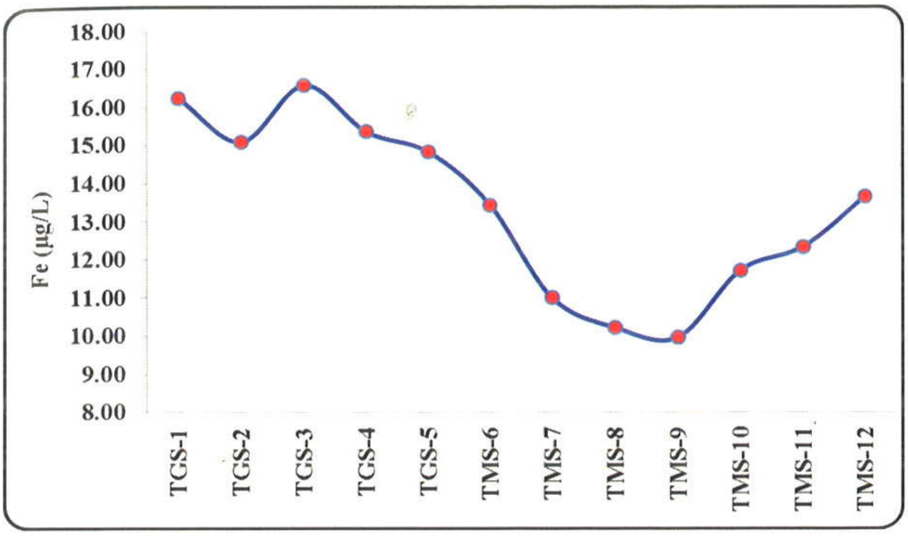


Fig. 19. Iron level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Zinc

The zinc level varied from 11.43 to 19.83µg/L (Fig. 20). The maximum was recorded at TGS-4 and the minimum was recorded at TMS-9.

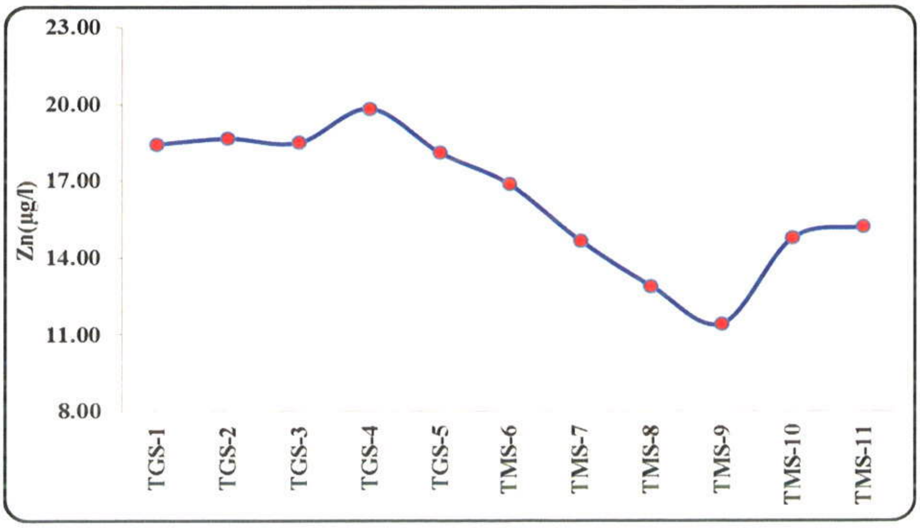


Fig. 20. Zinc level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Manganese

The Manganese concentration varied from 16.98 to 16.70µg/L (Fig. 21). The maximum was recorded TGS-2 and the minimum was recorded at TMS-10.

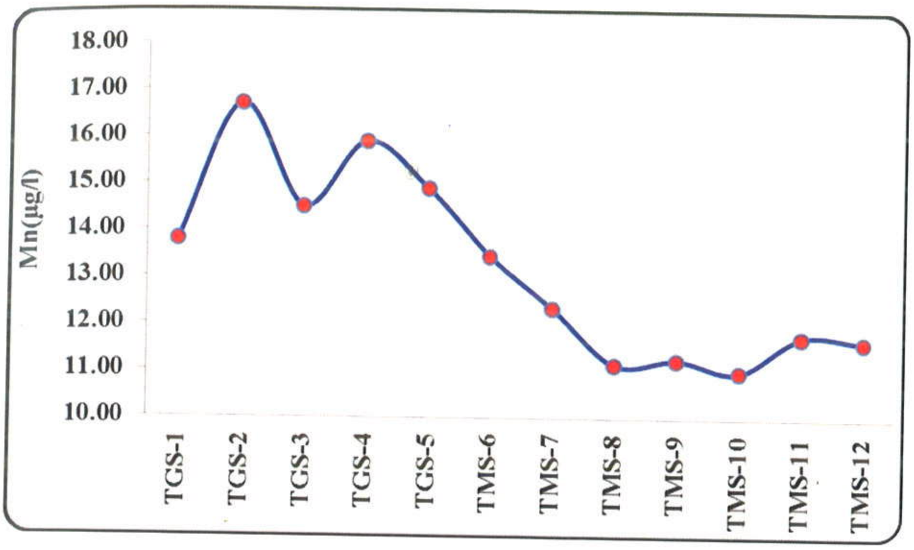


Fig. 21. Manganese concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Cadmium

The Cadmium concentration varied from 1.03 to 1.92µg/L (Fig. 22). The maximum was recorded at TGS-2 and the minimum was recorded at TMS-9.

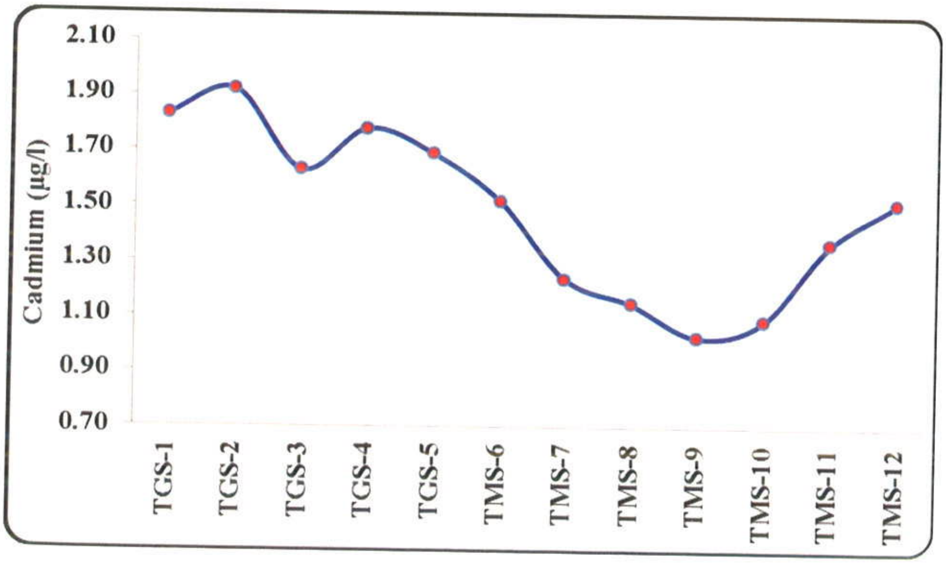


Fig. 22. Cadmium concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Nickel

The Nickel level varied from 0.71 to 1.72µg/L (Fig. 23). The maximum level was recorded at TGS-2 and the minimum was recorded at TMS-10.

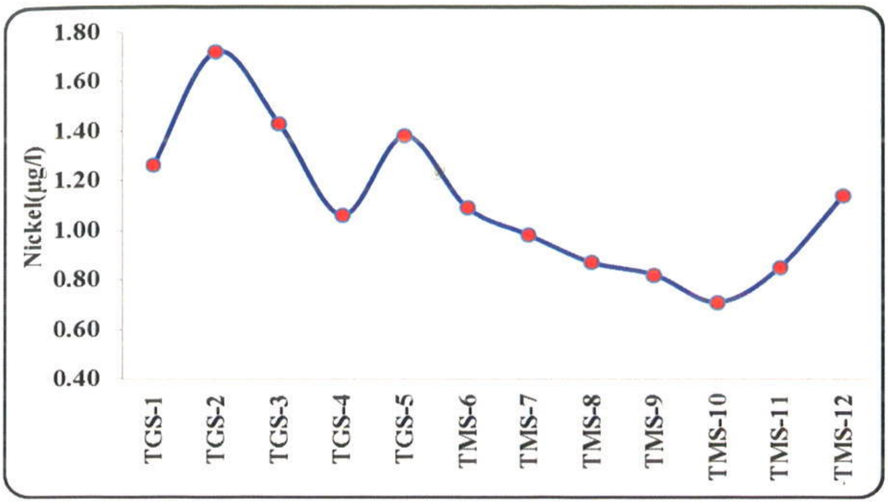


Fig. 23. Nickel level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Chromium

The chromium level varied from 1.08 to 2.34µg/L (Fig. 24). The maximum value was recorded at TGS-5 and the minimum was recorded at TMS-8.

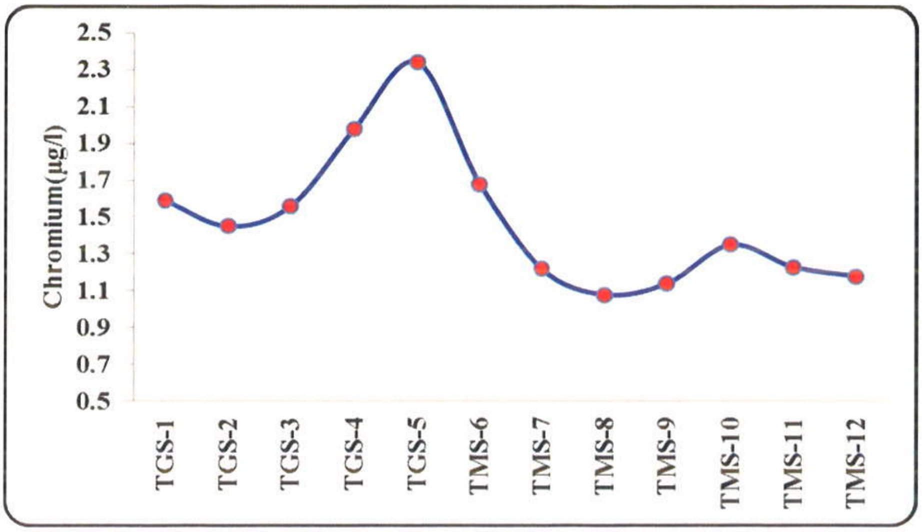


Fig. 24. Chromium level recorded at various stations at Tiruvottiyur Kuppam coastal waters

Lead

The Lead concentration ranged from 1.05 to 2.376µg/L (Fig. 25) with maximum value was recorded at TGS-5 and the minimum was recorded at TMS-10 during this survey

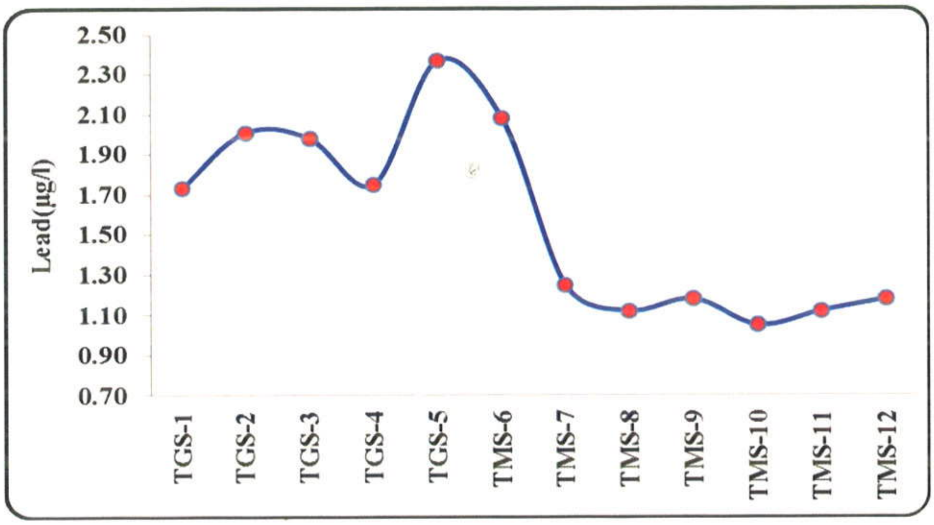


Fig. 25. Lead concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Copper

The copper concentration varied from 2.28 to 5.27µg/L (Fig. 26). The maximum was recorded at TGS-2 and the minimum was recorded at TMS-9 during this survey

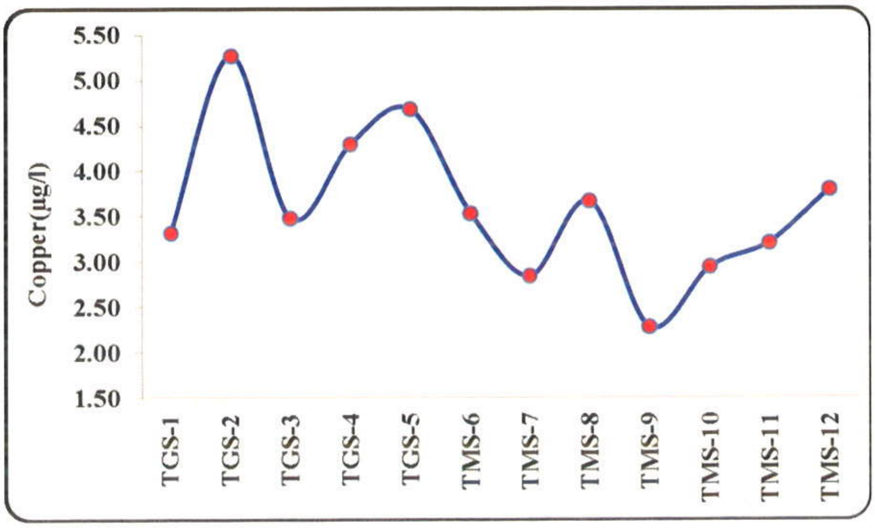


Fig. 26. Copper concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Mercury

The mercury level varied from 0.25 to 1.07µg/L (Fig. 27). The maximum value was recorded at TGS-2 and the minimum was recorded at TMS-9 during this survey.

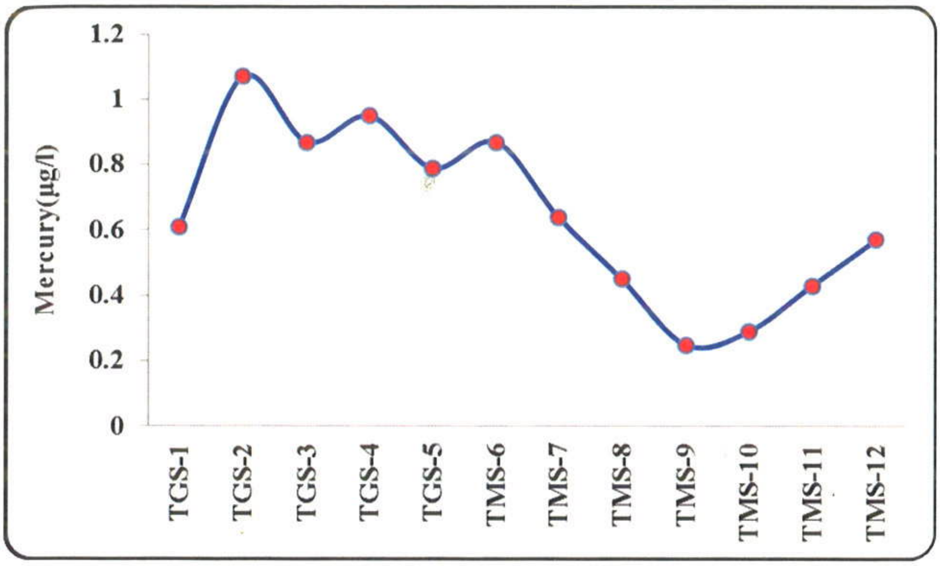


Fig. 27. Mercury level recorded at various stations at Tiruvottiyur Kuppam coastal waters

4. 2. Sediment Characteristics

Sediment pH

The maximum value (8.39) of soil pH was recorded at TMS-10 and minimum of 7.76 at TGS-2 (Fig. 28).

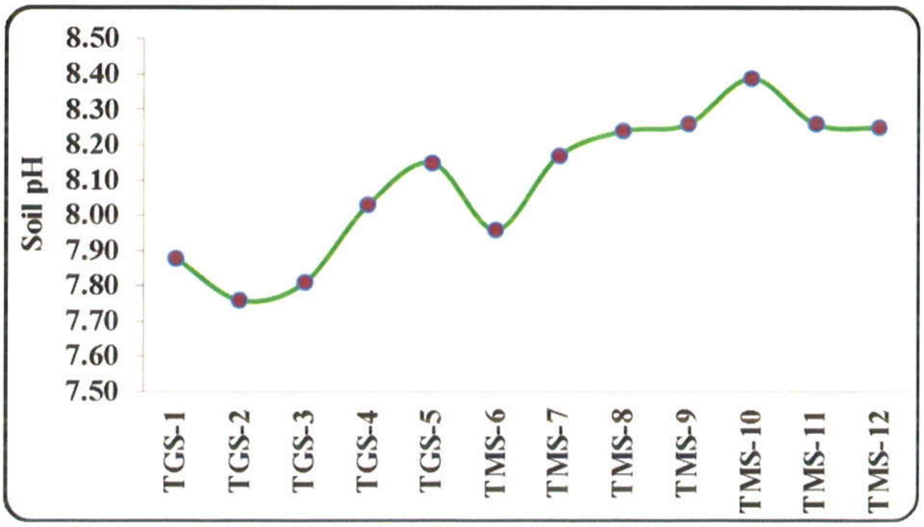


Fig. 28. Soil pH values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Soil Texture

The sand content varied from 5.96 to 78.77 % with maximum value was at TMS-9 and the minimum at TGS-3; maximum Silt content (64.82%) was found at TGS-2 and minimum (13.43%) at TMS-9 and the maximum Clay content (69.04%) was found at TGS-3 and minimum (6.0%) at TMS-10 (Fig. 29).

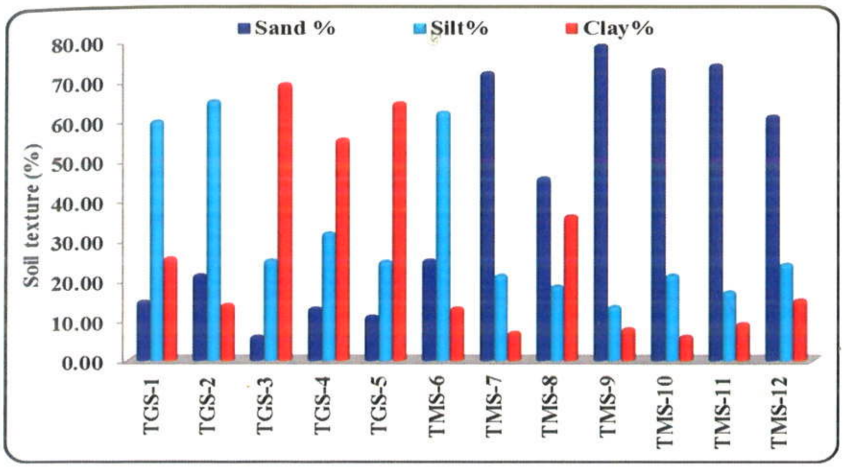


Fig. 29. Variations in soil texture recorded in various stations of Tiruvottiyur Kuppam coastal waters

Total organic Carbon

The total organic carbon ranged between 6.35 and 9.76mgC/g. The maximum level (9.76mgC/g) was found at TGS-4 and minimum (6.35mgC/g) at TMS-8 (Fig. 30).

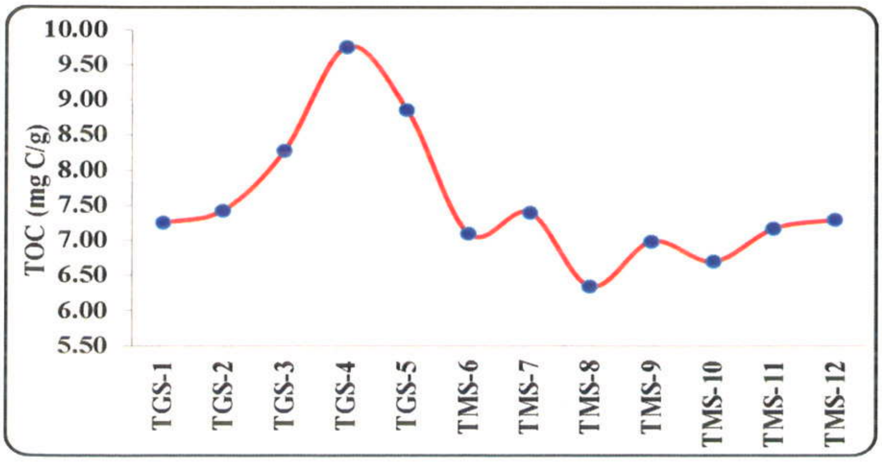


Fig. 30. Total organic carbon values recorded in various stations of Tiruvottiyur Kuppam coastal waters

Sediment PHC

The Sediment PHC level varied from 0.468 to 0.889µg/g (Fig. 31). The maximum level was recorded at TGS-2 and the minimum was recorded at TMS-9 during this survey

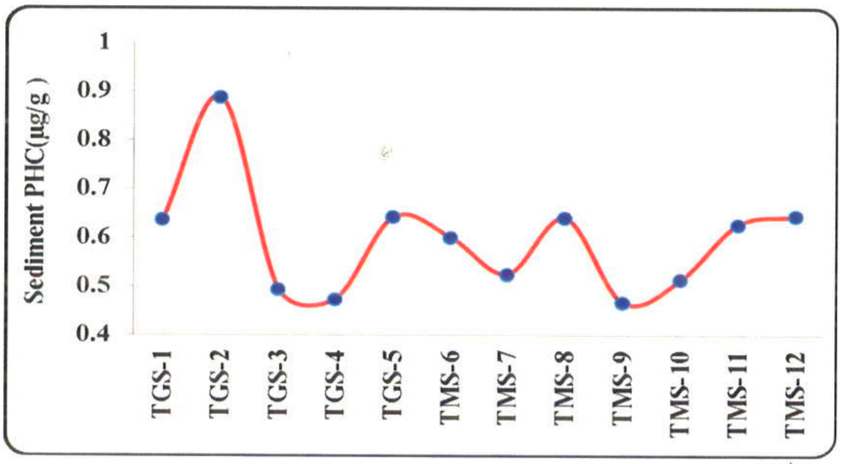


Fig. 31. Sediment PHC level recorded at various stations at Tiruvottiyur Kuppam coastal waters

4. 2. 1. Heavy Metals in sediments

Iron

The Iron level varied from 1166.23 to 1965.24µg/g (Fig. 32). The maximum was recorded at TGS-4 and the minimum was recorded at TMS-9.

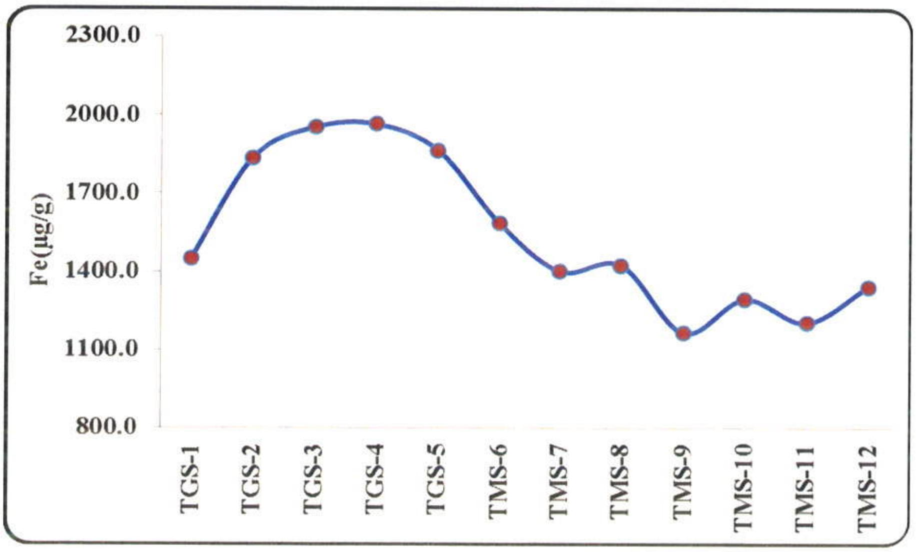


Fig. 32. Iron level recorded in various stations Tiruvottiyur Kuppam coastal waters

Zinc

Zinc concentration varied from 23.70 to 33.40µg/g (Fig. 33). The maximum level was recorded at TGS-3 and the minimum was recorded at TMS-8.

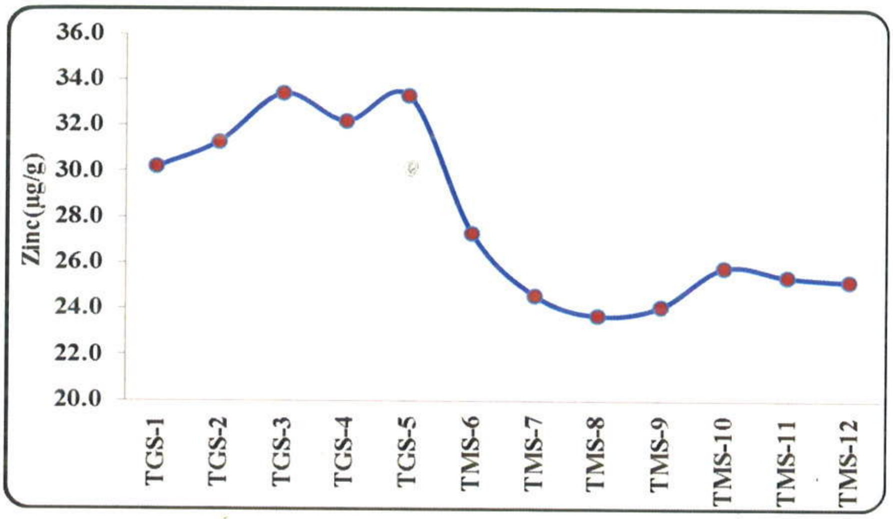


Fig. 33. Zinc concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Manganese

The Manganese level varied from 60.17 to 80.55µg/g (Fig. 34). The maximum level was recorded at TGS-5 and the minimum was recorded at TMS-10.

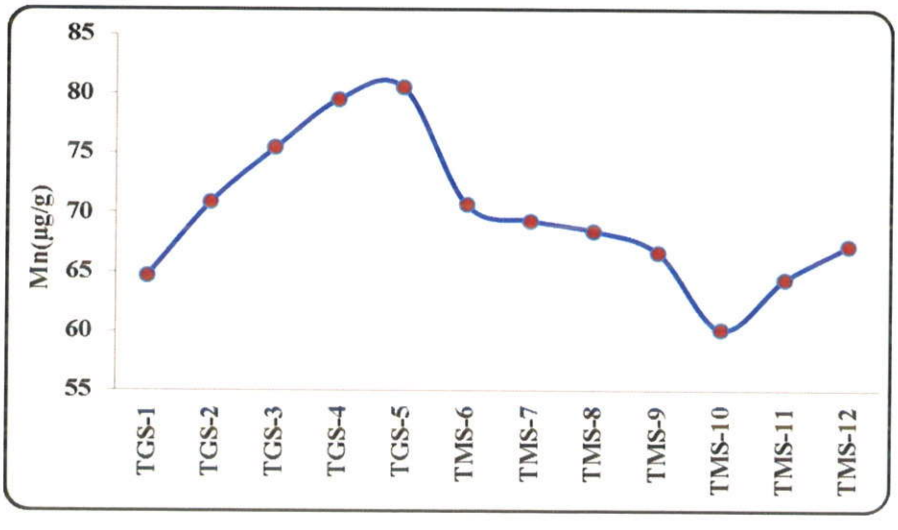


Fig. 34. Manganese level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Cadmium

The Cadmium level varied from 1.03 to 4.54µg/g (Fig. 35). The maximum level was recorded at TGS-2 and the minimum was recorded at TMS-10.

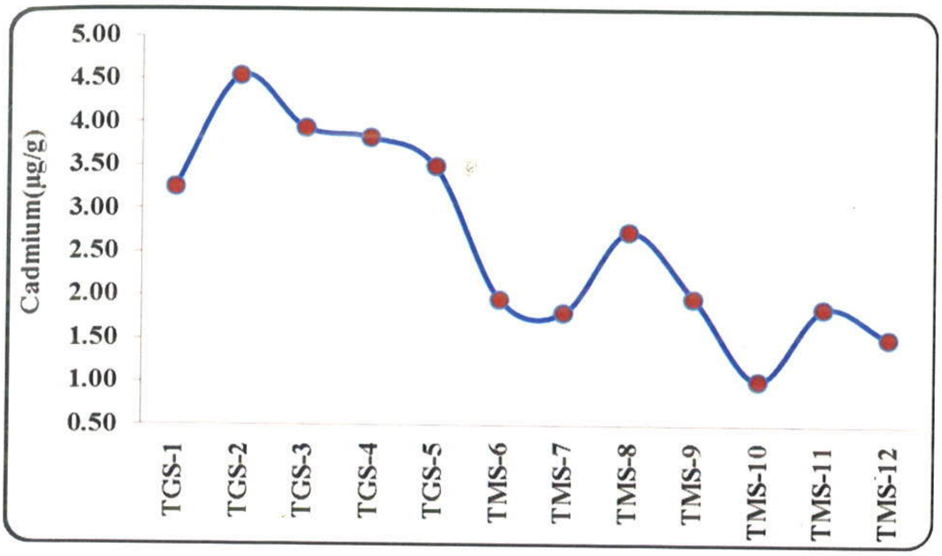


Fig. 35. Cadmium level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Nickel

The nickel concentration varied from 5.37 to 10.93µg/g (Fig. 36). The maximum was recorded at TGS-3 and the minimum was recorded at TMS-9.

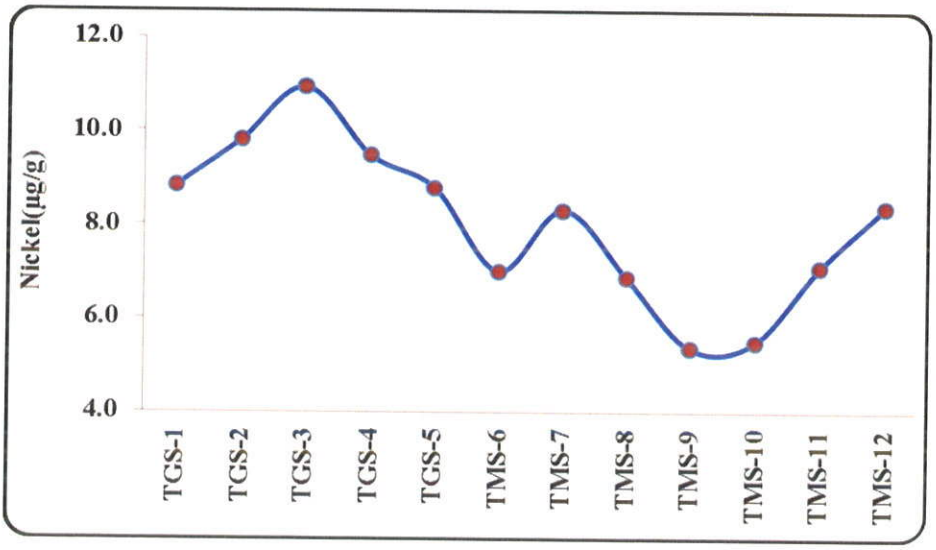


Fig. 36. Nickel concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Chromium

The Chromium level varied from 5.24 to 7.41µg/g (Fig. 37) with the maximum was recorded at TGS-2 and the minimum was recorded at TMS-9.

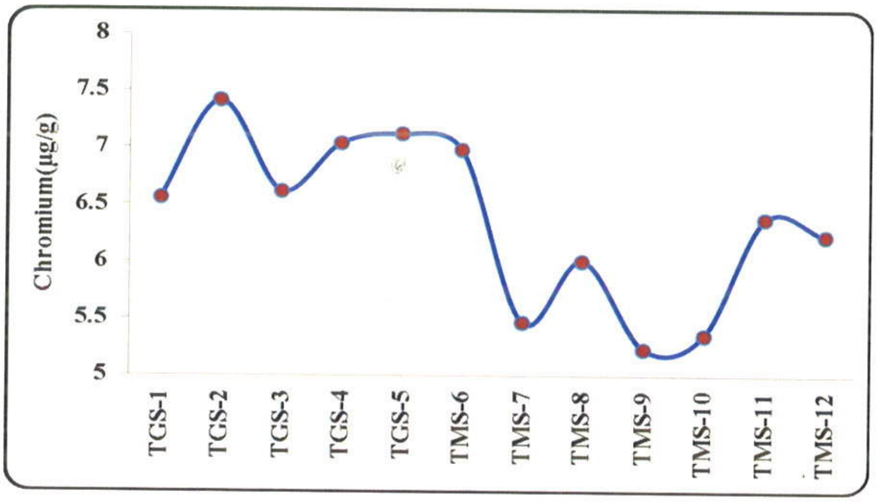


Fig. 37. Chromium level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Lead

The lead concentration varied from 4.06 to 6.97µg/g (Fig. 38). The maximum value was recorded at TGS-3 and the minimum was recorded at TMS-9.

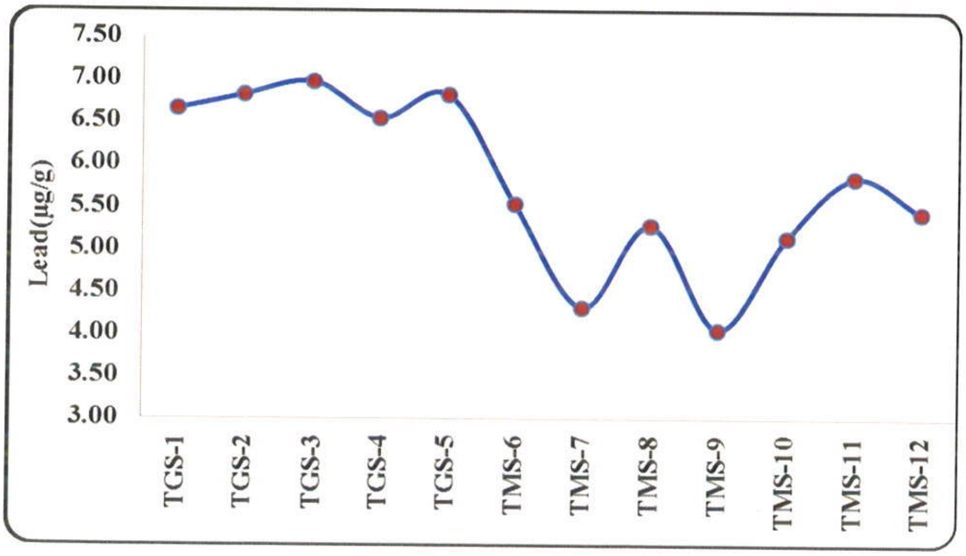


Fig. 38. Lead concentration recorded in various stations of Tiruvottiyur Kuppam coastal waters

Copper

The copper level varied from 6.23 to 11.74µg/g (Fig. 39). The maximum value was recorded at TGS-2 and the minimum was recorded at TMS-8.

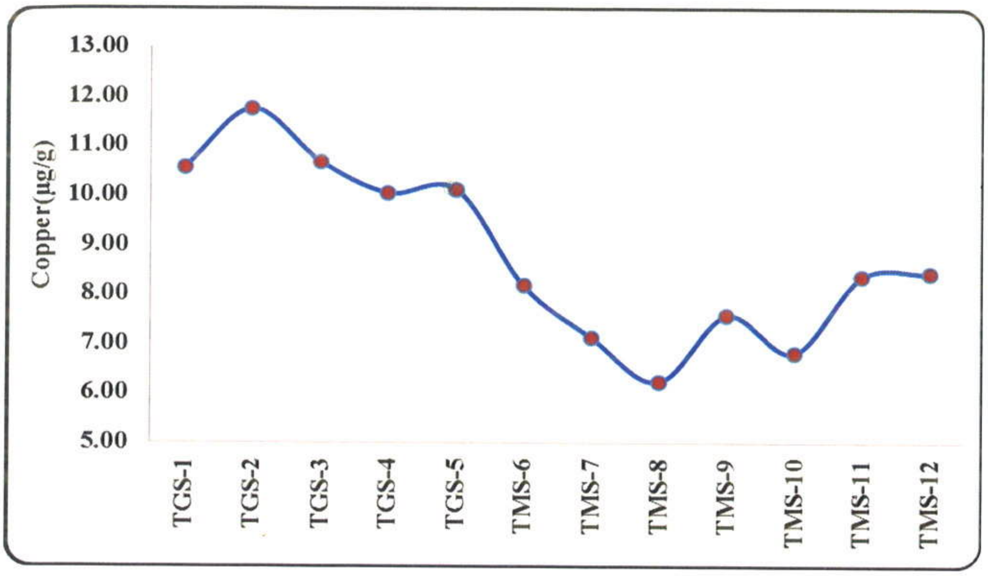


Fig. 39. Copper level recorded in various stations of Tiruvottiyur Kuppam coastal waters

Mercury

The mercury concentration varied from 0.71 to 1.56µg/g (Fig. 40). The maximum was recorded at TGS-5 and the minimum was recorded at TMS-9.

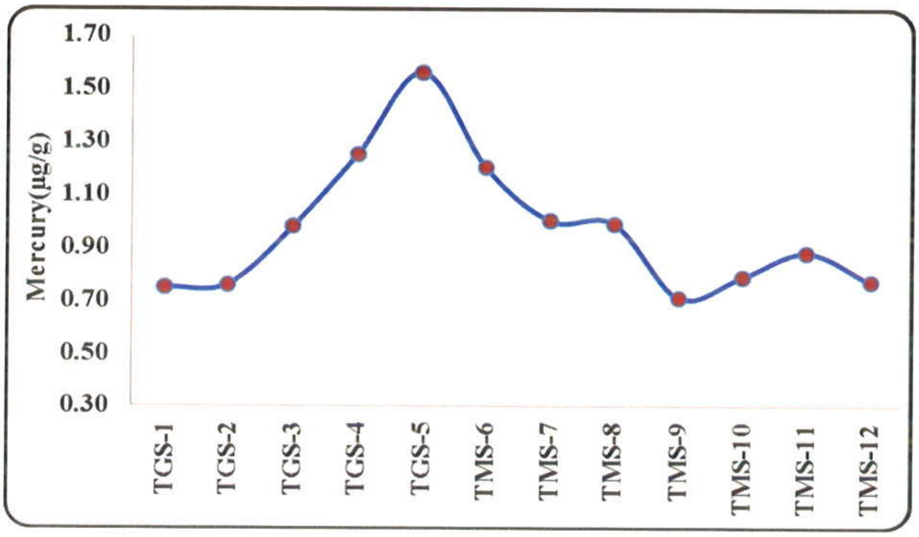


Fig. 40. Mercury concentration recorded in various stations of Tiruvottiyur Kuppam coastal waters

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, sand and Mn got correlated with stations TGS-5, TGS-3 TGS-2, TGS-1, TMS-6, TMS-8 and TMS-9 while the rest of the parameters showed strong correlation with stations TMS-10, TMS-11, TMS-12 TMS-7 and TGS-4.

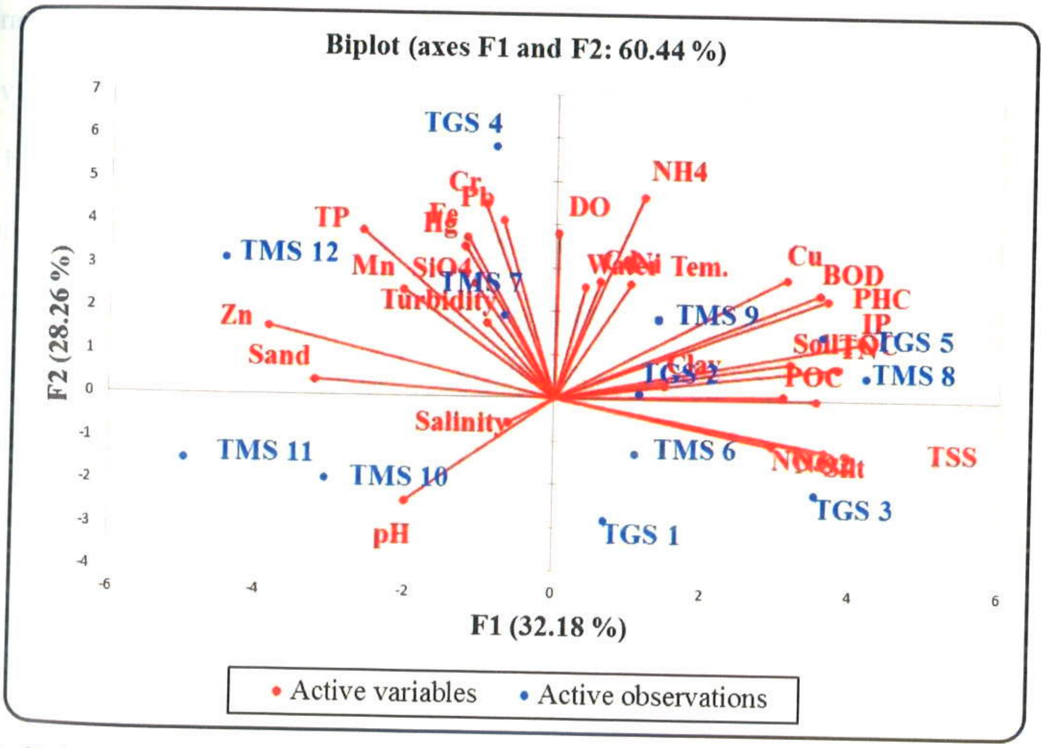


Fig. 41. Principal Component Analysis plot drawn for the correlation between various environmental variables and stations of Tiruvottiyur Kuppam coastal waters

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, sand and Mn got correlated with stations TGS-5, TGS-3 TGS-2, TGS-1, TMS-6, TMS-8 and TMS-9 while the rest of the parameters showed strong correlation with stations TMS-10, TMS-11, TMS-12 TMS-7 and TGS-4.

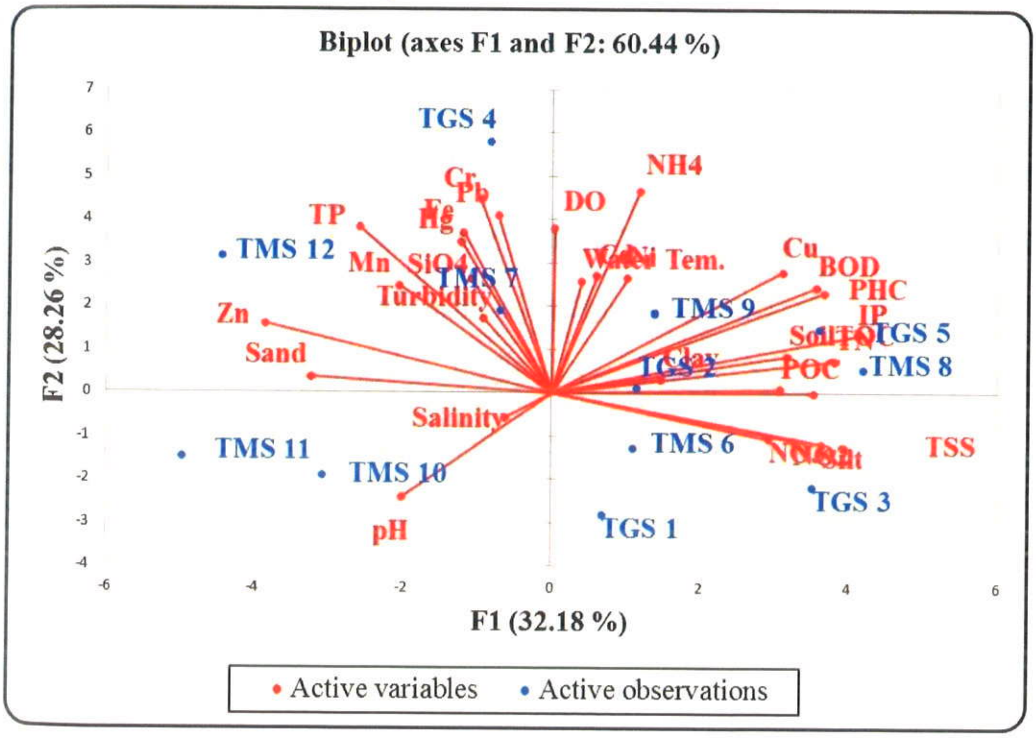


Fig. 41. **Principal Component Analysis plot drawn for the correlation between various environmental variables and stations of Tiruvottiyur Kuppam coastal waters**

4.3. MICROBIOLOGY

4. 3. 1. Water sample

The total viable count in water samples ranged from 11x103 to $28x10^4$ CFU/ml. The maximum count was found at TGS-2 and the minimum count was found at TMS-10. The Total coliform count in the samples varied from $10x10^3$ to $29x10^4$ CFU/ml with the high colony count at TGS-1 and the low count at TMS-9. The *E. coli* count ranged from $9x10^3$ to $25x10^3$ CFU/ml with a maximum value at TGS-2 and the minimum value at TMS-9. The *Faecal coliform* was found to vary from $10x10^2$ to $26x10^2$ CFU/ml with higher value at TGS-2 and the lower value at TMS-9. The *Pseudomonas aeurginosa* count ranged from $05x10^2$ to $17x10^4$ CFU/ml with maximum value at TMS-12 and the minimum value at TMS-10. The *Streptococcus faecalis* count ranged from $09x10^3$ to $14x10^4$ CFU/ml. The higher values were recorded at TGS-1 and the lower values were recorded at TMS-8. The *Shigella* count varied from $07x10^3$ to $17x10^4$ CFU/ml with a higher value at TGS-2 and the lower value at TMS-8. The *Salmonella* colony count varied from $06x10^2$ to $15x10^4$CFU/ml with the higher value at TMS-12 and the lower value at TMS-10. The *Vibrio cholera* colony count was found to fluctuate from $06x10^2$ to $21x10^2$CFU/ml. The higher colony count was observed at TGS-2 and the lower count was recorded at TMS-9. *Vibrio parahaemolyticus* colony count varied from $07x10^2$ to $15x10^4$ CFU/ml with the maximum value at TGS-2 and minimum value at TMS-8 (Table 2).

Table 2. Bacterial populations recorded in water sample at Tiruvottiyur kuppam coastal waters

S. No	Stations	FC	TVC	TC	EC	VC	VP	PA	SF	SH	SL
1	TGS-1	$20x10^3$	$27x10^3$	$29x10^4$	$21x10^4$	$19x10^3$	$13x10^2$	$17x10^3$	$14x10^4$	$14x10^4$	$12x10^3$
2	TGS-2	$26x10^2$	$28x10^4$	$25x10^2$	$25x10^3$	$21x10^2$	$15x10^4$	$13x10^4$	$12x10^4$	$17x10^4$	$11x10^4$
3	TGS-3	$17x10^3$	$21x10^5$	$21x10^3$	$21x10^3$	$10x10^3$	$11x10^2$	$13x10^3$	$11x10^2$	$12x10^3$	$08x10^2$
4	TGS-4	$15x10^3$	$17x10^3$	$18x10^2$	$16x10^3$	$09x10^3$	$10x10^3$	$11x10^2$	$10x10^3$	$10x10^3$	$09x10^2$
5	TGS-5	$17x10^4$	$19x10^3$	$16x10^2$	$13x10^3$	$10x10^3$	$08x10^3$	$12x10^2$	$10x10^2$	$09x10^2$	$11x10^2$
6	TMS-6	$11x10^3$	$18x10^4$	$14x10^4$	$17x10^4$	$13x10^3$	$11x10^2$	$13x10^4$	$13x10^2$	$12x10^4$	$13x10^3$
7	TMS-7	$12x10^4$	$12x10^3$	$12x10^3$	$11x10^4$	$08x10^3$	$09x10^3$	$07x10^3$	$10x10^2$	$08x10^4$	$08x10^3$
8	TMS-8	$11x10^4$	$15x10^3$	$10x10^3$	$10x10^3$	$08x10^2$	$07x10^2$	$10x10^4$	$11x10^3$	$07x10^3$	$09x10^3$
9	TMS-9	$10x10^2$	$14x10^4$	$12x10^2$	$09x10^3$	$06x10^2$	$09x10^3$	$07x10^2$	$09x10^3$	$08x10^4$	$06x10^2$
10	TMS-10	$12x10^2$	$11x10^3$	$11x10^4$	$14x10^4$	$07x10^3$	$08x10^2$	$05x10^2$	$11x10^2$	$10x10^2$	$12x10^2$
11	TMS-11	$13x10^2$	$12x10^4$	$14x10^3$	$13x10^4$	$12x10^3$	$10x10^3$	$10x10^2$	$11x10^3$	$10x10^2$	$10x10^2$
12	TMS-12	$24x10^3$	$21x10^2$	$16x10^4$	$15x10^3$	$18x10^4$	$13x10^2$	$17x10^4$	$12x10^3$	$12x10^3$	$15x10^4$

4. 3. 2. Sediment sample

With respect to sediment samples, the total viable count in sediment samples ranged from $17x10^5$ to $28x10^4$ CFU/g. The maximum was found at TGS-2 and the minimum value was found at TMS-10. The Total coliform count was found to vary from $16x10^3$ to $31x10^3$ CFU/g with the higher value at TGS-1 and the lower value at TMS-8. The *E. coli* count ranged from $16x10^4$ to $29x10^4$CFU/g with the higher value at TGS-2 and the lower value at TMS-9. The *Faecal coliform* count in the samples varied from $14x10^2$ to $30x10^2$ CFU/g with the higher colony count at TGS-2 and the lower count at TMS-9. *Pseudomonas aeurginosa* counts ranged from $10x10^3$ to $18x10^4$ CFU/g with the maximum at TGS-1 and the minimum at TMS-7. The *Streptococcus faecalis* count ranged from $11x10^3$ to $25x10^4$ CFU/g. The higher value was recorded at TGS-2 and the lower value was recorded at TMS-9. The *Shigella* counts varied from $11x10^3$ to $24x10^3$ CFU/g with the higher value at TMS-12 and lower value at TMS-7. *Salmonella* colony counts varied from $10x10^3$ to $23x10^3$ CFU/g with the maximum value at TGS-1 and the minimum value at TMS-8. *Vibrio parahaemolyticus* colony count varied from $11x10^3$ to $24x10^4$ CFU/g. The higher value was found at TGS-2 and the lower value at TMS-9. The other species *Vibrio cholerae* colony was found to range from $12x10^3$ to $26x10^2$ CFU/g with the maximum colony count at TGS-1 and the minimum count was observed at TMS-8 (Table 3).

Table 3. Bacterial populations recorded in sediment sample at Tiruvottiyur kuppam coastal waters

S. No	Stations	FC	TVC	TC	EC	VC	VP	PA	SF	SH	SL
1	**TGS-1**	29×10^2	27×10^4	31×10^3	27×10^5	26×10^2	16×10^3	18×10^4	16×10^3	15×10^3	23×10^3
2	**TGS-2**	30×10^2	28×10^4	29×10^2	29×10^4	19×10^3	24×10^4	18×10^4	25×10^4	17×10^5	17×10^4
3	**TGS-3**	21×10^5	20×10^4	28×10^3	25×10^4	16×10^3	21×10^3	14×10^4	15×10^4	13×10^4	11×10^4
4	**TGS-4**	17×10^3	19×10^5	21×10^4	22×10^4	13×10^4	13×10^4	14×10^4	14×10^4	12×10^4	13×10^4
5	**TGS-5**	20×10^5	18×10^4	23×10^5	18×10^2	15×10^5	14×10^4	15×10^4	13×10^4	13×10^4	11×10^4
6	**TMS-6**	23×10^3	26×10^4	29×10^4	22×10^4	16×10^4	15×10^4	16×10^2	19×10^5	14×10^3	19×10^4
7	**TMS-7**	19×10^4	23×10^4	19×10^5	18×10^3	14×10^4	13×10^3	10×10^3	12×10^3	11×10^3	12×10^4
8	**TMS-8**	19×10^4	21×10^4	16×10^3	19×10^5	12×10^3	12×10^3	14×10^4	12×10^4	12×10^4	10×10^3
9	**TMS-9**	14×10^2	23×10^4	23×10^4	16×10^4	14×10^4	11×10^3	13×10^4	11×10^3	13×10^4	11×10^3
10	**TMS-10**	18×10^3	17×10^5	20×10^4	19×10^3	13×10^3	12×10^4	14×10^4	13×10^4	12×10^5	13×10^4
11	**TMS-11**	21×10^4	19×10^5	25×10^4	22×10^3	15×10^4	12×10^3	15×10^3	15×10^3	13×10^4	12×10^3
12	**TMS-12**	27×10^4	20×10^5	27×10^5	24×10^5	17×10^3	15×10^3	17×10^3	17×10^4	24×10^3	15×10^4

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 1.053 to 2.804 mg/m^3, with maximum at TGS-3 and minimum at TMS-12. The Phaeopigments content varied from 1.107 to 2.475 mg/m^3 with maximum was at TGS-3 and the minimum was observed at TMS-9. The Total biomass values varied from 1.968 to 5.803 $ml/100m^3$, with maximum at TGS-4 and minimum at TMS-10 (Table 4).

Table 4. Chlorophyll *a*, Phaeopigments and total biomass recorded in Tiruvottiyur kuppam coastal waters

Stations	Chlorophyll 'a' (mg/m^3)	Phaeopigments (mg/m^3)	Total biomass ($ml/100m^3$)
TGS-1	1.225	1.238	2.754
TGS-2	1.208	1.284	3.857
TGS-3	2.804	2.475	2.528
TGS-4	1.149	1.361	5.803
TGS-5	2.008	1.742	3.086
TMS-6	1.260	1.268	2.043
TMS-7	2.526	1.957	3.094
TMS-8	1.872	1.430	3.126
TMS-9	1.317	1.107	2.241
TMS-10	1.850	1.446	1.968
TMS-11	1.472	1.137	2.168
TMS-12	1.053	1.168	2.037

Primary productivity

The primary productivity was measured using the dark and light reaction method. The values ranged from 114.15 to 168.72mgC$m^{-3}d^{-1}$. The maximum value was recorded at TGS-5 and minimum value at TMS-10 (Fig. 42).

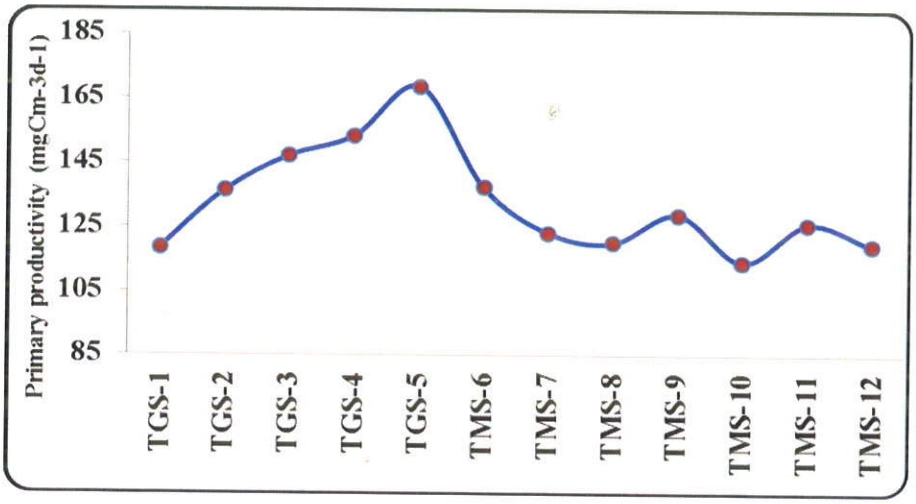


Fig. 42. Primary productivity values recorded at various stations of Tiruvottiyur kuppam coastal waters

4.5 PLANKTON

4.5.1 Phytoplankton

In the present study, as many as 42 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 30 species, Dinophyceae formed next group with 11 species and Cyanophyceae with one species.

Among the Bacillariophyceae, *Skeletonema costatum* was observed highly dominated in all the stations and followed by *Asterionella glacialis, Chaetoceros curvisetus* and *Cyclotella* sp also were found in all sampling sites except station second (TGS-2) in Thiruvottiyur kuppam coastal area. The Dinophyceae, (*Dinophysis caudate*) and Cyanophyceae (*Trichodesmium erythraeum*) similarly were recorded in all the twelve sampling sites. Among the various species, *Bellerochea malleus, Chaetoceros coarctatus, Coscinodiscus centralis, Navicula* sp, *Nitzschia longissima, Odontella mobiliensis, Planktoniella sol, Rhizosolenia alata, Thalassionema nitzschioides, Ceratium furca, Ceratium macroceros* and *Peridinium claudicans* were the most abundant forms. The distribution and abundance of phytoplankton varied considerably following seasonal environmental fluctuations.

Population density

Density of phytoplankton varied from 6,905 to 20972 Cells/l with maximum was at TGS-4 and minimum at TGS-2 (Fig. 43).

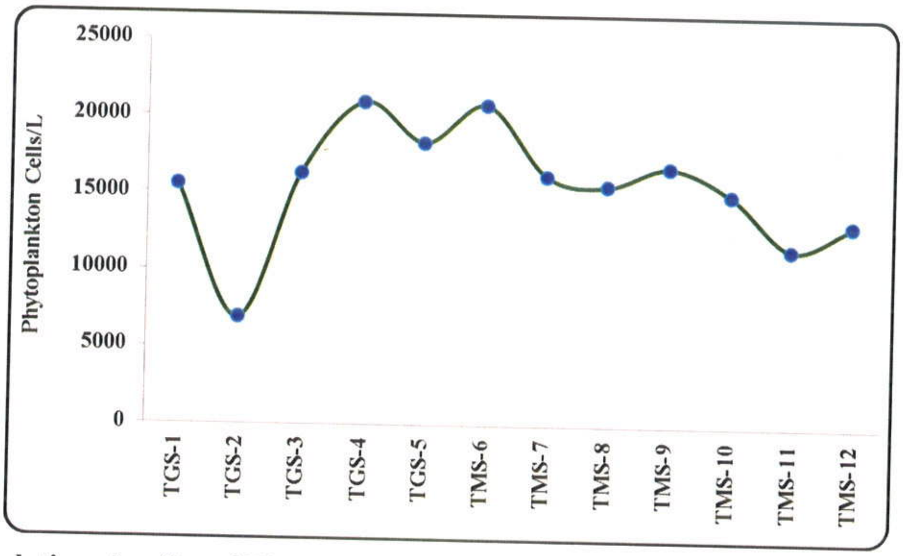


Fig. 43. Population density of Phytoplankton in various stations of Tiruvottiyur kuppam coastal waters

Percentage composition

When the results of percentage composition of phytoplankton were looked at, Bacillariophyceae constituted the maximum with 80% of the total followed by Dinophyceae with 13% and Cyanophyceae with 7% of the total (Fig. 44).

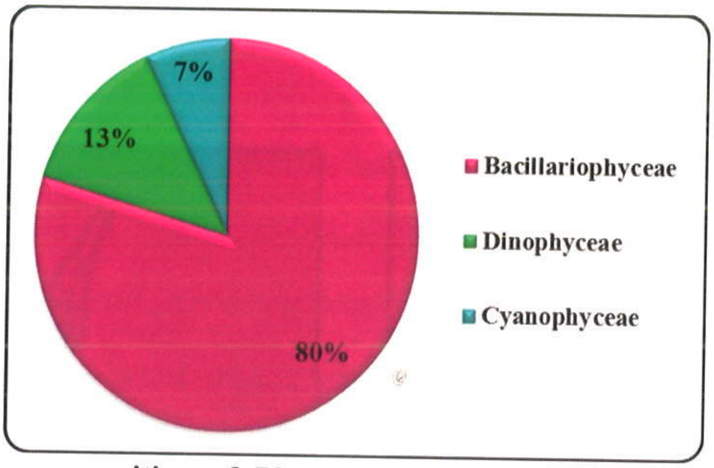


Fig. 44. Percentage composition of Phytoplankton in various stations of Tiruvottiyur kuppam coastal waters

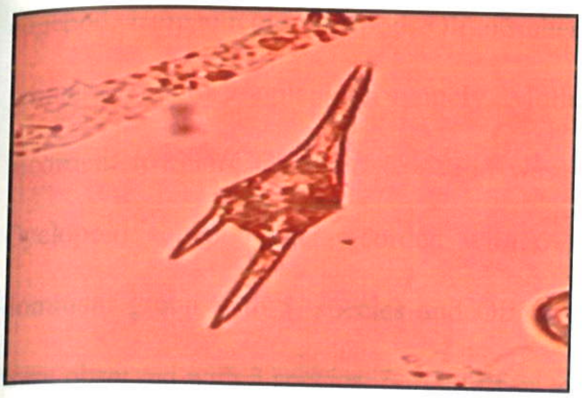
Diversity indices

The phytoplankton species diversity (H') varied from 2.988 to 3.643 with maximum at TMS-8 and minimum at TGS-2. The species richness (d) ranged between 4.824 and 6.233 with maximum at TGS-2 and minimum at TMS-9. The species evenness varied from 0.545 to 0.892 with the maximum at TGS-3 and minimum at TMS-9 (Table - 5).

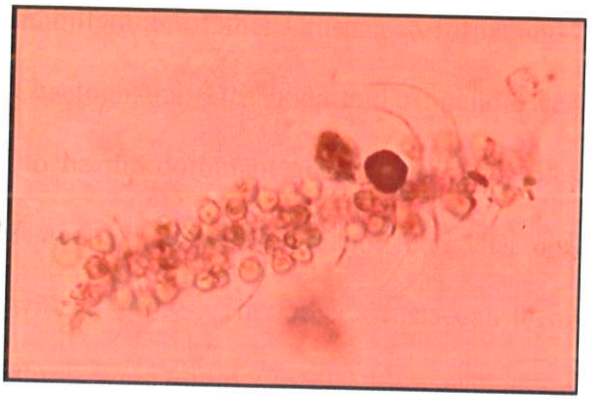
Table 5. Diversity indices; Shannon diversity (H'); Margalef richness (d) and Pielou's evenness (J') calculated for Phytoplankton in Tiruvottiyur kuppam coastal waters

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
TGS-1	3.011	5.583	0.594
TGS-2	2.988	6.233	0.631
TGS-3	3.149	5.653	0.545
TGS-4	3.326	6.824	0.623
TGS-5	3.271	5.328	0.791
TMS-6	3.388	5.811	0.734
TMS-7	3.465	4.971	0.795
TMS-8	3.643	5.909	0.843
TMS-9	3.320	4.824	0.892
TMS-10	3.218	5.554	0.835
TMS-11	3.036	5.352	0.761
TMS-12	3.028	5.041	0.798

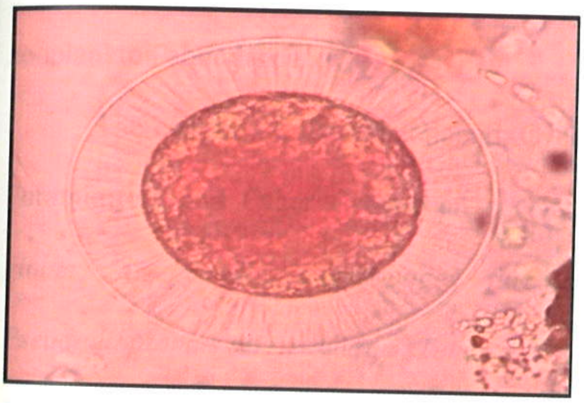
PLATE -I PHYTOPLANKTON



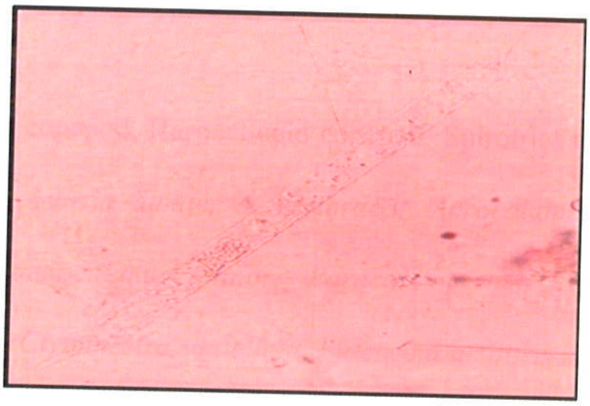
Ceratium furca



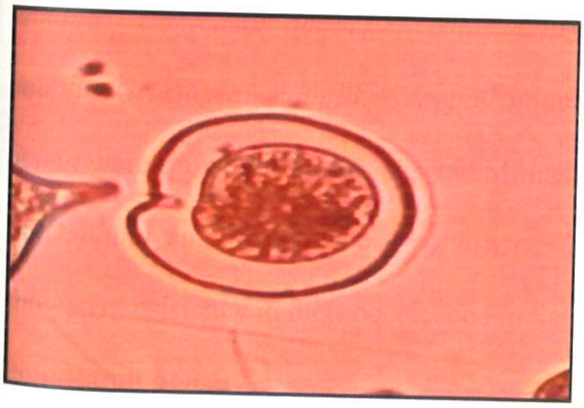
Chaetoceros coarctatus



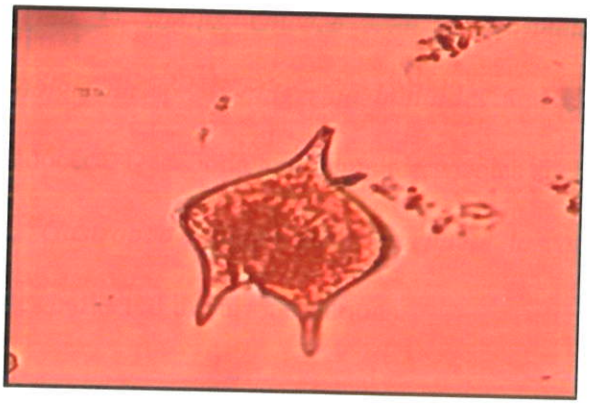
Planktoniella sol



Rhizosolenia alata



Noctiluca sp



Peridinium sp

4.5.2 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 11 species. Cyclopoid copepod was recorded with 6 species and Harpacticoid copepod came as next dominant group with 5 species and Oligotrichea with 4 species. The Other Crustacean forms were observed with 3 species, Foraminifera and Mollusca were found 2 species from each group, Chaetognatha, 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, A. erythraea, Acrocalanus gibber, A. gracilis, Centropages furcatus, Nannocalanus minor, Paracalanus parvus, Pseudodiaptomus serricaudatus, Temora turbinate, Clytmnestra scutellata, Euterpina acutifrons, Macrosetella* sp., *Microsetella* sp., *Favella brevis, F. philipiensis, Tintinnopsis tocantinensis, T. tubulosa, Corycaeus danae, C. catus, Oithona rigida, O. similis, Oncaea venusta, Barnacle nauplii, Crustacean nauplii, Copepod nauplii, Globigernia* sp., *Globigernia bulloides* and *G. opima* were found during this survey. Mollusca, Cladocera, Decapoda and Annelida species such as *Daphina* sp., *Lucifer hanseni, Bivalve veliger, Gastropod veliger* and *Polychaete larvae* showed consistency in their occurrence in the samples collected in various stations.

Population density

The zooplankton density varied from 4,225 to 6,682Nos/m^3 with maximum at TGS-5 and minimum at TSG-2 (Fig. 45).

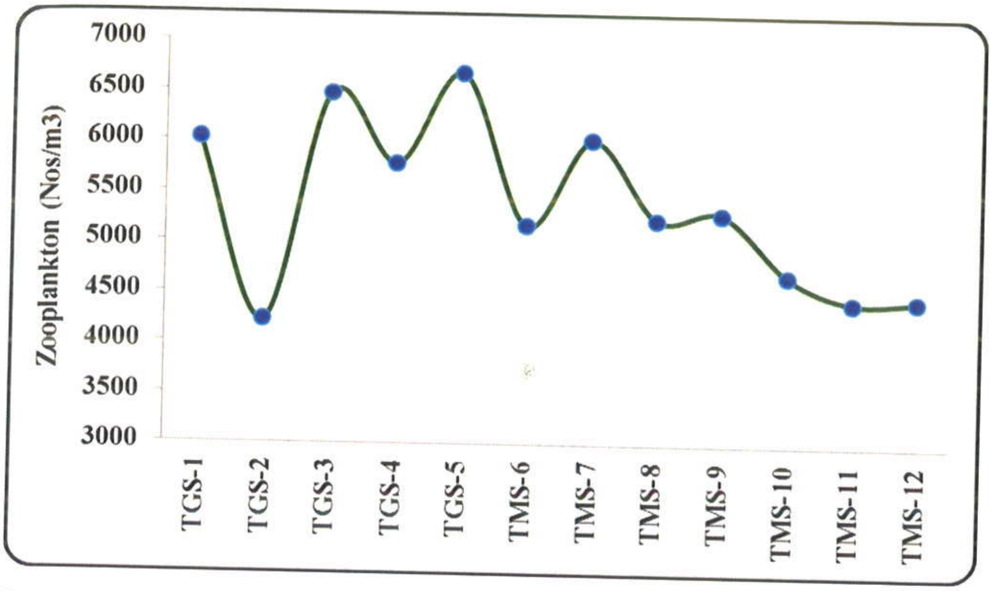


Fig. 45. Population density of zooplankton recorded in various stations of Tiruvottiyur kuppam coastal waters

Percentage composition

Calanoid copepod emerged as the dominant group by constituting 35% and followed by Cyclopoid copepod with 22%, Harpacticoid copepod and Other Crustacean forms with 13% each and Oligotrichea with 10% each and Mollusca with 5%, Foraminifera with 4% and Annelida, Decapoda and Cladocera with 2% each and Chaetognatha 2% of the total percentage composition (Fig. 46).

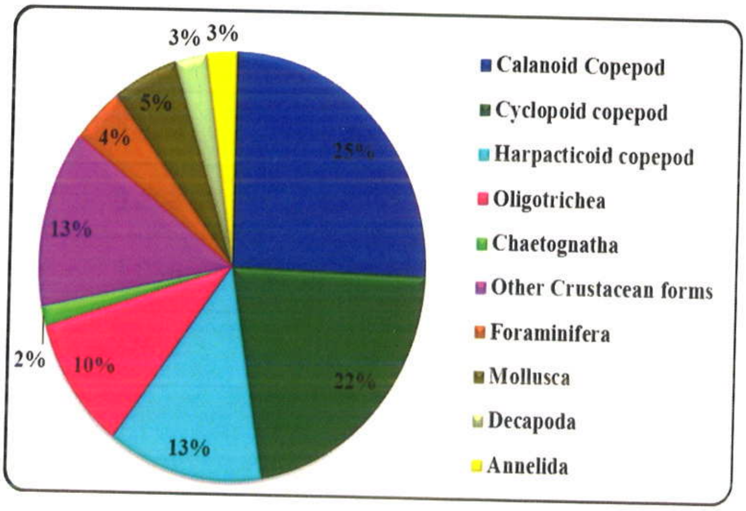


Fig. 46. Percentage composition of Zooplankton in various stations of Tiruvottiyur kuppam coastal waters

Diversity Indices

As done for phytoplankton, the zooplankton species diversity (H') varied from 2.626 to 3.763 with maximum in TGS-5 and minimum in TGS-1. The species richness (d) ranged between 4.192 and 5.684 with maximum in TGS-2 and minimum in TMS-8. The species evenness varied from 0.652 to 0.897 with the maximum in TGS-9 and minimum in TGS-2 (Table 6).

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

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
TGS-1	2.626	5.645	0.697
TGS-2	2.738	5.684	0.652
TGS-3	2.989	5.596	0.779
TGS-4	2.846	5.273	0.737
TGS-5	3.763	5.758	0.759
TMS-6	3.224	5.308	0.816
TMS-7	3.385	4.890	0.843
TMS-8	3.165	4.192	0.852
TMS-9	3.725	5.508	0.897
TMS-10	3.568	5.164	0.736
TMS-11	3.036	4.591	0.711
TMS-12	2.982	4.440	0.695

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 within the groynes TGS-1, TGS-2, TGS-4, TGS-5 and TGS-3 were forming a cluster based on the species composition and abundance. Similarly, the stations outside groynes TMS-6, TMS-12, TMS-7, TMS-9, TMS-8, TMS-11 and TMS-10 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 (0.16), 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 (Fig. 48).

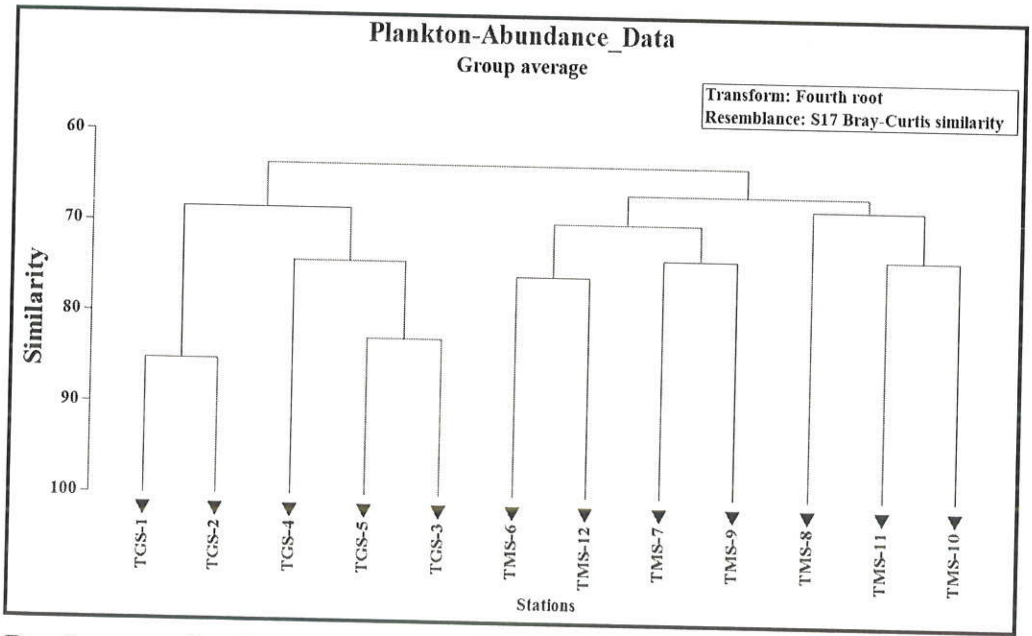


Fig. 47. Dendrogram for the Plankton abundance data collected from Tiruvottiyur kuppam coastal waters

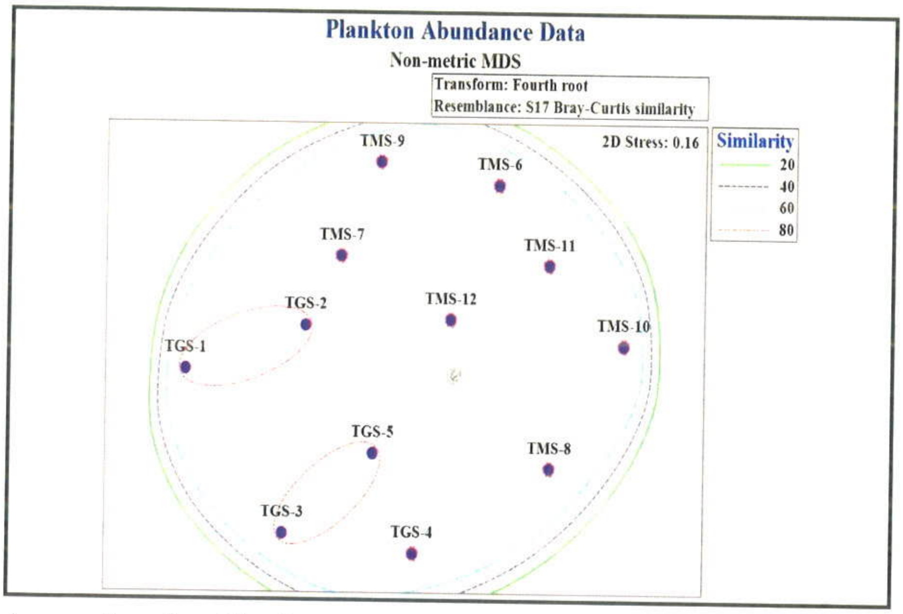


Fig. 48. MDS drawn for the Plankton abundance in various stations of Tiruvottiyur kuppam coastal waters

BIO-ENV (Biota-Environment matching)

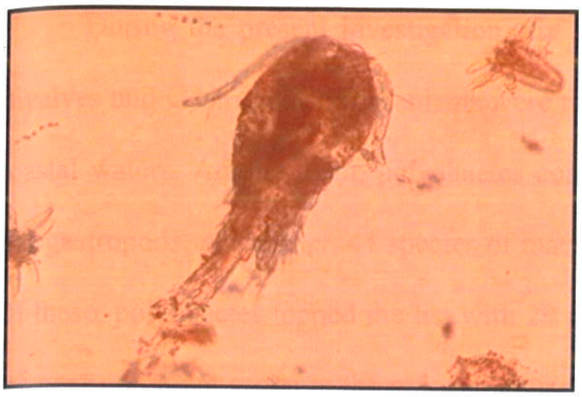
The BIO-ENV procedure was adopted to measure the agreement between the rank correlations of the biological (Bray-Curtis similarity) and environmental (Euclidean distance) matrices. To achieve this, twelve environmental variables (Primary productivity, Total nitrogen, Nitrite, Nitrate, Dissolved oxygen, Salinity, 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 Dissolved Oxygen, Total phosphate, Total Nitrogen, Chlorophyll 'a', Silicate, Primary productivity and Total biomass were featured as the major variables explaining the best match ($\rho\omega$= 0.896) with plankton (both phytoplankton and zooplankton) distributions. The other parameters such as Total Nitrogen, Silicate, Salinity, Chlorophyll 'a', Dissolved Oxygen and Primary productivity ($\rho\omega$= 835) which also got manifested in the next best variable combinations in determining the plankton distribution in Tiruvottiyur kuppam coastal waters.

Table-7. Harmonic rank correlations (ρω) between plankton (both phytoplankton and zooplankton) abundance against environmental variables in Tiruvottiyur kuppam coastal waters

S. No.	No. of variables	Best variable combinations	Correlation (ρω)
1.	7	Dissolved Oxygen – Total phosphate – Total Nitrogen – Chlorophyll 'a' – Silicate – Primary productivity –Total biomass	0.896
2.	6	Total Nitrogen – Silicate – Salinity – Chlorophyll 'a' – Dissolved Oxygen – Primary productivity	0.835
3.	6	Total Nitrogen – Chlorophyll 'a' – Salinity – Dissolved oxygen – Inorganic phosphate – Total biomass	0.817
4.	5	Primary productivity – Chlorophyll 'a' – Total Nitrogen – Total Phosphate – Dissolved Oxygen	0.781
5.	4	Dissolved Oxygen – Primary productivity – Chlorophyll 'a' – Total biomass	0.764

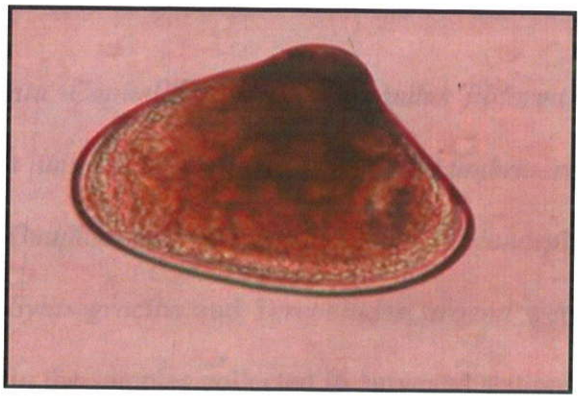
PLATE-II ZOOPLANKTON



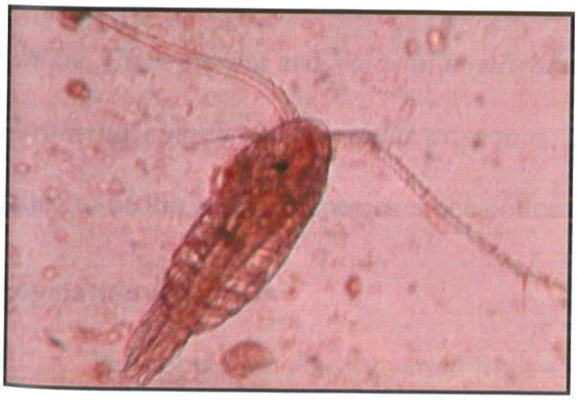
Oithona brevicornis

Oithona similis

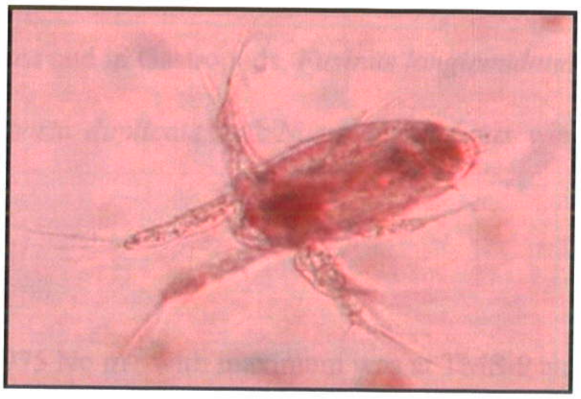
Paracalanus sp



Bivalve veliger



Paracalanus parvus



Copepod nauplii

4.6. Benthos

4.6.1. Macro-benthos

During the present investigation, six groups of benthic organisms namely Polychaetes, Bivalves and Gastropods of organisms were recorded in various stations in Tiruvottiyur kuppam coastal waters. Among them, polychaetes constituted the dominant group followed by bivalves and gastropods. Altogether, 41 species of macro fauna were recorded from the surveyed stations. Of these, polychaetes topped the list with 29 species. Bivalves and Gastropods were found to be the next dominant group in the order of abundance with 6 species each was also recorded during the present study.

Among the polychaetes *Armandia lanceolata, Capitella capitata, Cirratulus filiformis, Cossura coasta, Euclymene annandalei, Glycera unicornis, Goniada emerita, Lumbrineris inflate, Magelona cincta, Nephtys dibranchis, Onuphis eremita, Pista indica, Prionospio cirrifera, Prionospio pinnata, Scoloplos armiger, Syllis gracilis* and *Terebellides stroemi* were found to be the most commonly occurring species in the samples collected in surveyed stations. Coming to bivalves *Donax incarnates, Gafrarium tumidum, Seapharca inaequivalves, Siliqua radiate, Circe scripta* and *Volachilamys traquebarica* and in Gastropods, *Fusinus longicaudatus, Cerithedia cingulata, Turridella attenuate, Duplicaria duplicate* and *Nassarius stolatus* were found to be the common species in the collection.

Population density

The population density varied from 450 to 975 No m^{-2} with maximum was at TMS-9 and minimum TGS-1 (Fig. 49).

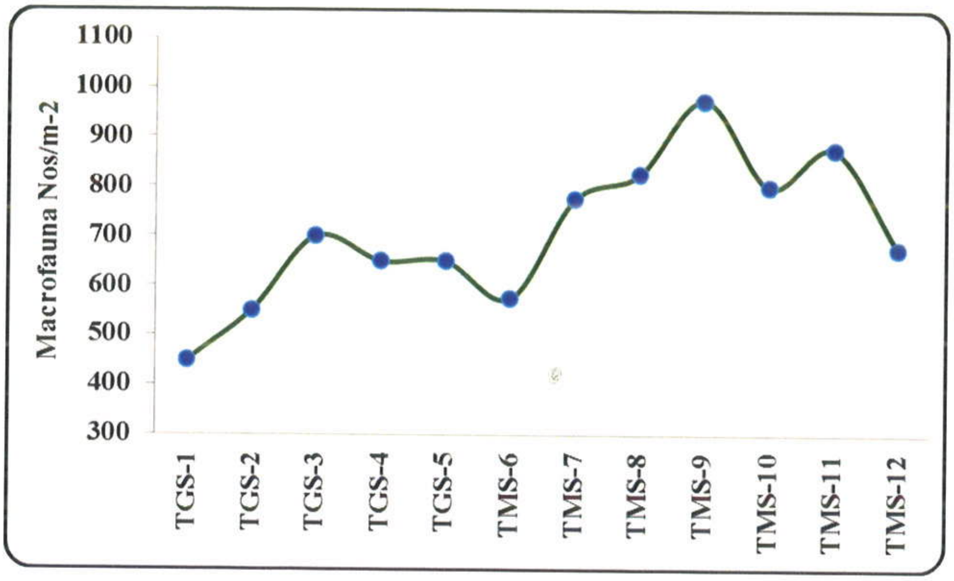


Fig. 49. Population density of Macro benthos in various stations of Tiruvottiyur kuppam coastal waters

Percentage composition

When the results of percentage composition of benthic fauna were viewed, polychaetes constituted the maximum with 73% to the total benthic organisms. Bivalves and Gastropods contributed to 15% and 12% respectively to the total benthic faunal community (Fig. 50).

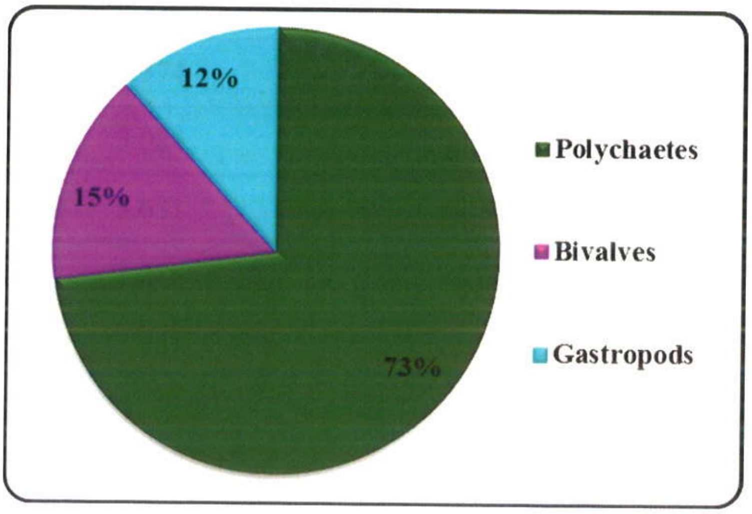


Fig. 50. Percentage composition of macro benthos in various stations of Tiruvottiyur kuppam coastal waters

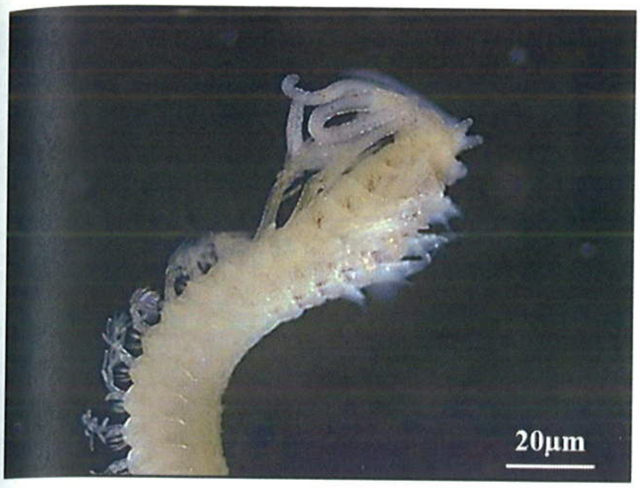
Diversity Indices:

The macro-benthic species diversity (H') varied from 2.705 to 3.631 with maximum was in TGM-10 and minimum in TGS-1. The species richness (d) ranged between 4.372 and 6.687 withmaximum in TGS-3 and minimum in TMS-10. The species evenness varied from 0.639 to 0.874 with the maximum in TMS-9 and minimum in TGS-2 (Table 8).

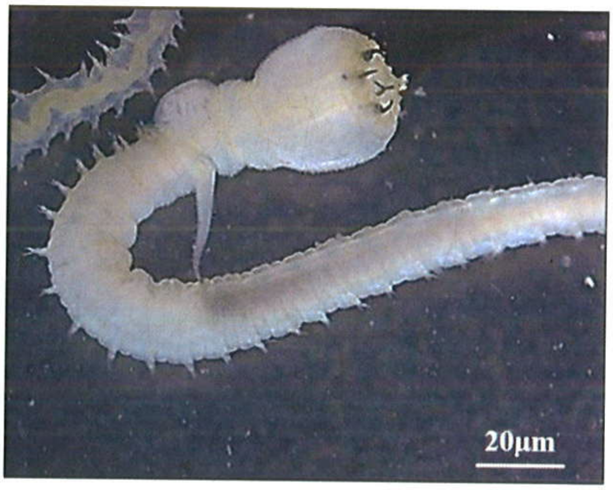
Table 8. Diversity indices Shannon diversity (H'); Margalef richness (d) and Pielou's evenness (J') calculated for macro benthos in Tiruvottiyur kuppam coastal waters

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
TGS-1	2.705	5.944	0.642
TGS-2	3.044	6.184	0.639
TGS-3	2.940	6.697	0.653
TGS-4	2.824	5.913	0.647
TGS-5	3.089	6.344	0.692
TMS-6	2.942	4.752	0.754
TMS-7	2.990	4.880	0.812
TMS-8	3.374	4.681	0.869
TMS-9	3.084	4.836	0.874
TMS-10	3.631	4.527	0.835
TMS-11	3.214	5.065	0.791
TMS-12	3.041	5.129	0.807

PLATE-III MACRO BENTHOS
POLYCHAETES

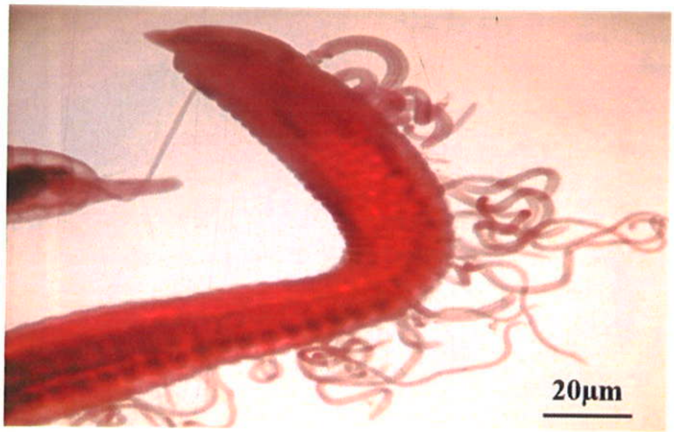


Diopatra sp.



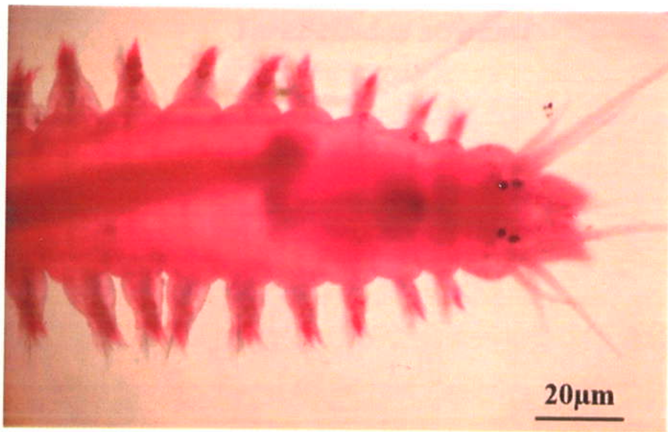
Goniada sp.

Capitella capitata



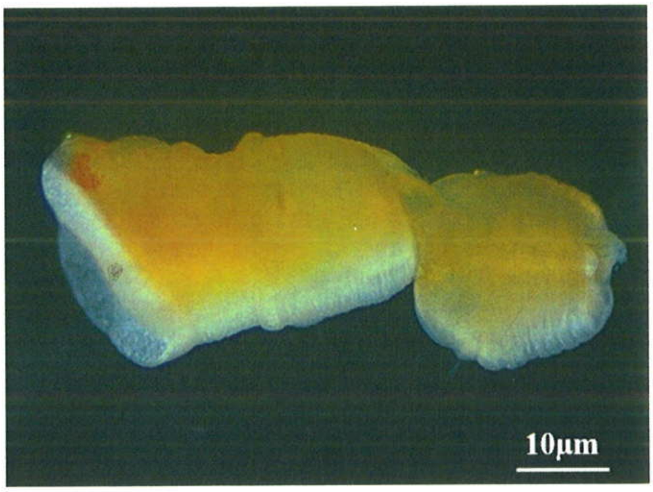
Cirratulus filiformis

Nephtys dibranchis



Nereis sp.

Prionospio cirrifera

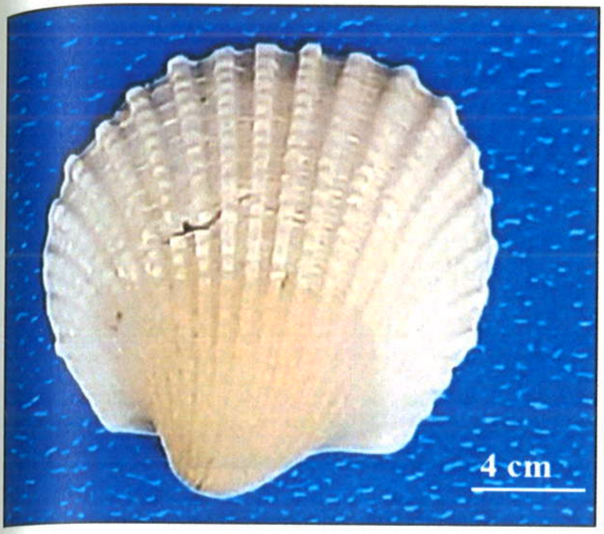


***Sabaco* sp.**

***Spionidae* sp.**

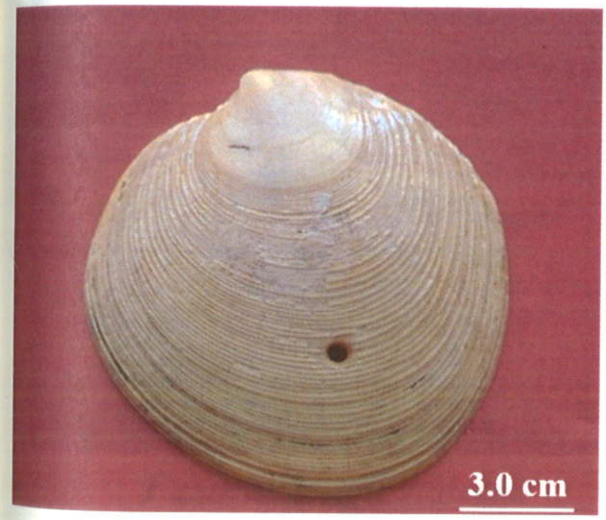
Terebellides stroemi

BIVALVES



Scapharca inaequivalvis

Circe scripta



Donax incarnatus

Siliqua radiata

<u>GASTROPODS</u>

Nassarius stolatus

Cerithedia cingulata

Fusinus longicaudatus

Turridella attenuata

4.6.2. Meio-benthos:

In the present study, as many as 45 species belonging to four groups of Meio-benthic organisms namely Foraminiferans, Nematodes, Ostracodes and Harpacticoids were recorded. Among them, Foraminiferans topped the list with 27 species. Nematodes were found to be the next dominant group in the order of abundance with 8 species and Ostracods came next with 6 species and Harpacticoids with 4 species.

Among the foraminiferans, *Ammonia beccarii, A. tepida, Bolivina compacta, Discorbinella bertheloti, Elphidium texanum, Lagena lacunata, L. semistriata, Nonion depressulus, Operculina ammonoidea, Q. apicula, Q. bicarinata, Rosalina globularis, S. angulosa, Spiroloculina depressa, Thurammina cariosa* and *Trochammina inflate* were found commonly in various stations. With respect to nematodes, *Epsilonema steiner, Daptonema conicum, Astomonema jenneri, Draconema cephalatum, Neochromadora craspedota, Enoplolaimus abnormis, Halalaimus filum* and *Oxystomina clavicauda* were found to be the common species in the samples collected in various stations. The Ostracodes species such as *Basslerites liebaui, Neocytherideis senescens, Keijella reticulata, Basslerites liebaui, Paijenborchella cymbula, Eucythere argus* and in Harpacticoids, *Macrosetella gracilis, Laophonte thoracica, Cylindropsyllus laevis* and *Leptastacus mocronyx* were found to be common species in the surveyed stations.

Population density

The population density of Meio-benthic fauna varied from 158 to 276 Nos.10cm^{-2} with maximum was recorded at TMS-10 and minimum at TGS-2 (Fig. 51).

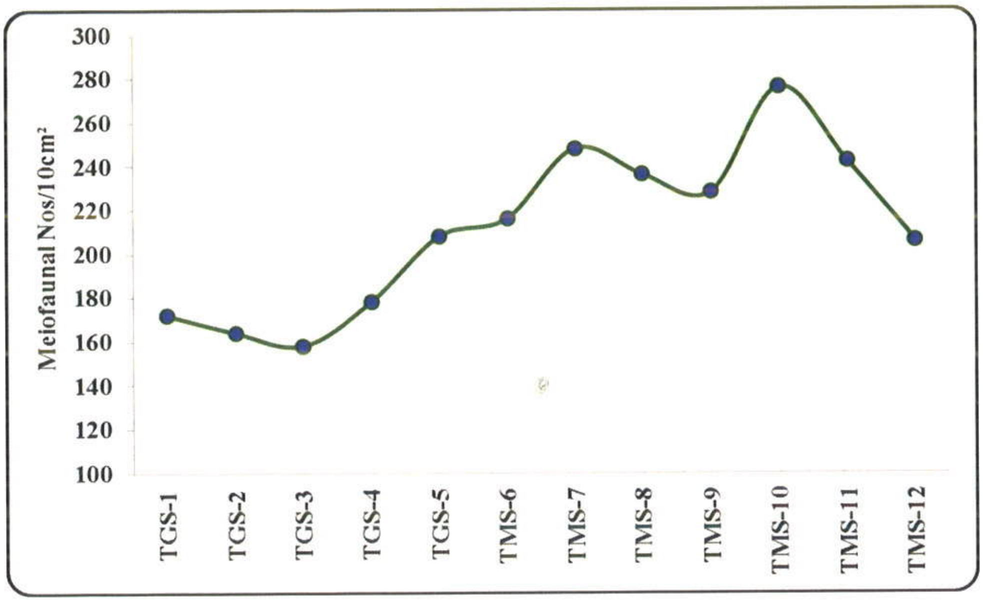


Fig. 51. Population density of Meio-fauna recorded in various stations of Tiruvottiyur kuppam coastal waters

Percentage composition:

The results of percentage composition of Meio-fauna revealed that Foraminiferans constituted maximum with 70% of the total Meio-benthic organisms. Nematodes, Ostracodes and Harpacticoids contributed with 13%, 12% and 5% respectively to the total Meio-benthic samples collected (Fig. 52).

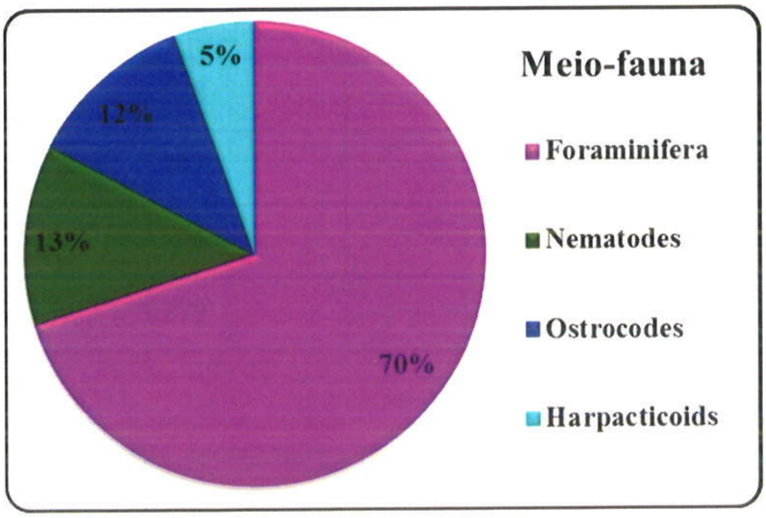


Fig. 52. Percentage composition of Meio-benthos in various stations of Tiruvottiyur kuppam coastal waters

Diversity Indices

The Meio-benthic species diversity (H') varied from 2.863 to 3.478 with maximum was in TGS-9 and minimum in TGS-2 and similarly the species richness (d) ranged between 4.495 and 6.135 with maximum in TGS-2 and minimum in TMS-10. The species evenness varied from 0.715 to 0.914 with the maximum in TMS-9 and minimum in TGS-1 (Table 9).

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

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
TGS-1	2.982	5.872	0.715
TGS-2	2.863	6.153	0.744
TGS-3	3.011	5.057	0.726
TGS-4	2.928	5.895	0.805
TGS-5	2.941	5.392	0.718
TMS-6	3.279	5.679	0.874
TMS-7	3.265	4.567	0.853
TMS-8	3.398	4.723	0.865
TMS-9	3.478	4.509	0.914
TMS-10	3.092	4.495	0.805
TMS-11	3.151	5.325	0.797
TMS-12	3.279	5.518	0.762

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 within Groyne TMS-7, TMS-6, TMS-8, TMS-10, TMS-11, TMS-12, and TMS-9 were forming cluster separately based on the species composition and abundance. Similarly, the stations outside groyne TGS-1, TGS-2, TGS-3, TGS-5 and TGS-4 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 (0.14), 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 (Fig. 54).

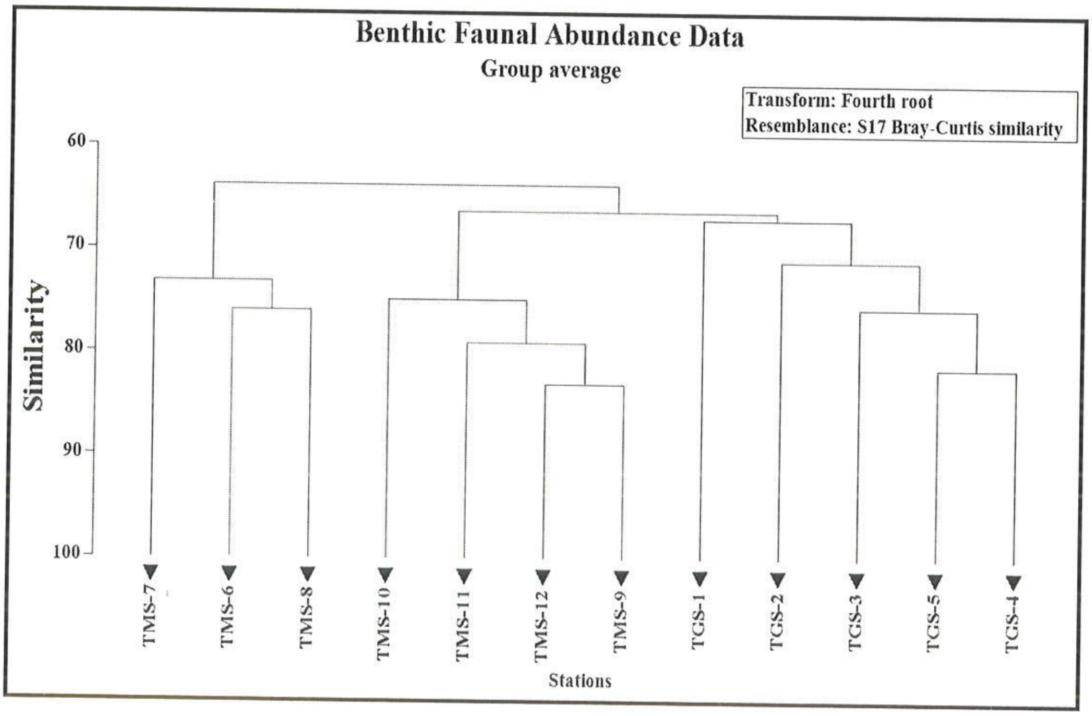


Fig. 53. Dendrogram for the benthic fauna abundance data collected in Tiruvottiyur kuppam coastal waters

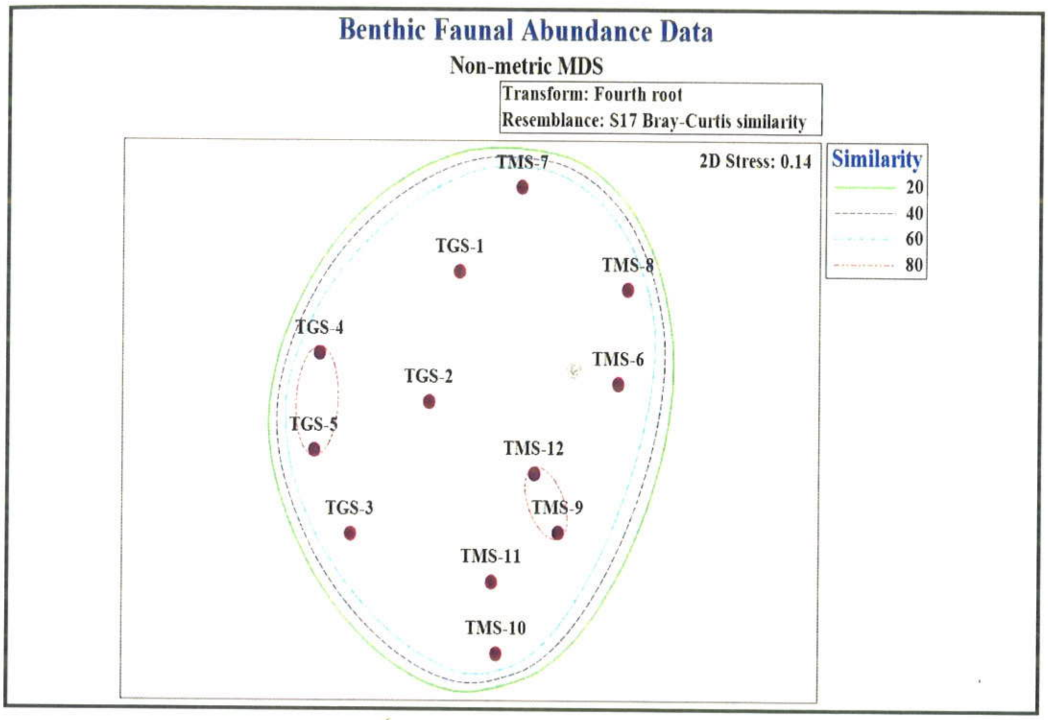


Fig. 54. MDS drawn for the benthic faunal abundance in various Tiruvottiyur kuppam coastal waters

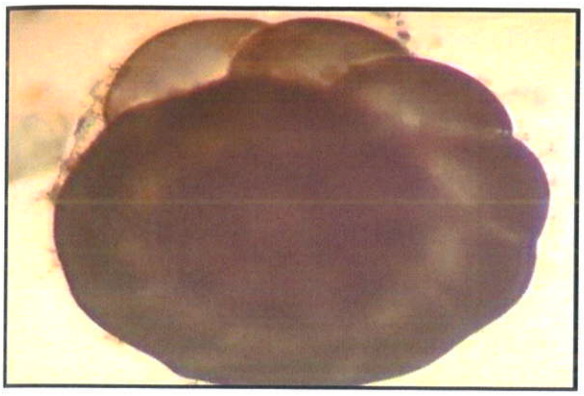
BIO-ENV (Biota-Environment matching)

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, eight environmental variables (Temperature, Salinity, Silt, Sand, Clay, DO, TOC S. pH, Evenness and Diversity) were allowed to match the biota. The results revealed that, a combination of eight environmental parameters ($p\omega = 0.918$) namely Salinity, Dissolved Oxygen, S. pH, Sand, Diversity, Evenness, Clay and TOC got manifested as best match in determining benthic faunal distribution followed by Dissolved Oxygen, Clay, S. pH, TOC, Salinity, Sand, Diversity ($p\omega = 0.873$) which also got manifested as second best variable combinations, in determining the faunal distribution in the Tiruvottiyur kuppam coastal waters (Table 10).

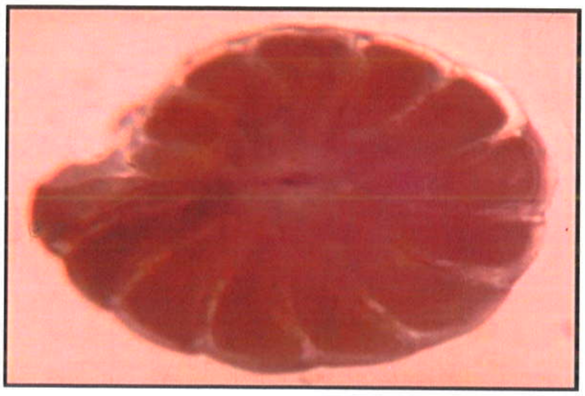
Table 10. Harmonic rank correlations (ρω) between benthic faunal (both Macro-benthos and Meio-benthos) abundance against environmental variables in Tiruvottiyur kuppam coastal waters

S. No.	No. of variables	Best variable combinations	Correlation (ρω)
1.	8	Salinity – Dissolved Oxygen – S. pH – Sand – Diversity – Evenness – Clay – TOC	0.918
2.	7	Dissolved Oxygen - Clay – S. pH – TOC - Salinity – Sand - Diversity	0.873
3.	6	Sand - TOC – Evenness – S. pH – Salinity - Dissolved Oxygen	0.841
4.	5	Clay - TOC – S. pH - Dissolved Oxygen - Salinity	0.805
5.	5	Salinity – S. pH – Clay – TOC - Evenness	0.764

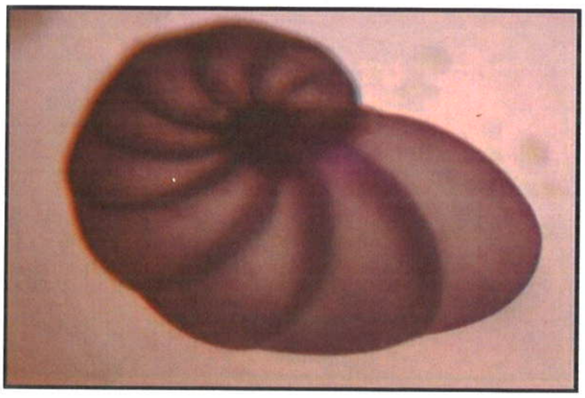
PLATE-IV MEIO-BENTHOS FORAMINIFERANS



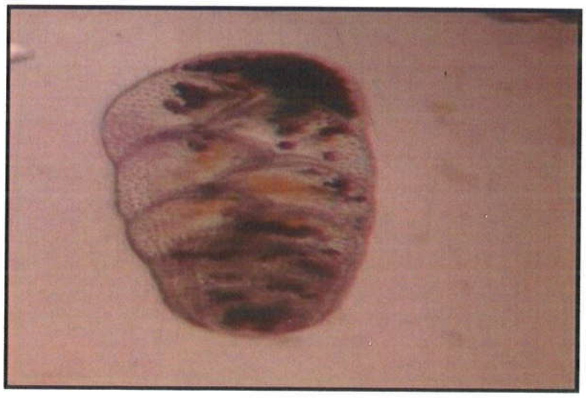
Ammonia tepida



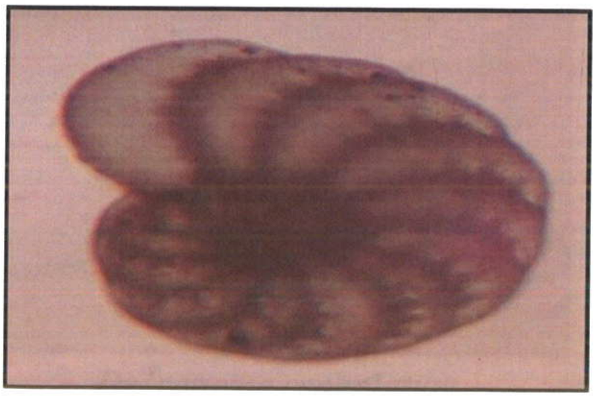
A. beccarii



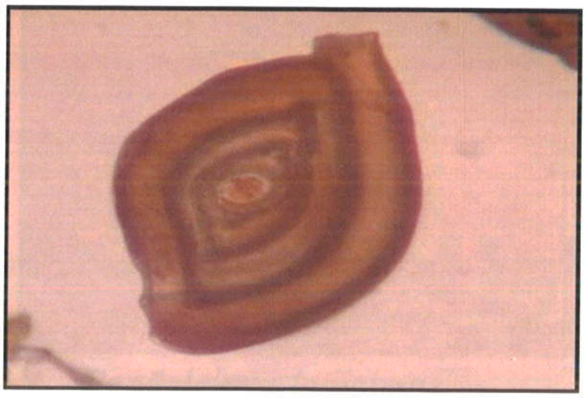
Nonion depressulus



Bolivina compacta

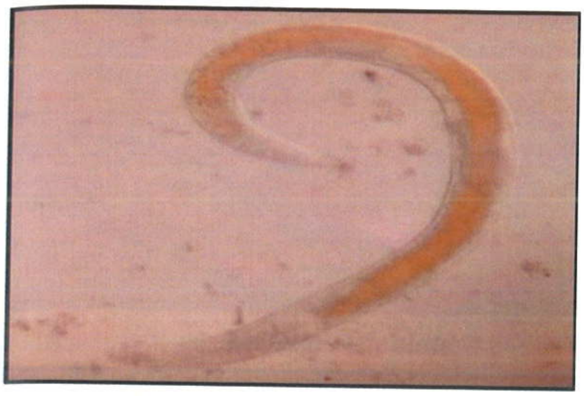


Elphidium advenum



Spiroloculina angulosa

NEMATODES

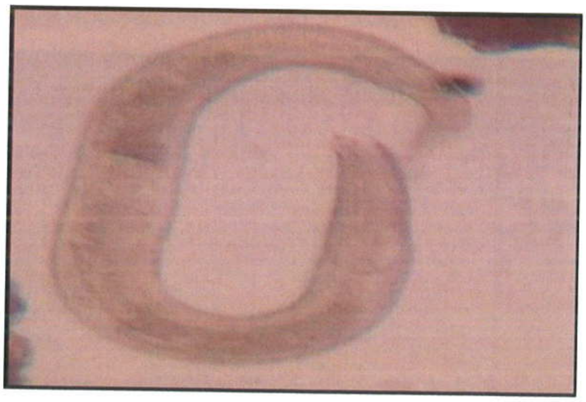


Daptonema conicum

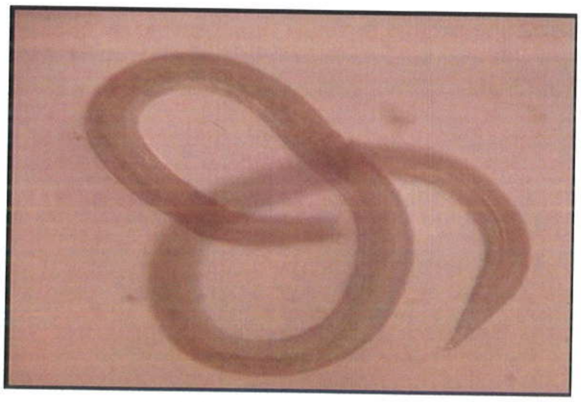
Epsilonema steiner

Neochromadora craspedota

Halalaimus filum

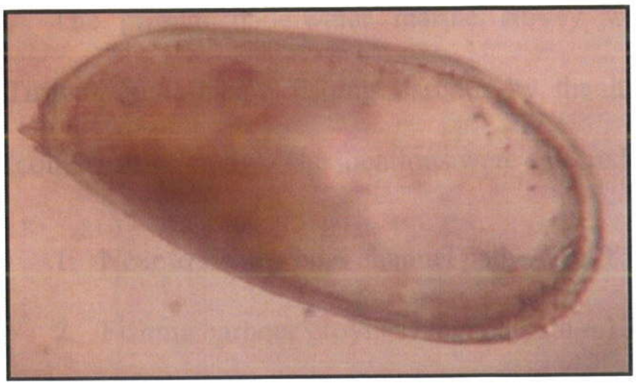


Draconema cephalatum

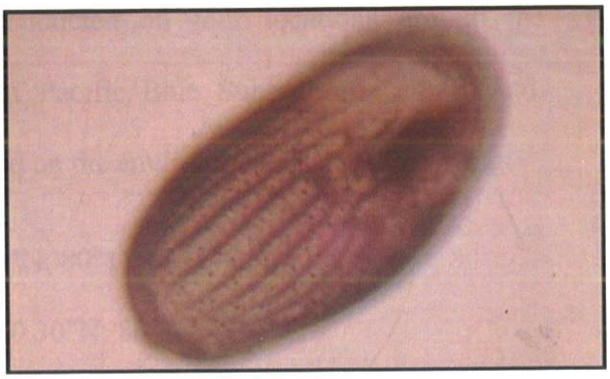


Pandolaimus latilaimus

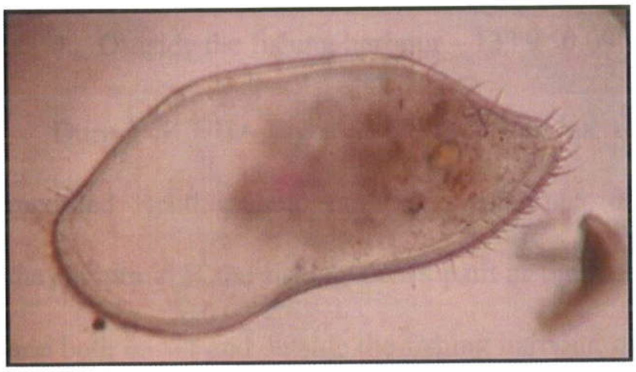
HARPACTICOIDS



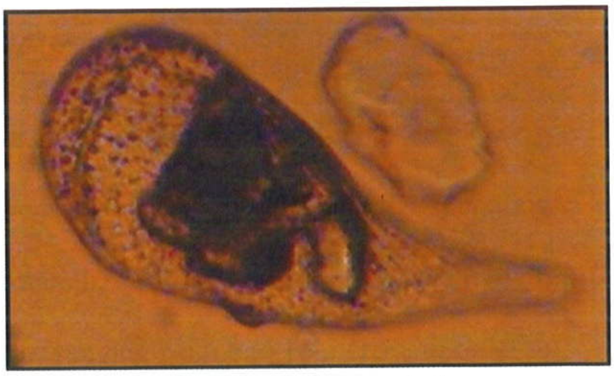
Keijella reticulata



Basslerites liebaui

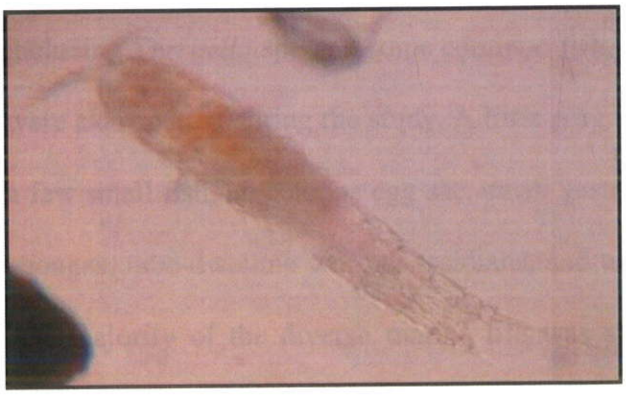


Bairdoppilata scaura



Paijenborchella cymbula

OSTRACODES



Laophonte thoracica

Cylindropsyllus laevis

4.7. Marine Underwater SCUBA survey

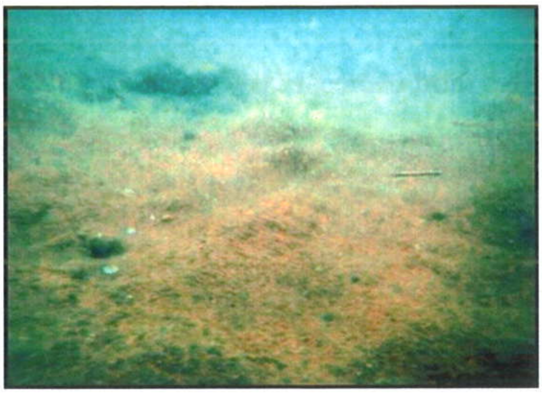
The present underwater marine survey was conducted on four locations around the Tiruvottiyur kuppam fishing harbour by the help of Pacific Blue Subsea services (P) Ltd. (collaborative study). The locations were selected based on the environment such as following:

1. Near to fishing boat channel path – 13° 9'55.34"N; 80°18'44.32"E
2. Fishing harbour groynes channel path – 13° 9'50.30"N; 80°18'50.41"E
3. Inside the fishing harbour – 13° 9'38.59"N; 80°18'54.27"E
4. Outside the fishing harbour – 13° 9'50.09"N; 80°19'20.13"E

During SCUBA dives at the four stations, the water temperature, salinity, and depth were recorded. Benthic photography and video recording were conducted in four locations, including the midpoint of the fishing boat's path at the harbour mouth, 500 meters away from the mouth, and both inside and outside the fishing harbour, at depths ranging from 6 to 16 meters, in order to analyse the habitat and ecological condition of the chosen harbour.

A muddy and sandy bottom with a few scattered patches of mixed seagrass, including *Oceana serrulata* and *Syringodium isoetifolium*, were observed. Dead shells, some gastropods, including *Turritella* sp., and some common fish, including flathead mullet, herring, and milkfish, were also spotted during the study. A little gorgonian up to 15 cm in size, as well as tube worms, a few small fish, an octopus egg sac, small gastropods, plastic litters, one jellyfish, rock oysters, sponges, tube-dwelling worms, ascidians, and turf algae, were seen beyond the fishing harbour. The majority of the diverse marine life was spotted beyond the fishing harbour, where boat access is scarce. The common visuals taken during under water using SCUBA is shown below:

Underwater SCUBA Survey



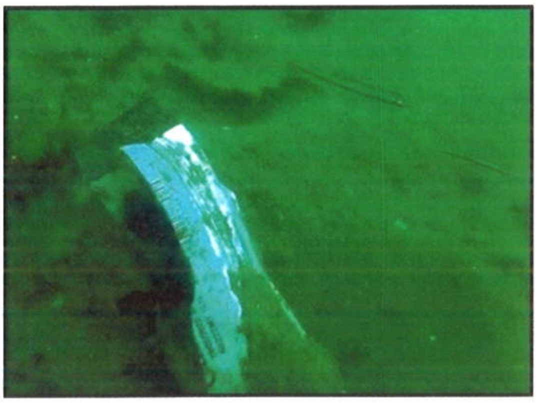
Muddy sandy bottom

Dead shells marine bottom

Turritella sp. Gastropod

Flathead mullet fish

Tube-dwelling Worms attached groyne



Plastic litter in bottom

4.8. Other ecologically sensitive groups

4. 8. 1. Mangroves

No mangroves were recorded from the surveyed coastal stations.

4. 8. 2. Corals

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

4. 8. 3. Turtles

During the survey near Tiruvottiyur kuppam coastal waters, no organized turtle nesting ground was noticed in the sampled area.

4. 8. 4. Other Endangered Species

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

4. 8. 5. Avifauna

In the project region, no significant bird population is observed.

4. 8. 6. Seaweeds

The following seaweed species found near the surveyed stations are *Sargassum ilicifolium, S. polycystum, Padina pavonica, Ulva* sp.

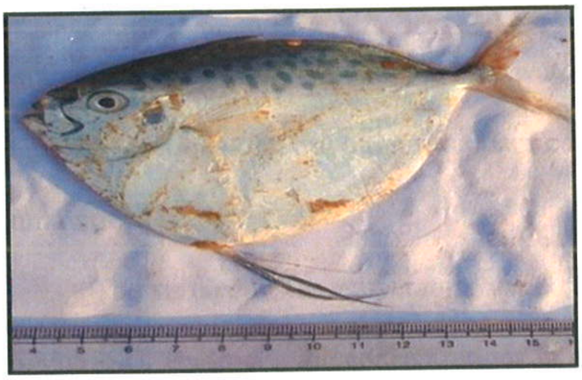
4. 8. 7. Sea grasses

During the survey scattered patches of two different species of seagrass: *Oceana serrulata* and *Syringodium isoetifolium* are found commonly at Tiruvottiyur kuppam region.

4. 8. 8. Fisheries

Selaroides leptolepis, Ariomma indicum, Coryphaena hippurus, Lethrinus nebulosus, Antennarius indicus, Mene maculate, Platax orbicularis, Xanthichthys ringens, Rhabdosargus *sarba, Lates calcarifer, Trachinotus blochii, Hilisa keele, Chanos chanos, Plotosus canius, Platycephalus indicus, Leiognathus daura, Sillago sihama, Caranx sem, Lutjanus* sp., *Mugil cephalus, Epinephelus tauvina, Siganus canaliculatus, Euthynnus affinis, Hemirampus far, Sardinella* sp., and *Lates calcarifer* caught using gillnets, purse-seines & bag nets. The crustacean resources like prawns, lobsters & crabs formed an important commercial catch for the local fishing community.

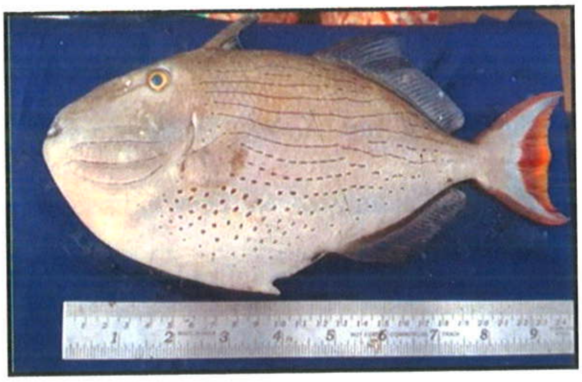
COMMERCIALLY IMPORTANT FISHES



Mene maculate

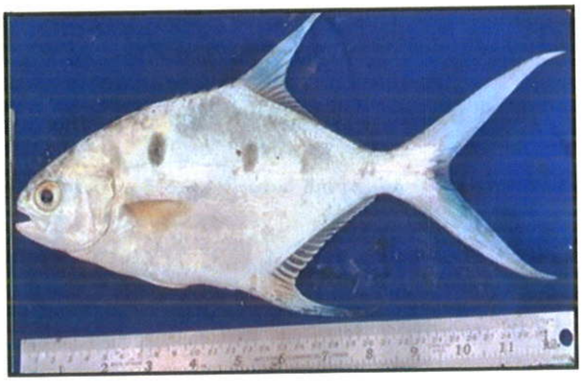
Platax orbicularis

Rhabdosargus sarba



Xanthichthys ringens

Lates calcarifer



Trachinotus blochii

5. SUMMARY AND CONCLUSION

In the present survey, which lasted for two days, the physico-chemical and biological parameters were analyzed both in the water and sediment samples from predetermined (12 stations) locations of Tiruvottiyur kuppam coastal waters. The results of various parameters are summarized below:

The surface water temperature varied from 27.2 to 29.5°C. The salinity varied from 33.5 to 35.5PSU. Hydrogen ion concentrations in surface waters remained alkaline and the maximum value of 8.3 was recorded at TMS-10. The observations made on the key physical factors such as TSS and turbidity was within the safe level. The turbidity ranged between 3.8 and 8.4NTU. The TSS values fluctuated from 71.20 and 135.20ppm. The maximum TSS and turbidity values were at TGS-2 and minimum at TMS-9. 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 4.495 and 6.265mg/l, with the maximum DO level was recorded at TMS-10 and the minimum was recorded at TGS-2. The DO concentration remained fairly well within the prescribed limit of water quality. The BOD level was found to be ranged from 1.03 and 2.38mg/l with the maximum BOD was observed at TMS-10 during this survey.

In the present investigation, the ammonia concentration ranged between 0.31 to 0.97μmol/l. The concentration of nitrite fluctuated from 0.86 to 2.82μmol/l. The nitrate values ranged from 2.10 and 3.75μmol/l and the total nitrogen varied between 13.14 to 19.41μmol/l. The inorganic phosphate ranged from 0.49 and 0.68μmol/l. The observed total phosphorus values ranged between 1.68 to 3.14μmol/l. The silicate concentration ranged from 62.55 and 82.46μmol/l. The particulate organic carbon values ranged from 74.37 and 125.45μgC/l respectively.

In the present survey, Petroleum Hydrocarbon in water varied between 0.306 and 0.498μg/l. with higher concentration at station TGS-2. The total organic carbon content varied from 6.35 and 9.76mgC/g with the maximum was at TGS-4 and minimum at TMS-8. The present survey showed that the Petroleum hydrocarbon relatively higher in sediment than the water and the values ranged from 0.468 to 0.889μg/g. The maximum was recorded at TGS-2 and the minimum was recorded at TMS-9 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 (1166.23 to 1965.20μg/g) compared to iron concentration in water (9.97 to 16.58μg/L). The maximum was recorded at TGS-2 and the minimum was recorded at TMS-9. 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, sand and Mn got correlated with stations TGS-5, TGS-3 TGS-2, TGS-1, TMS-6, TMS-8 and TMS-9 while the rest of the parameters showed strong correlation with stations TMS-10, TMS-11, TMS-12, TMS-7 and TGS-4 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 1.053 to 2.804 mg/m^3, with maximum at TGS-3 and minimum at TMS-12. The Phaeopigments content varied from 1.107 to 2.475 mg/m^3 with maximum was at TGS-3 and the minimum was observed at TMS-9. The Total biomass values varied from 1.968 to 5.803 ml/100m^3, with maximum at TGS-4 and minimum at TMS-10. The primary productivity was measured using the dark and light reaction method. The values ranged from 114.15 to 168.72mgCm^{-3}d^{-1}. The maximum value was recorded at TGS-5 and minimum value at TMS-10.

Density of phytoplankton varied from 6,905 to 20972 Cells/l with maximum was at TGS-4 and minimum at TGS-2. In the present study, as many as 42 phytoplankton species belonging to three major groups namely Bacillariophyceae (Diatom), Dinophyceae (Dinoflagellates) and Cyanophyceae (Cyanobacteria) were recorded in Thiruvottiyur kuppam coastal area. Of these, Bacillariophyceae were found to be the dominant group with 30 species, Dinophyceae formed next group with 11 species and Cyanophyceae with one species.

The phytoplankton species diversity (H') varied from 2.988 to 3.643 with maximum at TMS-8 and minimum at TGS-2. The species richness (d) ranged between 4.824 and 6.233 with maximum at TGS-2 and minimum at TMS-9. The species evenness varied from 0.545 to 0.892 with the maximum at TGS-3 and minimum at TMS-9.

The zooplankton density varied from 4,225 to 6,682Nos/m^3 with maximum at TGS-5 and minimum at TSG-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 11 species. Cyclopoid copepod was recorded with 6 species and Harpacticoid copepod came as next dominant group with 5 species and Oligotrichea with 4 species. The Other Crustacean forms were observed with 3 species, Foraminifera and Mollusca were found 2 species from each group, Chaetognatha, Decapoda and Annelida were recorded with 1 species each of total zooplankton abundance.

With regard to diversity indices, the zooplankton species diversity (H') varied from 2.626 to 3.763 with maximum was in TGS-5 and minimum in TGS-1. The species richness (d) ranged between 4.192 and 5.684 with maximum in TGS-2 and minimum in TMS-8. The species evenness varied from 0.652 to 0.897 with the maximum in TGS-9 and minimum in TGS-2.

The abundance data of phytoplankton and zooplankton were amalgamated and subjected to classification and ordination methods. The resulting dendrogram revealed that the stations within the groynes TGS-1, TGS-2, TGS-4, TGS-5 and TGS-3 were forming a cluster based on the species composition and abundance. Similarly, the stations outside groynes TMS-6, TMS-12, TMS-7, TMS-9, TMS-8, TMS-11 and TMS-10 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 stress value (0.16), 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. 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 Dissolved Oxygen, Total phosphate, Total Nitrogen, Chlorophyll 'a', Silicate, Primary productivity and Total biomass were featured as the major variables explaining the best match ($\rho\omega$= 0.896) with plankton (both phytoplankton and zooplankton) distributions. The other parameters such as Total Nitrogen, Silicate, Salinity, Chlorophyll 'a', Dissolved Oxygen and Primary productivity ($\rho\omega$= 835) which also got manifested in the next best variable combinations in determining the plankton distribution in Tiruvottiyur kuppam 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).

The population density varied from 450 to 975 No m-2 with maximum was at TMS-9 and minimum TGS-1. During the present investigation, six groups of benthic organisms namely Polychaetes, Bivalves and Gastropods of organisms were recorded in various stations in Tiruvottiyur kuppam coastal waters. Among them, polychaetes constituted the dominant group followed by bivalves and gastropods. Altogether, 41 species of macro fauna were recorded from the surveyed stations. Of these, polychaetes topped the list with 29 species. Bivalves and Gastropods were found to be the next dominant group in the order of abundance with 6 species each was also recorded during the present study.

The macro-benthic species diversity (H') varied from 2.705 to 3.631 with maximum in TGM-10 and minimum in TGS-1. The species richness (d) ranged between 4.372 and 6.687 with maximum in TGS-3 and minimum in TMS-10. The species evenness varied from 0.639 to 0.874 with the maximum in TMS-9 and minimum in TGS-2.

Regarding meiobenthic organisms, the population density of Meio-benthic fauna varied from 158 to 276 Nos.10cm^{-2} with maximum was recorded at TMS-10 and minimum at TGS-2. In the present study, as many as 45 species belonging to four groups of Meio-benthic organisms namely Foraminiferans, Nematodes, Ostracodes and Harpacticoids were recorded. Among them, Foraminiferans topped the list with 27 species. Nematodes were found to be the next dominant group in the order of abundance with 8 species and Ostrocods came next in the order with 6 species and Harpacticoids with 4 species.

The Meio-benthic species diversity (H') varied from 2.863 to 3.478 with maximum was in TGS-9 and minimum in TGS-2 and similarly the species richness (d) ranged between 4.495

and 6.135 with maximum in TGS-2 and minimum in TMS-10. The species evenness varied from 0.715 to 0.914 with the maximum in TMS-9 and minimum in TGS-1.

The cluster/dendrogram revealed that the stations within groyne TMS-7, TMS-6, TMS-8, TMS-10, TMS-11, TMS-12, and TMS-9 were forming cluster separately based on the species composition and abundance. Similarly, the stations outside groyne TGS-1, TGS-2, TGS-3, TGS-5 and TGS-4 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 (0.14), 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 procedure indicated that the combination of eight environmental parameters (pω = 0.918) namely Salinity, Dissolved Oxygen, S. pH, Sand, Diversity, Evenness, Clay and TOC got manifested as best match in determining benthic faunal distribution followed by Dissolved Oxygen, Clay, S. pH, TOC, Salinity, Sand, Diversity (pω = 0.873) which also got manifested as second best variable combinations, in determining the faunal distribution in the Tiruvottiyur kuppam 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 under water survey, only dead molluscan shells and a few Dead Sea grass species were recorded. During survey, not even single pieces of corals were noticed in the project location.

With respect to ecologically sensitive groups, the occurrence of Corals, Turtle nesting ground and any endangered species like Sea horse, *Olive ridley* turtle, Indian otter, Salt water crocodile etc., were not noticed from the surveyed stations.

As regards fish population, *Mene maculate, Xanthichthys ringens, Trachinotus blochii, Hilisa keele, Chanos chanos, Sillago sihama, Euthynnus affinis, Mugil cephalus & Lates calcarifer* were the most frequently landed commercial fishes, and they were captured using gillnets, purse-seines, and bag nets. The crustacean resources like prawns, lobsters & crabs also formed an important commercial catch for the local fishing industry. There is no national park, wildlife sanctuary and biosphere reserve within 10 km radius of the proposed project site.

Further, diversity indices calculated for the plankton and benthic data in the present study clearly indicated the fairly undisturbed nature of the environment since diversity values of plankton and benthos were found to be more than 3.05 in the study area as have been stated by the ecologist Sanders (1968).

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 marine Biodiversity survey made during 23rd to 25th February 2023 in Thiruvottiyur kuppam coastal waters and careful perusal of available secondary information suggested that the water quality parameters are within the safe level and did not indicate any alarming effect on the existing biological components. The observations on other ecologically sensitive organisms reflected the patchy occurrence of a few groups especially sea grass and seaweeds from the nearby regions, which is away from the proposed site.

From the ecological point of view, the proposed structure will have very marginal impact on biota during both pre-operational and operational phase but such impacts are confined to a limited period and a confined region, as most of the marine organisms are capable of recouping themselves quickly to its original state and thus there will not be any pronounced change/variations to the biotic community. Therefore, based on the biodiversity survey conducted and also under water SCUBA survey, the proposed facility can be initiated. At the same time, the present marine survey was done only short period, continuous monitoring is 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 and thereby a suite of mitigation measures could be suggested.

FACULTY OF MARINE SCIENCES
ANNAMALAI UNIVERSITY
PARANGIPETTAI - 608 502.

Dr. P. MURUGESAN, M.Sc., Ph.D.
ASSOCIATE PROFESSOR
C.A.S. in Marine Biology
Faculty of Marine Sciences
Annamalai University
Parangipettai - 608 502
Tamil Nadu, India

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MARINE BIODIVERSITY SURVEY FOR TUNA FISHING HARBOUR THIRUVOTTRIYUR KUPPAM, THIRUVALLUR DISTRICT, CHENNAI, TAMIL NADU

Research Team

Dr. P. Murugesan
Associate Professor & Principal Investigator
Annamalai University

Research Scholars

Dr. R. Punniyamoorthy

Dr. K. Manimaran

Dr. V. Bharathidasan

Mr. P. Chandrasekaran

Ms. Sasmita Swain

Mrs. R. Raguna

Centre of Advanced Study in Marine Biology
Faculty of Marine Sciences
Annamalai University
Parangipettai - 608 502

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Dr. P. MURUGESAN, M.Sc.,Ph.D.,
ASSOCIATE PROFESSOR
C.A.S. in Marine Biology
Faculty of Marine Sciences
Annamalai University
Parangipettai - 608 502
Tamil Nadu India

Centre of Advanced Study in Marine Biology
Faculty of Marine Sciences
Annamalai University
Parangipettai - 608 502

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MARINE BIODIVERSITY SURVEY FOR TUNA FISHING HARBOUR THIRUVOTTRIYUR KUPPAM, THIRUVALLUR DISTRICT, CHENNAI, TAMILNADU

1. Introduction

The coastal area, adjoining the north of the Chennai Port has been adversely affected by continued erosion due to the development of the port. Since several developmental activities such as advent of industries, improvement of fisheries, etc. a Groyne field was constructed stretching from Royapuram to northwards and the sea wall stretch of about 10 km length lying parallel to Ennore High Road to combat the erosion problems. A proposal was further made to expand existing groynes to form a fishing harbor. Accordingly, the Fisheries Department, Govt. of Tamilnadu requested the Department of Ocean Engineering, IIT Madras to revise/revive the proposed layout and perform numerical model studies to validate the same. Therefore, the layout was revised and subjected to tranquility and shoreline evolution studies. Thiruvallur District is historically known for its fishery resources and community living and presently it has a fishermen population of around 50,000 in the stretch of 25 Km that includes North Chennai. The project location is historically known for fishery resources and a strong fishermen settlement and more precisely, with a fishery harbor at about 3.5Km south as a landmark facility of Chennai since long time.

The proposed Tuna Fishing Harbour is a flag ship project of Government of Tamil Nadu which intended to create exclusive facilities to enhance Tuna catching and processing the same to add value to benefit the fishing community of the project location, Thiruvottriyur Kuppam, Chennai. The proposed fishing harbour facility is intended principally to ease out the congested Chennai Fishing Harbour as it is overflowing with more traffic and fishing activities. At times, there is an acute shortage of space to anchor the boats inside the harbour. The proposed Harbour location is about 3.5Km North from the Chennai Fishing Harbour which will provide location advantage and flexibility in harbour operation and fishing activities. Accordingly, the Department of Fisheries was mandated to enhance the harbour facilities. The project is much needed to improve the socio economic status of the local fishing community of more than a lakh in the North Chennai Zone of Tamil Nadu.

The project location is historically used by the local fishermen community and only in the recent past the coastline got eroded and it was then provided with groynes which were subsequently extended as a field with 13 numbers of groynes. It is evident that the project shoreline of about 10km stretch has been stabilized and with sand by passing over groynes over the years, the beach line has been restored and now, the project coastline is showing features of stabilization with accretion of sand and restored shoreline. The proposed harbour, as it is very close to Chennai Fishing Harbour, will serve as an extended harbour facility of it and intended to promote Tuna catching & processing. At present, from the Chennai Fishing Harbour, there are about 300 boats are operating exclusively to venture deep into the Bay of Bengal to catch tuna and bring in about 1,000 tonnes every month. Under these circumstances, the project proponent has been mandated to study marine biodiversity potential of the project site by a reputed Institute/University.

Justifiably, the task was entrusted to the Centre of Advanced Study (CAS) in Marine Biology of Annamalai University, Tamilnadu, who is the pioneer in Marine Sciences, to carry out Marine Ecological feasibility survey. Accordingly, the Experts from CAS in Marine Biology, Annamalai University carried out a detailed Marine Biodiversity survey including under water SCUBA survey during 27th to 28th July 2023 at Thiruvottiyur kuppam coastal waters, Thiruvallur District, Chennai, Tamilnadu. During this survey, water, sediment and biological samples (plankton, benthos, microbiological and other ecologically important flora and fauna) were collected from 12 different stations from the proposed sites. The latitude and longitude of the sampling stations are given in Table 1 and also in Map (Fig.1).

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:

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

Table 1. Sampling stations and their geographical Co-Ordinates

S. No.	Stations Code	Latitude	Longitude
1.	TGS-1	13°9'58.80"N	80°18'39.15"E
2.	TGS-2	13°9'52.98"N	80°18'35.17"E
3.	TGS-3	13°9'41.92"N	80°18'36.69"E
4.	TGS-4	13°9'48.90"N	80°18'42.45"E
5.	TGS-5	13°9'55.34"N	80°18'44.32"E
6.	TMS-6	13°10'3.92"N	80°18'42.96"E
7.	TMS-7	13°9'58.41"N	80°18'53.14"E
8.	TMS-8	13°9'50.30"N	80°18'50.41"E
9.	TMS-9	13°9'50.09"N	80°19'20.13"E
10.	TMS-10	13°9'38.59"N	80°18'54.27"E
11.	TMS-11	13°9'31.19"N	80°18'41.43"E
12.	TMS-12	13°9'34.84"N	80°18'31.45"E

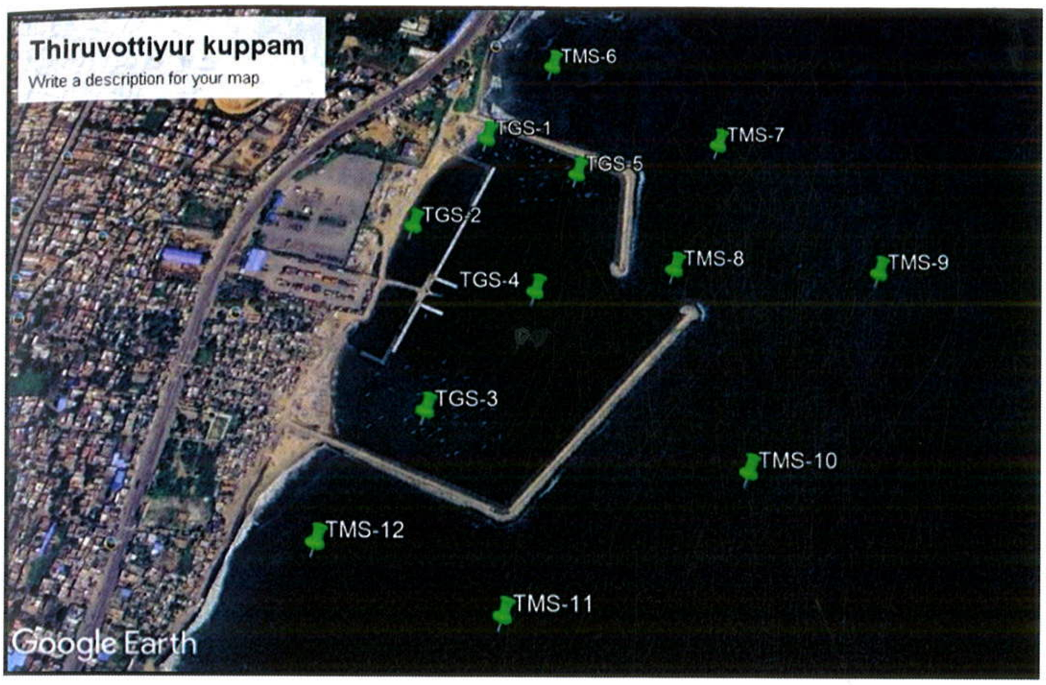


Fig. 1. Map showing the stations in Thiruvottiyur kuppam coastal waters

RESEARCH TEAM

3. MATERIALS AND METHODS

3.1. Water and Sediment Sampling

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 andrepeat 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.

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.

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.

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 analyzed 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 □mol ofNitrogen/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.

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.

3. 2. Microbiology methods

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 sterilized 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.

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-streakedin appropriate nutrient agar plates thrice before a pure culture was established in agar slants.

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. 3. Pigments concentration

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.

3.4. Plankton community

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).

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 bagnet (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.

3.5. 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 0.5mm 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 Muruganantham *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. 6. 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).

Cluster Analysis

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.

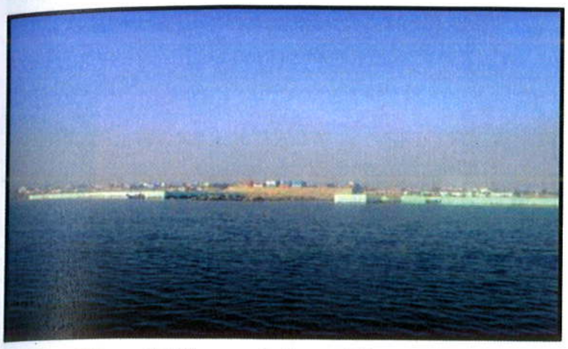
MDS (non - metric Multi-Dimensional Scaling)

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.

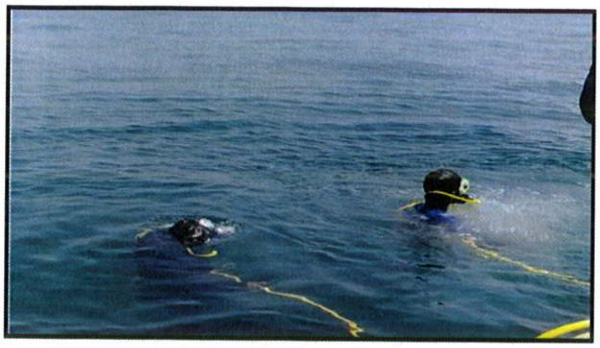
BIO-ENV procedure

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 AND ACTIVITIES



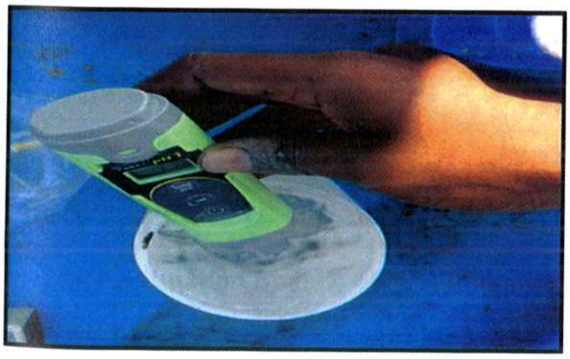
Near Thiruvottriyur Kuppam Fishing Harbor



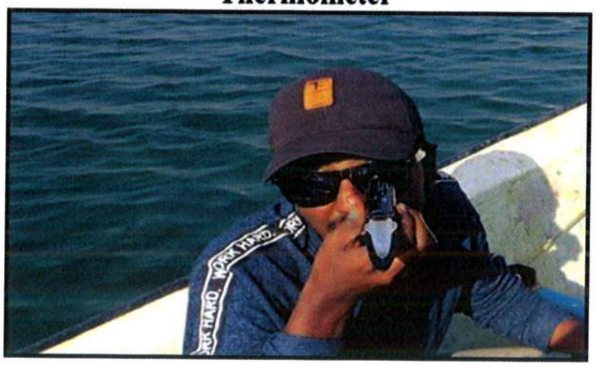
Biological sample collection by SUBA diving method

Locating sampling points by using GPS

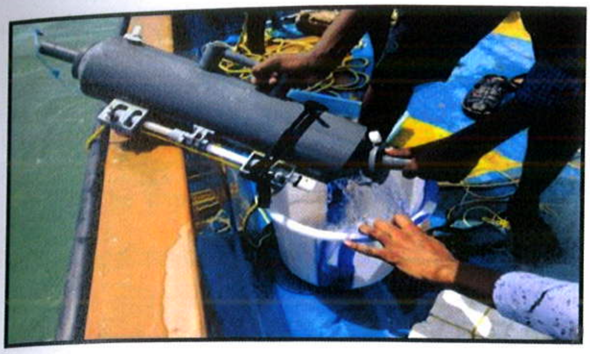
Temperature measurement by using Thermometer



pH measurement by using pH pen

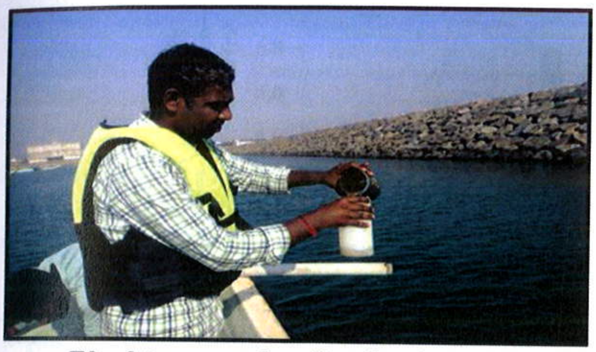


Salinity measurement by using Refractometer



Sub-surface water sample collection by using Niskin water sampler

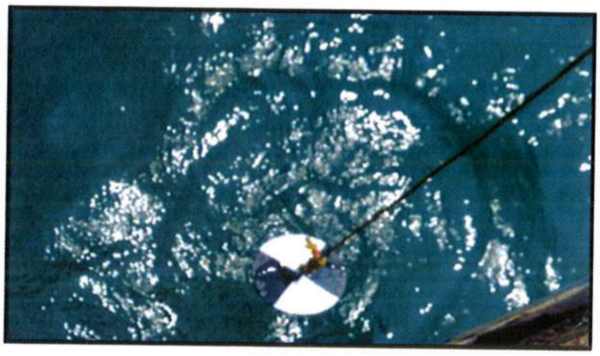
Sediment sample collected by using Van-Veen Grab



Plankton sample collection by using plankton net

Sieve retains-benthic samples

DO estimation by following Winkler's method



Vertical transparency measurement by using Secchi disc

3. OBSERVATION REPORT

4.1. Water Quality

Depth

The depth in the study area varied between 0.5 and 11 m, with maximum at TMS-9 and minimum at TGS-1 (Fig. 2).

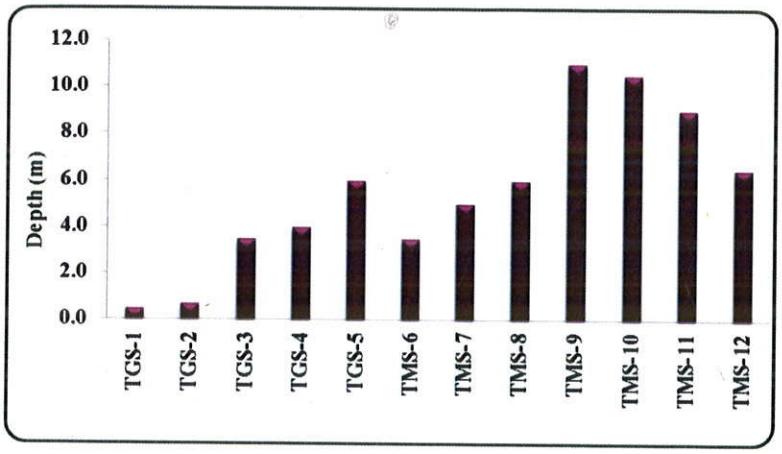


Fig. 2. Depth values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Water Temperature

The water temperature fluctuated from 28.2 to 30.7°C. The minimum value was recorded at TGS-2 and maximum was recorded at TMS-10 (Fig. 3).

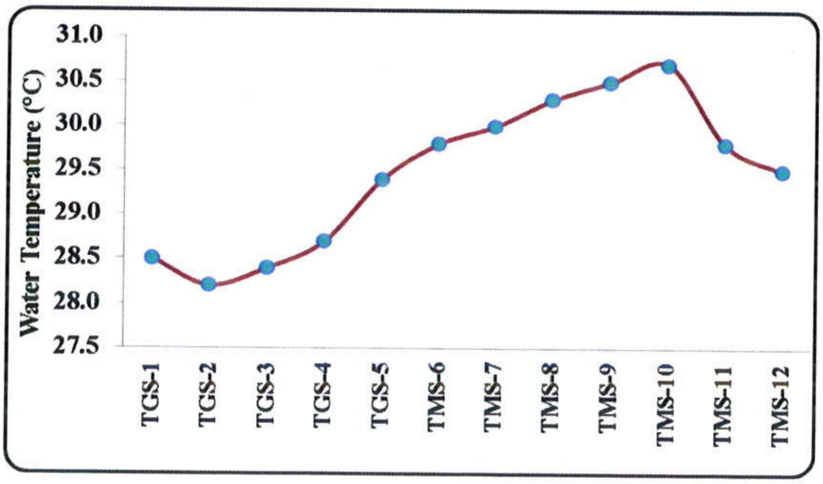


Fig. 3. Water temperature values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Salinity

The water salinity varied from 33.2 to 35.4PSU. The salinity was found to be lower at TGS-2 and higher value at TMS-9 (Fig. 4).

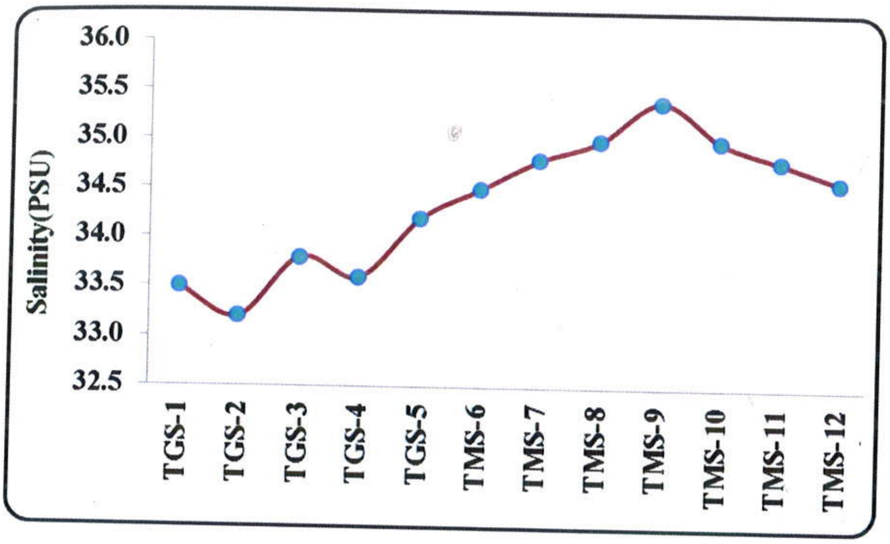


Fig. 4. Salinity level recorded at various stations in Tiruvottiyur Kuppam coastal waters

Water pH

The water pH varied between 7.8 and 8.3 with minimum value was recorded at TGS-2 and maximum value was recorded at TMS-8 (Fig. 5).

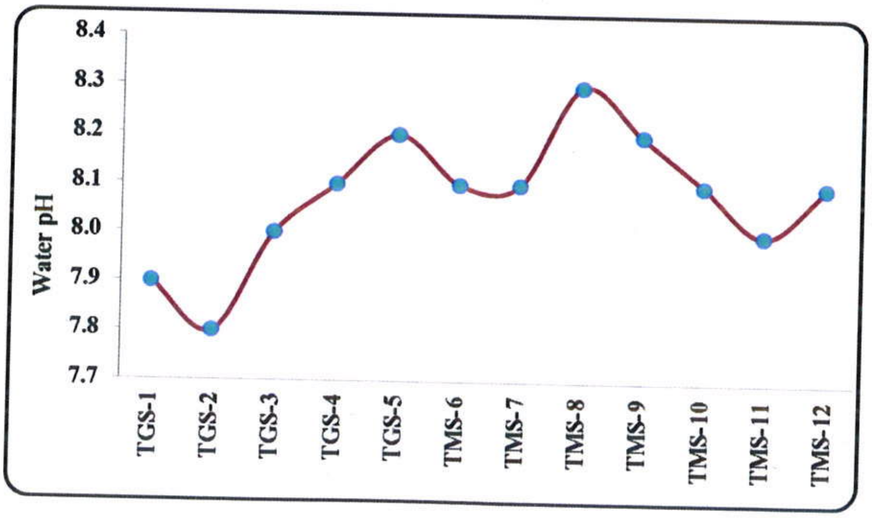


Fig. 5. Water pH level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Dissolved Oxygen

The Dissolved Oxygen level in the water varied between 4.009 and 5.457 mg/l. The lower value was recorded at TGS-2 and the higher value at TMS-10 (Fig. 6).

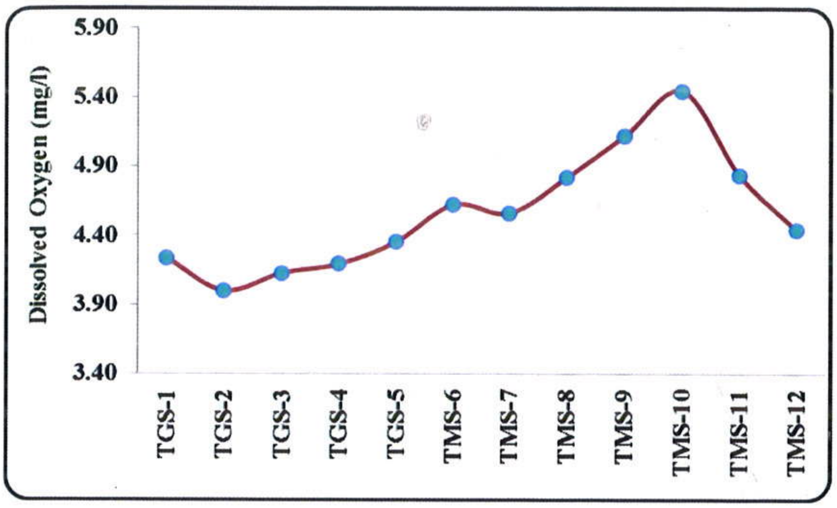


Fig. 8. Dissolved oxygen level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Biological Oxygen Demand

The BOD values varied between 1.02 and 2.56mg/l with minimum at TMS-9 and the maximum value was recorded at TGS-2 (Fig. 7).

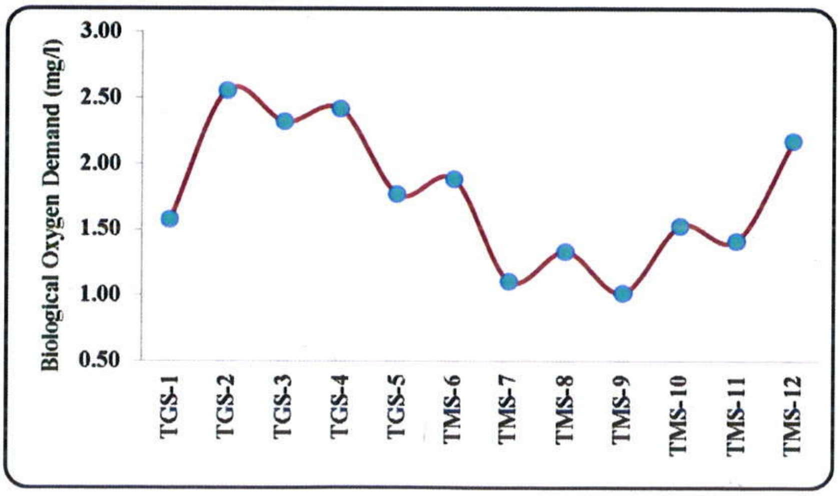


Fig. 9. Biological oxygen demand values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Total Suspended Solids (TSS)

The Total Suspended solids values ranged between 97.70 and 138.50ppm. The minimum value was recorded at TMS-9 and the maximum was recorded at TGS-2 (Fig. 8).

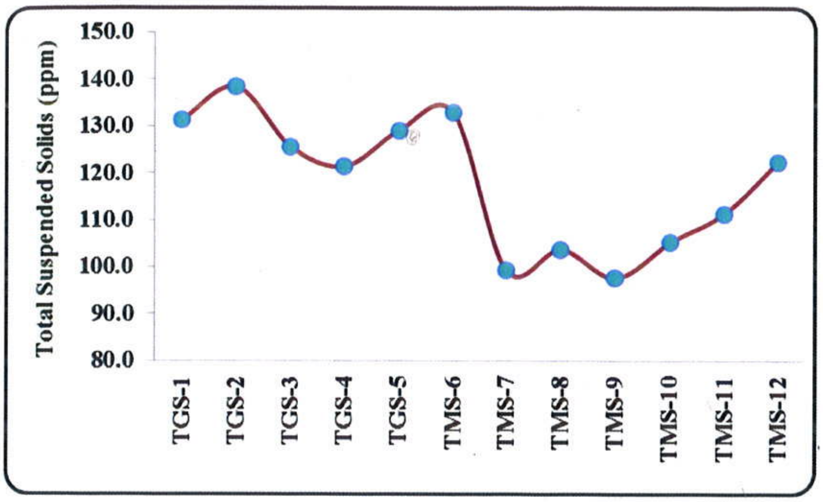


Fig. 6. Total suspended solids values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Turbidity

The turbidity values were between 4.7 and 8.2NTU. The minimum level was recorded at TMS-8 and the maximum level at TGS-1 (Fig. 9).

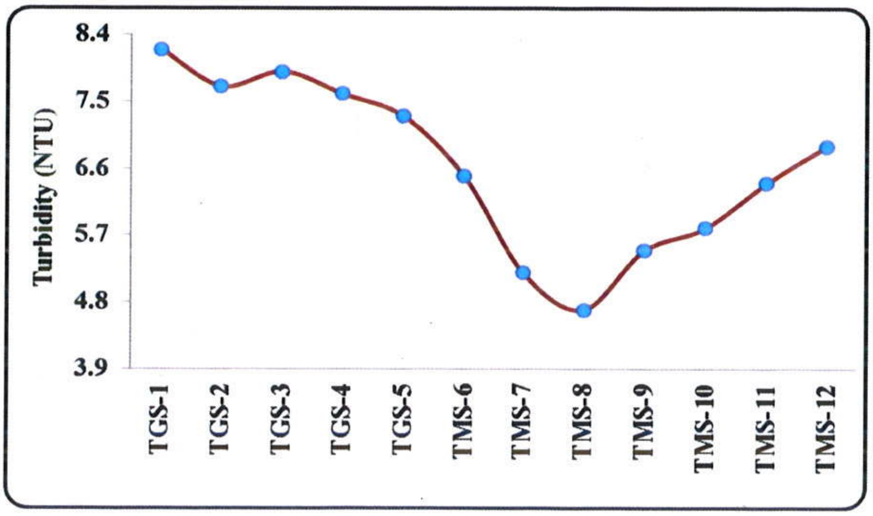


Fig. 7. Turbidity values recorded at various stations of Tiruvottiyur Kuppam coastal waters

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 0.65 to 3.21µmol/l with maximum at TGS-1 and minimum at TMS-8 (Fig. 10).

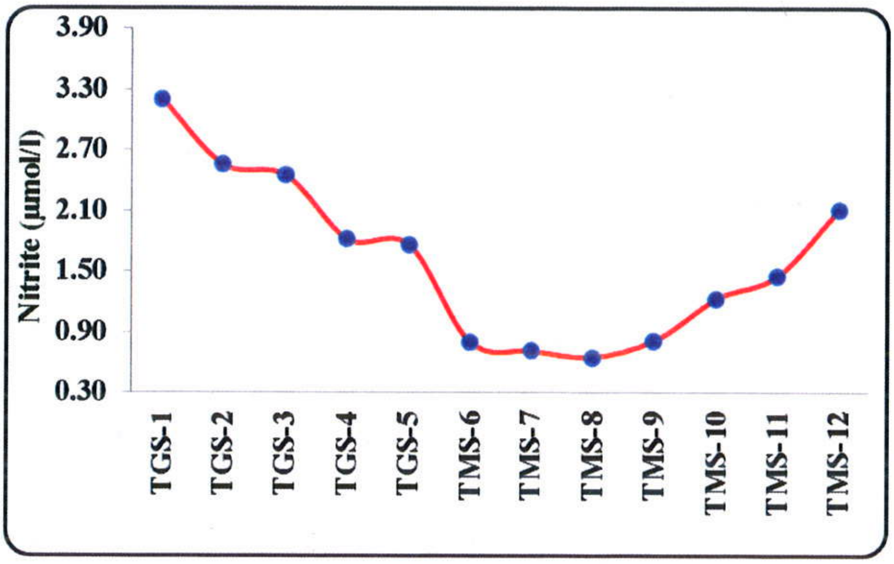


Fig. 10. Nitrite level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Nitrate

Nitrate concentration ranged between 1.17 and 4.46μmol/l with minimum at TMS-10 and maximum at TGS-2 (Fig. 11).

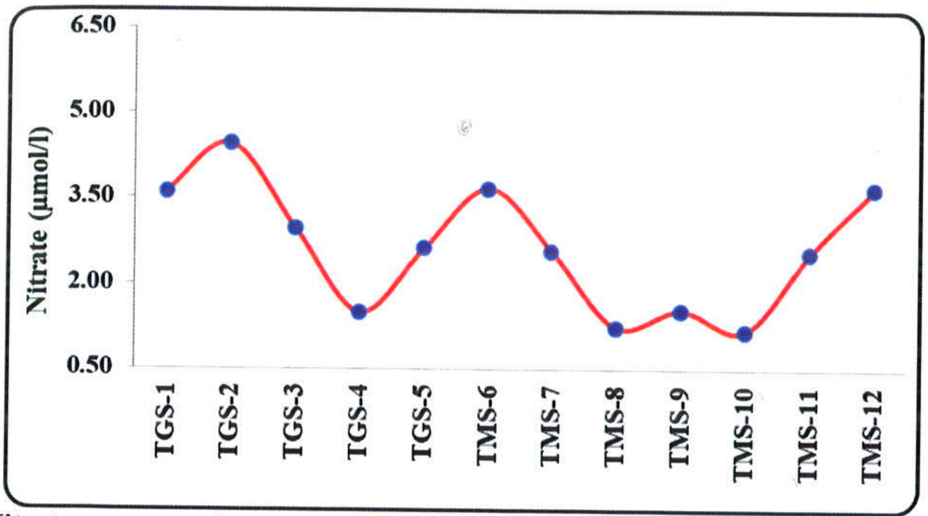


Fig. 11. Nitrate concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Total Nitrogen

The Total nitrogen values ranged from 6.43 to 13.49μmol/l. The minimum value was recorded at TMS-9 and the maximum value at TGS-2 (Fig. 12).

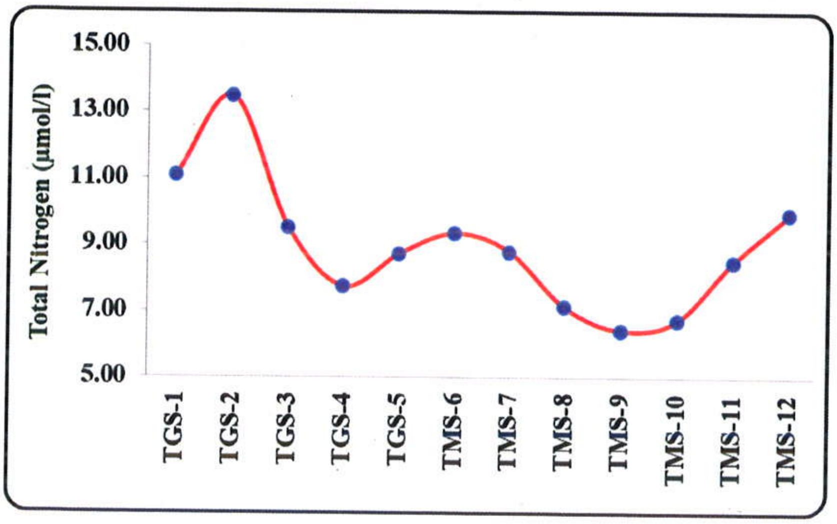


Fig. 12. Total nitrogen values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Ammonical Nitrogen

The ammonia concentration varied from 0.43 to 0.94µmol/l. The maximum concentration (0.94µmol/l) was recorded at TGS-2 and minimum (0.43µmol/l) at TMS-8 (Fig. 13).

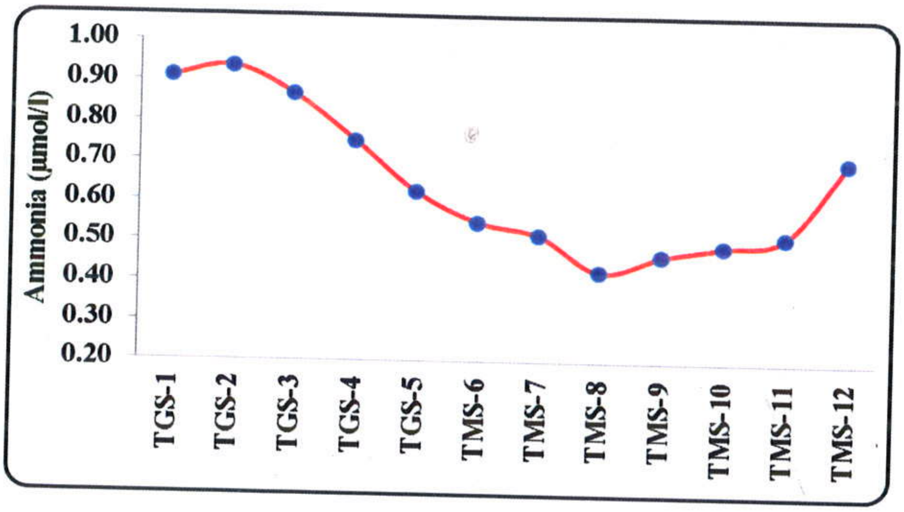


Fig. 13. Ammonical nitrogen concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Inorganic Phosphate

The inorganic phosphate values ranged between 0.468 and 1.835µmol/l with maximum atTGS-1 and minimum at TMS-8 (Fig. 14).

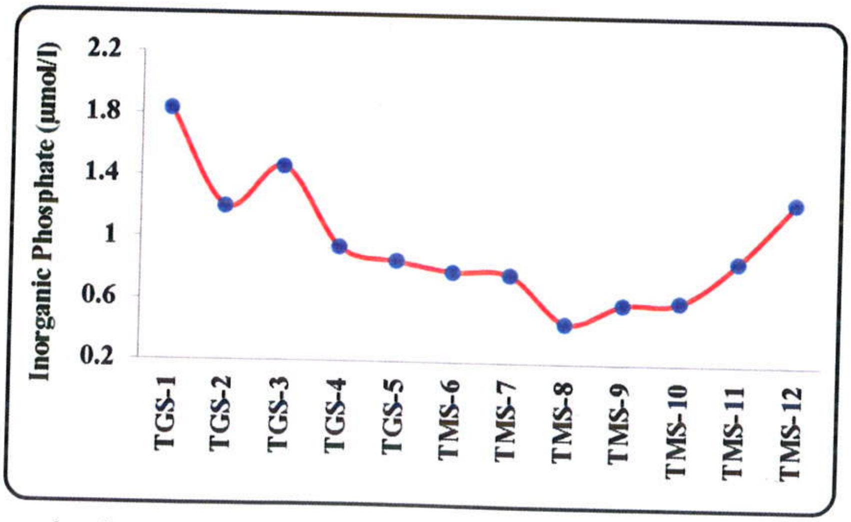


Fig. 14. Inorganic phosphate concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Total Phosphorus

The Total phosphorous values ranged from 1.47 to 3.77µmol/l with minimum value at TMS-9 and the maximum value at TGS-1 (Fig. 15).

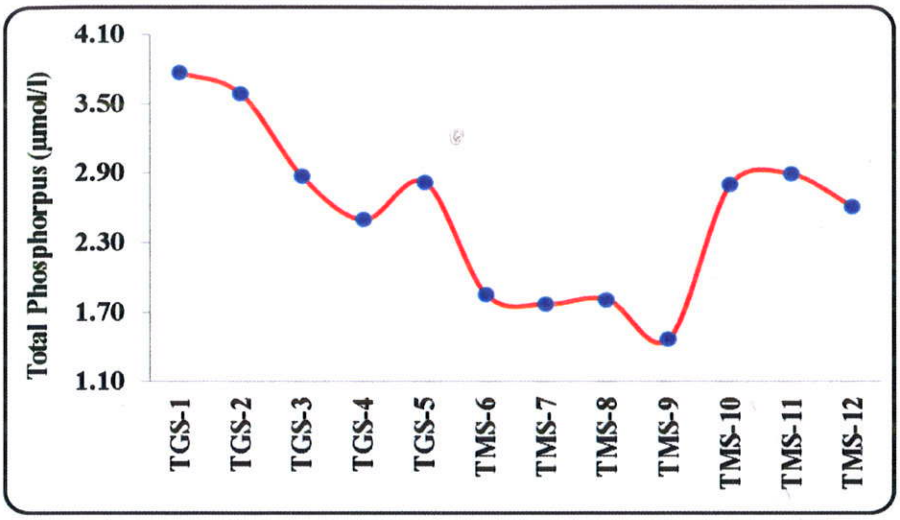


Fig. 15. Total phosphorous values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Reactive Silicate

The silicate values ranged between 13.20 and 25.50µmol/l with minimum was recoded TMS-9 and the maximum values were recorded at TGS-5 (Fig. 16).

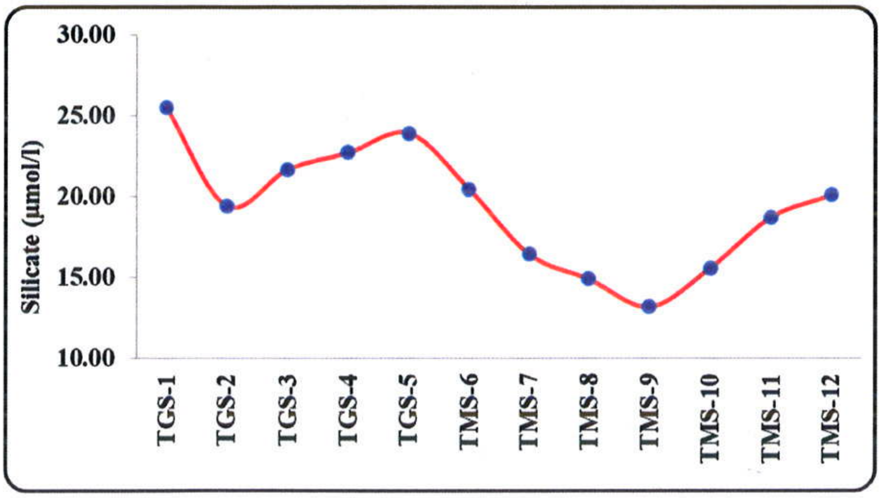


Fig. 16. Reactive silicate level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Particulate organic Carbon

The particulate organic carbon level ranged between 69.84 and 131.32µgC/l with minimum (69.84µgC/l) at TMS-9 and maximum (131.32µgC/l) at TGS-3 (Fig. 17).

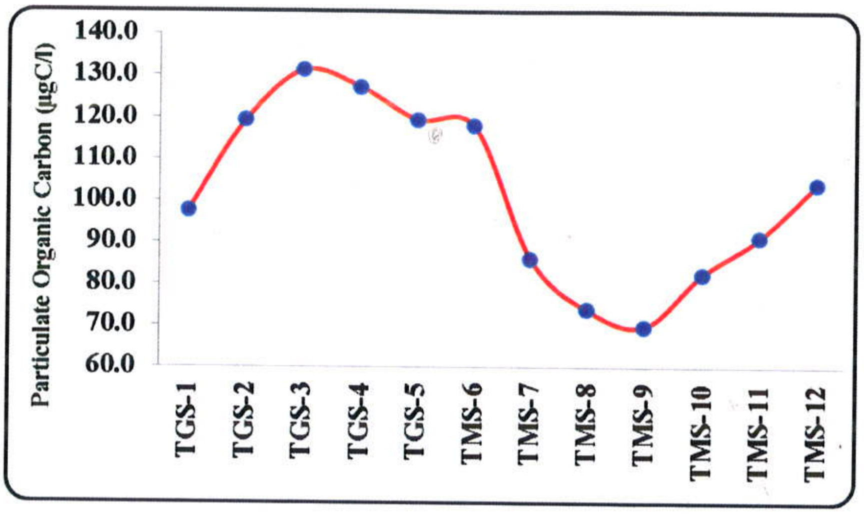


Fig. 17. Particulate organic carbon level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Petroleum hydrocarbons

PHC level in water fluctuated from 0.351 and 0.582µg/l. The maximum was recorded at TGS-2 and the minimum was recorded at TMS-9 (Fig. 18).

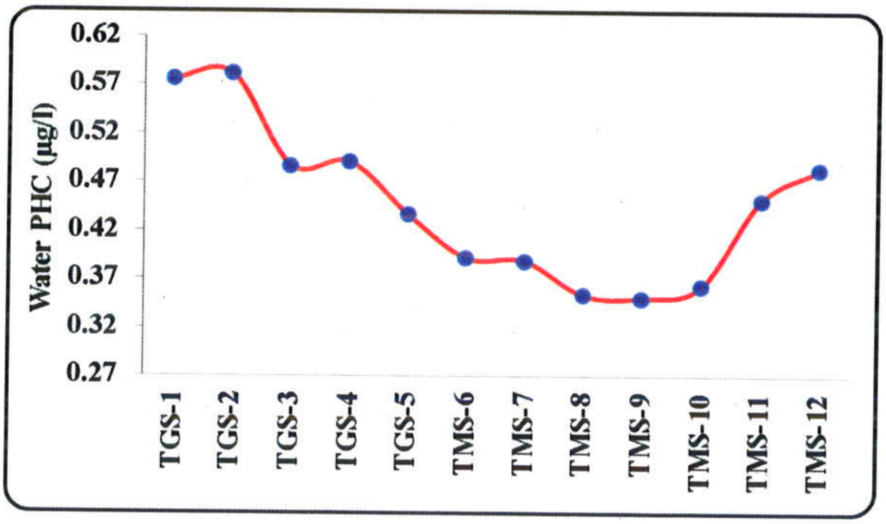


Fig. 18. Petroleum hydrocarbons concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

4. 1. 2. Heavy Metals in water

Iron

The iron level varied from 10.43 to 18.36µg/L (Fig. 19). The maximum was recorded atTGS-1 and the minimum was recorded at TMS-10.

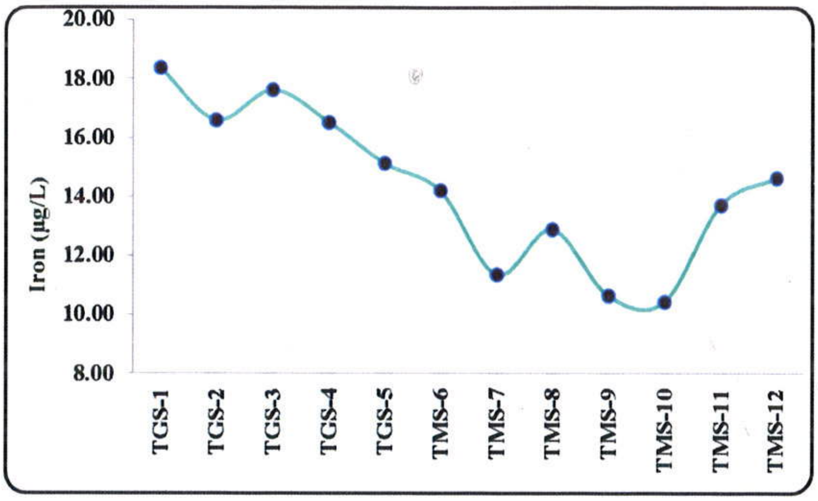


Fig. 19. Iron level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Zinc

The zinc level varied from 13.91 to 36.90µg/L (Fig. 20). The maximum was recorded at TGS-2 and the minimum were recorded at TMS-9.

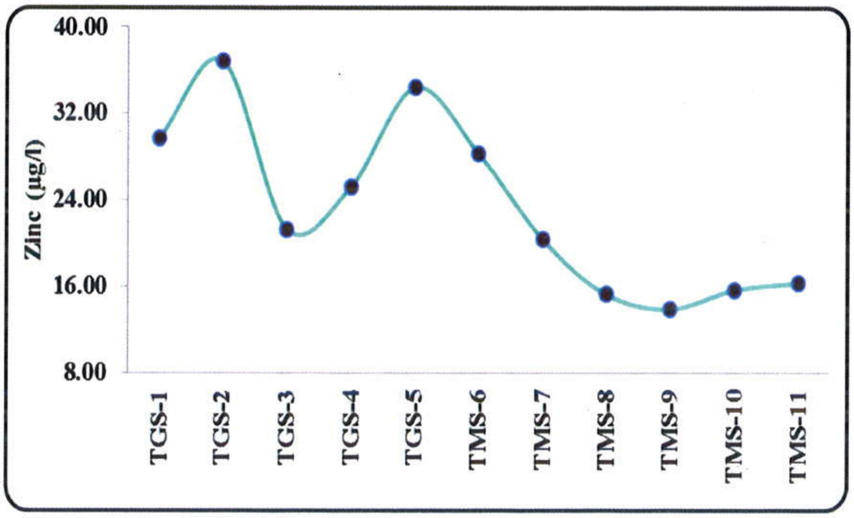


Fig. 20. Zinc level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Manganese

The Manganese concentration varied from 10.15 to 18.17µg/L (Fig. 21). The maximum was recorded TGS-3 and the minimum was recorded at TMS-9.

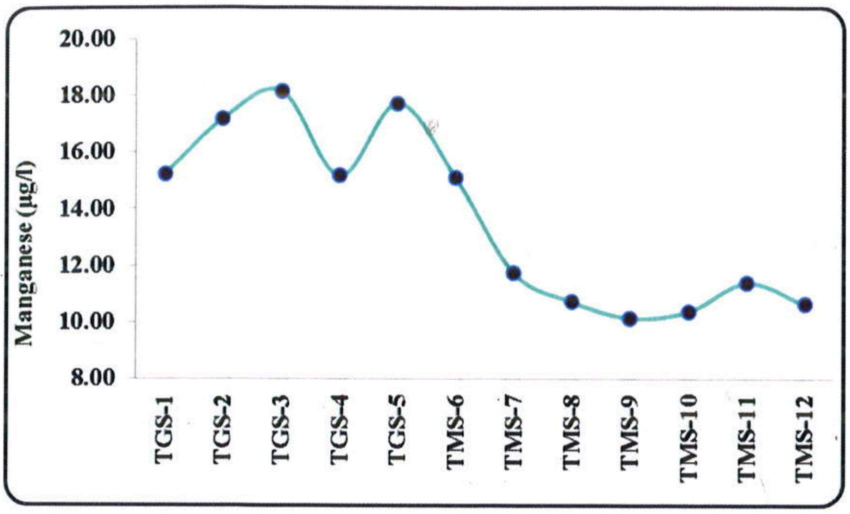


Fig. 21. Manganese concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Cadmium

The Cadmium concentration varied from 1.14 to 2.47µg/L (Fig. 22). The maximum was recorded at TGS-1 and the minimum was recorded at TMS-10.

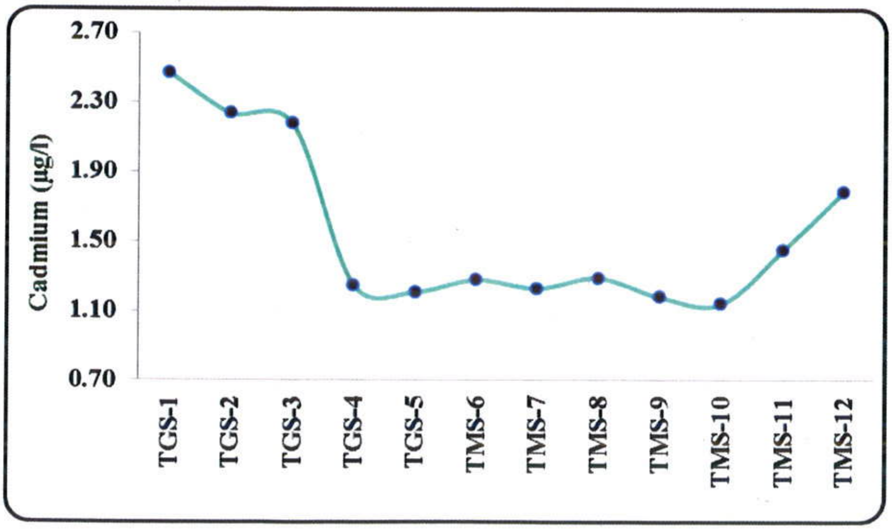


Fig. 22. Cadmium concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Nickel

The Nickel level varied from 0.83 to 1.81µg/L (Fig. 23). The maximum level was recorded at TGS-2 and the minimum was recorded at TMS-10.

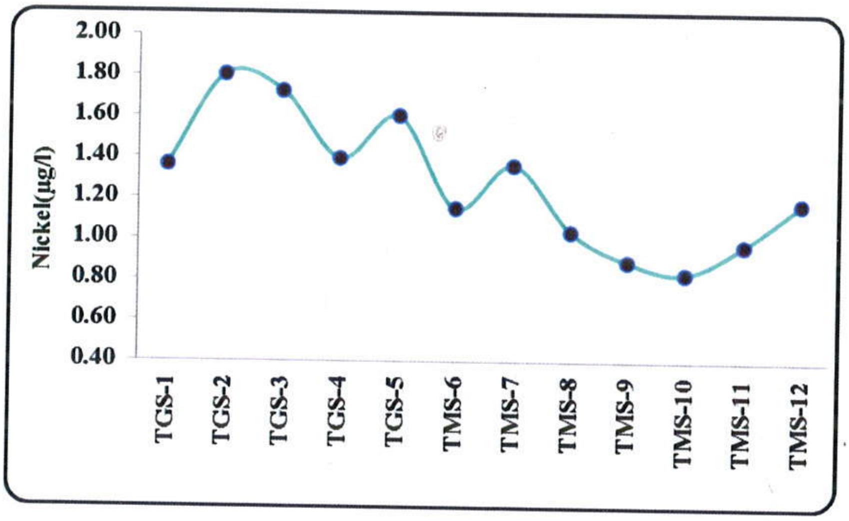


Fig. 23. Nickel level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Chromium

The chromium level varied from 1.08 to 2.79µg/L (Fig. 24). The maximum value was recorded at TGS-2 and the minimum was recorded at TMS-9.

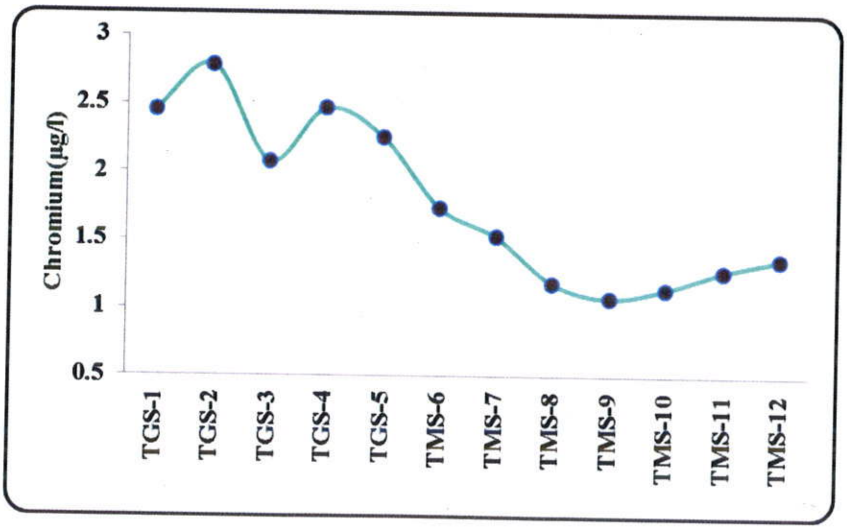


Fig. 24. Chromium level recorded at various stations at Tiruvottiyur Kuppam coastal waters

Lead

The Lead concentration ranged from 0.94 to 2.27µg/L (Fig. 25) with maximum value was recorded at TGS-2 and the minimum was recorded at TMS-9 during this survey.

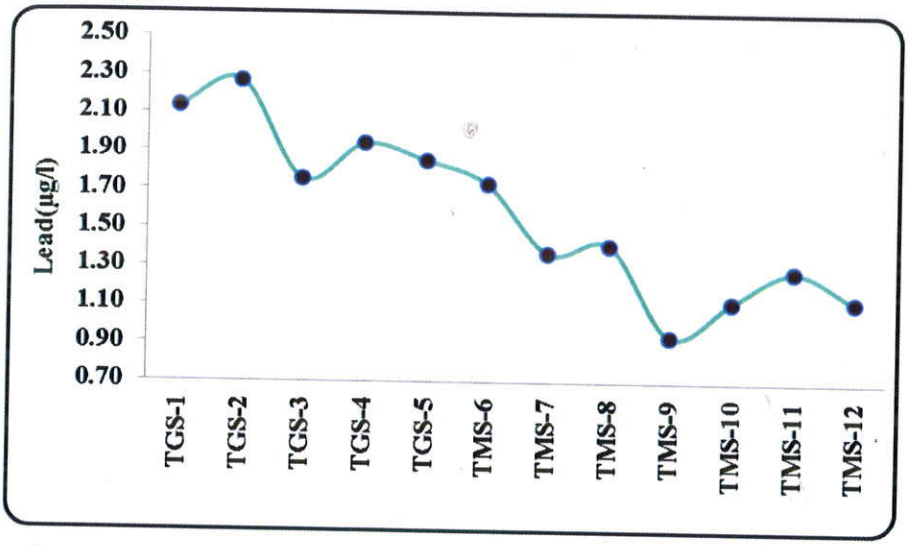


Fig. 25. Lead concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Copper

The copper concentration varied from 2.32 to 5.10µg/L (Fig. 26). The maximum was recorded at TGS-1 and the minimum was recorded at TMS-8 during this survey.

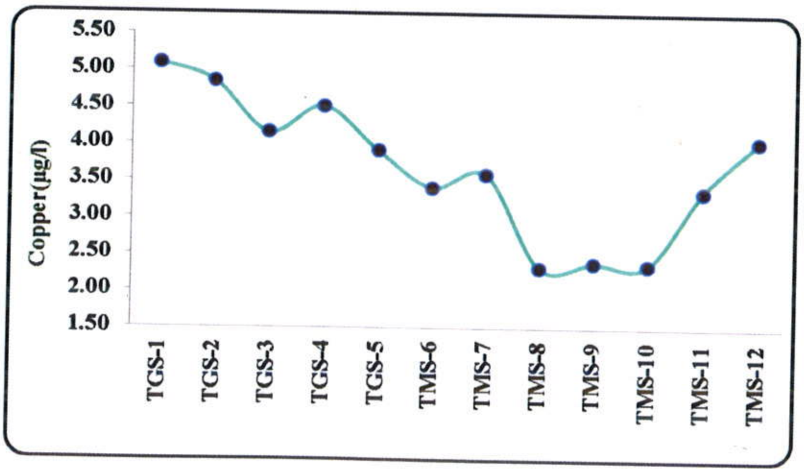


Fig. 26. Copper concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Mercury

The mercury level varied from 0.33 to 0.94µg/L (Fig. 27). The maximum value was recorded at TGS-1 and the minimum was recorded at TMS-10 during this survey.

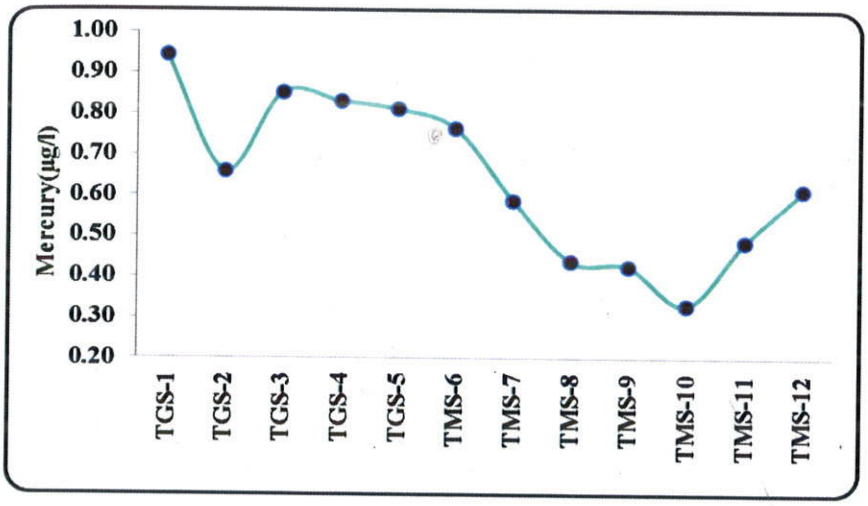


Fig. 27. Mercury level recorded at various stations at Tiruvottiyur Kuppam coastal waters

4. 2. Sediment Characteristics

Sediment pH

The maximum value (8.34) of soil pH was recorded at TMS-9 and minimum of 7.86 at TGS-2 (Fig. 28).

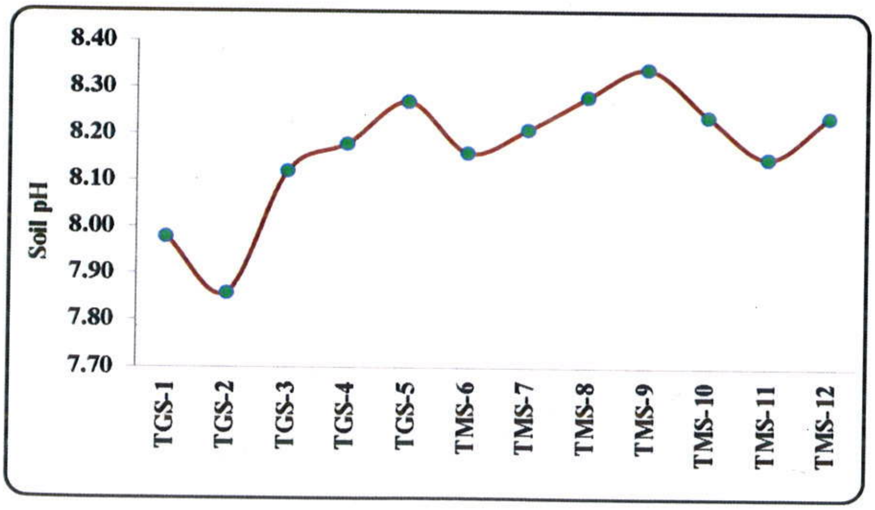


Fig. 28. Soil pH values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Soil Texture

The sand content varied from 12.30 to 78.20 % with maximum value was at TMS-10 and the minimum at TGS-5; maximum Silt content (27.50%) was found at TGS-7 and minimum (12.50%) at TMS-10 and the maximum Clay content (73.70%) was found at TGS-5 and minimum(9.30%) at TMS-10 (Fig. 29).

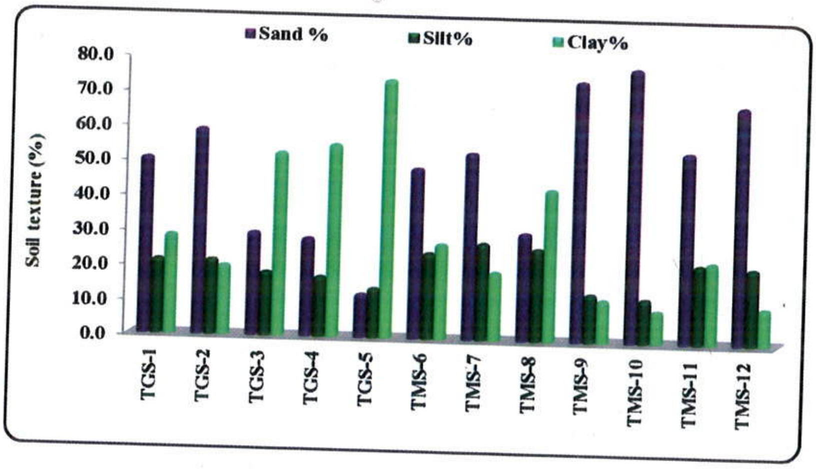


Fig. 29. Variations in soil texture recorded in various stations of Tiruvottiyur Kuppam coastal waters

Total organic Carbon

The total organic carbon ranged between 4.18 and 8.40mgC/g. The maximum level(8.40mgC/g) was found at TGS-5 and minimum (4.18mgC/g) was at TMS-9 (Fig. 30).

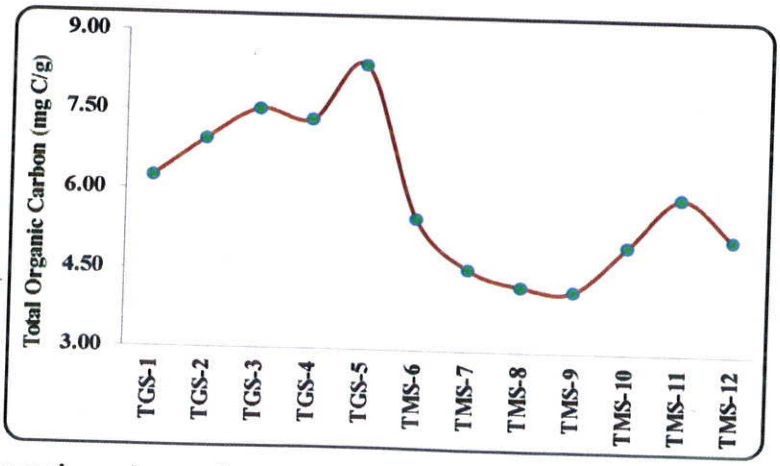


Fig. 30. Total organic carbon values recorded in various stations of Tiruvottiyur Kuppam coastal waters

Sediment PHC

The Sediment PHC level varied from 0.452 to 0.845µg/g (Fig. 31). The maximum level was recorded at TGS-2 and the minimum was recorded at TMS-10 during this survey.

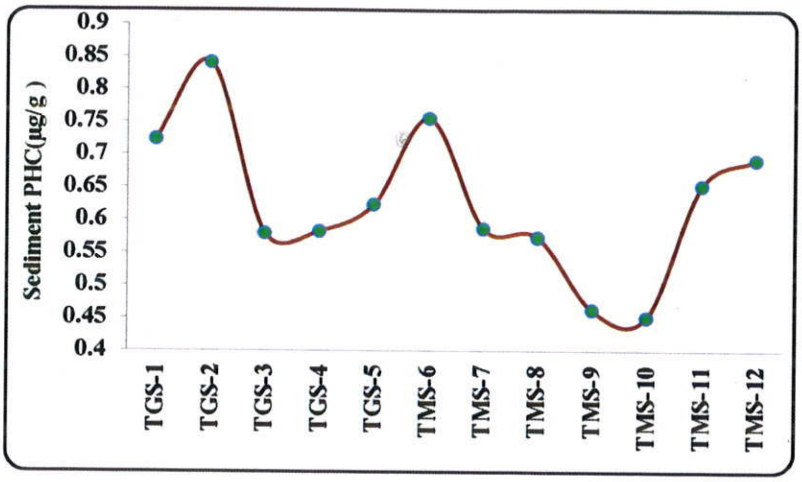


Fig. 31. Sediment PHC level recorded at various stations at Tiruvottiyur Kuppam coastal waters

4. 2. 1. Heavy Metals in sediments

Iron

The Iron level varied from 1128.90 to 1820.30µg/g (Fig. 32). The maximum was recorded at TGS-2 and the minimum was recorded at TMS-9.

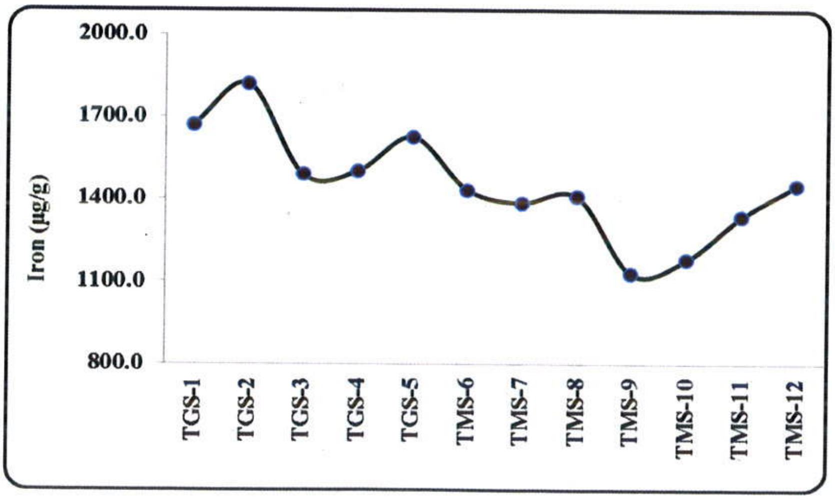


Fig. 32. Iron level recorded in various stations Tiruvottiyur Kuppam coastal waters

Zinc

Zinc concentration varied from 18.73 to 28.89µg/g (Fig. 33). The maximum level was recorded at TGS-2 and the minimum was recorded at TMS-9.

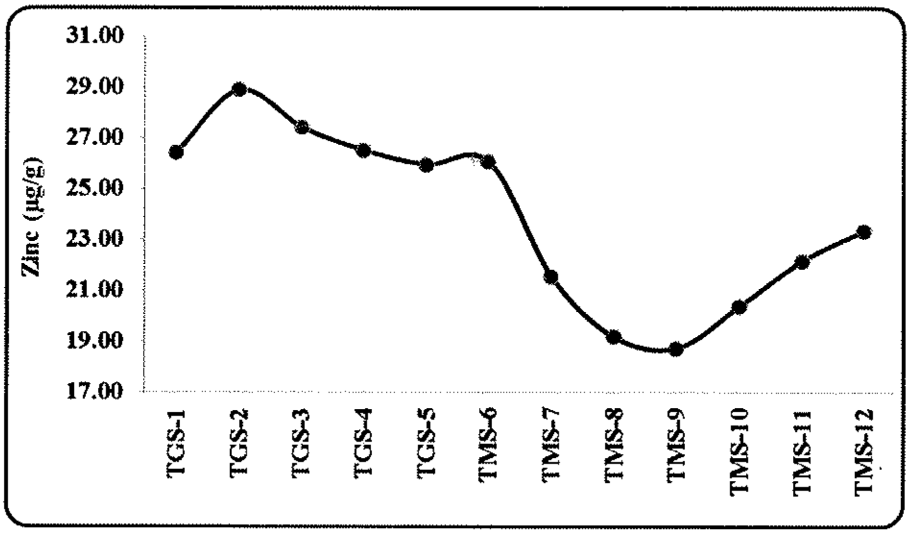


Fig. 33. Zinc concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Manganese

The Manganese level varied from 61.47 to 81.11µg/g (Fig. 34). The maximum level was recorded at TGS-3 and the minimum was recorded at TMS-10.

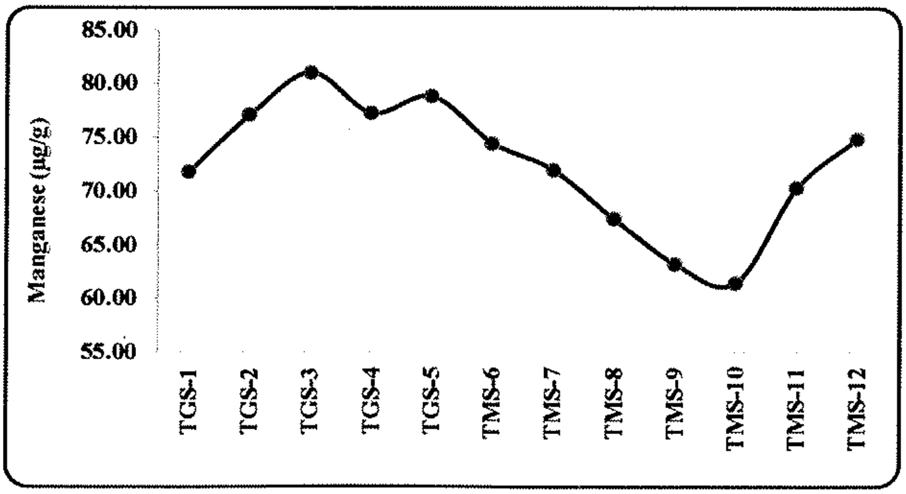


Fig. 34. Manganese level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Cadmium

The Cadmium level varied from 1.55 to 4.13µg/g (Fig. 35). The maximum level was recorded at TGS-3 and the minimum was recorded at TMS-10.

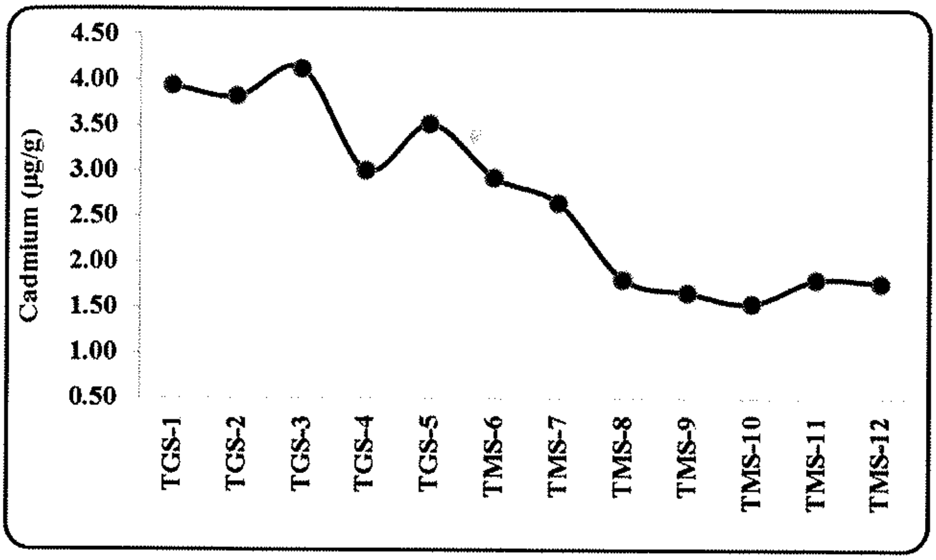


Fig. 35. Cadmium level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Nickel

The nickel concentration varied from 5.38 to 11.13µg/g (Fig. 36). The maximum was recorded at TGS-1 and the minimum was recorded at TMS-9.

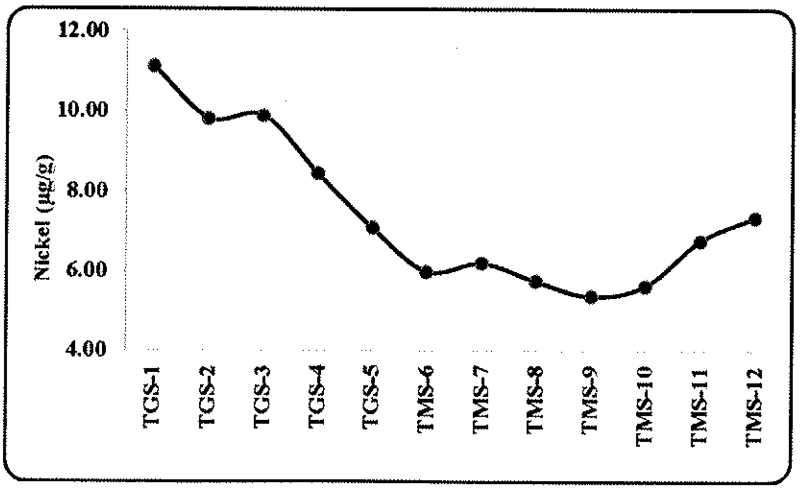


Fig. 36. Nickel concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Chromium

The Chromium level varied from 5.53 to 8.37µg/g (Fig. 37) with the maximum was recorded at TGS-2 and the minimum was recorded at TMS-9.

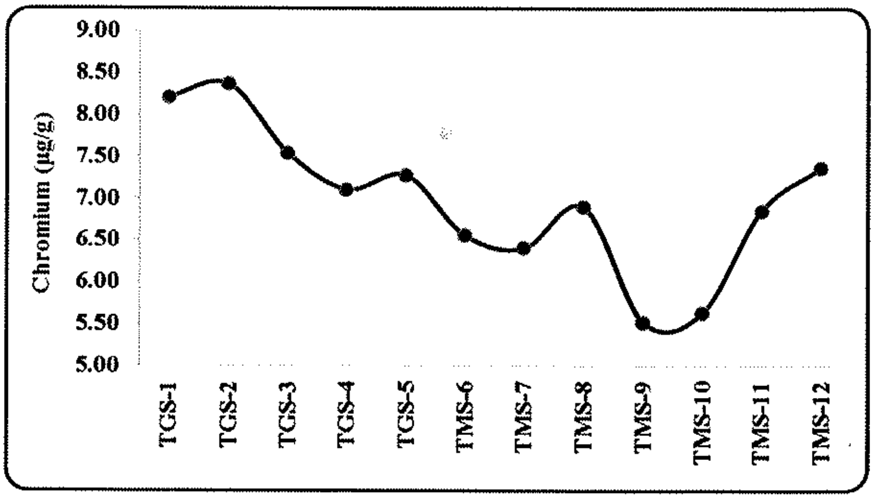


Fig. 37. Chromium level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Lead

The lead concentration varied from 4.34 to 8.21µg/g (Fig. 38). The maximum value was recorded at TGS-1 and the minimum was recorded at TMS-9.

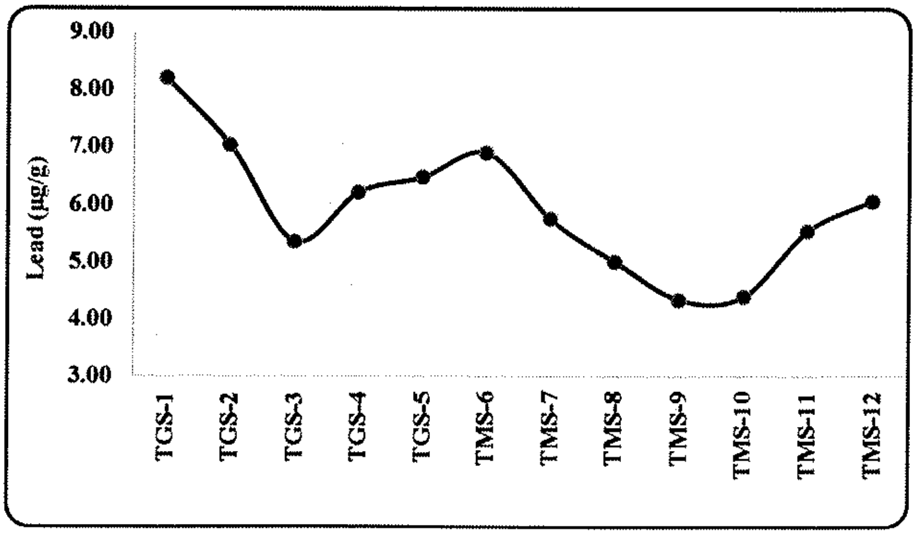


Fig. 38. Lead concentration recorded in various stations of Tiruvottiyur Kuppam coastal waters

Copper

The copper level varied from 6.98 to 12.33µg/g (Fig. 39). The maximum value wasrecorded at TGS-2 and the minimum was recorded at TMS-9.

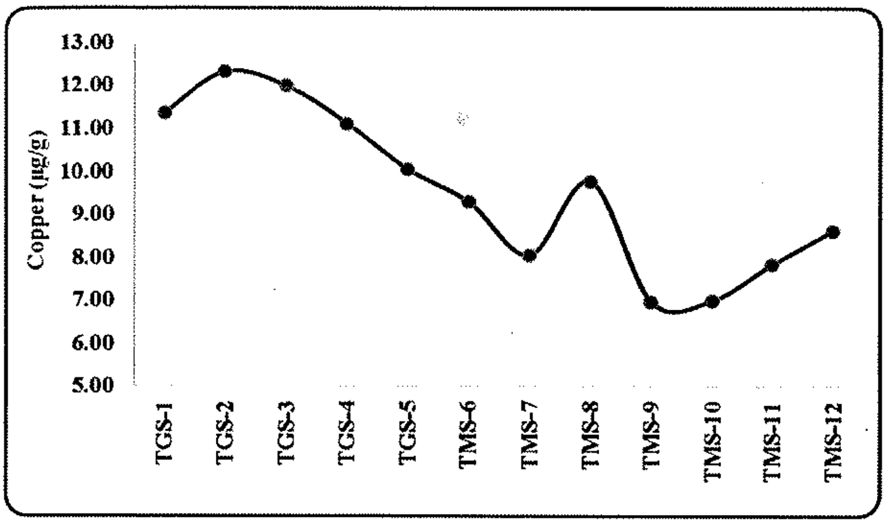


Fig. 39. Copper level recorded in various stations of Tiruvottiyur Kuppam coastal waters

Mercury

The mercury concentration varied from 0.61 to 1.18µg/g (Fig. 40). The maximum was recorded at TGS-1 and the minimum was recorded at TMS-9.

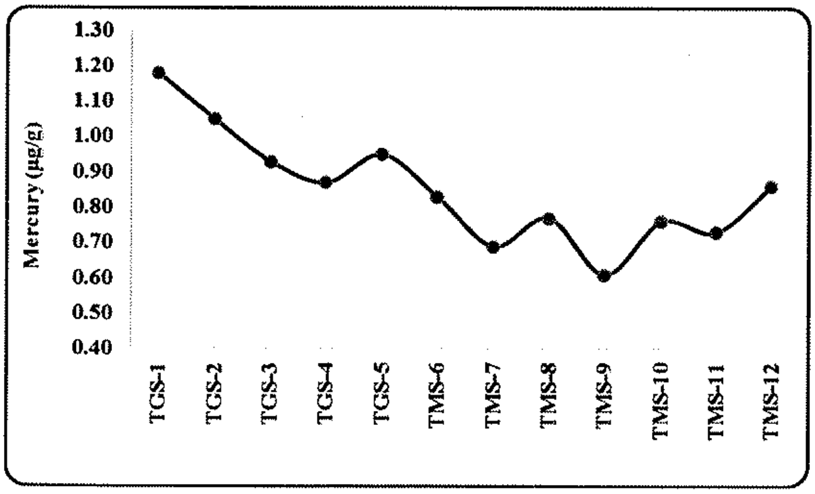


Fig. 40. Mercury concentration recorded in various stations of Tiruvottiyur Kuppam coastal waters

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 TGS-5, TGS-3 TGS-2, TGS-1, TMS-8, TMS-10 and TMS-9 while the rest of the parameters showed strong correlation with stations TMS-12, TMS-11, TMS-7, TMS-6 and TGS-4.

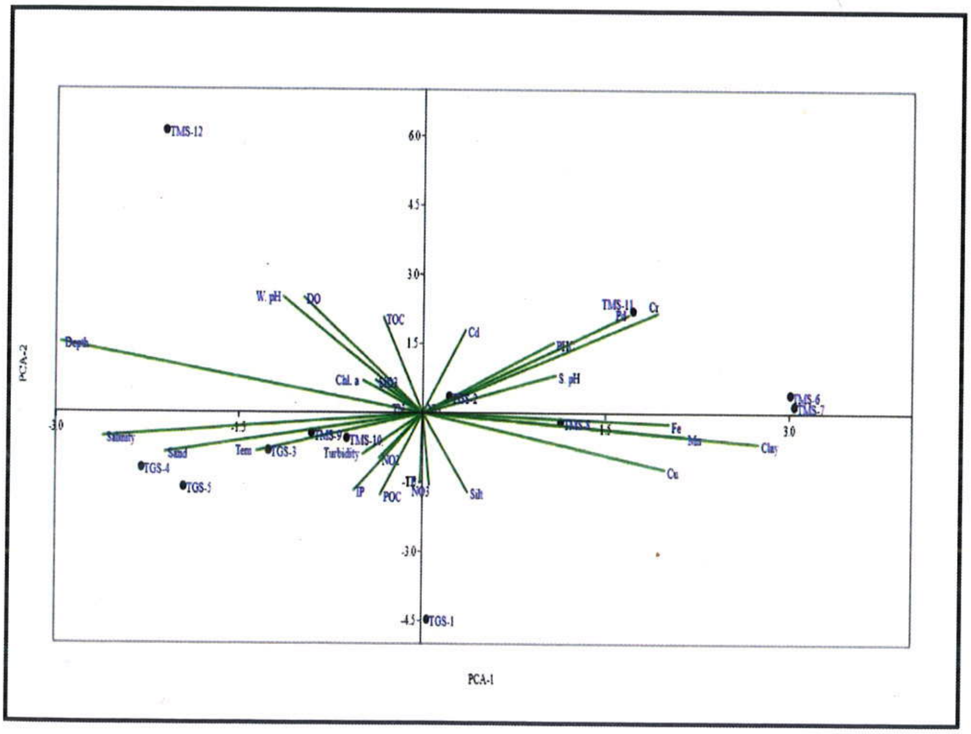


Fig. 41. Principal Component Analysis plot drawn for the correlation between various environmental variables and stations of Tiruvottiyur Kuppam coastal waters

4.3. MICROBIOLOGY

4. 3. 1. Water sample

The total viable count in water samples ranged from $10x10^3$ to $28x10^3$ CFU/ml. The maximum count was found at TGS-1 and the minimum count was found at TMS-10. The Total coliform count in the samples varied from $10x10^4$ to $28x10^4$ CFU/ml with the high colony count at TGS-1 and the low count at TMS-10. The *E. coli* count ranged from $08x10^3$ to $27x10^3$ CFU/ml with a maximum value at TGS-2 and the minimum value at TMS-9. The *Faecal coliform* was found to vary from $09x10^2$ to $27x10^2$ CFU/ml with higher value at TGS-2 and the lower value at TMS-9. The *Pseudomonas aeurginosa* count ranged from $04x10^2$ to $16x10^3$ CFU/ml with maximum value at TGS-2 and the minimum value at TMS-10. The *Streptococcus faecalis* count ranged from $07x10^3$ to $15x10^4$ CFU/ml. The higher values were recorded at TGS-1 and the lower values were recorded at TMS-9. The *Shigella* count varied from $05x10^4$ to $18x10^4$ CFU/ml with a higher value at TGS-2 and the lower value at TMS-9. The *Salmonella* colony count varied from $07x10^2$ to $14x10^4$CFU/ml with the higher value at TMS-12 and the lower value at TMS-9. The *Vibrio cholera* colony count was found to fluctuate from $05x10^3$ to $23x10^2$CFU/ml. The higher colony count was observed at TGS-2 and the lower count was recorded at TMS-10. *Vibrio parahaemolyticus* colony count varied from $06x10^2$ to $16x10^3$ CFU/ml with the maximum value at TGS-2 and minimum value at TMS-8 (Table 2).

Table 2. Bacterial populations recorded in water samples at Tiruvottiyur kuppam coastal waters

S. No	Stations	FC	TVC	TC	EC	VC	VP	PA	SF	SH	SL
1	TGS-1	$21x10^3$	$28x10^3$	$28x10^4$	$20x10^4$	$18x10^3$	$14x10^2$	$16x10^3$	$15x10^4$	$16x10^4$	$14x10^3$
2	TGS-2	$27x10^2$	$27x10^4$	$24x10^2$	$27x10^3$	$23x10^2$	$16x10^4$	$15x10^4$	$14x10^4$	$18x10^4$	$17x10^4$
3	TGS-3	$20x10^3$	$22x10^5$	$23x10^3$	$20x10^3$	$11x10^3$	$10x10^2$	$14x10^3$	$12x10^2$	$14x10^3$	$07x10^2$
4	TGS-4	$13x10^3$	$16x10^3$	$17x10^2$	$15x10^3$	$08x10^3$	$11x10^3$	$10x10^2$	$10x10^3$	$11x10^3$	$08x10^2$
5	TGS-5	$16x10^4$	$18x10^3$	$15x10^2$	$14x10^3$	$11x10^3$	$09x10^3$	$13x10^2$	$11x10^2$	$08x10^2$	$12x10^2$
6	TMS-6	$12x10^3$	$17x10^4$	$12x10^4$	$15x10^4$	$12x10^3$	$10x10^2$	$12x10^4$	$12x10^2$	$11x10^4$	$12x10^3$
7	TMS-7	$11x10^4$	$11x10^3$	$13x10^3$	$10x10^4$	$09x10^3$	$08x10^3$	$08x10^3$	$11x10^2$	$09x10^4$	$09x10^3$
8	TMS-8	$10x10^4$	$14x10^3$	$11x10^3$	$09x10^3$	$09x10^2$	$06x10^2$	$09x10^4$	$10x10^3$	$06x10^3$	$08x10^3$
9	TMS-9	$09x10^2$	$13x10^4$	$11x10^2$	$08x10^3$	$07x10^2$	$08x10^3$	$06x10^2$	$07x10^3$	$05x10^4$	$07x10^2$
10	TMS-10	$11x10^2$	$10x10^3$	$10x10^4$	$12x10^4$	$05x10^3$	$07x10^2$	$04x10^2$	$10x10^2$	$12x10^2$	$11x10^2$
11	TMS-11	$12x10^2$	$13x10^4$	$15x10^3$	$15x10^4$	$10x10^3$	$12x10^3$	$11x10^2$	$10x10^3$	$12x10^2$	$10x10^2$
12	TMS-12	$23x10^3$	$23x10^2$	$13x10^4$	$16x10^3$	$16x10^4$	$15x10^2$	$16x10^4$	$14x10^3$	$14x10^3$	$14x10^4$

4. 3. 2. Sediment sample

With respect to sediment samples, the total viable count in sediment samples ranged from $16x10^5$ to $31x10^4$ CFU/g. The maximum was found at TGS-1 and the minimum value was found at TMS-10. The Total coliform count was found to vary from $14x10^3$ to $31x10^3$ CFU/g with the higher value at TGS-1 and the lower value at TMS-8. The *E. coli* count ranged from $17x10^2$ to $30x10^2$CFU/g with the higher value at TGS-2 and the lower value at TMS-5. The *Faecal coliform* count in the samples varied from $11x10^2$ to $31x10^2$ CFU/g with the higher colony count at TGS-2 and the lower count at TMS-9. *Pseudomonas aeroginosa* counts ranged from $11x10^3$ to $19x10^4$ CFU/g with the maximum at TGS-1 and the minimum at TMS-7. The *Streptococcus faecalis* count ranged from $12x10^3$ to $23x10^4$ CFU/g. The higher value was recorded at TGS-2 and the lower value was recorded at TMS-9. The *Shigella* counts varied from $12x10^3$ to $24x10^3$ CFU/g with the higher value at TMS-12 and lower value at TMS-7. *Salmonella* colony counts varied from $11x10^3$ to $22x10^3$ CFU/g with the maximum value at TGS-1 and the minimum value at TMS-8. *Vibrio parahaemolyticus* colony count varied from $12x10^3$ to $23x10^4$ CFU/g. The higher value was found at TGS-2 and the lower value at TMS-9. The other species *Vibrio cholerae* colony was found to range from $12x10^3$ to $25x10^2$ CFU/g with the maximum colony count at TGS-1 and the minimum count was observed at TMS-10 (Table 3).

Table 3. Bacterial populations recorded in sediment samples at Tiruvottiyur kuppam coastal waters

S. No	Stations	FC	TVC	TC	EC	VC	VP	PA	SF	SH	SL
1	TGS-1	$28x10^2$	$31x10^4$	$31x10^3$	$26x10^5$	$25x10^2$	$17x10^3$	$19x10^4$	$17x10^3$	$18x10^3$	$22x10^3$
2	TGS-2	$31x10^2$	$29x10^4$	$28x10^2$	$30x10^2$	$24x10^3$	$23x10^4$	$17x10^4$	$23x10^4$	$19x10^5$	$19x10^4$
3	TGS-3	$22x10^5$	$23x10^4$	$26x10^3$	$23x10^4$	$15x10^3$	$20x10^3$	$16x10^4$	$16x10^4$	$15x10^4$	$12x10^4$
4	TGS-4	$16x10^3$	$18x10^5$	$20x10^4$	$21x10^4$	$12x10^4$	$14x10^4$	$13x10^4$	$12x10^4$	$13x10^4$	$11x10^4$
5	TGS-5	$21x10^5$	$19x10^4$	$22x10^5$	$17x10^2$	$16x10^5$	$13x10^4$	$14x10^4$	$14x10^4$	$12x10^4$	$14x10^4$
6	TMS-6	$22x10^3$	$24x10^4$	$28x10^4$	$21x10^4$	$14x10^4$	$16x10^4$	$17x10^2$	$18x10^5$	$15x10^3$	$18x10^4$
7	TMS-7	$18x10^4$	$22x10^4$	$18x10^5$	$17x10^3$	$13x10^4$	$15x10^3$	$11x10^3$	$13x10^3$	$12x10^3$	$11x10^4$
8	TMS-8	$17x10^4$	$20x10^4$	$14x10^3$	$18x10^5$	$14x10^3$	$14x10^3$	$13x10^4$	$13x10^4$	$11x10^4$	$11x10^3$
9	TMS-9	$11x10^2$	$22x10^4$	$21x10^4$	$17x10^4$	$12x10^4$	$12x10^3$	$14x10^4$	$12x10^3$	$14x10^4$	$12x10^3$
10	TMS-10	$17x10^3$	$16x10^5$	$21x10^4$	$17x10^3$	$12x10^3$	$13x10^4$	$13x10^4$	$14x10^4$	$14x10^5$	$14x10^4$
11	TMS-11	$20x10^4$	$18x10^5$	$24x10^4$	$20x10^3$	$14x10^4$	$15x10^3$	$14x10^3$	$13x10^3$	$14x10^4$	$13x10^3$
12	TMS-12	$25x10^4$	$26x10^5$	$20x10^5$	$22x10^5$	$18x10^3$	$18x10^3$	$19x10^3$	$16x10^4$	$22x10^3$	$16x10^4$

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 1.014 to 2.813 mg/m^3, with maximum at TGS-4 and minimum at TGS-1. The Phaeopigments content varied from 1.229 to 2.338 mg/m^3 with maximum was at TGS-4 and the minimum was observed at TGS-1. The Total biomass values varied from 2.245 to 6.218 ml/100m^3, with maximum was at TGS-4 and minimum at TGS-1 (Table 4).

Table 4. Chlorophyll *a*, Phaeopigments and total biomass recorded in Tiruvottiyur kuppam coastal waters

Stations	Chlorophyll 'a' (mg/m^3)	Phaeopigments (mg/m^3)	Total biomass (ml/100m^3)
TGS-1	1.014	1.341	2.245
TGS-2	1.064	1.229	4.143
TGS-3	2.782	1.295	5.434
TGS-4	2.813	2.338	6.218
TGS-5	1.099	2.263	4.848
TMS-6	1.041	1.385	4.392
TMS-7	1.505	1.279	3.548
TMS-8	1.017	1.241	3.944
TMS-9	1.863	1.406	4.914
TMS-10	1.035	1.311	4.103
TMS-11	1.487	1.642	3.482
TMS-12	1.792	1.875	4.340

Primary productivity

The primary productivity was measured using the dark and light reaction method. The values ranged from 121.57 to 172.49mgCm^{-3}d^{-1}. The maximum value was recorded at TGS-4 and minimum value was at TGS-1 (Fig. 42).

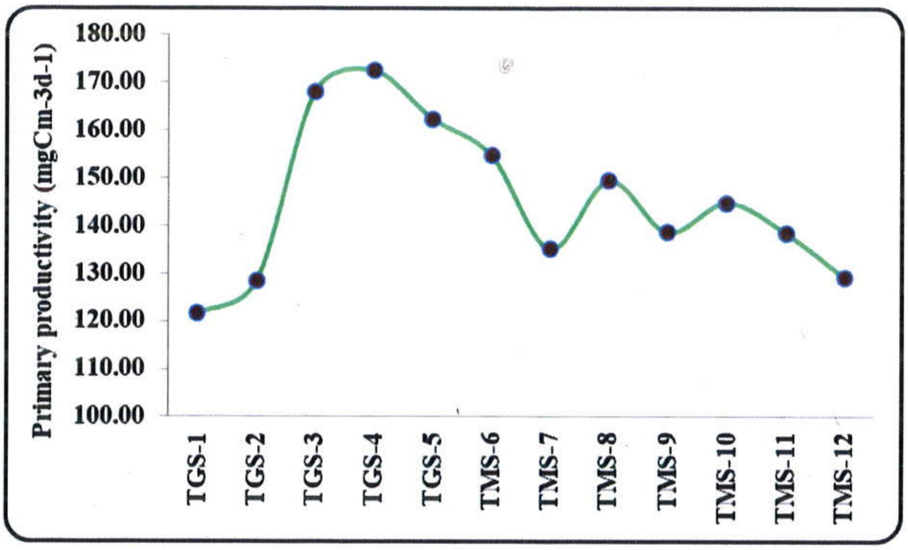


Fig. 42. Primary productivity values recorded at various stations of Tiruvottiyur kuppam coastal waters

4.5 PLANKTON

4.5.1 Phytoplankton

In the present study, as many as 46 phytoplankton species belonging to three major groups namely Bacillariophyceae (Diatom), Dinophyceae (Dinoflagellates) and Cyanophyceae (Cyanobacteria) were recorded in Thiruvottiyurkuppam coastal waters. Of these, Bacillariophyceaewas found to be the dominant group with 35 species, followed by Dinophyceae with 9 species and Cyanophyceae with two species.

Among the Bacillariophyceae, *Skeletonema costatum* was observed to be the dominant group in all the stations followed by *Asterionella glacialis* and *Chaetoceros curvisetus* also were found in all sampling sites except TGS-2 in Thiruvottiyur kuppam coastal area. The

Dinophyceae, (*Dinophysis caudate*) and Cyanophyceae (*Trichodesmium erythraeum*) were recorded in all the twelve sampling sites. Among the various species, *Bellerochea malleus, Chaetoceros coarctatus, Coscinodiscus centralis, Navicula* sp, *Nitzschia longissima, Odontella mobiliensis, Planktoniella sol, Rhizosolenia alata, Thalassionemanitzschioides, Ceratium furca, Ceratium macroceros* and *Peridinium claudicans* were the most abundant forms. The distribution and abundance of phytoplankton varied considerably conforming to the seasonal environmental fluctuations.

Population density

The density of phytoplankton varied from 3,964 to 18,976 Cells/l, with maximum was at TGS-4 and minimum was at TGS-2 (Fig. 43).

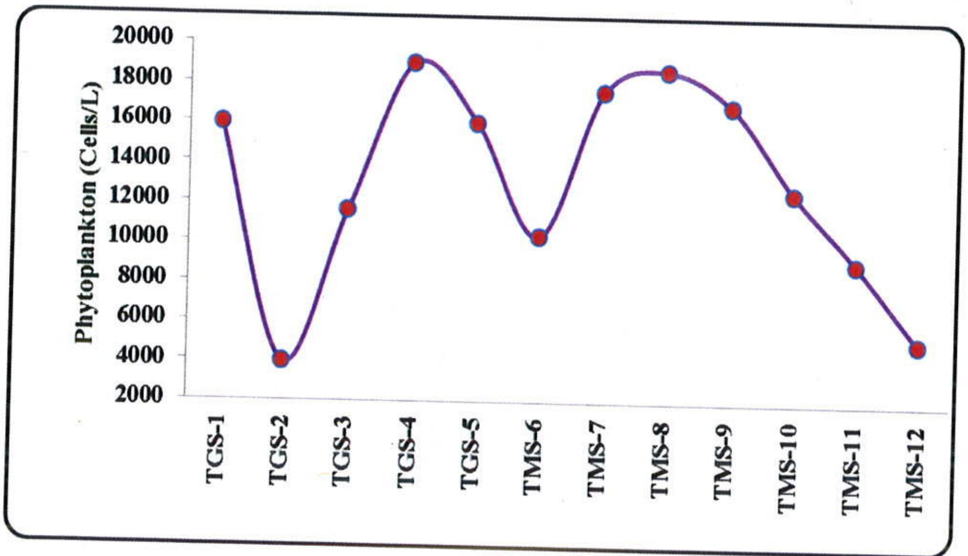


Fig. 43. Population density of Phytoplankton in various stations of Tiruvottiyur kuppam coastal waters

Percentage composition

When the results of percentage composition of phytoplankton were looked at, Bacillariophyceae constituted the maximum with 74% of the total, followed by Dinophyceae with15% and Cyanophyceae with 11% of the total biomass (Fig. 44).

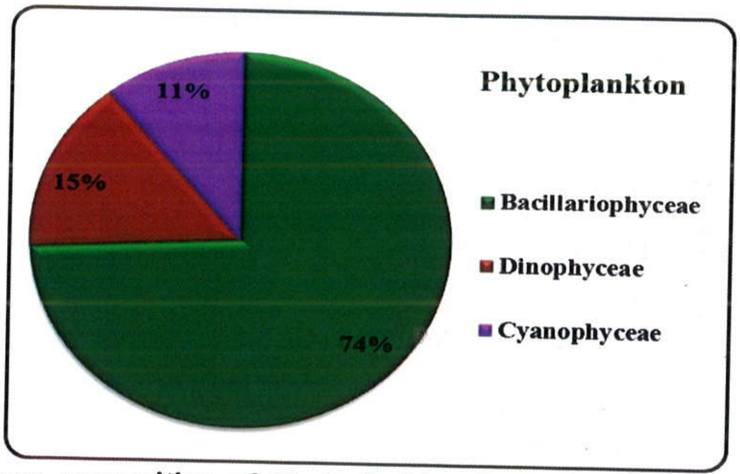


Fig. 44. Percentage composition of Phytoplankton in various stations of Tiruvottiyur kuppam coastal waters

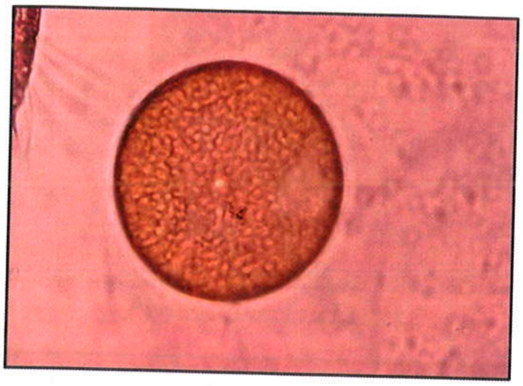
Diversity indices

The phytoplankton species diversity (H') varied from 2.203 to 3.620 with maximum at TMS-7 and minimum at TGS-2. The species richness (d) ranged between 4.372 and 6.607 with maximum at TGS-2 and minimum at TMS-8. The species evenness varied from 0.625 to 0.851 with the maximum at TGS-7 and minimum at TMS-1 (Table-5).

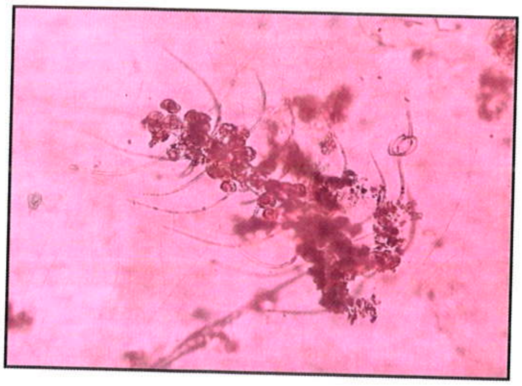
Table 5. Diversity indices; Shannon diversity (H'); Margalef richness (d) and Pielou's evenness (J') calculated for Phytoplankton in Tiruvottiyur kuppam coastal waters

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
TGS-1	3.115	5.893	0.625
TGS-2	2.203	6.607	0.719
TGS-3	3.211	5.993	0.754
TGS-4	3.580	6.467	0.640
TGS-5	3.502	6.029	0.749
TMS-6	3.289	5.462	0.741
TMS-7	3.620	4.500	0.851
TMS-8	3.589	4.372	0.838
TMS-9	3.570	4.416	0.844
TMS-10	3.406	5.812	0.743
TMS-11	3.135	5.961	0.741
TMS-12	2.862	5.222	0.655

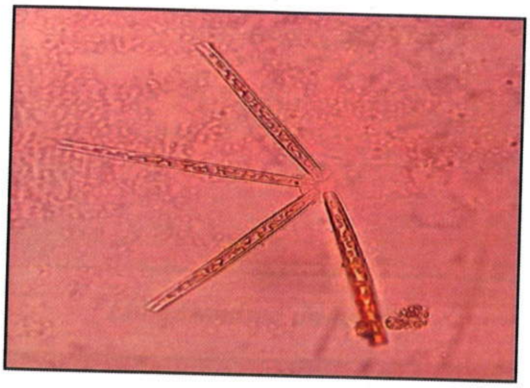
PLATE -I PHYTOPLANKTON



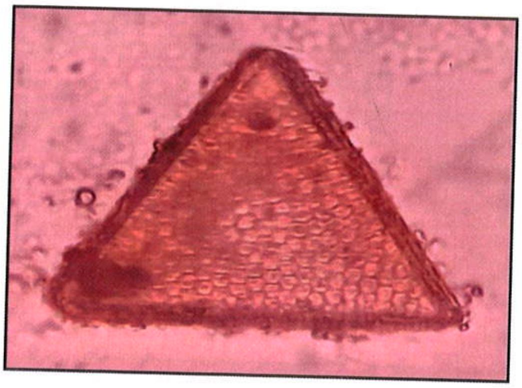
Coscinodiscus centralis



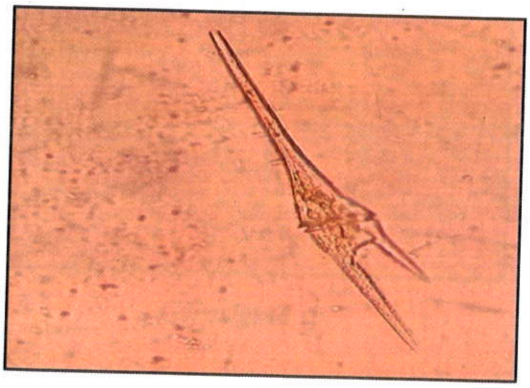
Chaetoceros coarctatus



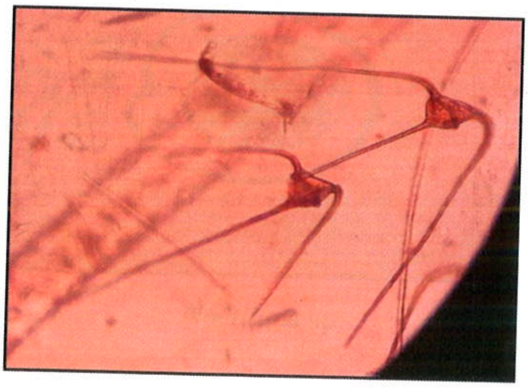
Thalassionema nitzschioides



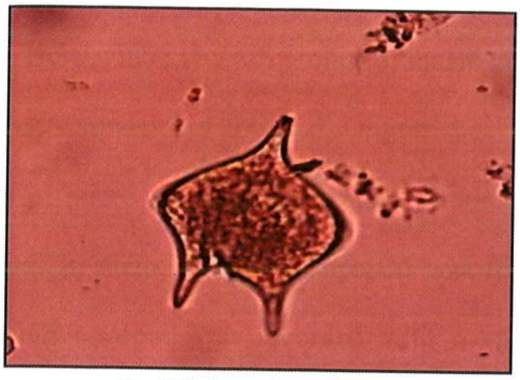
Triceratium favus



Ceratium furca

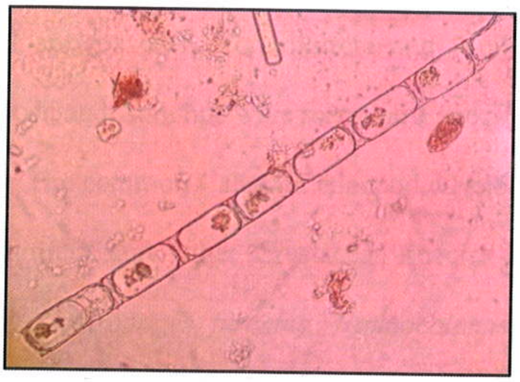


Ceratium macroceros

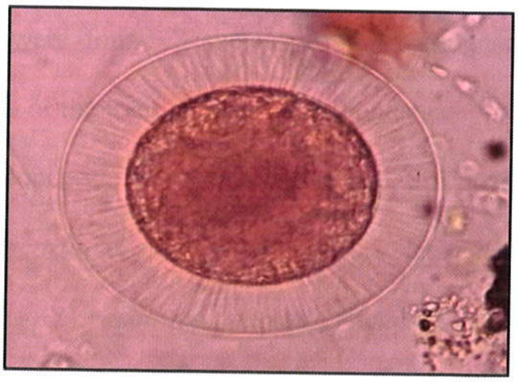


Peridinium claudicans

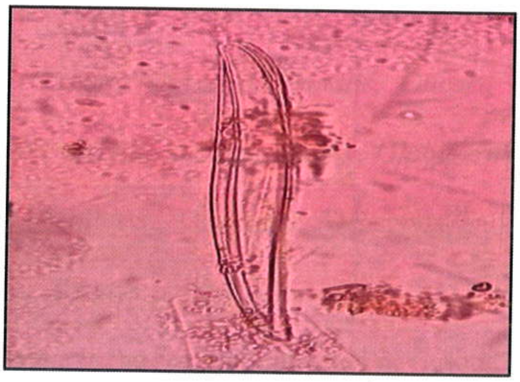
Hemidiscus hardmanianus



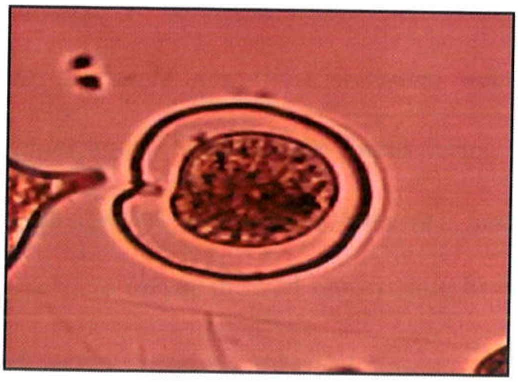
Lithodesmium undulatum



Planktoniella sol



Gyrosigma sp.



Noctiluca sp.

4.5.2 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 10 species. Cyclopoid copepod was recorded with 6 species and Harpacticoid copepod came as next dominant group with 4 species. The Other Crustacean forms and Oligotrichea were observed with 3 species each, Foraminifera and Mollusca were found 2 species each, Chaetognatha, Decapoda and Annelida were recorded 1 species each of the total zooplankton abundance.

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

Population density

The zooplankton density varied from 322 to 6305 Nos/m^3 with maximum at TGS-5 and minimum at TSG-2 (Fig. 45).

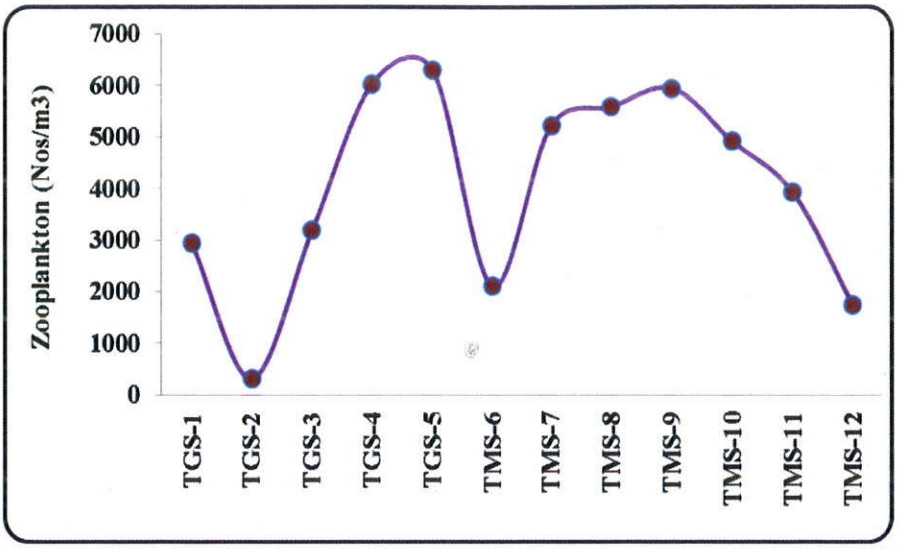


Fig. 45. Population density of zooplankton recorded in various stations of Tiruvottiyur kuppam coastal waters

Percentage composition

Calanoid copepod emerged as the dominant group by constituting 32% of the total followed by Cyclopoid copepod with 18%, Harpacticoid copepod with 13% and Oligotrichea and Other Crustacean forms with 9% each and Mollusca with 6%, Foraminifera and Annelida with 4% each, Chaetognatha and Cladocera with 2% each to the total percentage composition (Fig. 46).

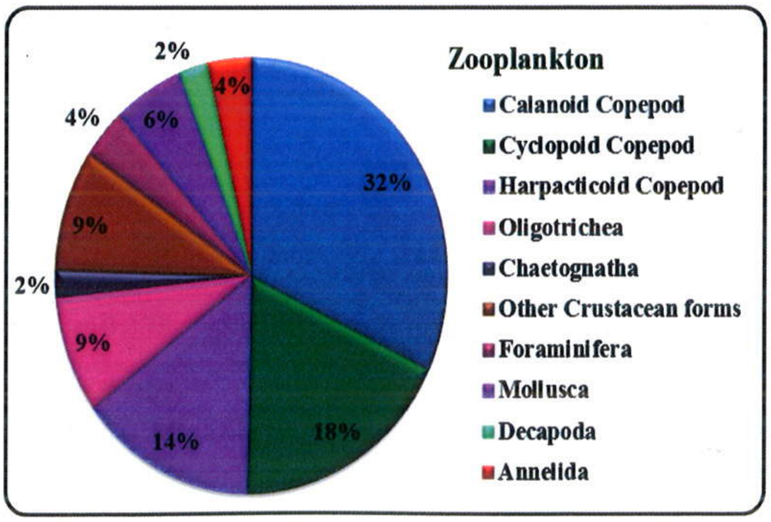


Fig. 46. Percentage composition of Zooplankton in various stations of Tiruvottiyur kuppam coastal waters

Diversity Indices

As done for phytoplankton, the zooplankton species diversity (H') varied from 2.588 to 3.399 with maximum in TMS-6 and minimum in TGS-2. The species richness (d) ranged between 3.592 and 6.658 with maximum in TGS-4 and minimum in TMS-8. The species evenness varied from 0.545 to 0.875 with the maximum in TGS-9 and minimum in TGS-2 (Table 6).

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

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
TGS-1	2.951	5.630	0.545
TGS-2	2.588	6.039	0.570
TGS-3	3.120	5.975	0.669
TGS-4	3.342	6.658	0.673
TGS-5	3.392	5.446	0.701
TMS-6	3.399	6.612	0.747
TMS-7	2.980	3.620	0.808
TMS-8	3.378	3.592	0.875
TMS-9	3.367	3.682	0.863
TMS-10	3.260	4.176	0.784
TMS-11	3.178	5.020	0.751
TMS-12	2.749	5.141	0.706

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 outside groynes TMS-11, TMS-9,TMS-10, TMS-7, TMS-8, TMS-6 and TMS-12 were forming a cluster based on the species composition and abundance. Similarly, the stations within the groynes TGS-1, TGS-4, TGS-5, TGS-3 and TGS-2 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 (0.16), 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 (Fig. 48).

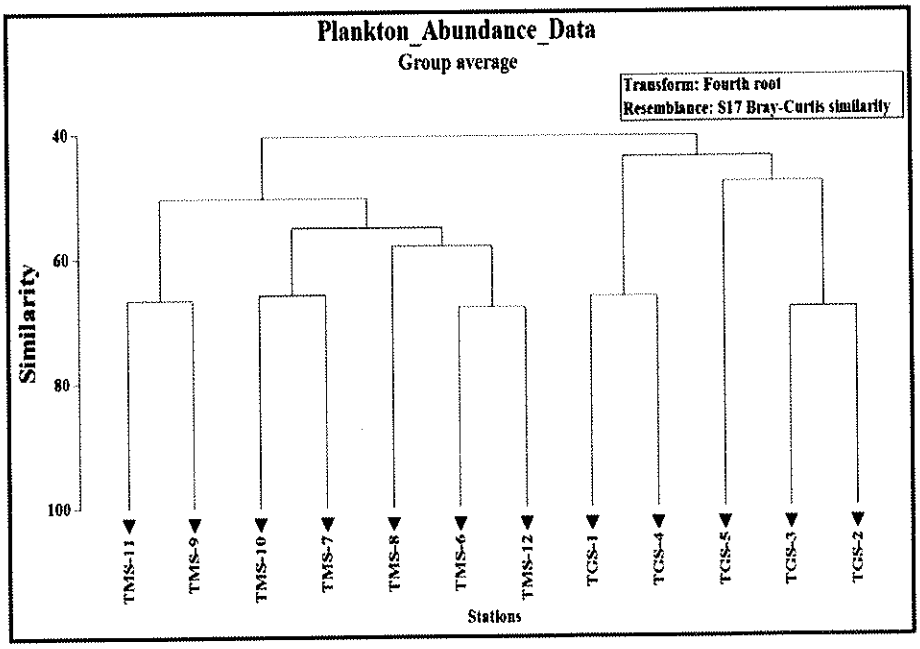


Fig. 47. Dendrogram for the Plankton abundance data collected from Tiruvottiyur kuppam coastal waters

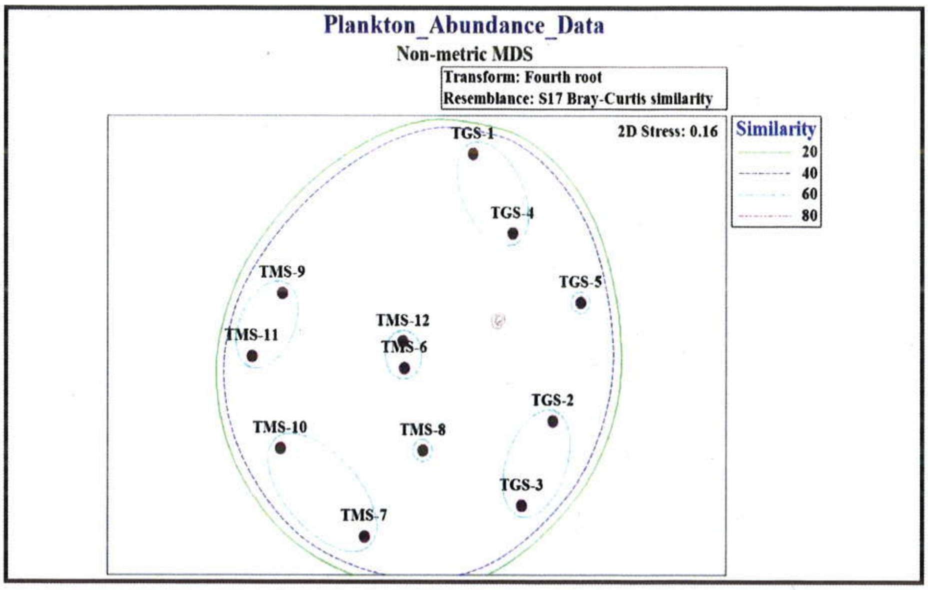


Fig. 48. MDS drawn for the Plankton abundance in various stations of Tiruvottiyur kuppam coastal waters

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, twelve environmental variables (Primary productivity, Total nitrogen, Nitrite, Nitrate, Dissolved oxygen, Salinity, 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 Salinity, Dissolved Oxygen, Total phosphate, Total Nitrogen, Chlorophyll 'a', Silicate, Primary productivity and Total biomass were featured as the major variables explaining the best match ($\rho\omega$= 0.915) with plankton (both phytoplankton and zooplankton) distributions. The other parameters such as Total Nitrogen, Total phosphate, Silicate, Salinity, Chlorophyll 'a', Dissolved Oxygen and Primary productivity ($\rho\omega$= 872) which also got manifested in the next best variable combinations in determining the plankton distribution in Tiruvottiyur kuppam coastal waters.

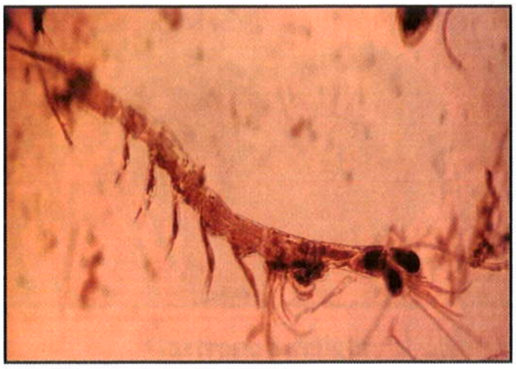
Table-7. Harmonic rank correlations (ρω) between plankton (both phytoplankton and zooplankton) abundance against environmental variables in Tiruvottiyur kuppam coastal waters

No. of variables	Best variable combinations	Correlation (ρω)
8	Salinity – Dissolved Oxygen – Total phosphate – Total Nitrogen –Chlorophyll 'a' – Silicate – Primary productivity – Totalbiomass	0.915
7	Total Nitrogen – Total phosphate – Silicate – Salinity – Chlorophyll 'a' –Dissolved Oxygen – Primary productivity	0.872
7	Salinity – Dissolvedoxygen– Total Nitrogen – Chlorophyll 'a'– Inorganic phosphate – Total biomass – Primary productivity	0.849
6	Primary productivity – Chlorophyll 'a' – Total Nitrogen –Total Phosphate – Silicate – Dissolved Oxygen	0.815
5	Dissolved Oxygen – Total Nitrogen – Primary productivity – Chlorophyll 'a' – Total biomass	0.781

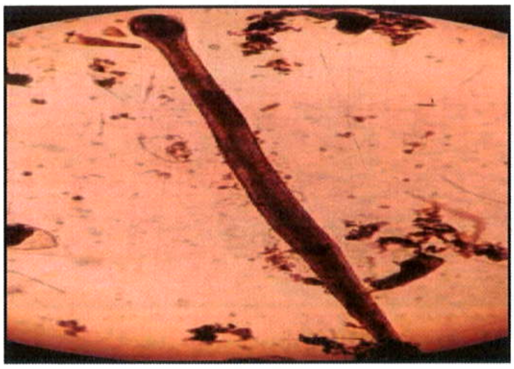
PLATE-II ZOOPLANKTON

Paracalanus parvus

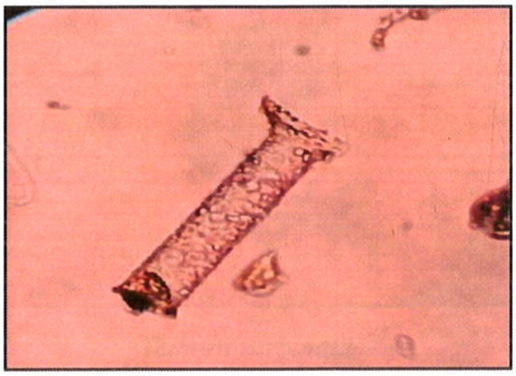
Acartia danae



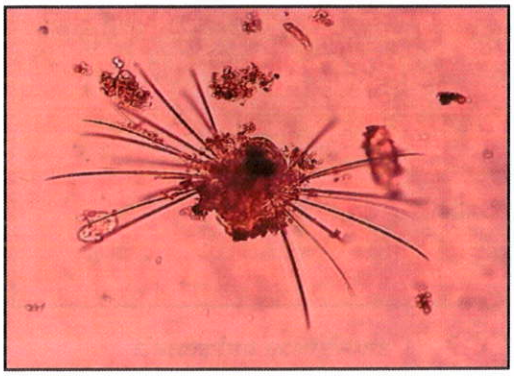
Lucifer hanseni



***Sagitta* sp**



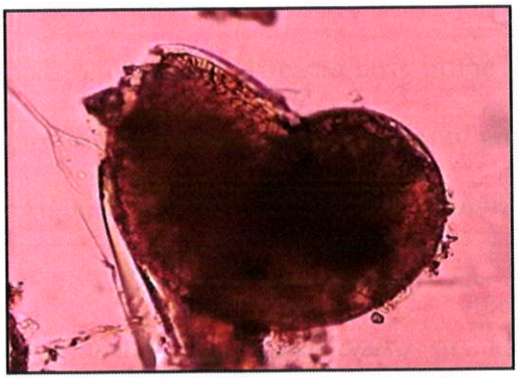
Tintinnopsis tubulosa



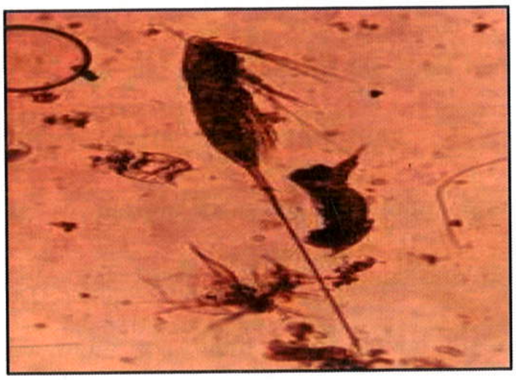
Polychaete larvae

Acrocalanus gibber

Corycaeus danae

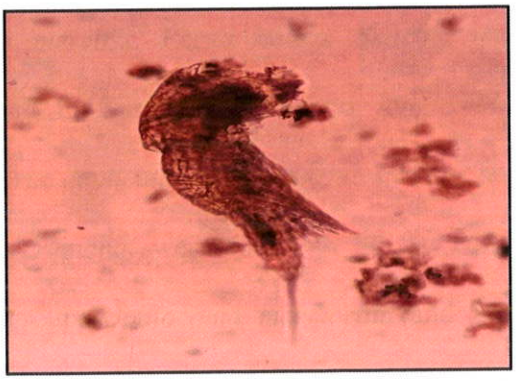


Gastropod veliger



Macrosetella **sp**

Temora turbinata



Euterpina acutifrons

4.6. Benthos

4.6.1. Macro-benthos

During the present investigation, five groups of benthic organisms namely polychaetes, Bivalves, Gastropods, Amphipoda and group "Others" were recorded in various stations in Tiruvottiyur kuppam coastal waters. Among them, polychaetes constituted the dominant group followed by bivalves, gastropods and amphipods. Altogether, 44 species of macro fauna were recorded from the surveyed stations. Of these, polychaetes topped the list with 25 species. Bivalves were found to be the next dominant group in the order of abundance with 8 species. Gastropods and amphipods came next in the order with 6 and 3 species of the total benthic organisms collected. There were 2 species of group "others" during the present study.

Among the polychaetes, *Nepthys dibranchis, Prionospio cirrifera, Capitella capitata, Phyllodoce* sp., *Lumbrenereis* sp., *Eunice* sp., *Scoloplos* sp., *Terebellides* sp., *Magelona cincta, Euclymene annandalei, Branchiomma* sp., and *Armandia* sp., were found to be the most commonly occurring species in the samples collected in Tiruvottiyur kuppam coastal waters. Coming to bivalves, *Donax incarnates, Meretrix meretrix, Perna indica, Sunettta meroe, Anadara* sp., *Circe scripta* and *Perna indica,* and in Gastropods, *Fusinus longicaudatus, Cerithedia cingulata, Turridella attenuate, Duplicaria duplicata* and *Nassarius stolatus* and in Amphipods, *Gitanopsis bisponosa* and *Amphithoe ramondi* were found to be the common species in the collection. Among miscellaneous group, *Ophiocoma marmorata* and *Penaus indicus* (post larvae) were recorded commonly in the collection.

Population density

The population density varied from 550 to 1075 No m^{-2} with maximum was at TMS-9 and minimum TMS-12 (Fig. 49).

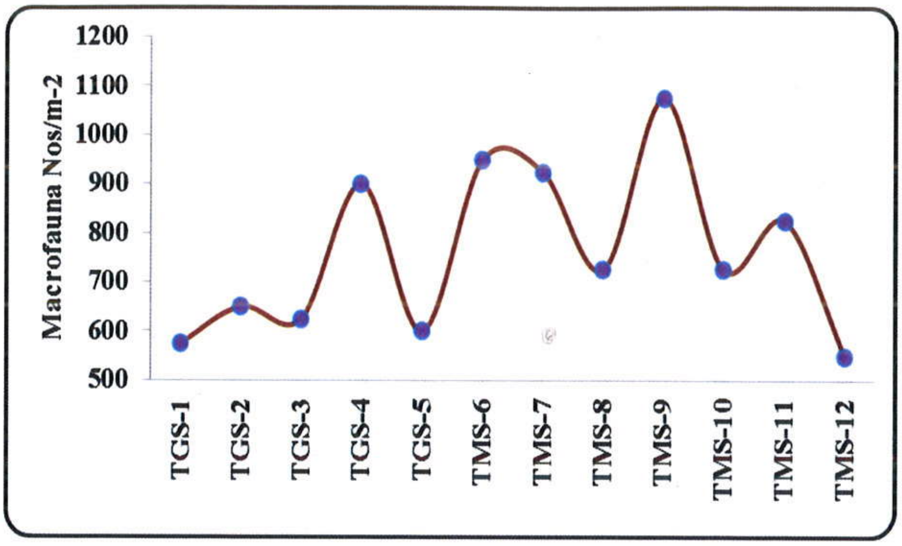


Fig. 49. Population density of Macro benthos recorded in various stations of Tiruvottiyur kuppam coastal waters

Percentage composition

When the results of percentage composition of benthic fauna were viewed, polychaetes constituted the maximum with 59% to the total benthic organisms. Bivalves, Gastropods, Amphipods and Others contributed to 18%, 13%, 8% and 2% respectively to the total benthic faunal community (Fig. 50).

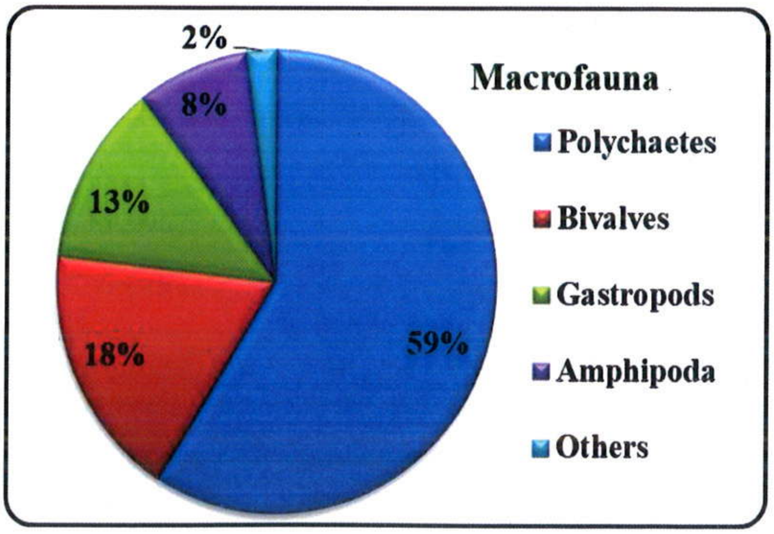


Fig. 50. Percentage composition of macro benthos in various stations of Tiruvottiyur kuppam coastal waters

Diversity Indices:

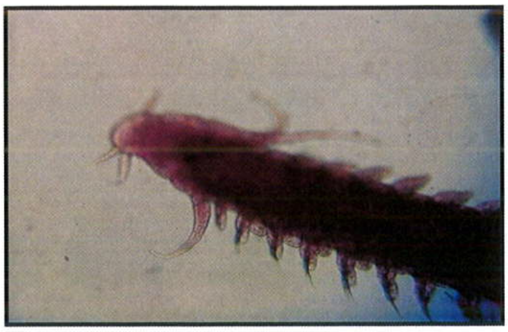
The macro-benthic species diversity (H') varied from 2.665 to 3.970 with maximum was in TGM-9 and minimum in TGS-1. The species richness (d) ranged between 4.006 and 6.969 withmaximum in TGS-3 and minimum in TMS-10. The species evenness varied from 0.541 to 0.783 with the maximum in TMS-10 and minimum in TGS-1 (Table 8).

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

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
TGS-1	2.665	6.518	0.541
TGS-2	2.918	6.933	0.574
TGS-3	2.886	6.796	0.580
TGS-4	3.261	6.969	0.679
TGS-5	2.810	5.658	0.672
TMS-6	3.223	5.792	0.778
TMS-7	3.081	5.368	0.696
TMS-8	3.062	5.340	0.677
TMS-9	3.970	4.006	0.755
TMS-10	3.967	4.037	0.783
TMS-11	3.145	4.574	0.669
TMS-12	2.839	5.694	0.622

PLATE-III MACRO BENTHOS

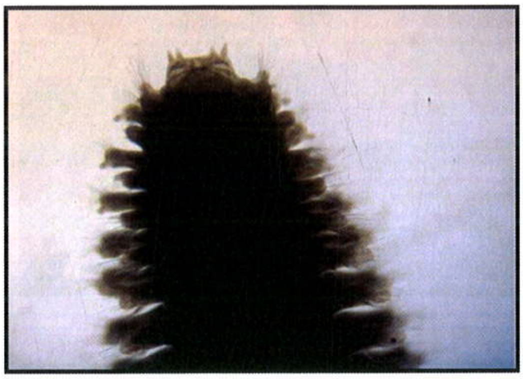
POLYCHAETES



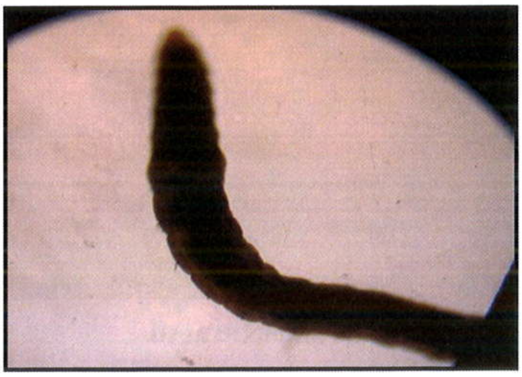
***Phyllodoce* sp.**

***Lumbrenereis* sp.**

Prionospio cirrifera

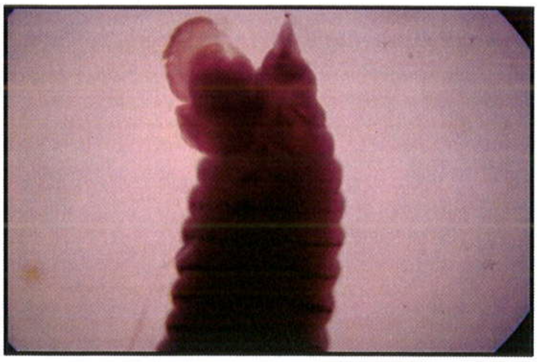


Nepthys dibranchis

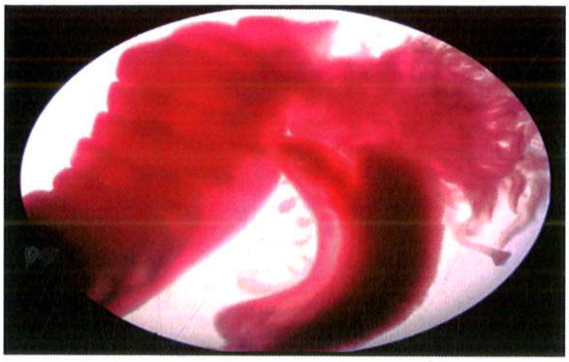


Capitella capitata

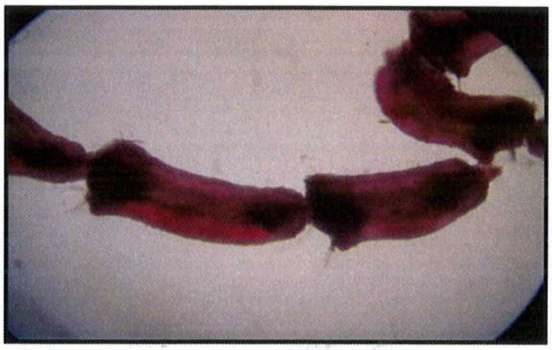
***Eunice* sp.**



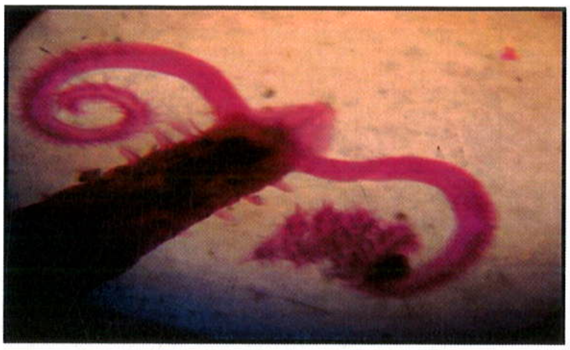
***Scoloplos* sp.**



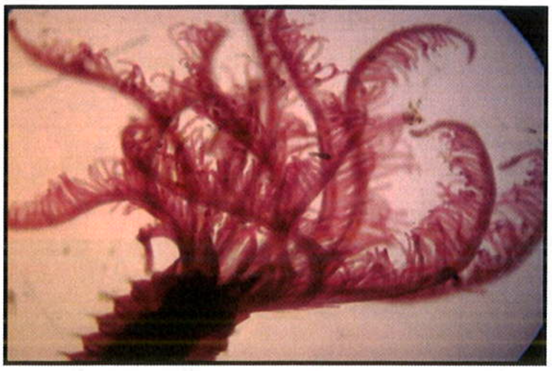
***Terebellides* sp.**



Euclymene annandalei



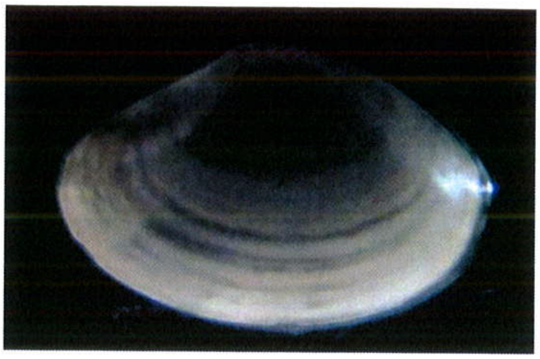
Magelona cincta



***Branchiomma* sp.**

***Armandia* sp.**

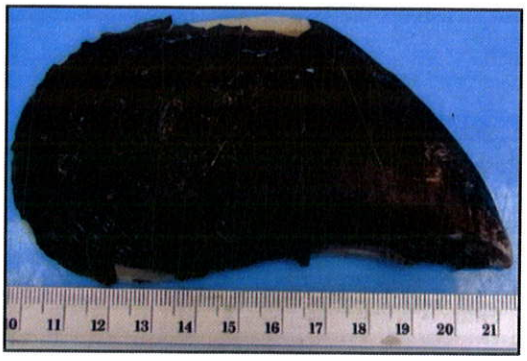
BIVALVES



Meretrix meretrix

Sunetta meroe

Anadara sp.



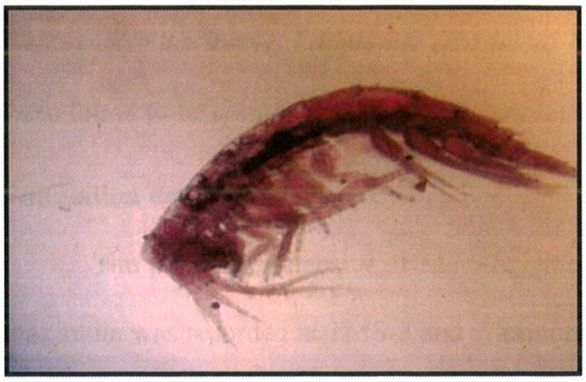
Perna indica

GASTROPODS

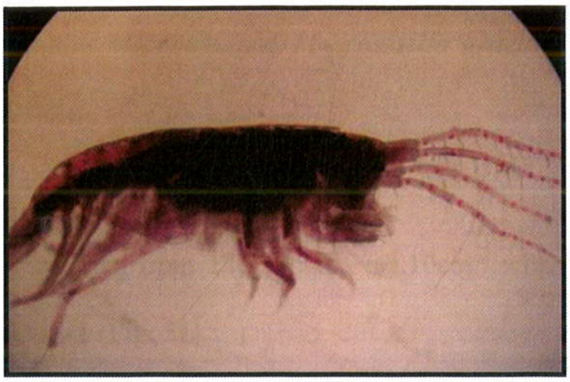
Nassarius stolatus

Turritella duplicata

AMPHIPODS



Ampithoe ramondi



Gitanopsis bispinosa

4.6.2. Meio-benthos:

In the present study, as many as 41 species belonging to four groups of Meio-benthic organisms namely Foraminiferans, Nematodes, Ostracodes and Harpacticoids were recorded. Among them, Foraminiferans topped the list with 24 species. Nematodes were found to be the next dominant group in the order of abundance with 7 species and Ostracodes and Harpacticoids came next with 5 species each.

Among the foraminiferans, *Ammonia beccarii, A. tepida, Bolivina limbata, B. tortuosa, Cymbaloporetta bradyi, Discoanomalina semipunctata, Discorbinella bertheloti, Elphidium advenum, E. subevolutum, Globigerina aequilateralis, G. rubber, Lagena quadrata, Miliolinella semicostata, Nonion depressulum, Operculina ammonoidea, Pararotalia ozawai, Quinqueloculina apicula, Q. bicarinata, Q. debenayi, Rosalina globularis, Spiroloculina angulosa, S. depressa, Textilaria foliacea* and *Thurammina cariosa* were found commonly in various stations. With respect to nematodes, *Araeolaimus longicauda, Astomonema jenneri, Daptonema conicum, Draconema cephalatum, Epsilonema steiner, Halalaimus filum* and *Oxystomina clavicauda* were found to be the common species in the samples collected in various stations. The Ostracodes species such as *Basslerites liebaui, Candona candida, Eucythere argus, Keijella reticulate* and *Stenocypris major* and in Harpacticoids, *Euterpina acutifrons, Cylindropsyllus laevis, Laophonte thoracica, Leptastacus mocronyx* and *Macrosetella gracilis* were found to be common species in the surveyed stations.

Population density

The population density of Meio-benthic fauna varied from 146 to 240 Nos.10cm^{-2} with maximum was recorded at TMS-7 and minimum at TGS-1 (Fig. 51).

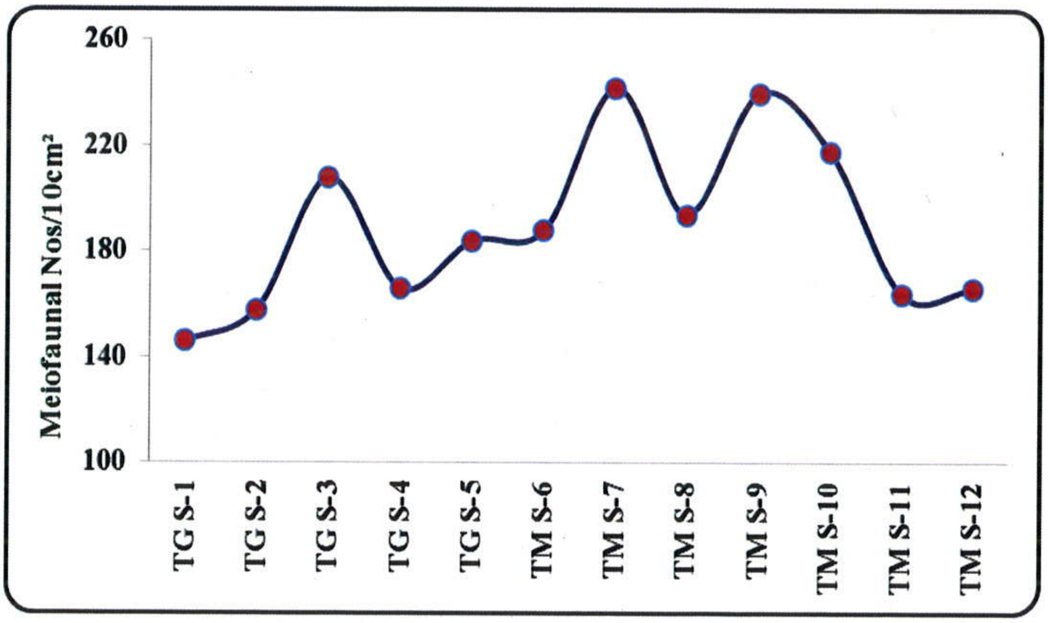


Fig. 51. Population density of Meio-fauna recorded in various stations of Tiruvottiyur kuppam coastal waters

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 15%, 12% and 11% respectively to the total Meio-benthic samples collected (Fig. 52).

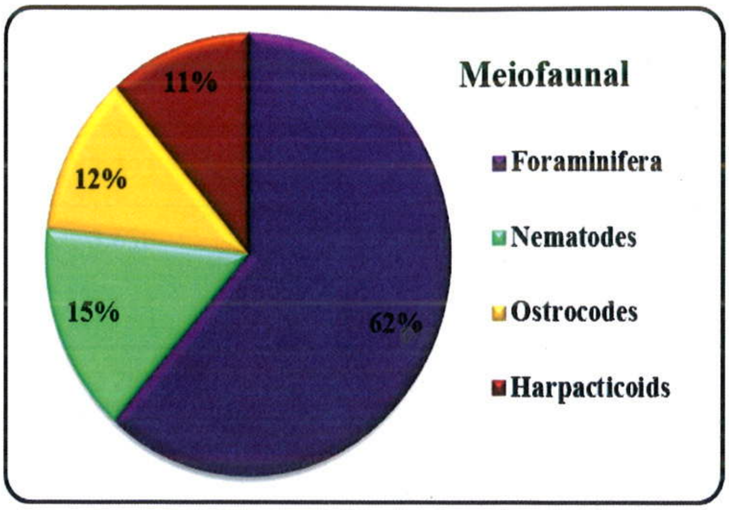


Fig. 52. Percentage composition of Meio-benthos in various stations of Tiruvottiyur kuppam coastal waters

Diversity Indices

The Meio-benthic species diversity (H') varied from 2.468 to 3.793 with maximum was in TGS-9 and minimum in TGS-1 and similarly the species richness (d) ranged between 4.904 and 6.816 with maximum in TGS-1 and minimum in TMS-9. The species evenness varied from 0.543 to 0.917 with the maximum in TMS-10 and minimum in TGS-2 (Table 9).

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

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
TGS-1	2.468	6.816	0.589
TGS-2	2.596	6.333	0.543
TGS-3	2.934	6.808	0.590
TGS-4	3.193	5.982	0.590
TGS-5	2.915	5.869	0.685
TMS-6	3.036	5.792	0.627

TMS-7	3.481	5.741	0.745
TMS-8	3.538	5.505	0.716
TMS-9	3.793	4.904	0.859
TMS-10	3.636	5.500	0.917
TMS-11	3.035	5.612	0.793
TMS-12	2.761	5.786	0.694

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 within Groynes namely TGS-3, TGS-2, TGS-5, TGS-4 and TGS-1 T were forming cluster separately based on the species composition and abundance. Similarly, the stations outside groyne such as MS-7, TMS-6, TMS-9, TMS-8, TMS-10, TMS-12, and TMS-11 also formed separate cluster (Fig. 53). This fact was further confirmed through MDS, which was also revealed the same pattern of groupingsas observed in cluster analysis. The stress value (0.12), 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).

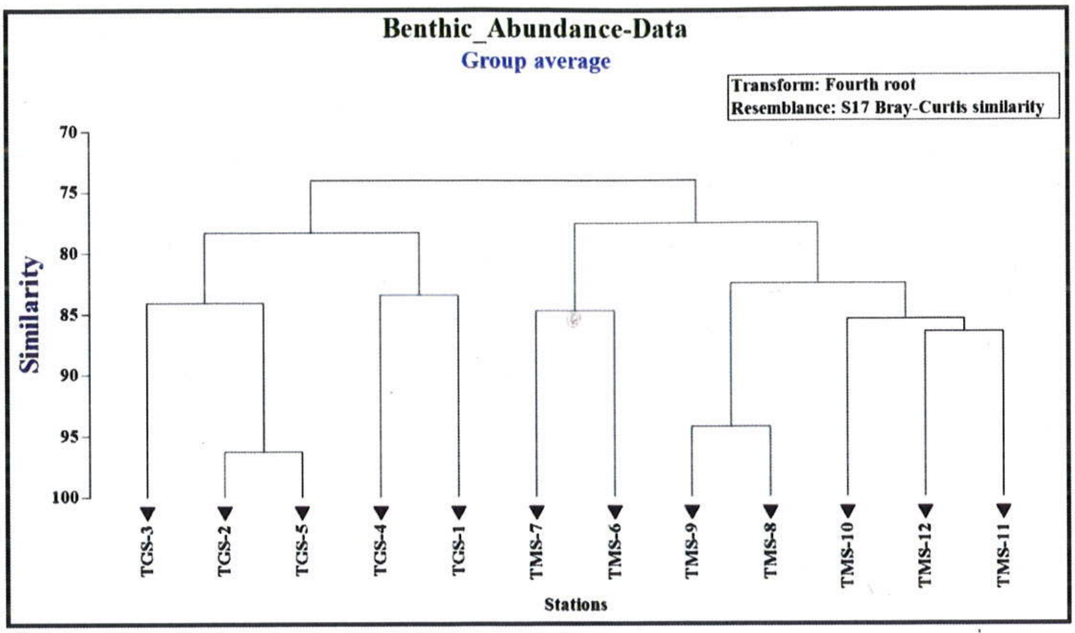


Fig. 53. Dendrogram for the benthic fauna abundance data collected in Tiruvottiyur kuppam coastal waters

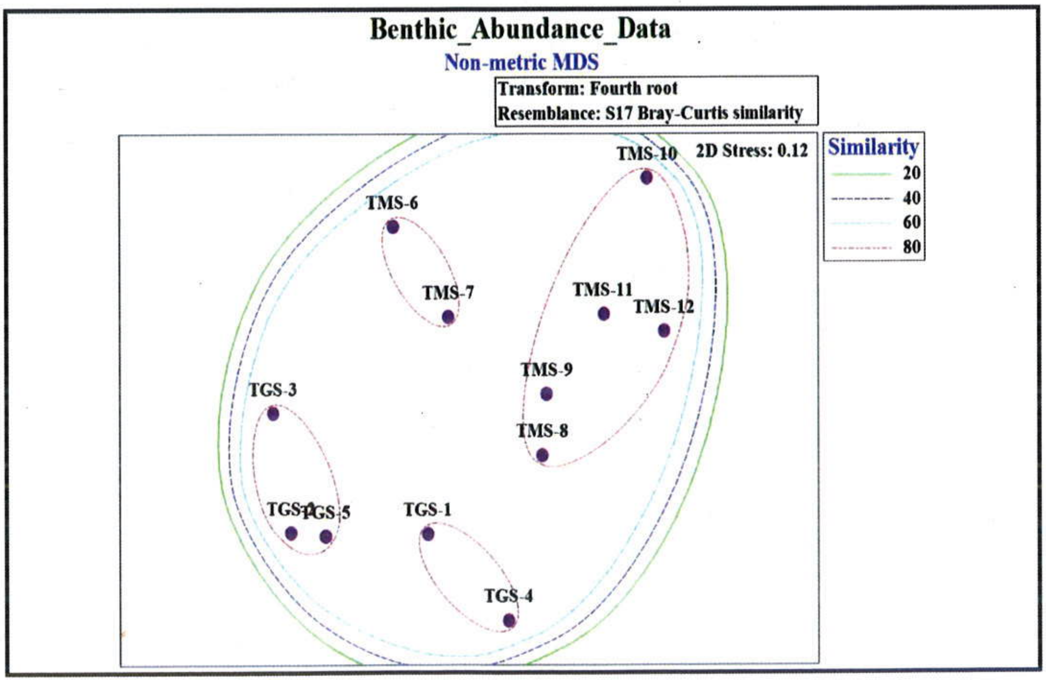


Fig. 54. MDS drawn for the benthic faunal abundance in various Tiruvottiyur kuppam coastal waters

BIO-ENV (Biota-Environment matching)

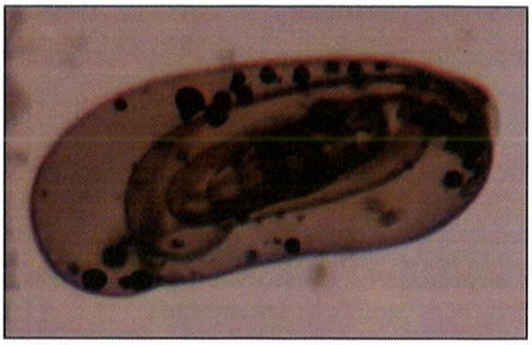
As done for plankton data, the BIO-ENV matching was employed to measure the rank correlations of the benthic faunal abundance (Bray-Curtis similarity) and environmental (Euclidean distance) matrices as well. For this, eleven environmental variables (Temperature, Salinity, W. pH, Silt, Sand, Clay, DO, TOC, S. pH, Evenness, Richness and Diversity) were allowed to match the biota. The results revealed that, a combination of nine environmental parameters ($\rho\omega = 0.927$) namely Salinity, W. pH, Dissolved Oxygen, S. pH, Sand, Diversity, Evenness, Clay and TOC gotmanifested as best match in determining benthic faunal distribution followed by DissolvedOxygen, Clay, S. pH, TOC, Salinity, Sand, Diversity and Evenness ($\rho\omega$ = 0.882) which also got manifested as second best variable combinations, in determining the faunal distribution in the Tiruvottiyur kuppam coastal waters (Table 10).

Table 10. Harmonic rank correlations ($\rho\omega$) between benthic faunal (both Macro-benthos and Meio-benthos) abundance against environmental variables in Tiruvottiyur kuppam coastal waters

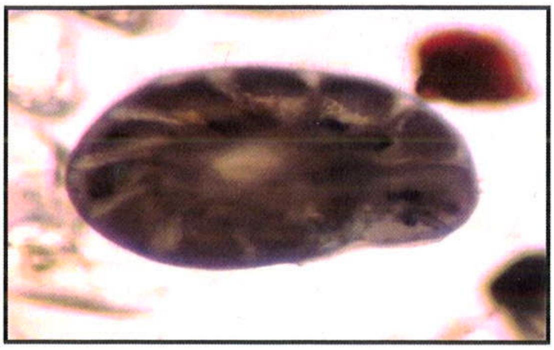
No. of variables	Best variable combinations	Correlation ($\rho\omega$)
9	Salinity – W. pH – Dissolved Oxygen – S. pH – Sand –Diversity – Evenness – Clay – TOC	0.927
8	Dissolved Oxygen - Clay – S. pH – TOC - Salinity – Sand – Diversity – Evenness	0.882
7	Sand - TOC – Evenness – S. pH – Salinity - Dissolved Oxygen – Diversity	0.839
6	Clay - TOC – S. pH - Dissolved Oxygen – Salinity - Sand	0.805
6	Salinity – S. pH – Clay – TOC – Evenness – Diversity	0.773

PLATE-IV MEIO-BENTHOS

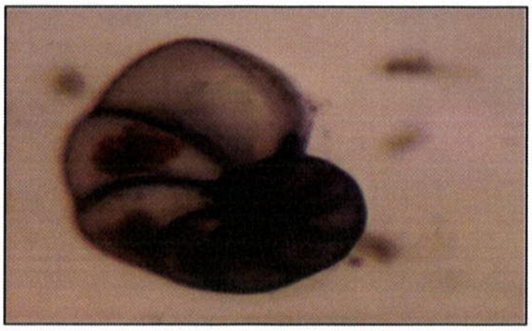
FORAMINIFERANS



Spiroloculina excavata

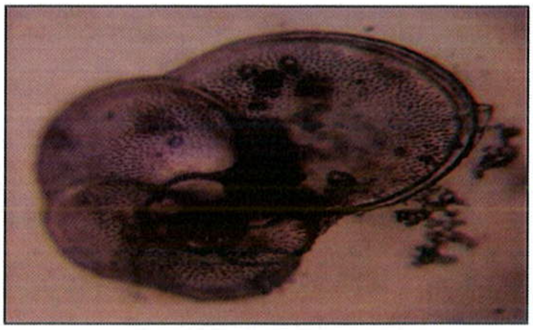


Ammonia tepida

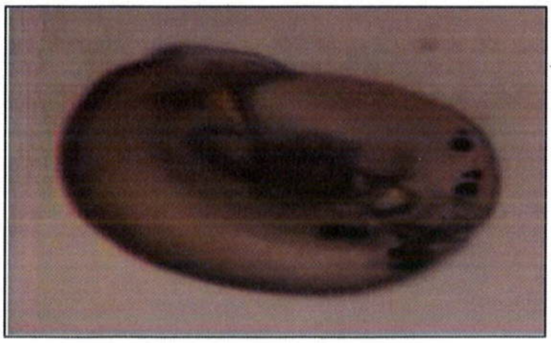


Nonion depressulus

Ammonia beccarii

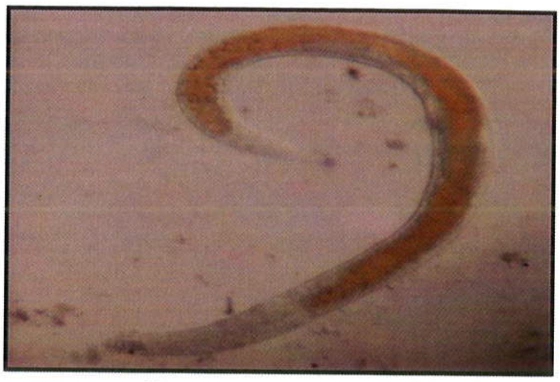


Rosalina globularis



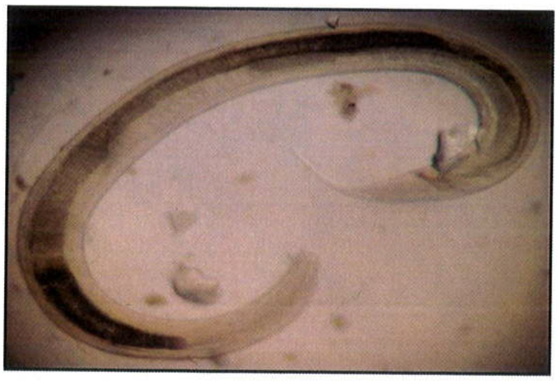
Miliolinella subrotunda

NEMATODES



Daptonema conicum

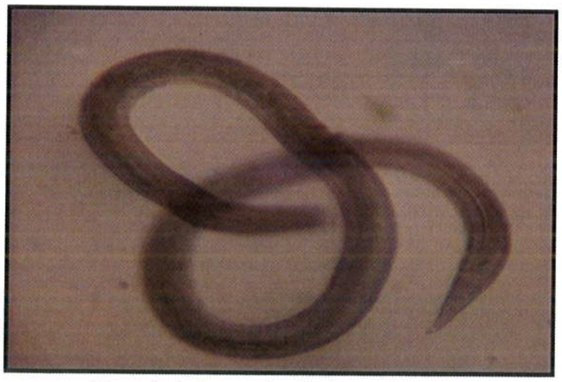
Epsilonema steiner



Odontophora sp

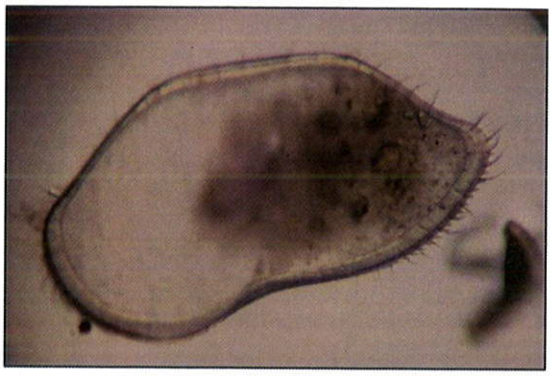
Halalaimus filum

Draconema cephalatum

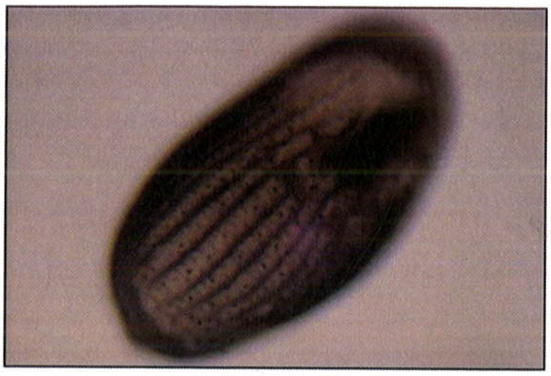


Pandolaimus latilaimus

OSTRACODES



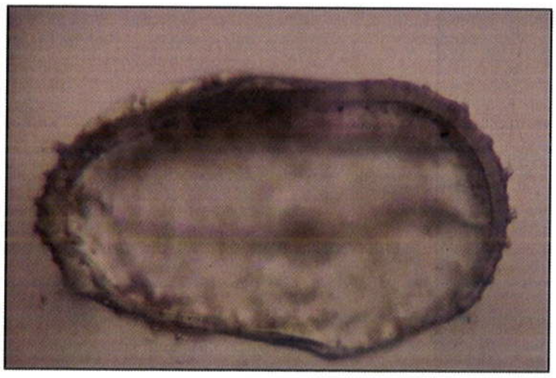
Bairdoppilata scaura



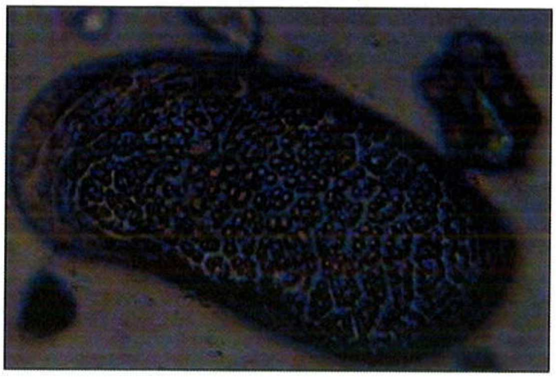
Basslerites liebaui

Keijella reticulata

Paijenborchella cymbula



Echinocythereis sp.



Eucythere argus

HARPACTICOIDS

Laophonte thoracica

Cylindropsyllus laevis

Harpacticus chelifer

Canuella perplexa

4.7. Marine Underwater SCUBA survey

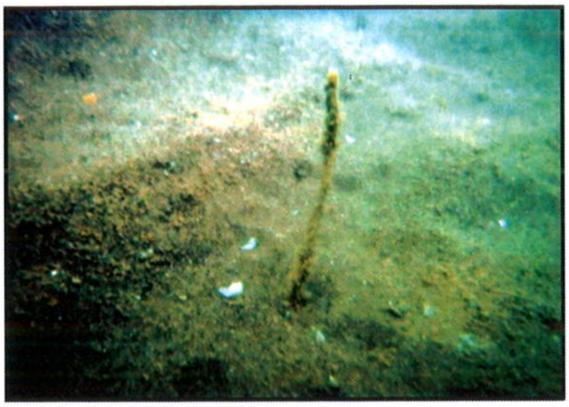
The underwater marine survey was conducted on four locations around the Tiruvottiyur kuppam fishing harbour by engaging Pacific Blue Subsea services (P) Ltd.(collaborative study). The locations were selected based on the environment such as following:

1. Near to fishing boat channel path – 13° 9'55.34"N; 80°18'44.32"E
2. Fishing harbour groynes channel path – 13° 9'50.30"N; 80°18'50.41"E
3. Inside the fishing harbour – 13° 9'38.59"N; 80°18'54.27"E
4. Outside the fishing harbour – 13° 9'50.09"N; 80°19'20.13"E

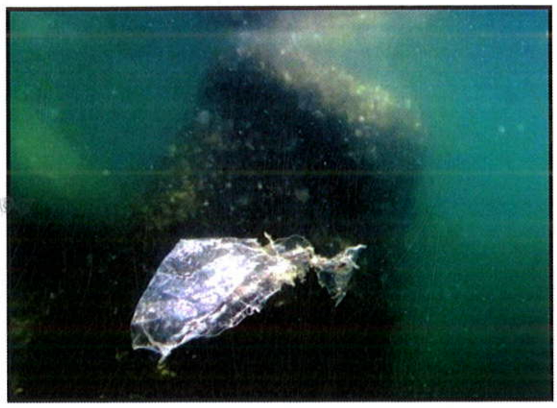
During survey, the water temperature, salinity, and depth were recorded. Benthic photography and video recording were conducted in four locations, including the midpoint of the fishing boat's path at the harbour mouth, 500 meters away from the mouth, and both inside and outside the fishing harbour, at depths ranging from 5 to 18 meters, in order to analyze the habitat and ecological condition of the chosen harbour.

A muddy and sandy bottom with a few scattered patches of mixed seagrass, namely *Oceana serrulata* and *Syringodium isoetifolium*, were observed. Dead gastropods, bivalves, including *Turritella* sp., and some common fish, including flathead mullet, herring, and milkfish, were also spotted during the study. Further tube worms, a few small fish, an octopus egg sac, small gastropods, plastic litters, one jellyfish, rock oysters, sponges, tube-dwelling worms, ascidians, and turf algae, were seen beyond the fishing harbour. The majority of the diverse marine life was spotted beyond the fishing harbour, where boat access is scarce. The common visuals taken during under water using SCUBA is shown below:

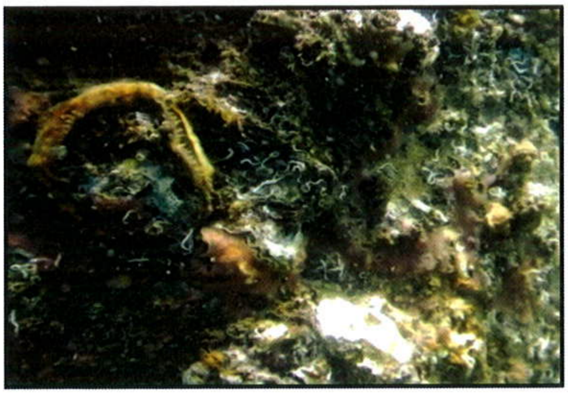
Underwater SCUBA Survey



Muddy sandy bottom

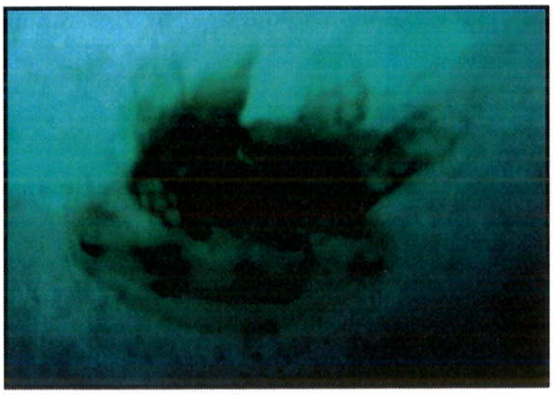


Plastic litter floating around waters



Tude-dwelling Worms attached groyne

Abudefduf vaigiensis



Jellyfish

Dead shells marine bottom

4.8. Other ecologically sensitive groups

4. 8. 1. Mangroves

No mangroves were recorded from the surveyed coastal stations.

4. 8. 2. Corals

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

4. 8. 3. Turtles

During the survey near Tiruvottiyur kuppam coastal waters, no organized turtle nesting ground was noticed in the sampled area.

4. 8. 4. Other Endangered Species

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

4. 8. 5. Avifauna

In the project region, no significant bird population is observed.

4. 8. 6. Seaweeds

A patchy occurrence of following seaweed species namely *Sargassum ilicifolium,* and *Padina pavonica,* were found near the surveyed stations

4. 8. 7. Sea grasses

During the survey scattered patches of two different species of seagrass: *Oceana serrulata* and *Syringodium isoetifolium* were found commonly at Tiruvottiyur kuppam region.

4. 8. 8. Fisheries

Selaroides leptolepis, Ariomma indicum, Coryphaena hippurus, Lethrinus nebulosus, Antennarius indicus, Mene maculate, Platax orbicularis, Xanthichthys ringens, Rhabdosargus sarba, Lates calcarifer, Trachinotus blochii, Hilisa keele, Chanos chanos, Plotosus canius, Platycephalus indicus, Leiognathus daura, Sillago sihama, Caranx sem, Lutjanus sp., *Mugil cephalus, Epinephelus tauvina, Siganus canaliculatus, Euthynnus affinis, Hemirampus far, Sardinella* sp., and *Lates calcarifer* caught using gillnets, purse-seines & bag nets. The crustacean resources like prawns, lobsters & crabs formed an important commercial catch for the local fishing community.

<u>**COMMERCIALLY IMPORTANT FISHES**</u>

Mugil cephalus

Thryssa malabrica

Stolephorus indicus

Lutjanus argentimaculatus

Plicofollis tenuispinis

Pseudorhombus elevatus

5. SUMMARY AND CONCLUSION

In the present survey, which lasted for two days, the physico-chemical and biological parameters were analyzed both in the water and sediment samples from predetermined (12 stations) locations of Tiruvottiyur kuppam coastal waters. The results of various parameters are summarized below:

The surface water temperature varied from 28.2 to 30.7°C. The salinity varied from 33.2 to 35.4PSU. Hydrogen ion concentrations in surface waters remained alkaline and the maximum value of 8.3 was recorded at TMS-8. The observations made on the key physical factors such as TSS and turbidity was within the safe level. The turbidity ranged between 4.7 and 8.2NTU. The TSS values fluctuated from 97.70 and 138.50ppm. The maximum TSS and turbidity values were at TGS-2 and minimum at TMS-9. 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 4.009 and 5.457mg/l, with the maximum DO level was recorded at TMS-10 and the minimum was recorded at TGS-2. The DO concentration remained fairly well within the prescribed limit of water quality. The BOD level was found to be ranged from 1.02 and 2.56mg/l with the maximum BOD was observed at TGS-2 during this survey.

In the present investigation, the ammonia concentration ranged between 0.43 to 0.94μmol/l. The concentration of nitrite fluctuated from 0.65 to 3.21μmol/l. The nitrate values ranged from 2.17 and 5.46μmol/l and the total nitrogen varied between 14.43 to 21.49μmol/l. The inorganic phosphate ranged from 0.468 and 1.835μmol/l. The observed total phosphorus values ranged between 1.47 to 3.77μmol/l. The silicate concentration ranged from 59.20 and 87.94μmol/l. The particulate organic carbon values ranged from 69.84 and 131.32μgC/l respectively.

In the present survey, Petroleum Hydrocarbon in water varied between 0.351 and 0.582μg/l. with higher concentration at station TGS-2. The total organic carbon content varied from 4.18 and 8.40mgC/g with the maximum was at TGS-5 and minimum at TMS-9. The present survey showed that the Petroleum hydrocarbon relatively higher in sediment than the water and the values ranged from 0.452 to 0.845μg/g. The maximum was recorded at TGS-2 and the minimum was recorded at TMS-10 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 1820.30μg/g) compared to iron concentration in water (10.43 to 18.36μg/L). The maximum was recorded at TGS-2 and the minimum was recorded at TMS-9. 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 TGS-5, TGS-3 TGS-2, TGS-1, TMS-8, TMS-10 and TMS-9 while the rest of the parameters showed strong correlation with stations TMS-12, TMS-11, TMS-7, TMS-6 and TGS-4. 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 1.014 to 2.813 mg/m^3, with maximum at TGS-4 and minimum at TGS-1. The Phaeopigments content varied from 1.229 to 2.338 mg/m^3 with maximum was at TGS-4 and the minimum was observed at TGS-1. The Total biomass values varied from 2.245 to 6.218 ml/100m^3, with maximum was at TGS-4 and minimum at TGS-1. The primary productivity was measured using the dark and light reaction method. The values ranged from 121.57 to 172.49mgCm^{-3}d^{-1}. The maximum value was recorded at TMS-8 and minimum value at GMS-1.

Density of phytoplankton varied from 3,964 to 18,976 Cells/l with maximum was at TGS-4 and minimum at TGS-2. In the present study, as many as 46 phytoplankton species belonging to three major groups namely Bacillariophyceae (Diatom), Dinophyceae (Dinoflagellates) and Cyanophyceae (Cyanobacteria) were recorded in Thiruvottiyurkuppam coastal area. Of these, Bacillariophyceaewere found to be the dominant group with 35 species, Dinophyceae formed next group with 9 species and Cyanophyceae with two species.

The phytoplankton species diversity (H') varied from 2.203 to 3.620 with maximum was at TMS-7 and minimum at TGS-2. The species richness (d) ranged between 4.372 and 6.607 with maximum at TGS-2 and minimum at TMS-8. The species evenness varied from 0.625 to 0.851 with the maximum at TGS-7 and minimum at TMS-1.

The zooplankton density varied from 322 to 6305Nos/m^3 with maximum at TGS-5 and minimum at TSG-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 10 species. Cyclopoid copepod was recorded with 6 species and Harpacticoid copepod came as next dominant group with 4 species. The Other Crustacean forms and Oligotrichea were observed with 3 species each group, Foraminifera and Mollusca were found 2 species from each group,Chaetognatha, Decapoda and Annelida were recorded 1 species from each division of total zooplankton abundance.

With regard to diversity indices, the zooplankton species diversity (H') varied from 2.588 to 3.399 with maximum in TMS-6 and minimum in TGS-2. The species richness (d) ranged between 3.592 and 6.658 with maximum in TGS-4 and minimum in TMS-8. The species evenness varied from 0.545 to 0.875 with the maximum in TGS-9 and minimum in TGS-2.

The abundance data of phytoplankton and zooplankton were amalgamated and subjected to classification and ordination methods. The resulting dendrogram revealed that the stations outside groynes TMS-11, TMS-9, TMS-10, TMS-7, TMS-8, TMS-6 and TMS-12 were forming a cluster based on the species composition and abundance. Similarly, the stations within the groynes TGS-1, TGS-4, TGS-5, TGS-3 and TGS-2 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 stress value (0.16), 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. 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 Salinity, Dissolved Oxygen, Total phosphate, Total Nitrogen, Chlorophyll 'a', Silicate, Primary productivity and Total biomass were featured as the major variables explaining the best match ($\rho\omega$= 0.915) with plankton (both phytoplankton and zooplankton) distributions. The other parameters such as Total Nitrogen, Total phosphate, Silicate, Salinity, Chlorophyll 'a', Dissolved Oxygen and Primary productivity ($\rho\omega$= 872) which also got manifested in the next best variable combinations in determining the plankton distribution in Tiruvottiyur kuppam 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).

The population density varied from 550 to 1075 No m-2 with maximum was at TMS-9 and minimum TMS-12. During the present investigation, five groups of benthic organisms namely Polychaetes, Bivalves, Gastropods, Amphipoda and other groups of organisms were recorded in various stations in Tiruvottiyur kuppam coastal waters. Among them, polychaetes constituted the dominant group followed by bivalves, gastropods and amphipods. Altogether, 44 species of macro fauna were recorded from the surveyed stations. Of these, polychaetes topped the list with 25 species. Bivalves were found to be the next dominant group in the order of abundance with 8 species. Gastropods and amphipods came next in the order with 6 and 3 species of the total benthic organisms collected. There were 2 species of group "others" during the present study.

The macro-benthic species diversity (H') varied from 2.665 to 3.970 with maximum was in TGM-9 and minimum in TGS-1. The species richness (d) ranged between 4.006 and 6.969 with maximum in TGS-3 and minimum in TMS-10. The species evenness varied from 0.541 to 0.783 with the maximum in TMS-10 and minimum in TGS-1.

Regarding meiobenthic organisms, the population density of Meio-benthic fauna varied from 146 to 240 Nos.$10cm^{-2}$ with maximum was recorded at TMS-9 and minimum at TGS-2. In the present study, as many as 41 species belonging to four groups of Meio-benthic organisms namely Foraminiferans, Nematodes, Ostracodes and Harpacticoids were recorded. Among them, Foraminiferans topped the list with 24 species. Nematodes were found to be the next dominant group in the order of abundance with 7 species and Ostracodes and Harpacticoids came next with 5 species each.

The Meio-benthic species diversity (H') varied from 2.468 to 3.793 with maximum was in TGS-7 and minimum in TGS-1 and similarly the species richness (d) ranged between 4.904 and 6.816 with maximum in TGS-1 and minimum in TMS-9. The species evenness varied from

0.543 to 0.917 with the maximum in TMS-10 and minimum in TGS-2.

The cluster/dendrogram revealed that the stations within groyne TGS-3, TGS-2, TGS-5, TGS-4 and TGS-1 T were forming cluster separately based on the species composition and abundance. Similarly, the stations outside groyne MS-7, TMS-6, TMS-9, TMS-8, TMS-10, TMS-12, and TMS-11 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 (0.12), 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 procedure indicated that the combination of nine environmental parameters ($p\omega = 0.927$) namely Salinity, W. pH, Dissolved Oxygen, S. pH, Sand, Diversity, Evenness, Clay and TOC got manifested as best match in determining benthic faunal distribution followed by Dissolved Oxygen, Clay, S. pH, TOC, Salinity, Sand, Diversity and Evenness ($p\omega = 0.882$) which also got manifested as second best variable combinations, in determining the faunal distribution in the Tiruvottiyur kuppam 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.

As regards fish population, *Euthynnus affinis, Xanthichthys ringens, Trachinotus blochii, Hilisa keele, Chanos chanos, Sillago sihama, Mugil cephalus* and *Lates calcarifer* were the most frequently landed commercial fishes, and they were captured using gillnets, purse-seines, and bag nets. The crustacean resources like prawns, lobsters & crabs also formed an important commercial catch for the local fishing industry

With respect to SCUBA under water survey, predominantly dead molluscan shells, a few Dead Sea grass species besides plastic debris were recorded. During survey, not even single pieces of corals were noticed in the project location.

With respect to ecologically sensitive groups, the occurrence of Corals, Turtle nesting ground and any endangered species like Sea horse, *Olive ridley* turtle, Indian otter, Salt water crocodile etc., were not noticed from the surveyed stations. There is no national park, wildlife sanctuary and biosphere reserve within 10 km radius of the proposed project site.

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.

Further, diversity indices calculated for the plankton and benthic data in the present study clearly indicated the fairly undisturbed nature of the environment since diversity values of plankton and benthos were found to be more than 3.05 in the study area as have been stated by the benthic ecologist Sanders (1968).

In short, the marine Biodiversity survey made during 27th to 28th July 2023 in Thiruvottiyur kuppam coastal waters and careful perusal of available secondary information suggested that the water quality parameters are within the safe level and did not indicate any alarming effect on the existing biological components. The observations on other ecologically sensitive organisms reflected the patchy occurrence of a few groups especially sea grass and seaweeds from the nearby regions, which is away from the proposed site.

From the ecological point of view, the proposed structure will have very marginal impact on biota during both pre-operational and operational phase but such impacts are confined to a limited period and a confined region, as most of the marine organisms are capable of recouping themselves quickly to its original state and thus there will not be any pronounced change/variations to the biotic community. Therefore, based on the biodiversity survey conducted and also underwater SCUBA survey, the proposed facility can be initiated. At the same time, continuous monitoring is 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 and thereby a suite of mitigation measures could be suggested.

ANNEXURE 4

Marine Biodiversity Survey for TUNA FISHING HARBOUR Thiruvottriyur Kuppam, Thiruvallur district, Chennai, Tamil nadu

Research Team

Dr. P. Murugesan

(Associate Professor & Principal Investigator)

Research Scholars

Dr. V. Bharathidasan

Dr. K. Manimaran

Dr. R. Punniyamoorthy

Mr. P. Chandrasekaran

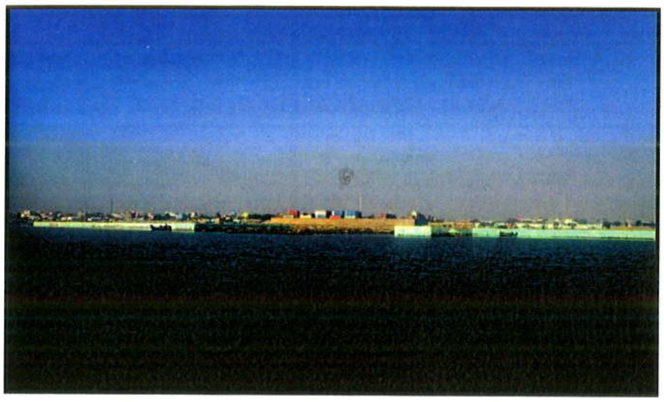
Mr. S. Mariyappan

Ms. Sasmita Swain

Annamalai University
Centre of Advanced Study in Marine Biology
Faculty of Marine Sciences
Parangipettai – 608 502

July 2023

Marine Biodiversity Survey for TUNA FISHING HARBOUR
Thiruvottriyur Kuppam, Thiruvallur district, Chennai, Tamil nadu



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Dr. P. Murugesan

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Research Scholars

Dr. V. Bharathidasan

Dr. K. Manimaran

Dr. R. Punniyamoorthy

Mr. P. Chandrasekaran

Mr. S. Mariyappan

Ms. Sasmita Swain

Dr. P. MURUGESAN, M.Sc.,Ph.D.,
ASSOCIATE PROFESSOR
C.A.S. in Marine Biology
Faculty of Marine Sciences
Annamalai University
Parangipettai - 608 502
Tamil Nadu India

Annamalai University
Centre of Advanced Study in Marine Biology
Faculty of Marine Sciences
Parangipettai – 608 502

July 2023

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Marine Biodiversity Survey for TUNA FISHING HARBOUR

Thiruvottriyur Kuppam, Thiruvallur District, Chennai, Tamilnadu

1. Introduction

The coastal area, adjoining the north of the Chennai Port has been adversely affected by continued erosion due to the development of the port. Since several developmental activities such as advent of industries, improvement of fisheries, etc. a groyne field was constructed stretching from Royapuram to northwards and the sea wall stretch of about 10 km length lying parallel to Ennore High Road to combat the erosion problems. A proposal was further made to expand existing groynes to form a fishing harbor. Accordingly, the Fisheries Department, Govt. of Tamilnadu requested the Department of Ocean Engineering, IIT Madras to revise/revive the proposed layout and perform numerical model studies to validate the same. Therefore, the layout was revised and subjected to tranquility and shoreline evolution studies. Thiruvallur District is historically known for its fishery resources and community living and presently it has a fishermen population of around 50,000 in the stretch of 25 Km that includes North Chennai. The project location is historically known for fishery resources and a strong fishermen settlement and more precisely, with a fishery harbor at about 3.5Km south as a landmark facility of Chennai since long time.

The proposed Tuna Fishing Harbour is a flag ship project of Government of Tamil Nadu which intended to create exclusive facilities to enhance Tuna catching and processing the same to add value to benefit the fishing community of the project location, Thiruvottriyur Kuppam, Chennai. The proposed fishing harbour facility is intended principally to ease out the congested Chennai Fishing Harbour as it is overflowing with more traffic and fishing activities. At times, there is an acute shortage of space to anchor the boats inside the harbour. The proposed Harbour location is about 3.5Km North from the Chennai Fishing Harbour which will provide location advantage and flexibility in harbour operation and fishing activities. Accordingly, the Department of Fisheries was mandated to enhance the harbour facilities. The project is much needed to improve the socio economic status of the local fishing community of more than a lakh in the North Chennai Zone of Tamil Nadu.

The project location is historically used by the local fishermen community and only in the recent past the coastline got eroded and it was then provided with groynes which were subsequently extended as a field with 13 numbers of groynes. It is evident that the project shoreline of about 10km stretch has been stabilized and with sand by passing over groynes over the years, the beach line has been restored and now, the project coastline is showing features of stabilization with accretion of sand and restored shoreline. The proposed harbour, as it is very close to Chennai Fishing Harbour, will serve as an extended harbour facility of it and intended to promote Tuna catching & processing. At present, from the Chennai Fishing Harbour, there are about 300 boats are operating exclusively to venture deep into the Bay of Bengal to catch tuna and bring in about 1,000 tonnes every month. Under these circumstances, the project proponent has been mandated to study marine biodiversity potential of the project site by a reputed Institute/University.

Justifiably, the task was entrusted to the Centre of Advanced Study (CAS) in Marine Biology of Annamalai University, Tamilnadu, who is the pioneer in Marine Sciences, to carry out Marine Ecological feasibility survey. Accordingly, the Experts from CAS in Marine Biology, Annamalai University carried out a detailed Marine Biodiversity survey including under water SCUBA survey during 23rd to 25th February 2023 at Thiruvottiyur kuppam coastal waters, Thiruvallur District, Chennai, Tamilnadu. During this survey, water, sediment and biological samples (plankton, benthos, microbiological and other ecologically important flora and fauna) were collected from 12 different stations from the proposed sites. The latitude and longitude of the sampling stations are given in Table 1 and also in Map (Fig.1).

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:

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

Table-1. Sampling stations and their geographical Co-Ordinates

S. No.	Stations Code	Latitude	Longitude
1.	TGS-1	13°9'58.80"N	80°18'39.15"E
2.	TGS-2	13°9'52.98"N	80°18'35.17"E
3.	TGS-3	13°9'41.92"N	80°18'36.69"E
4.	TGS-4	13°9'48.90"N	80°18'42.45"E
5.	TGS-5	13°9'55.34"N	80°18'44.32"E
6.	TMS-6	13°10'3.92"N	80°18'42.96"E
7.	TMS-7	13°9'58.41"N	80°18'53.14"E
8.	TMS-8	13°9'50.30"N	80°18'50.41"E
9.	TMS-9	13°9'50.09"N	80°19'20.13"E
10.	TMS-10	13°9'38.59"N	80°18'54.27"E
11.	TMS-11	13°9'31.19"N	80°18'41.43"E
12.	TMS-12	13°9'34.84"N	80°18'31.45"E

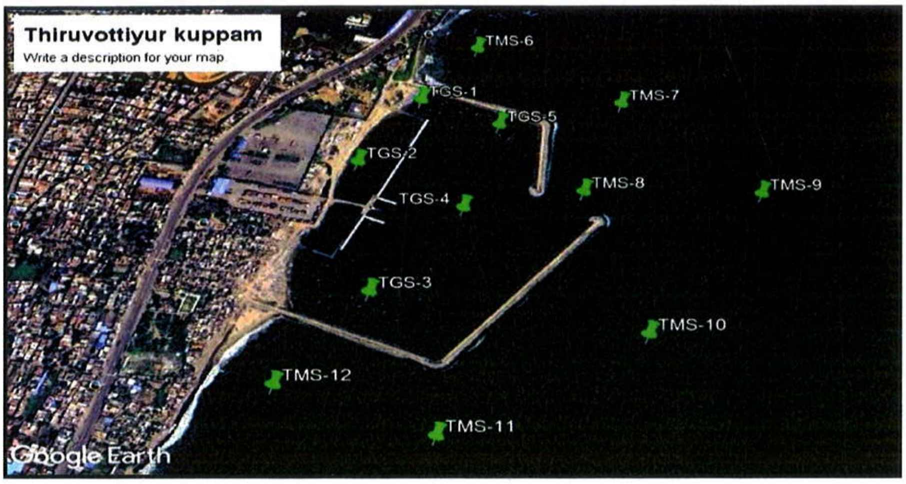


Fig. 1. Map showing the stations in Thiruvottiyur kuppam coastal wat

3. Materials and Methods

3.1. Water and Sediment Sampling

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.

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.

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.

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 analyzed 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 fixedand 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 methodsdescribed 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 ofNitrogen/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).

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 themethod 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.

4. 2. Microbiology methods

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.

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-streakedin appropriate nutrient agar plates thrice before a pure culture was established in agar slants.

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 48h. 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. 3. Pigments concentration

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. 4. **Plankton community**

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) forhalf 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).

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 bagnet (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.

5. 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 0.5mm 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 theseparation 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 Muruganantham *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. 6. 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).

Cluster Analysis

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)

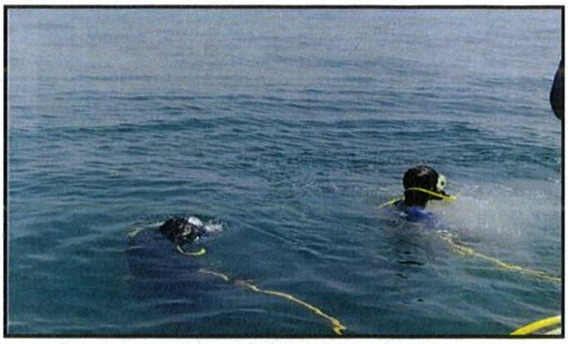
This method was proposed by Shepard (1962) and Kruskal (1964). To confirm the clustering pattern, this was used to find out the similarities (or dissimilarities) between each pair of entities to produce a 'map', which would ideally show the interrelationships of all.

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 AND ACTIVITIES

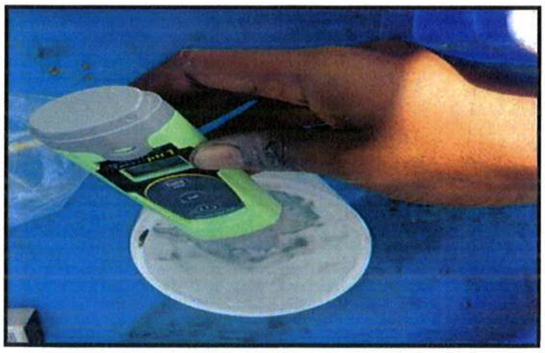
Near Thiruvottriyur Kuppam Fishing Harbor



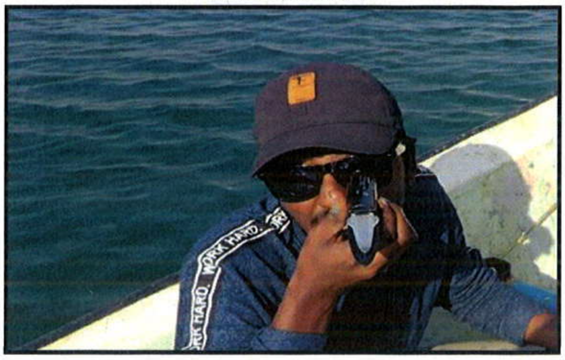
Biological sample collection by SUBA diving method

Locating sampling points by using GPS

Temperature measurement by using Thermometer

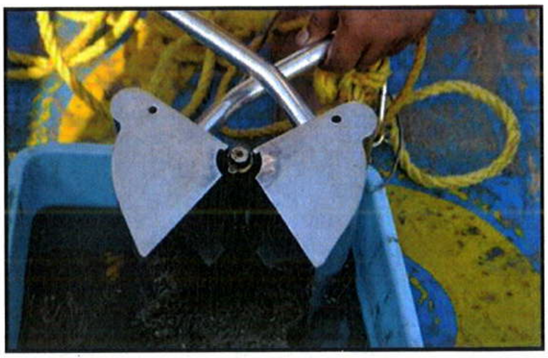


pH measurement by using pH pen

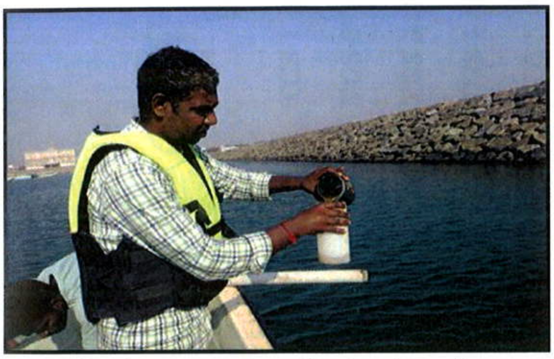


Salinity measurement by using Refractometer

Sub-surface water sample collection by using Niskin water sampler



Sediment sample collected by using Van-Veen Grab



Plankton sample collection by using plankton net

Sieve retains-benthic samples

DO estimation by following Winkler's method

Vertical transparency measurement by using Secchi disc

3. OBSERVATION REPORT

4.1. Water QualityDepth

The depth in the study area varied between 0.8 and 12.5m, with maximum at TMS-10and minimum at TGS-1 (Fig. 2).

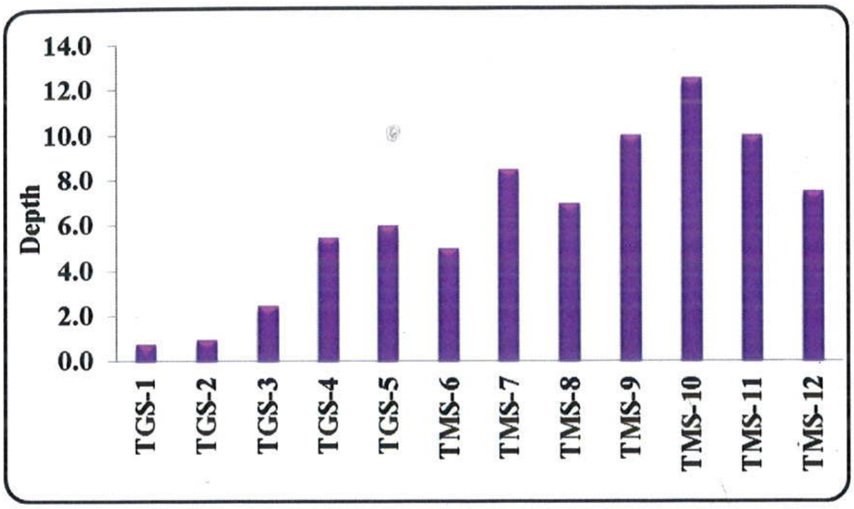


Fig. 2. Depth values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Water Temperature

The water temperature fluctuated from 27.2 to 29.5°C. The minimum value was recordedat TGS-1 and maximum was recorded at TMS-12 (Fig. 3).

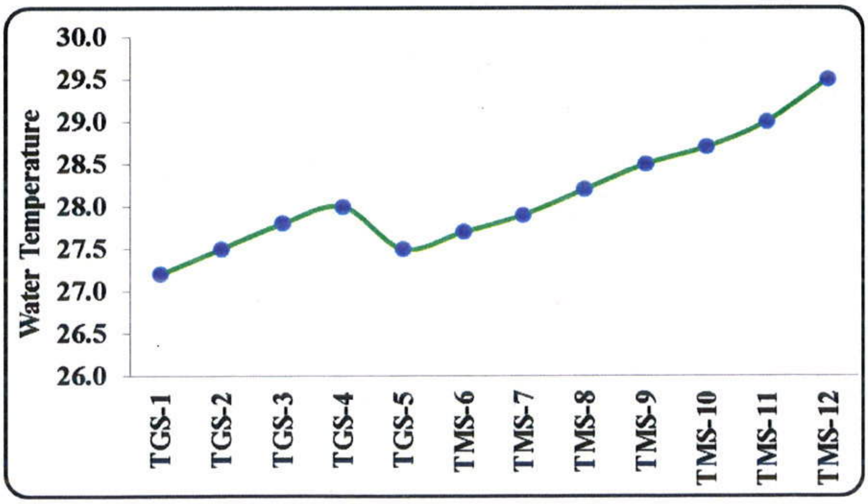


Fig. 3. Water temperature values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Salinity

The water salinity varied from 33.5 to 35.5PPT. The salinity was found to be lower at TGS-2 and higher value at TMS-10 (Fig. 4).

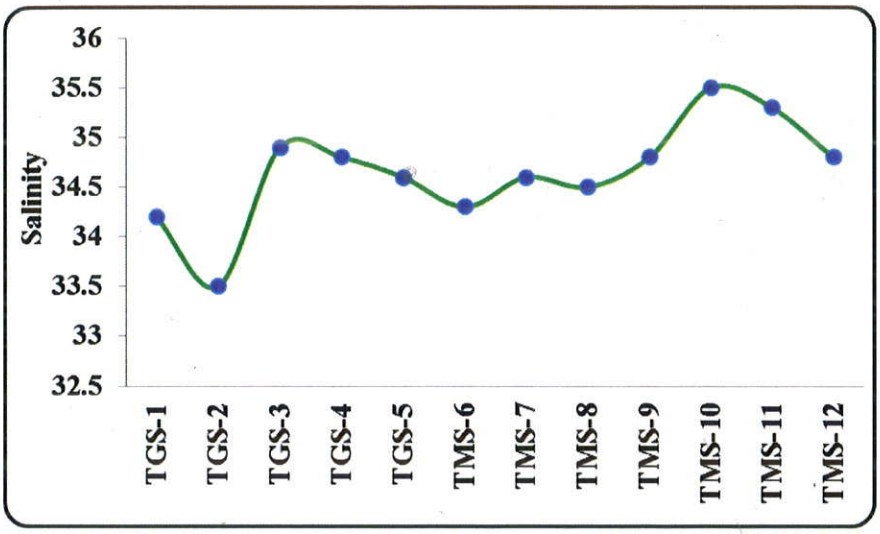


Fig. 4. Salinity level recorded at various stations in Tiruvottiyur Kuppam coastal waters

Water pH

The water pH varied between 7.7 and 8.3 with minimum value was recorded at TGS-2 and maximum value was recorded at TMS-10 (Fig. 5).

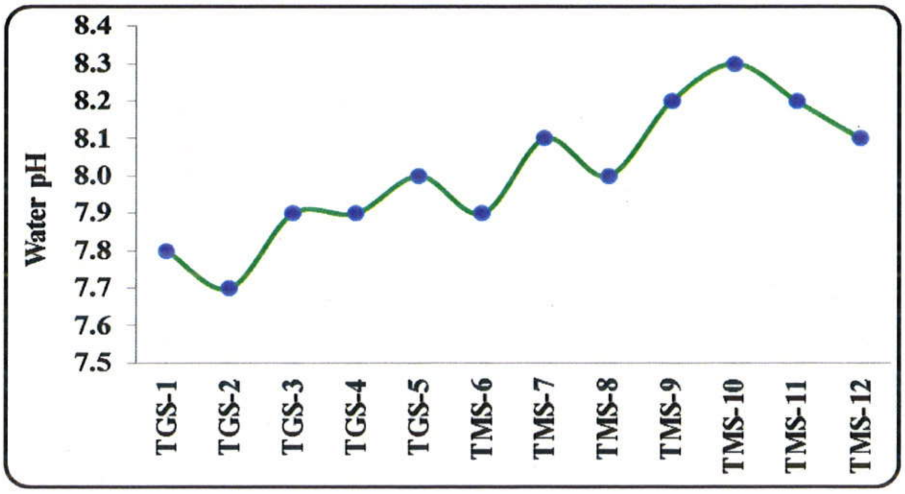


Fig. 5. Water pH level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Dissolved Oxygen

The Dissolved Oxygen level in the water varied between 4.495 and 6.265 mg/l. Thelower value was recorded at TGS-2 and the higher value at TMS-10 (Fig. 8).

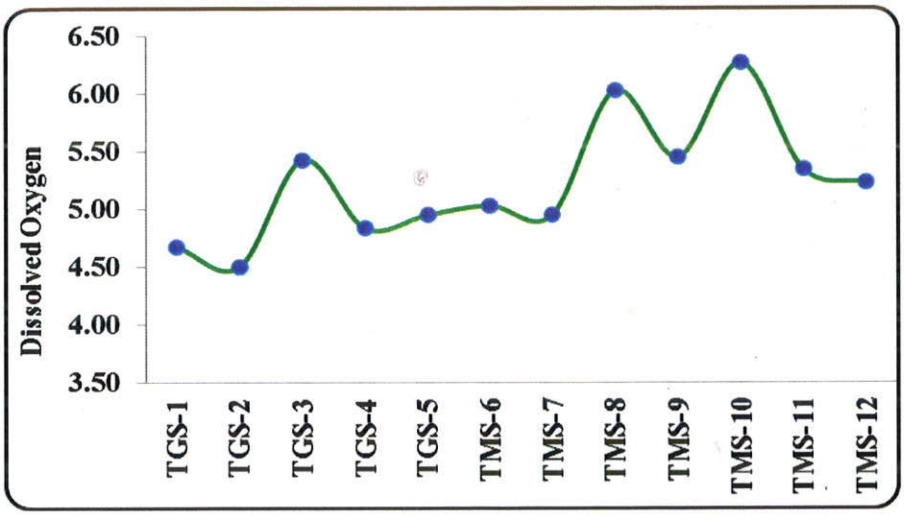


Fig. 8. Dissolved oxygen level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Biological Oxygen Demand

The BOD values varied between 1.03 and 2.38mg/l with minimum was at TMS-11 and the maximum value was recorded at TGS-2 (Fig. 9).

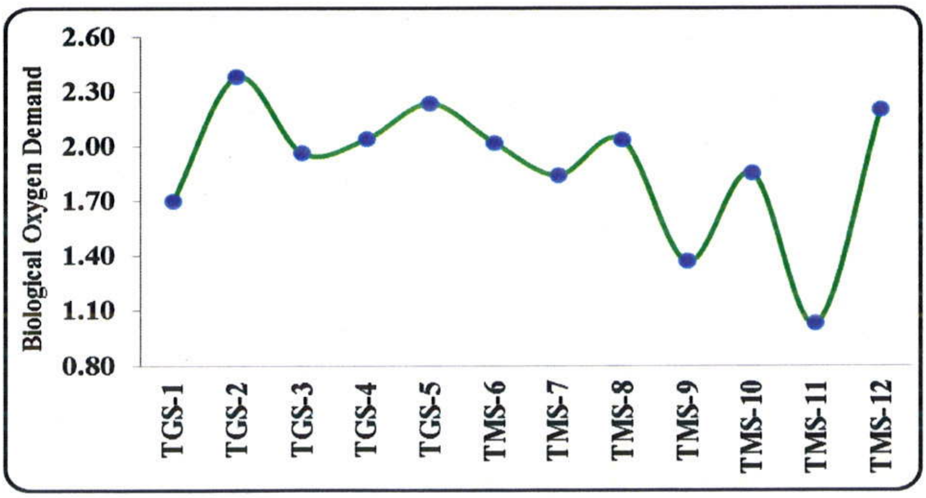


Fig. 9. Biological oxygen demand values recorded at various stations of TiruvottiyurKuppam coastal waters

Total Suspended Solids (TSS)

The Total Suspended solids values ranged between 71.20 and 135.20 mg/l. The minimum value was recorded at TMS-9 and the maximum was recorded at TGS-2 (Fig. 6).

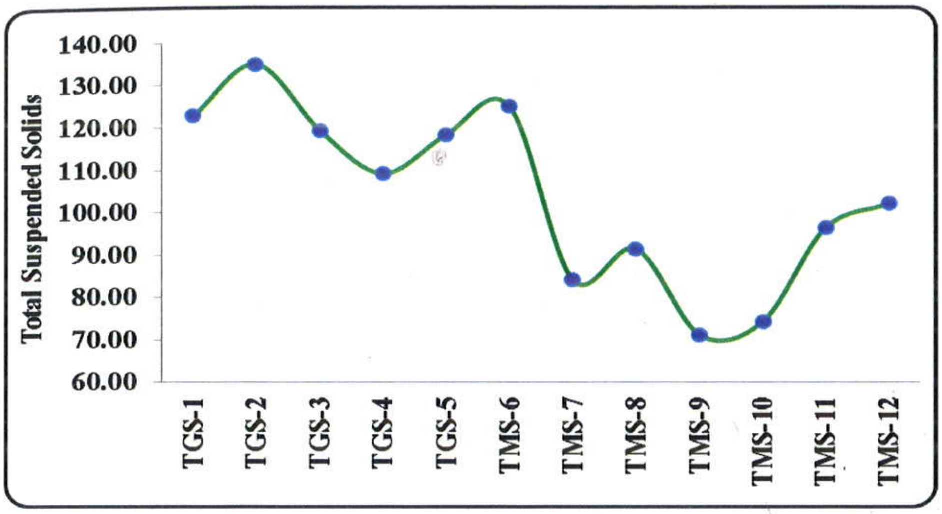


Fig. 6. Total suspended solids values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Turbidity

The turbidity values were between 3.8 and 8.4 NTU. The minimum level was recorded at TMS-9 and the maximum level at TGS-2 (Fig. 7).

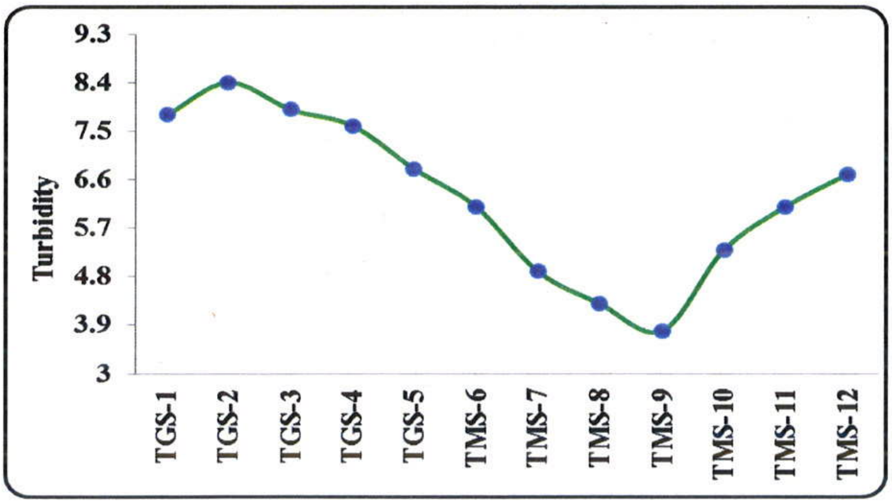


Fig. 7. Turbidity values recorded at various stations of Tiruvottiyur Kuppam coastalwaters

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 0.099 to 0.32 mg/l with maximum at TGS-2 and minimum was regarded at TMS-9 (Fig. 10).

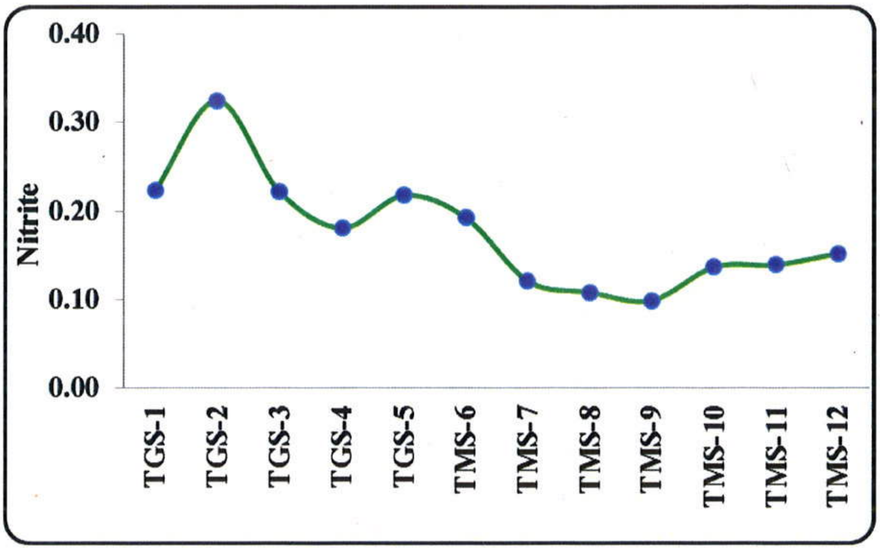


Fig. 10. Nitrite level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Nitrate

Nitrate concentration ranged between 0.18 and 0.56 mg/l with minimum at TMS-9 and maximum at TGS-2 (Fig. 11).

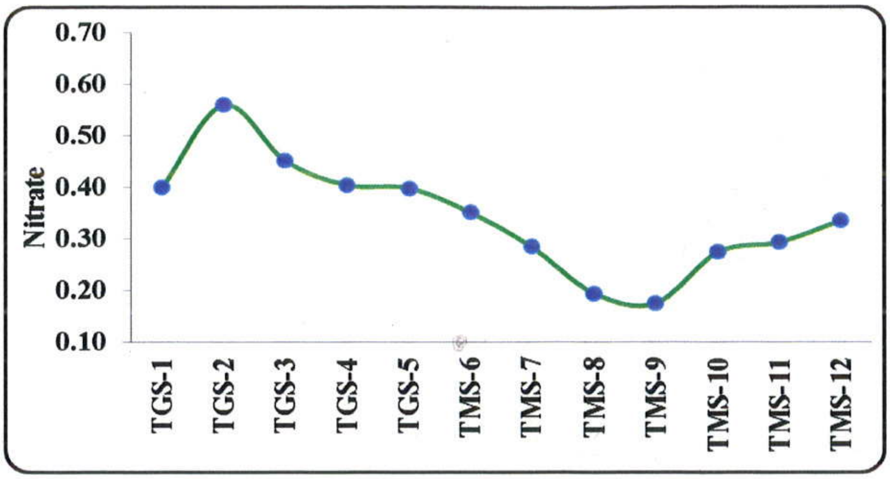


Fig. 11. Nitrate concentration recorded at various stations of Tiruvottiyur Kuppam coastalwaters

Total Nitrogen

The Total nitrogen values ranged from 1.51 to 2.23 mg/l. The minimum value was recorded at TMS-8 and the maximum value at TGS-3 (Fig. 12).

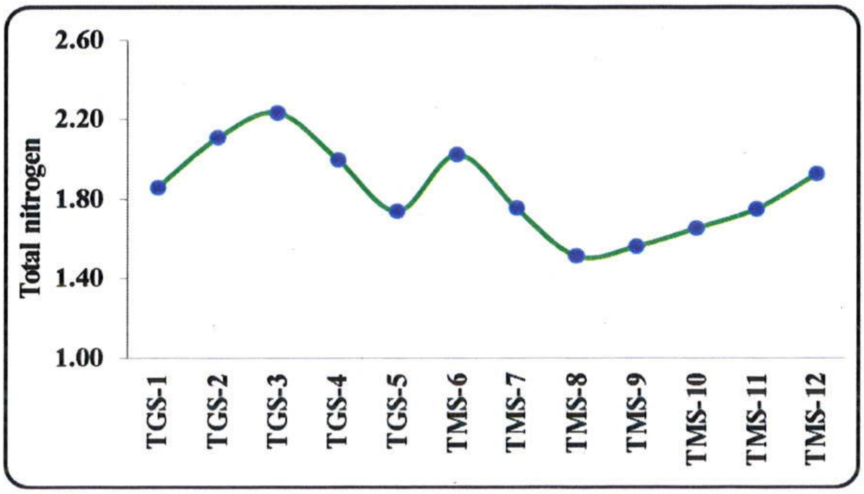


Fig. 12. Total nitrogen values recorded at various stations of Tiruvottiyur Kuppam coastalwaters

Ammonical Nitrogen

The ammonia concentration varied from 0.035 to 0.111 mg/l. The maximum concentration (0.035 mg/l) was recorded at TGS-2 and minimum (0.111 mg/l) at TMS-8 (Fig. 13).

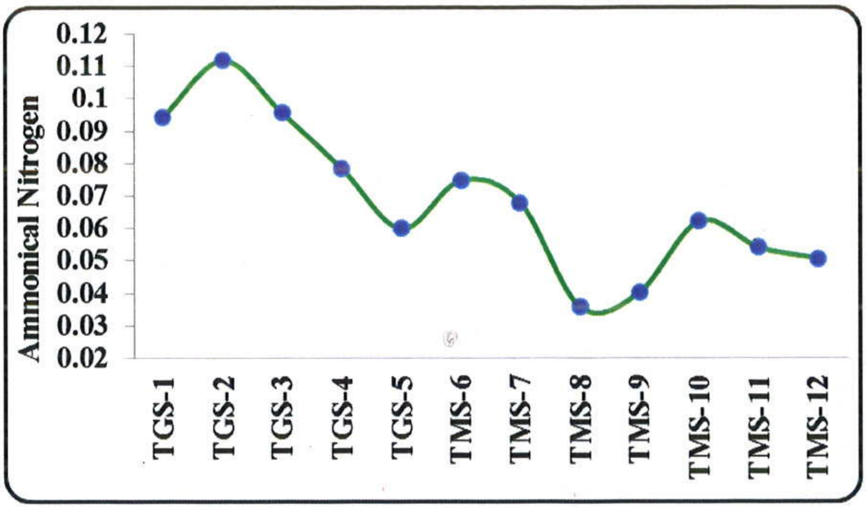


Fig. 13. Ammonical nitrogen concentration recorded at various stations of TiruvottiyurKuppam coastal waters

Inorganic Phosphate

The inorganic phosphate values ranged between 0.056 and 0.078 mg/l with maximum atTGS-4 and minimum at TMS-8 (Fig. 14).

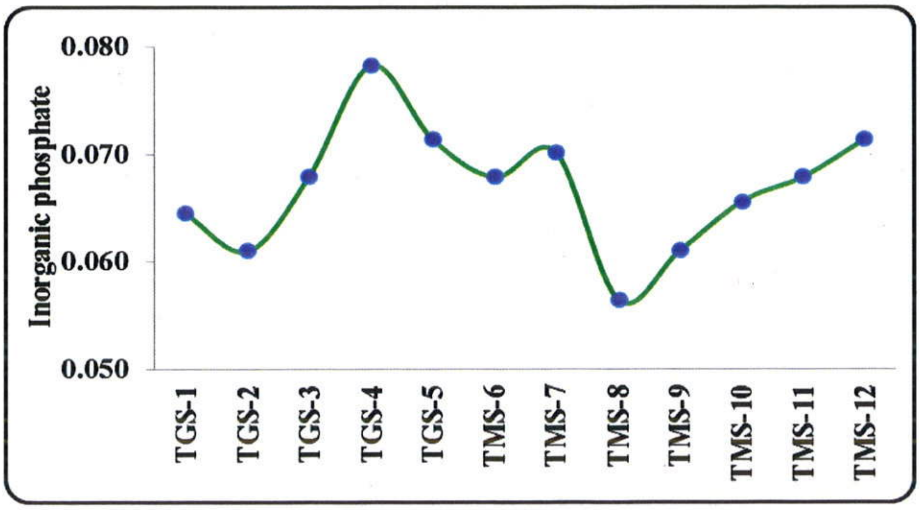


Fig. 14. Inorganic phosphate concentration recorded at various stations of TiruvottiyurKuppam coastal waters

Total Phosphorus

The Total phosphorous values ranged from 0.193 to 0.361 mg/l with minimum value atTMS-9 and the maximum value at TGS-3 (Fig. 15).

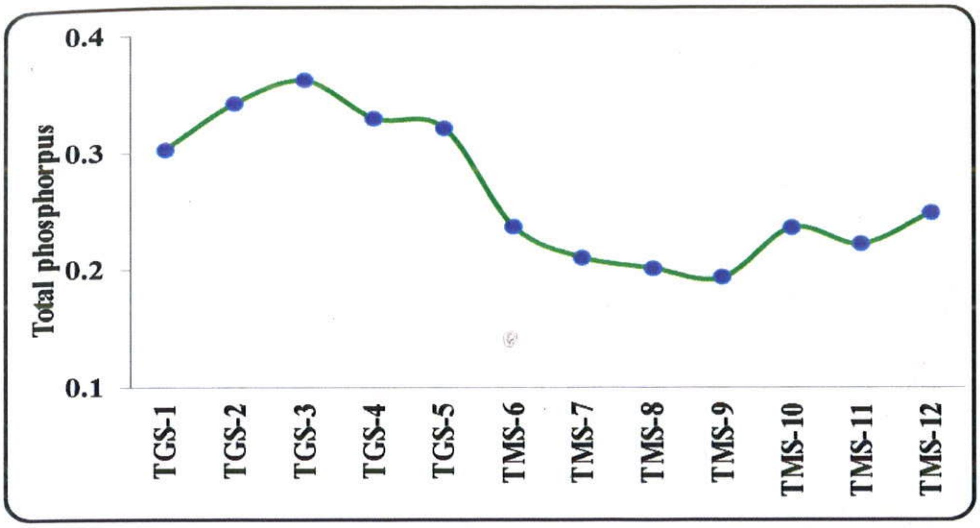


Fig. 15. Total phosphorous values recorded at various stations of Tiruvottiyur Kuppamcoastal waters

Reactive Silicate

The silicate values ranged between 7.20 and 9.49 mg/l with minimum was recodedTMS-9 and the maximum values were recorded at TGS-4 (Fig. 16).

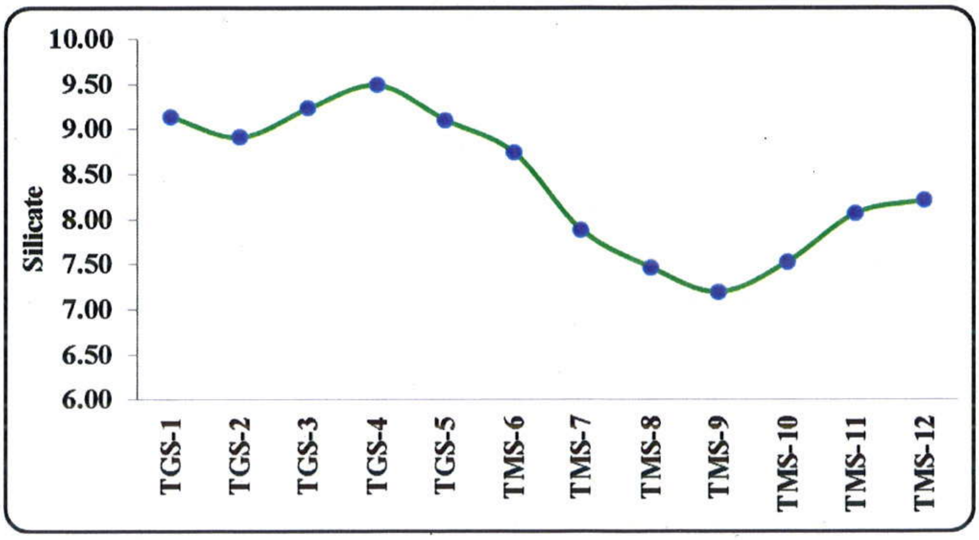


Fig. 16. Reactive silicate level recorded at various stations of Tiruvottiyur Kuppam coastalwaters

Particulate organic Carbon

The particulate organic carbon level ranged between 0.07 and 0.13mg/l withminimum (0.07 mg/l) at TMS-9 and maximum (0.13 mg/l) at TGS-3 (Fig. 17).

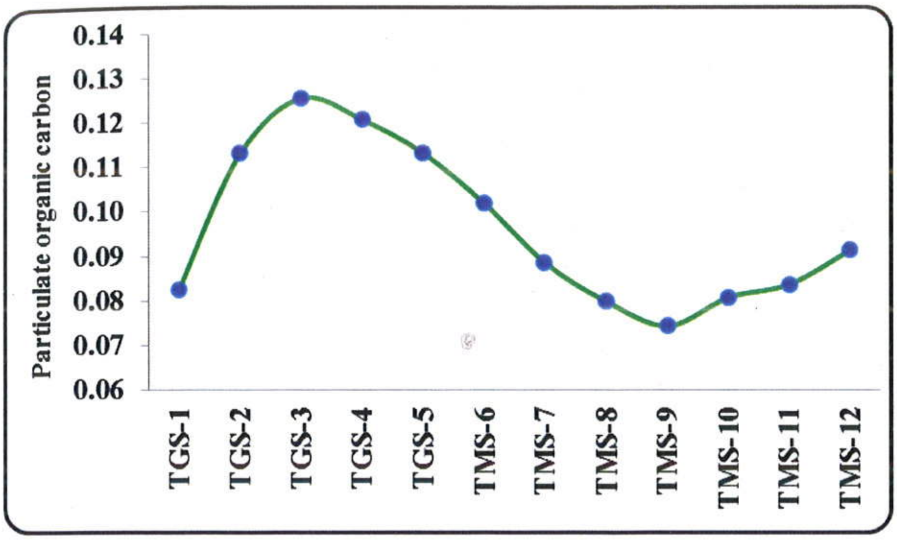


Fig. 17. Particulate organic carbon level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Petroleum hydrocarbons

PHC level in water fluctuated from 0.000306 and 0.000498 mg/l. The maximum was recorded atTGS-2 and the minimum was recorded at TMS-9 (Fig. 18).

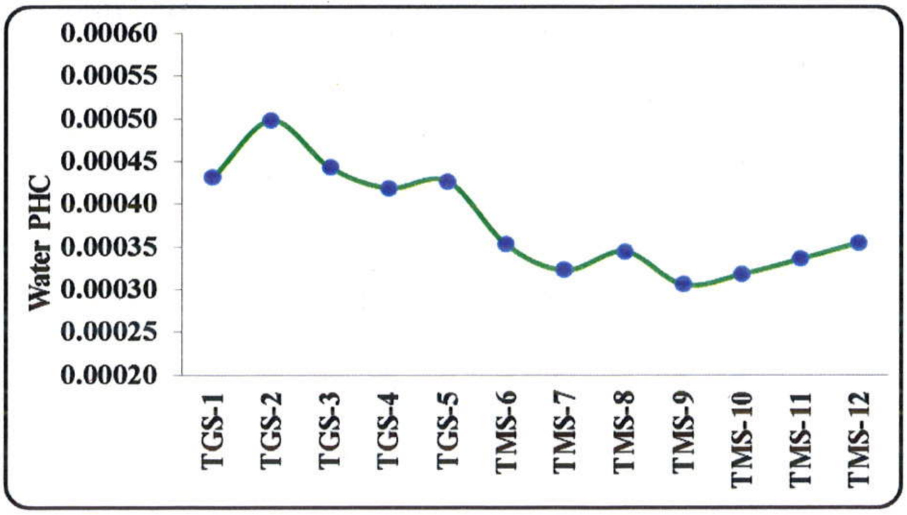


Fig. 18. Petroleum hydrocarbons concentration recorded at various stations of TiruvottiyurKuppam coastal waters

4. 1. 2. Heavy Metals in water

Iron

The iron level varied from 0.010 to 0.0117 mg/L (Fig. 19). The maximum was recorded at TGS-3 and the minimum was recorded at TMS-9.

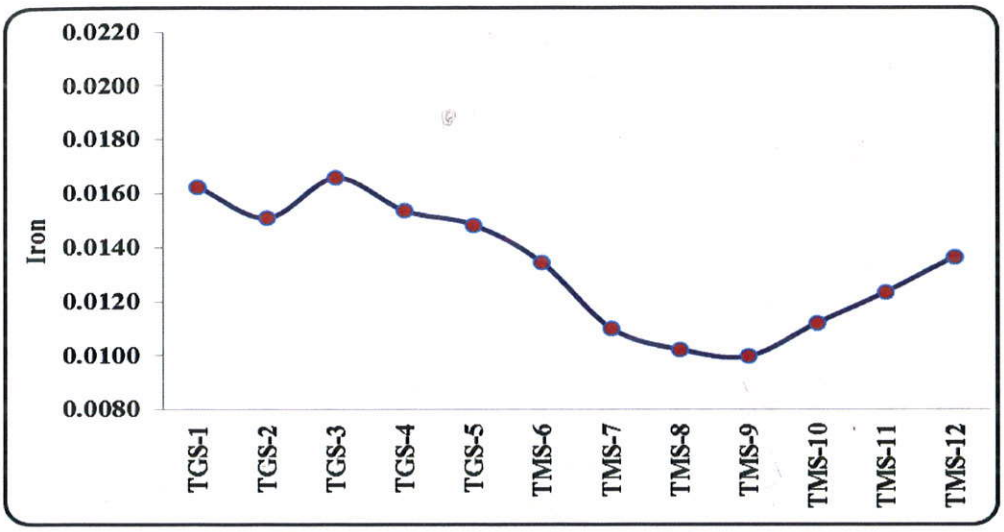


Fig. 19. Iron level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Zinc

The zinc level varied from 0.0114 to 0.0198 mg/L (Fig. 20). The maximum was recorded at TGS-4 and the minimum were recorded at TMS-9.

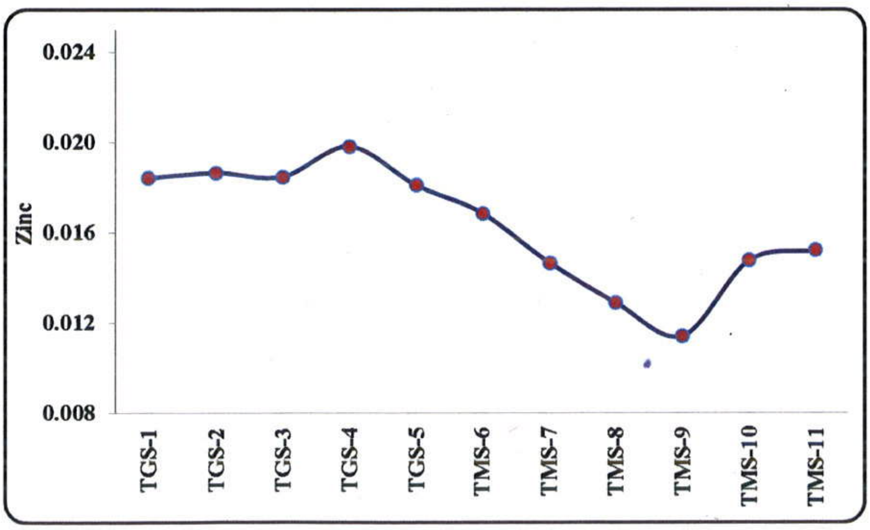


Fig. 20. Zinc level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Manganese

The Manganese concentration varied from 0.0109 to 0.0167 mg/L (Fig. 21). The maximumwas recorded TGS-2 and the minimum was recorded at TMS-10.

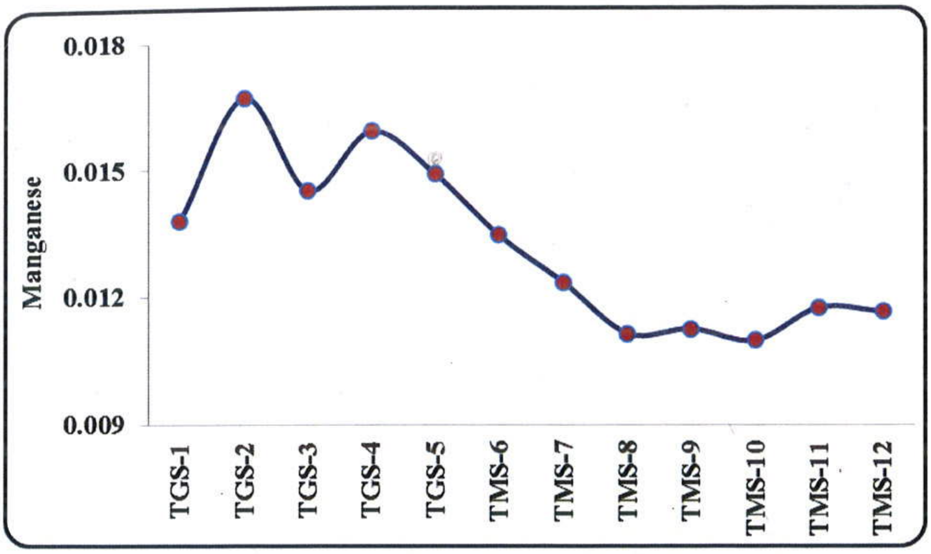


Fig. 21. Manganese concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Cadmium

The Cadmium concentration varied from 0.00103 to 0.00192 mg/L (Fig. 22). The maximum wasrecorded at TGS-2 and the minimum was recorded at TMS-9.

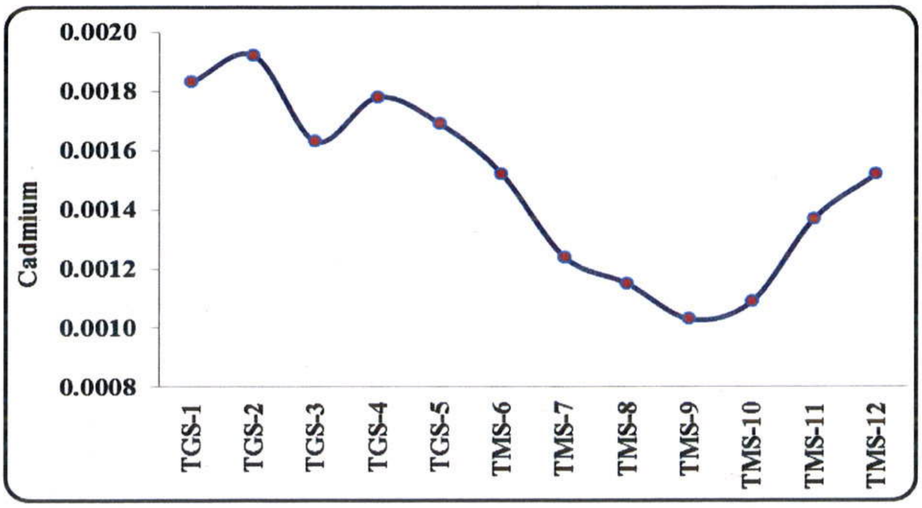


Fig. 22. Cadmium concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Nickel

The Nickel level varied from 0.00071 to 0.00172 mg/L (Fig. 23). The maximum level was recorded at TGS-2 and the minimum was recorded at TMS-10.

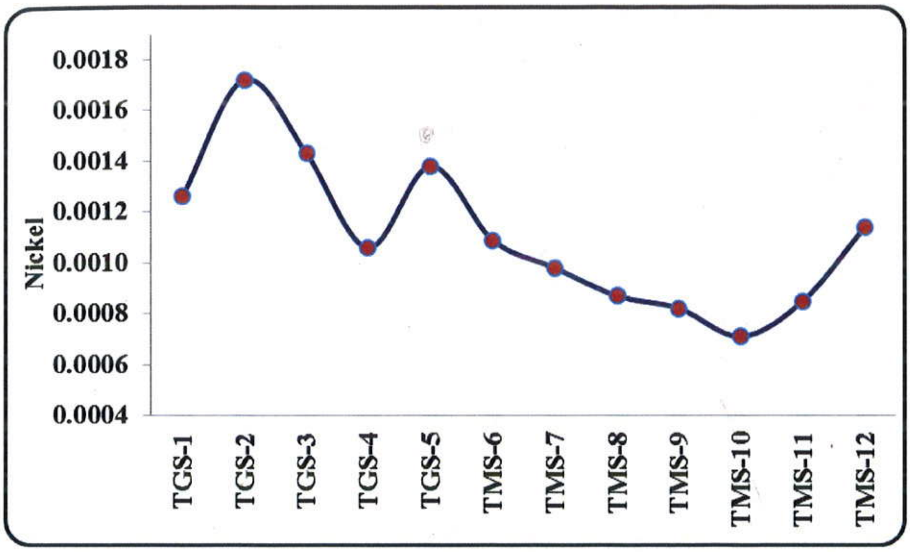


Fig. 23. Nickel level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Chromium

The chromium level varied from 0.00114 to 0.00234 mg/L (Fig. 24). The maximum value wasrecorded at TGS-5 and the minimum was recorded at TMS-8.

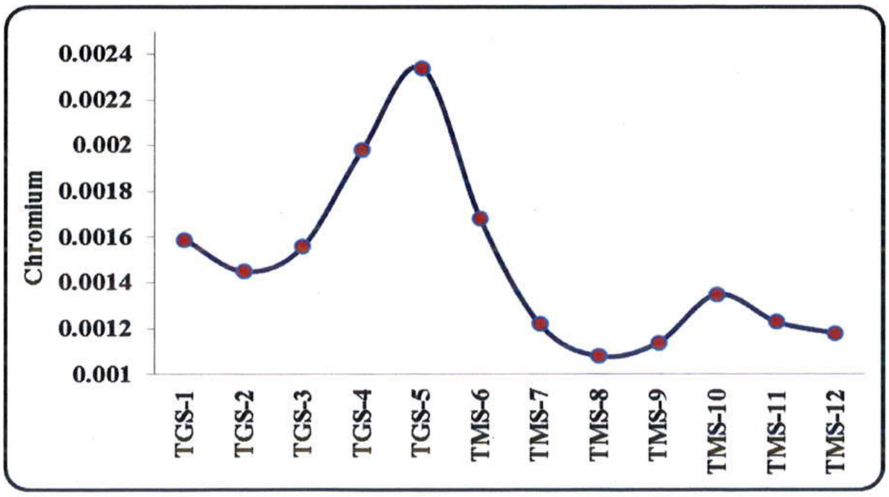


Fig. 24. Chromium level recorded at various stations at Tiruvottiyur Kuppam coastal waters

Lead

The Lead concentration ranged from 0.00105 to 0.00237 mg/L (Fig. 25) with maximum value was recorded at TGS-5 and the minimum was recorded at TMS-10 during this survey

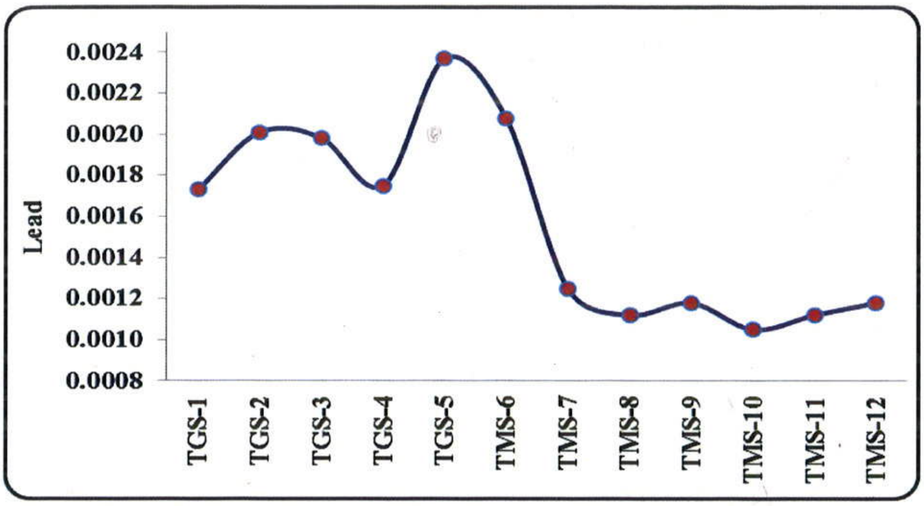


Fig. 25. Lead concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Copper

The copper concentration varied from 0.00228 to 0.00527 mg/L (Fig. 26). The maximum was recorded at TGS-2 and the minimum was recorded at TMS-9 during this survey

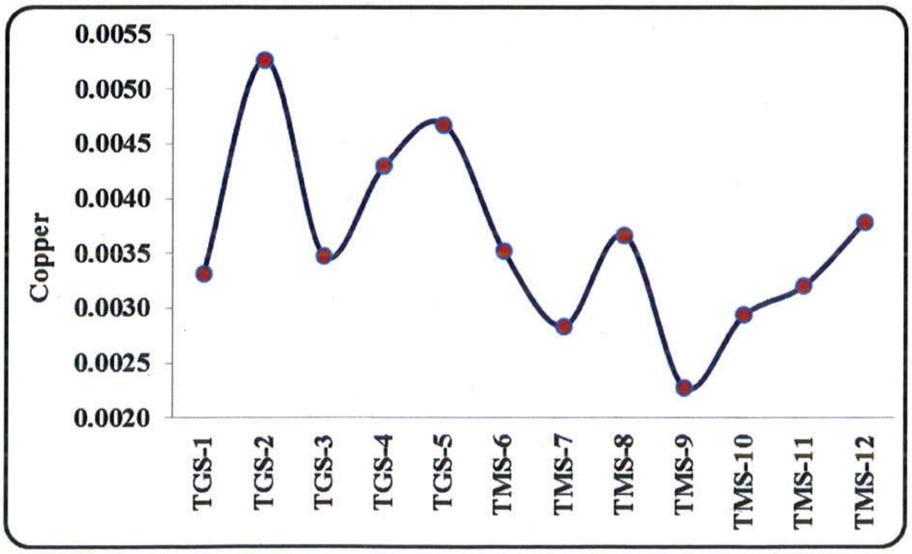


Fig. 26. Copper concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Mercury

The mercury level varied from 0.25 to 1.07 mg/L (Fig. 27). The maximum value was recorded at TGS-2 and the minimum was recorded at TMS-9 during this survey.

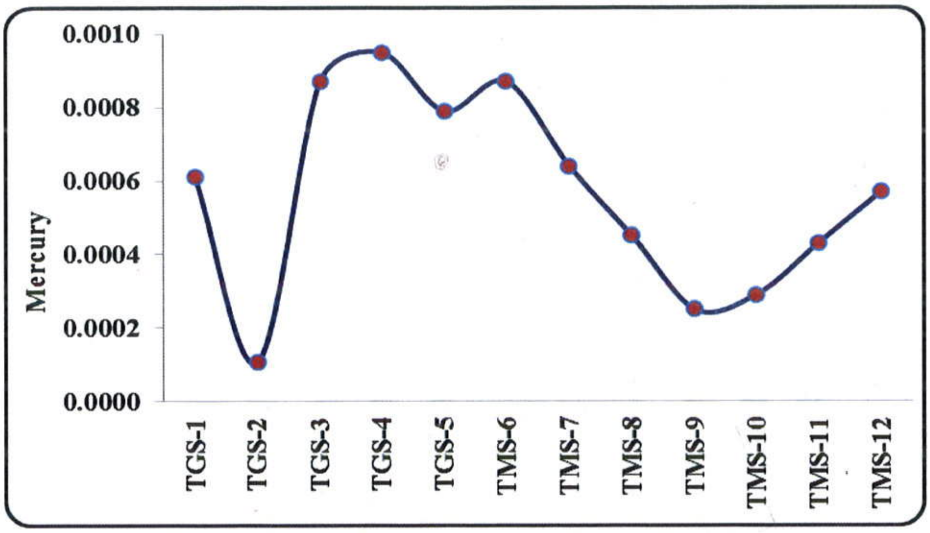


Fig. 27. Mercury level recorded at various stations at Tiruvottiyur Kuppam coastal waters

4. 2. Sediment CharacteristicsSediment pH

The maximum value (8.39) of soil pH was recorded at TMS-10 and minimum of 7.76 atTGS-2 (Fig. 28).

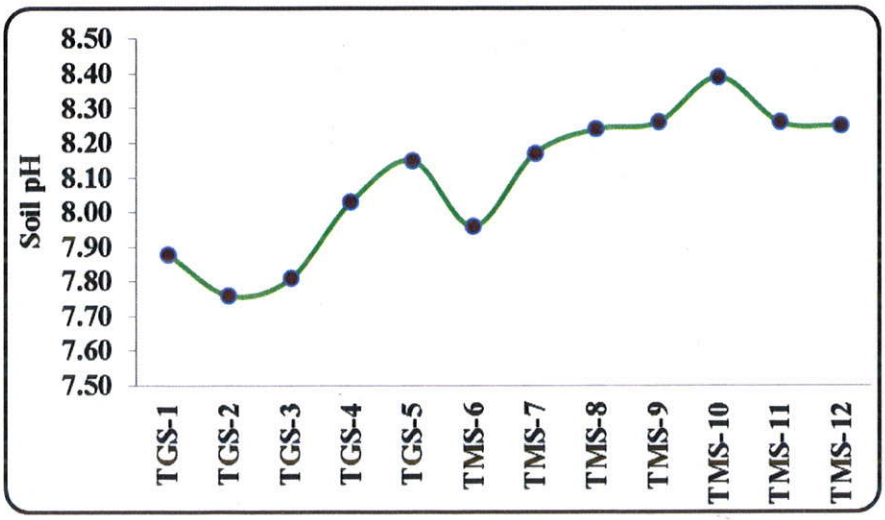


Fig. 28. Soil pH values recorded at various stations of Tiruvottiyur Kuppam coastal waters

Soil Texture

The sand content varied from 5.96 to 78.77 % with maximum value was at TMS-9 and the minimum at TGS-3; maximum Silt content (64.82%) was found at TGS-2 and minimum (13.43%) at TMS-9 and the maximum Clay content (69.04%) was found at TGS-3 and minimum(6.0%) at TMS-10 (Fig. 29).

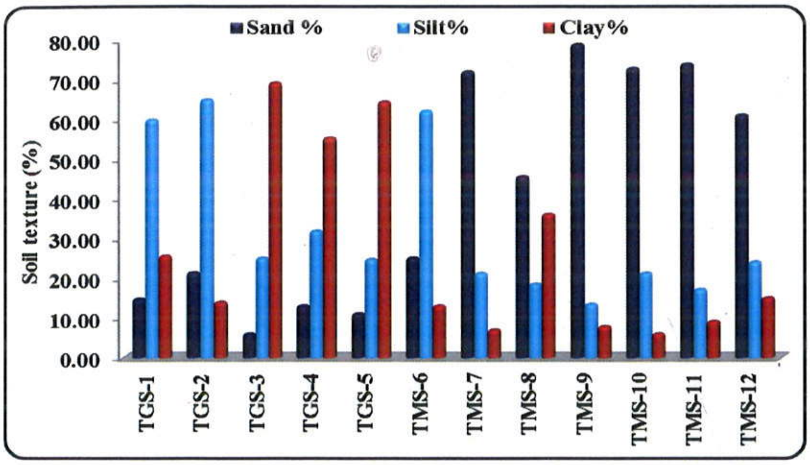


Fig. 29. Variations in soil texture recorded in various stations of Tiruvottiyur Kuppam coastal waters

Total organic Carbon

The total organic carbon ranged between 6.35 and 9.76mgC/g. The maximum level (9.76mgC/g) was found at TGS-4 and minimum (6.35mgC/g) at TMS-8 (Fig. 30).

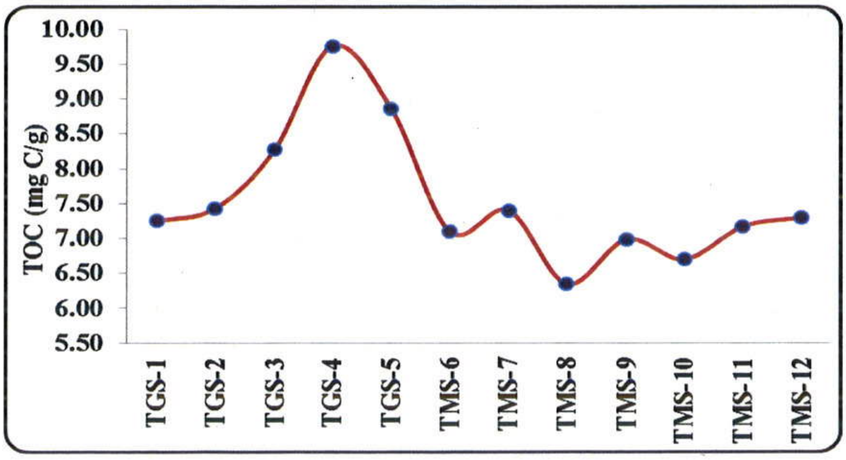


Fig. 30. Total organic carbon values recorded in various stations of Tiruvottiyur Kuppam coastal waters

Sediment PHC

The Sediment PHC level varied from 0.468 to 0.889 mg/kg (Fig. 31). The maximum levelwas recorded at TGS-2 and the minimum was recorded at TMS-9 during this survey

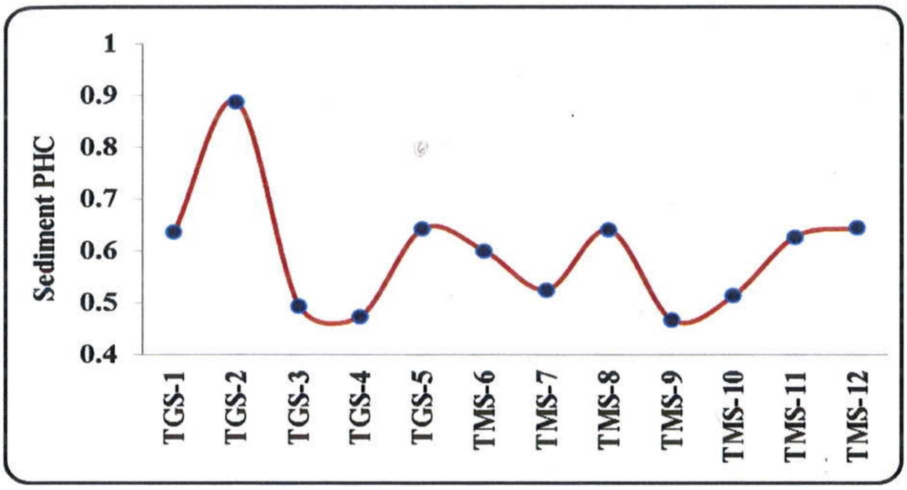


Fig. 31. Sediment PHC level recorded at various stations at Tiruvottiyur Kuppam coastal waters

4 2. 1. Heavy Metals in sediments

Iron

The Iron level varied from 1166.23 to 1965.24µg/g (Fig. 32). The maximum wasrecorded at TGS-4 and the minimum was recorded at TMS-9.

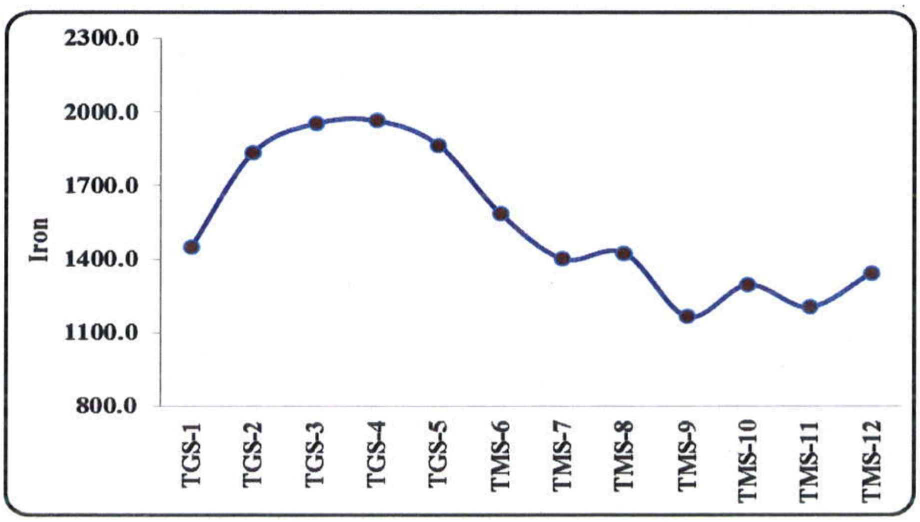


Fig. 32. Iron level recorded in various stations Tiruvottiyur Kuppam coastal waters

Zinc

Zinc concentration varied from 23.70 to 33.40µg/g (Fig. 33). The maximum level was recorded at TGS-3 and the minimum was recorded at TMS-8.

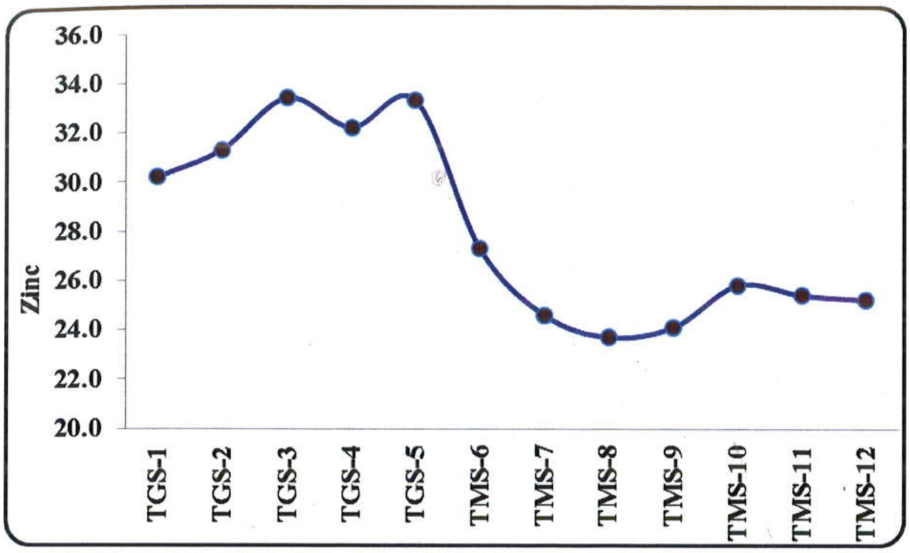


Fig. 33. Zinc concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Manganese

The Manganese level varied from 60.17 to 80.55µg/g (Fig. 34). The maximum level was recorded at TGS-5 and the minimum was recorded at TMS-10.

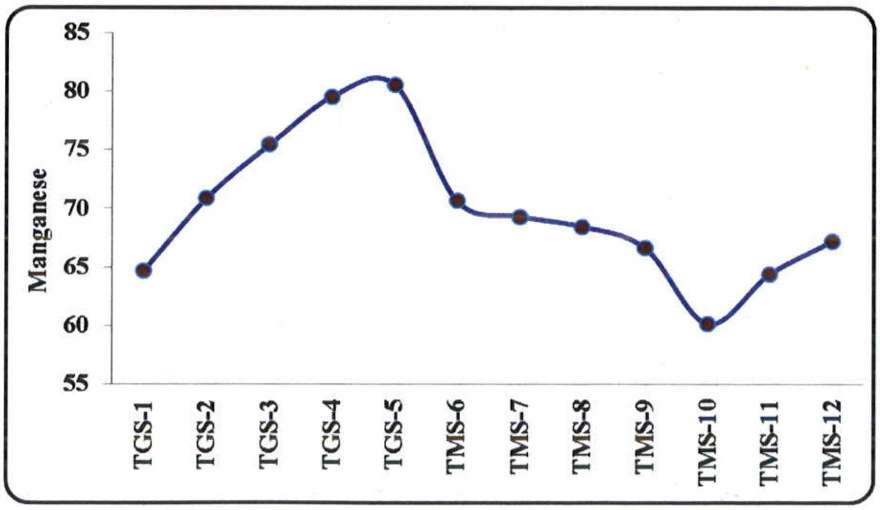


Fig. 34. Manganese level recorded at various stations of Tiruvottiyur Kuppam coastalwaters

Cadmium

The Cadmium level varied from 1.03 to 4.54µg/g (Fig. 35). The maximum level was recorded at TGS-2 and the minimum was recorded at TMS-10.

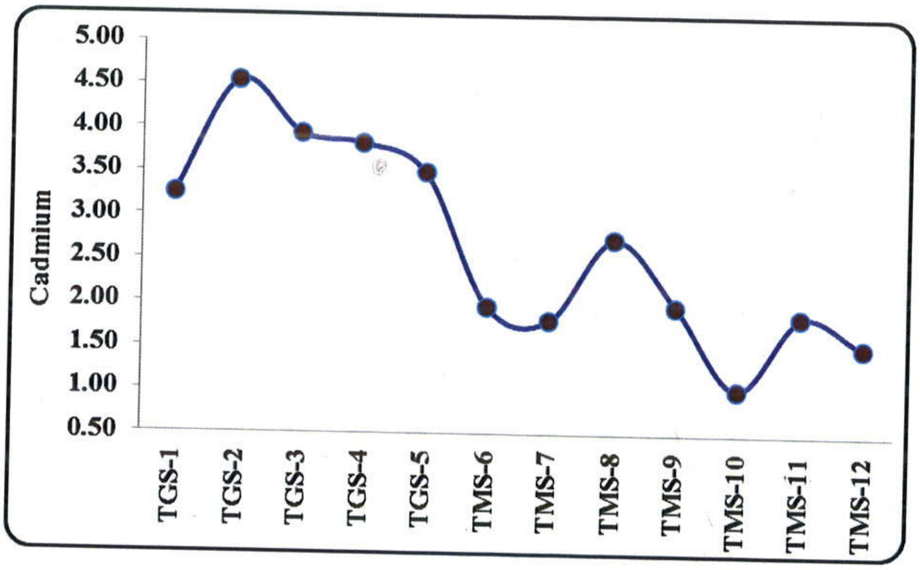


Fig. 35. Cadmium level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Nickel

The nickel concentration varied from 5.37 to 10.93µg/g (Fig. 36). The maximum was recorded at TGS-3 and the minimum was recorded at TMS-9.

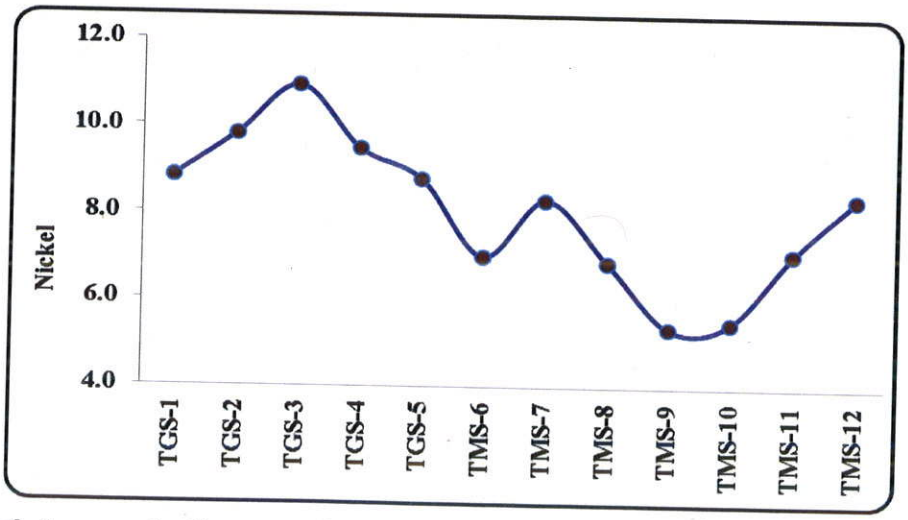


Fig. 36. Nickel concentration recorded at various stations of Tiruvottiyur Kuppam coastal waters

Chromium

The Chromium level varied from 5.24 to 7.41µg/g (Fig. 37) with the maximum was recorded at TGS-2 and the minimum was recorded at TMS-9.

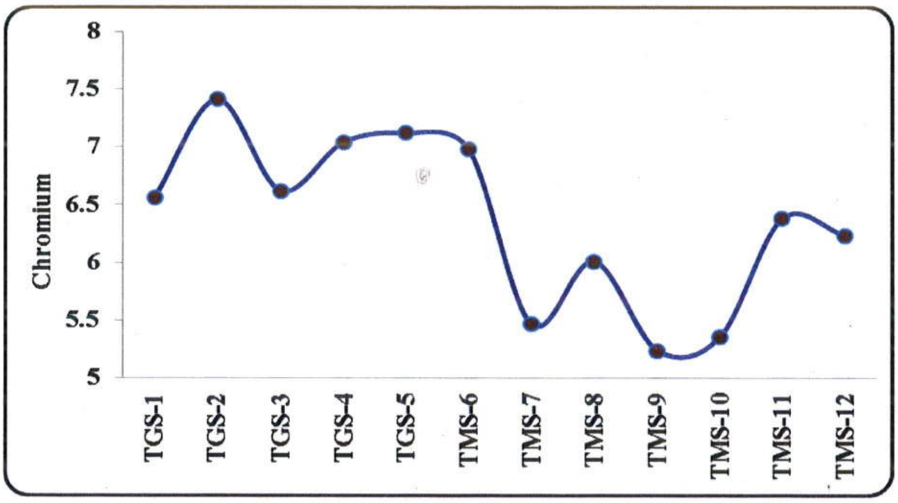


Fig. 37. Chromium level recorded at various stations of Tiruvottiyur Kuppam coastal waters

Lead

The lead concentration varied from 4.06 to 6.97µg/g (Fig. 38). The maximum value was recorded at TGS-3 and the minimum was recorded at TMS-9.

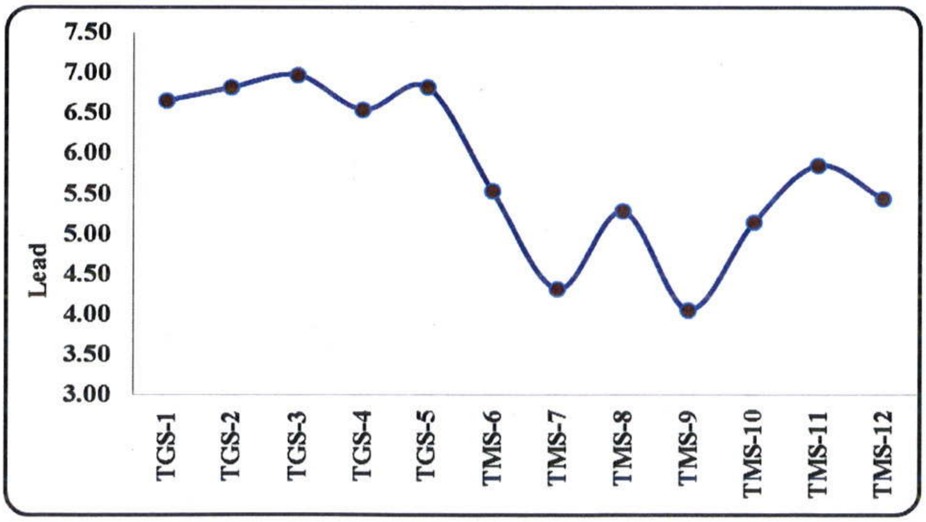


Fig. 38. Lead concentration recorded in various stations of Tiruvottiyur Kuppam coastal waters

Copper

The copper level varied from 6.23 to 11.74µg/g (Fig. 39). The maximum value was recorded at TGS-2 and the minimum was recorded at TMS-8.

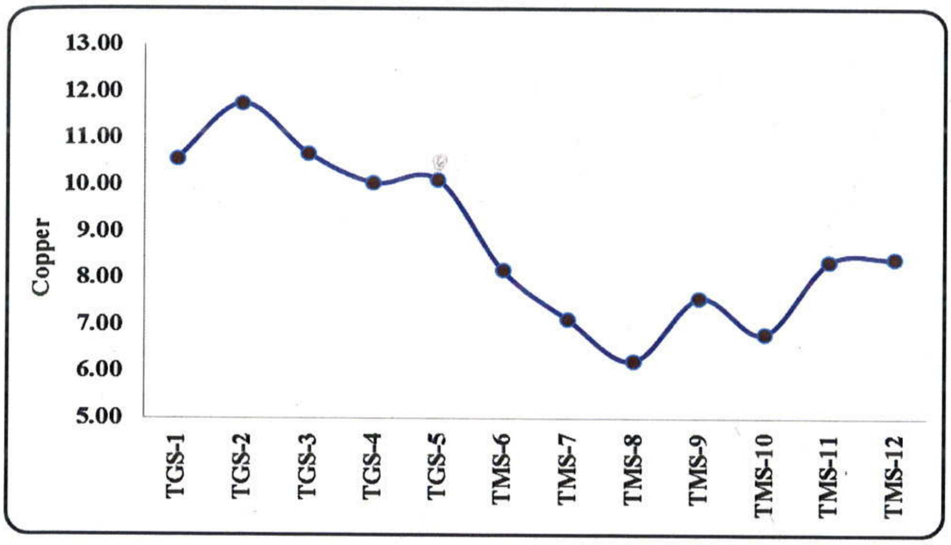


Fig. 39. Copper level recorded in various stations of Tiruvottiyur Kuppam coastal waters

Mercury

The mercury concentration varied from 0.71 to 1.56µg/g (Fig. 40). The maximum was recorded at TGS-5 and the minimum was recorded at TMS-9.

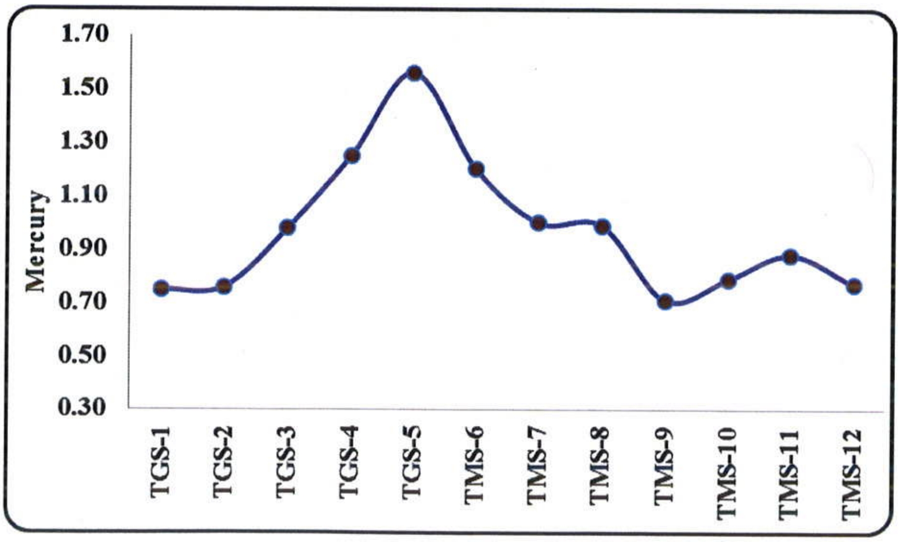


Fig. 40. Mercury concentration recorded in various stations of Tiruvottiyur Kuppamcoastal waters

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, sand andMn got correlated with stations TGS-5, TGS-3 TGS-2, TGS-1, TMS-6, TMS-8 and TMS-9 whilethe rest of the parameters showed strong correlation with stations TMS-10, TMS-11, TMS-12 TMS-7 and TGS-4.

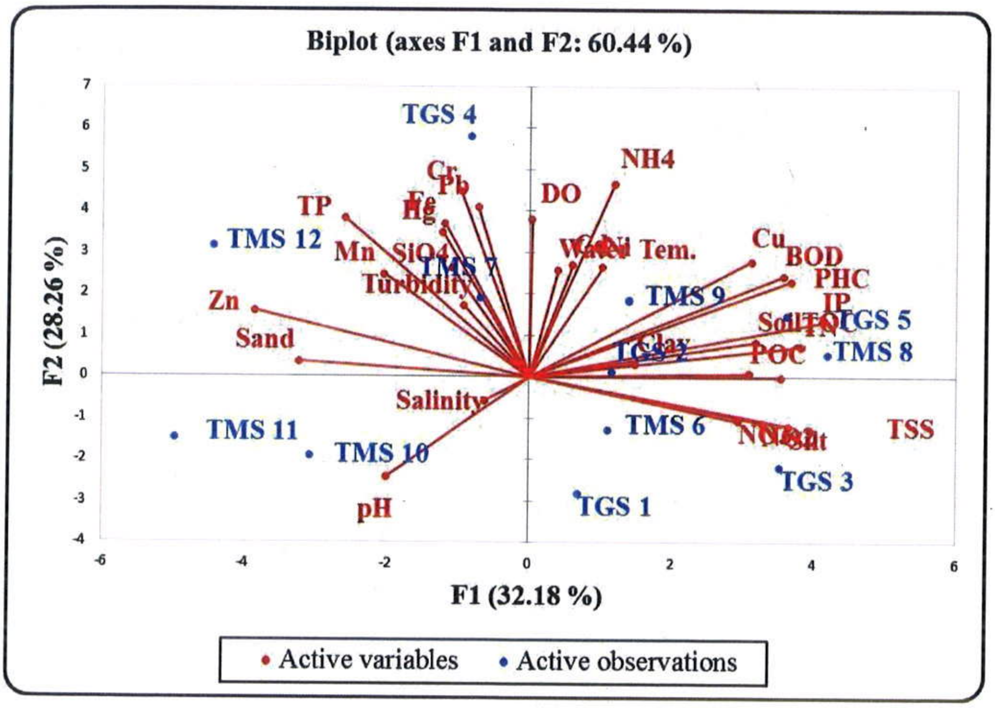


Fig. 41. Principal Component Analysis plot drawn for the correlation between various environmental variables and stations of Tiruvottiyur Kuppam coastal waters

4.3. MICROBIOLOGY

4. 3. 1. Water sample

The total viable count in water samples ranged from 11x103 to $28x10^4$ CFU/ml. The maximum count was found at TGS-2 and the minimum count was found at TMS-10. The Total coliform count in the samples varied from $10x10^3$ to $29x10^4$ CFU/ml with the high colony count at TGS-1 and the low count at TMS-9. The *E. coli* count ranged from $9x10^3$ to $25x10^3$ CFU/ml with a maximum value at TGS-2 and the minimum value at TMS-9. The *Faecal coliform* was found to vary from $10x10^2$ to $26x10^2$ CFU/ml with higher value at TGS-2 and the lower value at TMS-9. The *Pseudomonas aeurginosa* count ranged from $05x10^2$ to $17x10^4$ CFU/ml with maximum value at TMS-12 and the minimum value at TMS-10. The *Streptococcus faecalis* count ranged from $09x10^3$ to $14x10^4$ CFU/ml. The higher values were recorded at TGS-1 and the lower values were recorded at TMS-8. The *Shigella* count varied from $07x10^3$ to $17x10^4$ CFU/ml with a higher value at TGS-2 and the lower value at TMS-8. The *Salmonella* colony count variedfrom $06x10^2$ to $15x10^4$CFU/ml with the higher value at TMS-12 and the lower value at TMS-10. The *Vibrio cholera* colony count was found to fluctuate from $06x10^2$ to $21x10^2$CFU/ml. The higher colony count was observed at TGS-2 and the lower count was recorded at TMS-9. *Vibrio parahaemolyticus* colony count varied from $07x10^2$ to $15x10^4$ CFU/ml with the maximum value at TGS-2 and minimum value at TMS-8 (Table 2).

Table 2. Bacterial populations recorded in water sample at Tiruvottiyur kuppam coastal waters

S. No	Stations	FC	TVC	TC	EC	VC	VP	PA	SF	SH	SL
1	TGS-1	$20x10^3$	$27x10^3$	$29x10^4$	$21x10^4$	$19x10^3$	$13x10^2$	$17x10^3$	$14x10^4$	$14x10^4$	$12x10^3$
2	TGS-2	$26x10^2$	$28x10^4$	$25x10^2$	$25x10^3$	$21x10^2$	$15x10^4$	$13x10^4$	$12x10^4$	$17x10^4$	$11x10^4$
3	TGS-3	$17x10^3$	$21x10^5$	$21x10^3$	$21x10^3$	$10x10^3$	$11x10^2$	$13x10^3$	$11x10^2$	$12x10^3$	$08x10^2$
4	TGS-4	$15x10^3$	$17x10^3$	$18x10^2$	$16x10^3$	$09x10^3$	$10x10^3$	$11x10^2$	$10x10^3$	$10x10^3$	$09x10^2$
5	TGS-5	$17x10^4$	$19x10^3$	$16x10^2$	$13x10^3$	$10x10^3$	$08x10^3$	$12x10^2$	$10x10^2$	$09x10^2$	$11x10^2$
6	TMS-6	$11x10^3$	$18x10^4$	$14x10^4$	$17x10^4$	$13x10^3$	$11x10^2$	$13x10^4$	$13x10^2$	$12x10^4$	$13x10^3$
7	TMS-7	$12x10^4$	$12x10^3$	$12x10^3$	$11x10^4$	$08x10^3$	$09x10^3$	$07x10^3$	$10x10^2$	$08x10^4$	$08x10^3$
8	TMS-8	$11x10^4$	$15x10^3$	$10x10^3$	$10x10^3$	$08x10^2$	$07x10^2$	$10x10^4$	$11x10^3$	$07x10^3$	$09x10^3$
9	TMS-9	$10x10^2$	$14x10^4$	$12x10^2$	$09x10^3$	$06x10^2$	$09x10^3$	$07x10^2$	$09x10^3$	$08x10^4$	$06x10^2$
10	TMS-10	$12x10^2$	$11x10^3$	$11x10^4$	$14x10^4$	$07x10^3$	$08x10^2$	$05x10^2$	$11x10^2$	$10x10^2$	$12x10^2$
11	TMS-11	$13x10^2$	$12x10^4$	$14x10^3$	$13x10^4$	$12x10^3$	$10x10^3$	$10x10^2$	$11x10^3$	$10x10^2$	$10x10^2$
12	TMS-12	$24x10^3$	$21x10^2$	$16x10^4$	$15x10^3$	$18x10^4$	$13x10^2$	$17x10^4$	$12x10^3$	$12x10^3$	$15x10^4$

4. 3. 2. Sediment sample

With respect to sediment samples, the total viable count in sediment samples ranged from $17x10^5$ to $28x10^4$ CFU/g. The maximum was found at TGS-2 and the minimum value was found at TMS-10. The Total coliform count was found to vary from $16x10^3$ to $31x10^3$ CFU/g with the higher value at TGS-1 and the lower value at TMS-8. The *E. coli* count ranged from $16x10^4$ to $29x10^4$CFU/g with the higher value at TGS-2 and the lower value at TMS-9. The *Faecalcoliform* count in the samples varied from $14x10^2$ to $30x10^2$ CFU/g with the higher colony count at TGS-2 and the lower count at TMS-9. *Pseudomonas aeurginosa* counts ranged from $10x10^3$ to$18x10^4$ CFU/g with the maximum at TGS-1 and the minimum at TMS-7. The *Streptococcus faecalis* count ranged from $11x10^3$ to $25x10^4$ CFU/g. The higher value was recorded at TGS-2 and the lower value was recorded at TMS-9. The *Shigella* counts varied from $11x10^3$ to $24x10^3$ CFU/g with the higher value at TMS-12 and lower value at TMS-7. *Salmonella* colony counts varied from $10x10^3$ to $23x10^3$ CFU/g with the maximum value at TGS-1 and the minimum value at TMS-8. *Vibrio parahaemolyticus* colony count varied from $11x10^3$ to $24x10^4$ CFU/g. The higher value was found at TGS-2 and the lower value at TMS-9. The other species *Vibrio cholerae* colony was found to range from $12x10^3$ to $26x10^2$ CFU/g with the maximum colony count at TGS-1 and the minimum count was observed at TMS-8 (Table 3).

Table 3. Bacterial populations recorded in sediment sample at Tiruvottiyur kuppam coastal waters

S. No	Stations	FC	TVC	TC	EC	VC	VP	PA	SF	SH	SL
1	TGS-1	$29x10^2$	$27x10^4$	$31x10^3$	$27x10^5$	$26x10^2$	$16x10^3$	$18x10^4$	$16x10^3$	$15x10^3$	$23x10^3$
2	TGS-2	$30x10^2$	$28x10^4$	$29x10^2$	$29x10^4$	$19x10^3$	$24x10^4$	$18x10^4$	$25x10^4$	$17x10^5$	$17x10^4$
3	TGS-3	$21x10^5$	$20x10^4$	$28x10^3$	$25x10^4$	$16x10^3$	$21x10^3$	$14x10^4$	$15x10^4$	$13x10^4$	$11x10^4$
4	TGS-4	$17x10^3$	$19x10^5$	$21x10^4$	$22x10^4$	$13x10^4$	$13x10^4$	$14x10^4$	$14x10^4$	$12x10^4$	$13x10^4$
5	TGS-5	$20x10^5$	$18x10^4$	$23x10^5$	$18x10^2$	$15x10^5$	$14x10^4$	$15x10^4$	$13x10^4$	$13x10^4$	$11x10^4$
6	TMS-6	$23x10^3$	$26x10^4$	$29x10^4$	$22x10^4$	$16x10^4$	$15x10^4$	$16x10^2$	$19x10^5$	$14x10^3$	$19x10^4$
7	TMS-7	$19x10^4$	$23x10^4$	$19x10^5$	$18x10^3$	$14x10^4$	$13x10^3$	$10x10^3$	$12x10^3$	$11x10^3$	$12x10^4$
8	TMS-8	$19x10^4$	$21x10^4$	$16x10^3$	$19x10^5$	$12x10^3$	$12x10^3$	$14x10^4$	$12x10^4$	$12x10^4$	$10x10^3$
9	TMS-9	$14x10^2$	$23x10^4$	$23x10^4$	$16x10^4$	$14x10^4$	$11x10^3$	$13x10^4$	$11x10^3$	$13x10^4$	$11x10^3$
10	TMS-10	$18x10^3$	$17x10^5$	$20x10^4$	$19x10^3$	$13x10^3$	$12x10^4$	$14x10^4$	$13x10^4$	$12x10^5$	$13x10^4$
11	TMS-11	$21x10^4$	$19x10^5$	$25x10^4$	$22x10^3$	$15x10^4$	$12x10^3$	$15x10^3$	$15x10^3$	$13x10^4$	$12x10^3$
12	TMS-12	$27x10^4$	$20x10^5$	$27x10^5$	$24x10^5$	$17x10^3$	$15x10^3$	$17x10^3$	$17x10^4$	$24x10^3$	$15x10^4$

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 1.053 to 2.804 mg/m^3, with maximum at TGS-3 and minimum at TMS-12. The Phaeopigments content varied from 1.107 to 2.475 mg/m^3 with maximum was at TGS-3 and the minimum was observed at TMS-9. The Total biomass values varied from 1.968 to 5.803 ml/100m^3, with maximum at TGS-4 and minimum at TMS-10 (Table 4).

Table 4. Chlorophyll *a*, Phaeopigments and total biomass recorded in Tiruvottiyur kuppam coastal waters

Stations	Chlorophyll 'a' (mg/m^3)	Phaeopigments (mg/m^3)	Total biomass (ml/100m^3)
TGS-1	1.225	1.238	2.754
TGS-2	1.208	1.284	3.857
TGS-3	2.804	2.475	2.528
TGS-4	1.149	1.361	5.803
TGS-5	2.008	1.742	3.086
TMS-6	1.260	1.268	2.043
TMS-7	2.526	1.957	3.094
TMS-8	1.872	1.430	3.126
TMS-9	1.317	1.107	2.241
TMS-10	1.850	1.446	1.968
TMS-11	1.472	1.137	2.168
TMS-12	1.053	1.168	2.037

Primary productivity

The primary productivity was measured using the dark and light reaction method. The values ranged from 114.15 to 168.72mgCm^{-3}d^{-1}. The maximum value was recorded at TGS-5and minimum value at TMS-10 (Fig. 42).

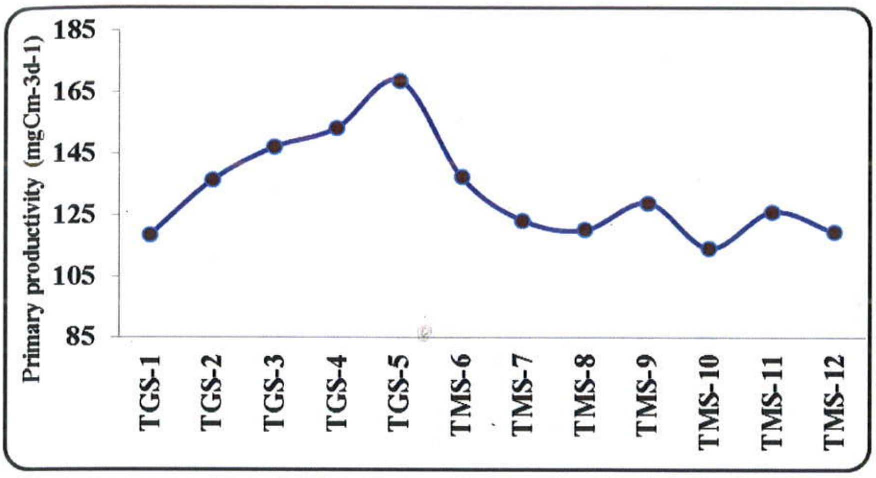


Fig. 42. Primary productivity values recorded at various stations of Tiruvottiyur kuppam coastal waters

4.5 PLANKTON

4.5.1 Phytoplankton

In the present study, as many as 42 phytoplankton species belonging to three major groups namely Bacillariophyceae (Diatom), Dinophyceae (Dinoflagellates) and Cyanophyceae (Cyanobacteria) were recorded in Thiruvottiyurkuppam coastal waters. Of these, Bacillariophyceae were found to be the dominant group with 30 species, Dinophyceae formed next group with 11 species and Cyanophyceae with one species.

Among the Bacillariophyceae, *Skeletonema costatum* was observed highly dominated in all the stations and followed by *Asterionella glacialis, Chaetoceros curvisetus* and *Cyclotella* sp also were found in all sampling sites except station second (TGS-2) in Thiruvottiyur kuppam coastal area. The Dinophyceae, (*Dinophysis caudate*) and Cyanophyceae (*Trichodesmium erythraeum*) similarly were recorded in all the twelve sampling sites. Among the various species,

Bellerochea malleus, Chaetoceros coarctatus, Coscinodiscus centralis, Navicula sp, *Nitzschia longissima, Odontella mobiliensis, Planktoniella sol, Rhizosolenia alata, Thalassionema nitzschioides, Ceratium furca, Ceratium macroceros* and *Peridinium claudicans* were the most abundant forms. The distribution and abundance of phytoplankton varied considerably following seasonal environmental fluctuations.

Population density

Density of phytoplankton varied from 6,905 to 20972 Cells/l with maximum was at TGS-4 and minimum at TGS-2 (Fig. 43).

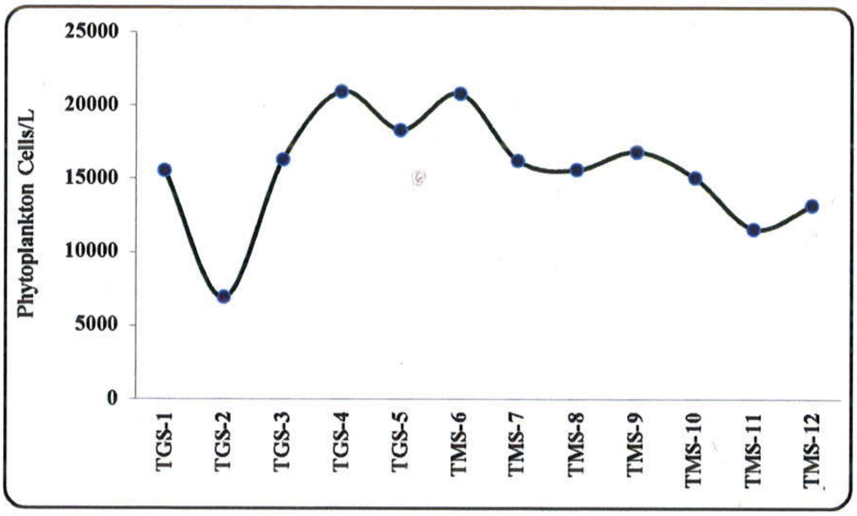


Fig. 43. Population density of Phytoplankton in various stations of Tiruvottiyur kuppam coastal waters

Percentage composition

When the results of percentage composition of phytoplankton were looked at, Bacillariophyceae constituted the maximum with 80% of the total followed by Dinophyceae with 13% and Cyanophyceae with 7% of the total (Fig. 44).

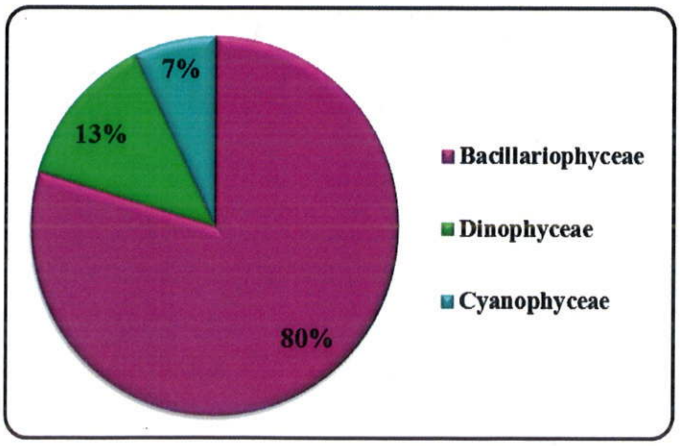


Fig. 44. Percentage composition of Phytoplankton in various stations of Tiruvottiyur kuppam coastal waters

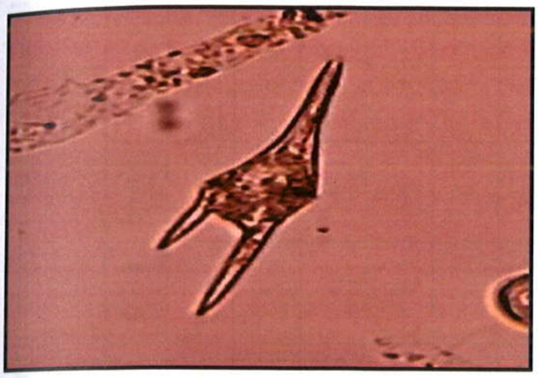
Diversity indices

The phytoplankton species diversity (H') varied from 2.988 to 3.643 with maximum at TMS-8 and minimum at TGS-2. The species richness (d) ranged between 4.824 and 6.233 with maximum at TGS-2 and minimum at TMS-9. The species evenness varied from 0.545 to 0.892 with the maximum at TGS-3 and minimum at TMS-9 (Table - 5).

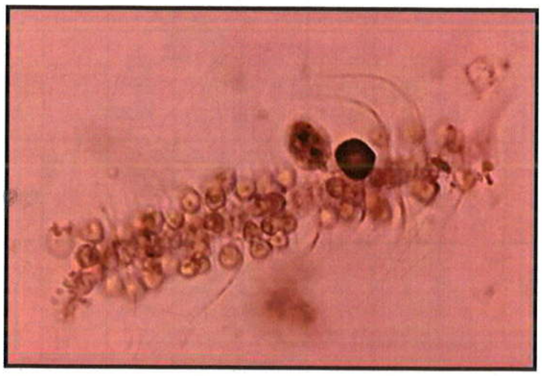
Table 5. Diversity indices; Shannon diversity (H'); Margalef richness (d) and Pielou's evenness (J') calculated for Phytoplankton in Tiruvottiyur kuppam coastal waters

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
TGS-1	3.011	5.583	0.594
TGS-2	2.988	6.233	0.631
TGS-3	3.149	5.653	0.545
TGS-4	3.326	6.824	0.623
TGS-5	3.271	5.328	0.791
TMS-6	3.388	5.811	0.734
TMS-7	3.465	4.971	0.795
TMS-8	3.643	5.909	0.843
TMS-9	3.320	4.824	0.892
TMS-10	3.218	5.554	0.835
TMS-11	3.036	5.352	0.761
TMS-12	3.028	5.041	0.798

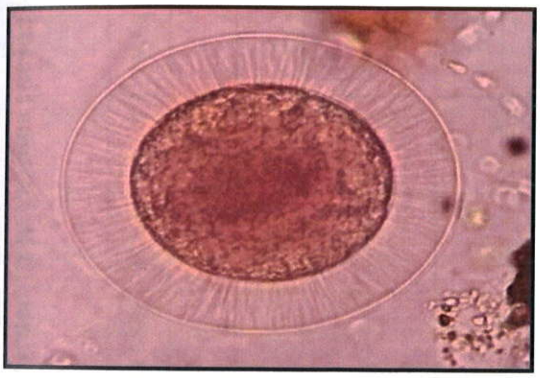
PLATE -I PHYTOPLANKTON



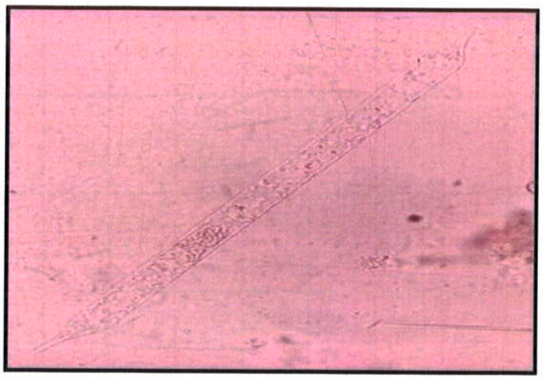
Ceratium furca



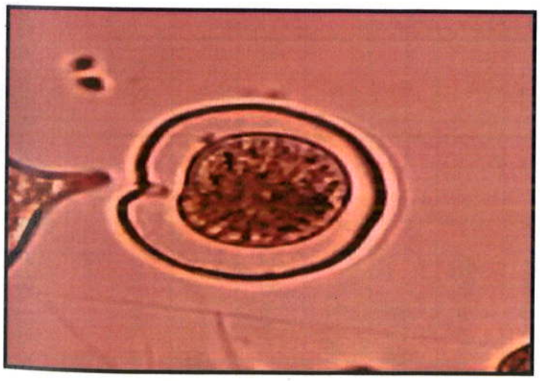
Chaetoceros coarctatus



Planktoniella sol



Rhizosolenia alata



Noctiluca sp

Peridinium sp

Table 6. Check list of Phytoplankton species recorded from various stations of Thiruvottriyur kuppam coastal waters

S. No.	Phytoplankton	TGS-1	TGS-2	TGS-3	TGS-4	TGS-5	TMS-6	TMS-7	TMS-8	TMS-9	TMS-10	TMS-11	TMS-12
1	*Asterionella glacialis*	+	−	+	+	+	+	+	+	+	+	+	+
2	*Bacteriastrum comosum*	−	−	+	+	−	+	+	+	−	−	−	−
3	*Bellerochea malleus*	+	−	+	+	+	+	+	−	+	+	−	−
4	*Chaetoceros affinis*	−	−	+	−	−	−	−	−	−	−	−	−
5	*Chaetoceros coarctatus*	+	−	+	+	+	+	+	+	+	−	+	+
6	*Chaetoceros curvisetus*	+	−	+	+	+	+	+	+	+	+	+	+
7	*Coscinodiscus centralis*	+	+	+	+	+	+	+	+	+	+	+	−
8	*Coscinodiscus granii*	−	−	−	−	+	+	−	−	+	+	−	+
9	*Coscinodiscus radiatus*	−	−	+	+	−	−	+	+	−	+	−	−
10	*Cyclotella sp.*	+	−	+	+	+	+	+	+	+	+	+	+
11	*Eucampia zodiacus*	+	−	+	+	−	−	−	+	−	+	−	+
12	*Hemidiscus hardmanianus*	+	−	+	+	−	−	+	−	+	−	+	+
13	*Lauderia borealis*	+	−	+	−	+	−	+	+	−	+	−	+
14	*Leptocylindrus danicus*	+	−	+	−	+	+	−	−	+	−	+	+
15	*Lithodesmium undulatum*	−	−	−	−	+	−	+	+	−	+	−	−

16	[illegible] sp.	+	−	+	+	+	+	−	+	+	+	−	+
17	*Nitzschia closterium*	−	−	−	−	−	+	+	+	+	+	+	+
18	*Nitzschia longissima*	+	+	+	+	+	+	−	+	−	+	−	−
19	*Odontella mobiliensis*	+	−	+	+	+	+	+	+	+	+	+	−
20	*Odontella sinensis*	−	−	+	+	+	−	−	−	+	−	−	−
21	*Planktoniella sol*	+	−	+	+	+	+	+	+	+	+	+	+
22	*Pleurosigma normanii*	+	+	+	+	+	−	−	+	−	−	+	−
23	*Pleurosigma directum*	−	−	−	−	−	+	+	+	+	+	−	+
24	*Rhizosolenia alata*	+	−	−	+	−	+	+	+	−	−	−	−
25	*Rhizosolenia styliformis*	+	−	−	+	−	−	−	−	−	−	−	−
26	*Skeletonema costatum*	+	−	+	+	+	+	+	+	+	+	+	+
27	*Streptotheca thamensis*	−	−	−	−	−	−	−	−	−	−	−	+
28	*Thalassionema nitzschioides*	+	+	+	+	+	+	+	+	+	+	+	−
29	*Thalassiothrix frauenfeldii*	−	+	+	+	+	+	+	−	+	+	+	−
30	*Triceratium favus*	+	−	+	+	+	+	+	−	+	+	+	+
31	*Ceratium furca*	+	−	+	−	+	+	+	+	−	+	−	+
32	*Ceratium lineatum*	−	−	+	+	−	−	−	−	−	−	−	−
33	*Ceratium longipes*	−	+	+	+	−	+	−	+	−	+	−	−
34	*Ceratium macroceros*	+	+	+	−	+	+	−	+	+	−	+	+

35	*Ceratium ranipes*	–	–	–	–	–	–	–	+	–	+	–	+
36	*Dinophysis caudata*	+	+	+	+	+	+	+	+	+	+	+	+
37	*Gonyaulax sp.*	+	–	+	+	+	+	–	–	+	–	+	–
38	*Gymnodinium sp.*	+	–	–	+	+	–	+	+	–	+	–	+
39	*Noctiluca sp.*	+	–	–	+	–	–	–	+	–	–	–	+
40	*Peridinium claudicans*	+	+	+	+	+	+	–	+	+	+	–	+
41	*Peridinium oceanicum*	–	+	+	–	–	+	+	+	+	–	+	+
42	*Trichodesmium erythraeum*	+	–	+	+	+	+	+	+	+	+	+	+

Footnote: (+: Present; -: Absent)

4.5.2 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 11 species. Cyclopoid copepod was recorded with 6 species and Harpacticoid copepod came as next dominant group with 5 species and Oligotrichea with 4 species. The Other Crustacean forms were observed with 3 species, Foraminifera and Mollusca were found 2 species from each group, Chaetognatha, 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, A. erythraea, Acrocalanus gibber, A. gracilis, Centropages furcatus, Nannocalanus minor, Paracalanus parvus, Pseudodiaptomus serricaudatus, Temora turbinate, Clytmnestra scutellata, Euterpina acutifrons, Macrosetella* sp., *Microsetella* sp., *Favella brevis, F. philipiensis, Tintinnopsis tocantinensis, T. tubulosa, Corycaeus danae, C. catus, Oithona rigida, O. similis, Oncaea venusta, Barnacle nauplii, Crustacean nauplii, Copepod nauplii, Globigernia* sp., *Globigernia bulloides* and *G. opima* were found during this survey. Mollusca, Cladocera, Decapoda and Annelida species such as *Daphina* sp., *Lucifer hanseni, Bivalve veliger, Gastropod veliger* and *Polychaete larvae*showed consistency in their occurrence in the samples collected in various stations.

Population density

The zooplankton density varied from 4,225 to 6,682Nos/m^3 with maximum at TGS-5 andminimum at TSG-2 (Fig. 45).

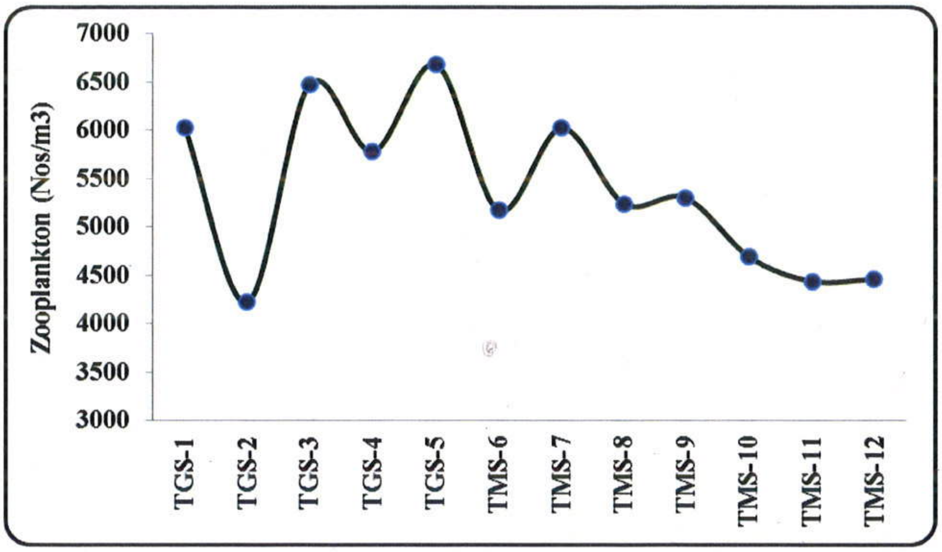


Fig. 45. Population density of zooplankton recorded in various stations of Tiruvottiyur kuppam coastal waters

Percentage composition

Calanoid copepod emerged as the dominant group by constituting 35% and followed by Cyclopoid copepod with 22%, Harpacticoid copepod and Other Crustacean forms with 13% eachand Oligotrichea with 10% each and Mollusca with 5%, Foraminifera with 4% and Annelida, Decapoda and Cladocera with 2% each and Chaetognatha 2% of the total percentage composition (Fig. 46).

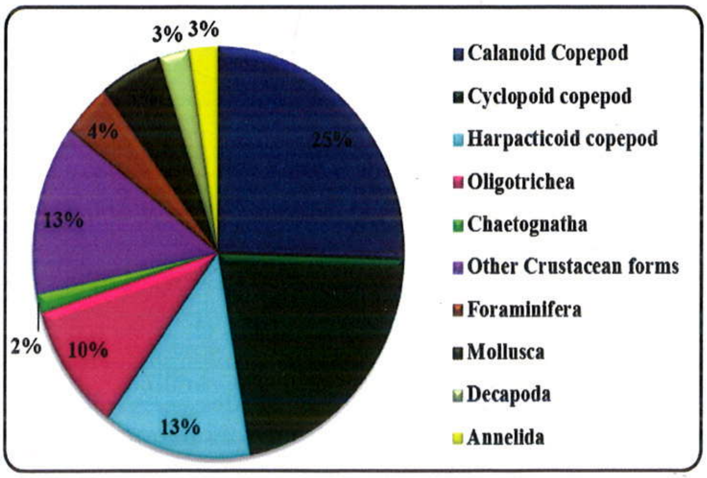


Fig. 46. Percentage composition of Zooplankton in various stations of Tiruvottiyur kuppam coastal waters

Diversity Indices

As done for phytoplankton, the zooplankton species diversity (H') varied from 2.626 to 3.763 with maximum in TGS-5 and minimum in TGS-1. The species richness (d) ranged between 4.192 and 5.684 with maximum in TGS-2 and minimum in TMS-8. The species evenness varied from 0.652 to 0.897 with the maximum in TGS-9 and minimum in TGS-2 (Table 7).

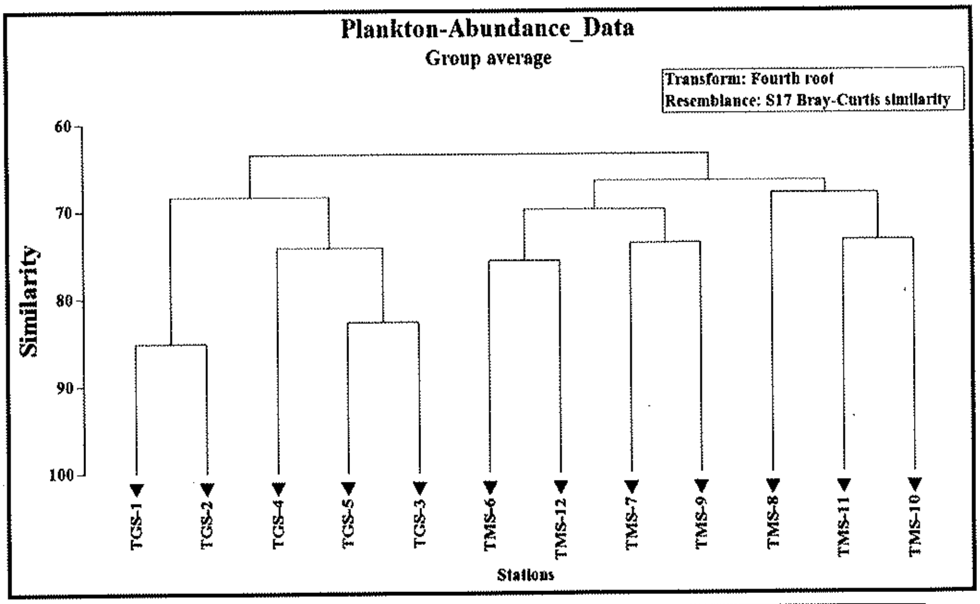
Table 7. Diversity indices, Shannon diversity (H'); Margalef richness (d) and Pielou'sevenness (J') calculated for zooplankton in Tiruvottiyur kuppam coastal waters

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
TGS-1	2.626	5.645	0.697
TGS-2	2.738	5.684	0.652
TGS-3	2.989	5.596	0.779
TGS-4	2.846	5.273	0.737
TGS-5	3.763	5.758	0.759
TMS-6	3.224	5.308	0.816
TMS-7	3.385	4.890	0.843
TMS-8	3.165	4.192	0.852
TMS-9	3.725	5.508	0.897
TMS-10	3.568	5.164	0.736
TMS-11	3.036	4.591	0.711
TMS-12	2.982	4.440	0.695

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 within the groynes TGS-1, TGS-2, TGS-4, TGS-5 and TGS-3 were forming a cluster based on the species composition and abundance. Similarly, the stations outside groynes TMS-6, TMS-12,TMS-7, TMS-9, TMS-8, TMS-11 and TMS-10 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 (0.16), 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 Tiruvottiyur kuppam Coastal Waters



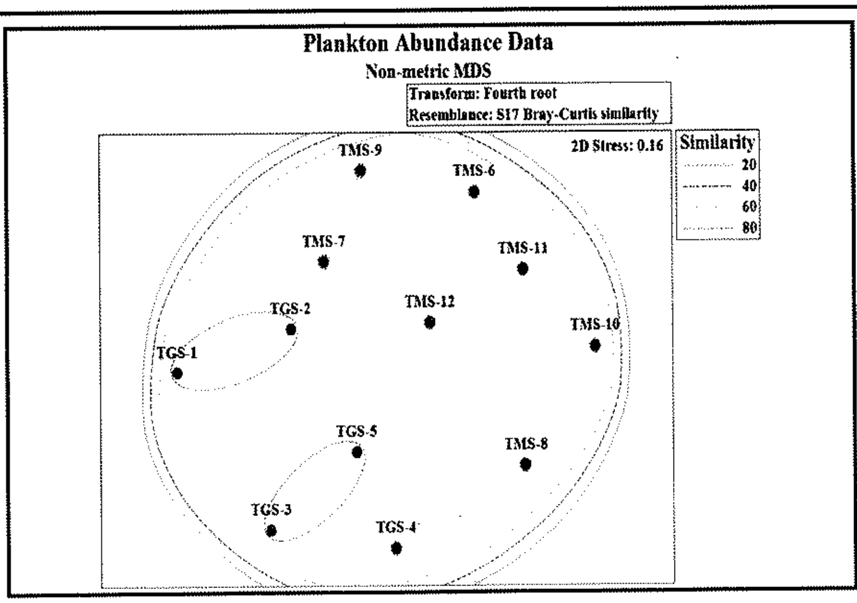


Fig. 48. MDS drawn for the Plankton abundance in various stations of Tiruvottiyur kuppam coastal waters

BIO-ENV (Biota-Environment matching)

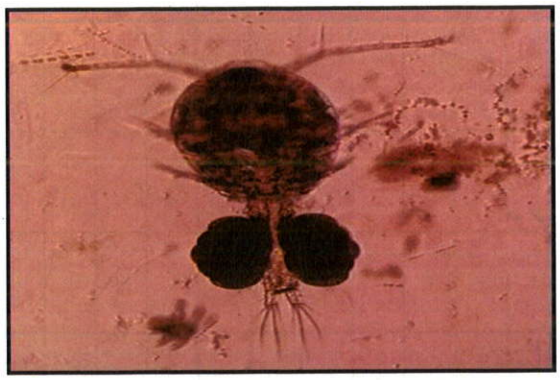
The BIO-ENV procedure was adopted to measure the agreement between the rank correlations of the biological (Bray-Curtis similarity) and environmental (Euclidean distance) matrices. To achieve this, twelve environmental variables (Primary productivity, Total nitrogen, Nitrite, Nitrate, Dissolved oxygen, Salinity, 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 8. In this case, the Dissolved Oxygen, Total phosphate, Total Nitrogen, Chlorophyll 'a', Silicate, Primary productivity and Total biomass were featured as the major variables explaining the best match (ρω= 0.896) with plankton (both phytoplankton and zooplankton) distributions. The other parameters such as Total Nitrogen, Silicate, Salinity, Chlorophyll 'a', Dissolved Oxygen and Primary productivity (ρω= 835) which also got manifested in the next best variable combinations in determining the plankton distribution in Tiruvottiyur kuppam coastal waters.

Table 8. Harmonic rank correlations (ρω) between plankton (both phytoplankton and zooplankton) abundance against environmental variables in Tiruvottiyur kuppam coastal waters

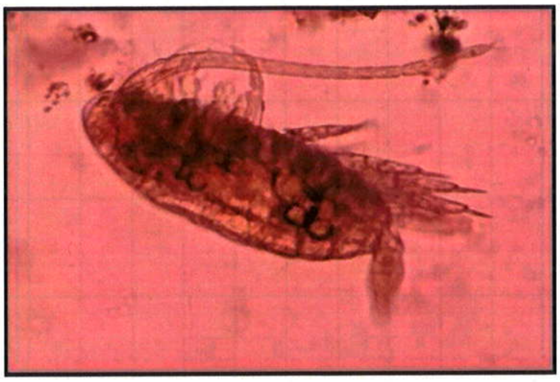
S. No.	No. of variables	Best variable combinations	Correlation(ρω)
1.	7	Dissolved Oxygen – Total phosphate – Total Nitrogen – Chlorophyll 'a' – Silicate – Primary productivity –Total biomass	0.896
2.	6	Total Nitrogen – Silicate – Salinity – Chlorophyll 'a' – Dissolved Oxygen – Primary productivity	0.835
3.	6	Total Nitrogen – Chlorophyll 'a' – Salinity – Dissolved oxygen – Inorganic phosphate – Total biomass	0.817
4.	5	Primary productivity – Chlorophyll 'a' – Total Nitrogen – Total Phosphate – Dissolved Oxygen	0.781
5.	4	Dissolved Oxygen – Primary productivity – Chlorophyll 'a' – Total biomass	0.764

PLATE-II ZOOPLANKTON

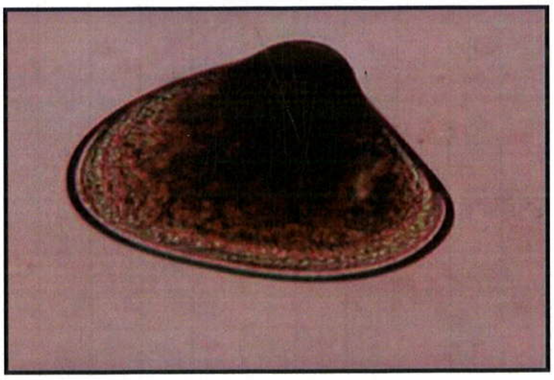
Oithona brevicornis



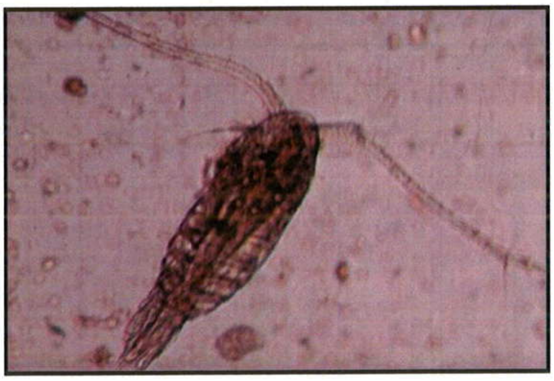
Oithona similis



Paracalanus sp



Bivalve veliger



Paracalanus parvus

Copepod nauplii

Table 9. Check list of Zooplankton species recorded from various stations of Thiruvottriyur kuppam coastal waters

S. No.	Zooplankton	TGS-1	TGS-2	TGS-3	TGS-4	TGS-5	TMS-6	TMS-7	TMS-8	TMS-9	TMS-10	TMS-11	TMS-12
1	*Acartia danae*	+	+	+	-	+	-	+	-	+	-	+	-
2	*Acartia erythraea*	+	-	+	+	-	+	-	+	-	-	+	+
3	*Acartia spinicauda*	-	+	+	+	+	-	+	+	+	+	+	+
4	*Acrocalanus gibber*	+	+	+	-	+	+	+	+	+	+	+	+
5	*Acrocalanus gracilis*	+	-	-	+	-	+	+	-	-	+	-	-
6	*Centropages furcatus*	+	+	+	+	+	+	-	+	+	-	+	+
7	*Labidocera* sp.	+	-	+	+	-	-	+	-	-	+	+	-
8	*Nannocalanus minor*	+	-	+	+	+	+	-	+	-	+	+	+
9	*Paracalanus parvus*	+	+	+	+	+	+	+	+	+		+	+
10	*Pseudodiaptomus serricaudatus*	-	-	+	+	-	-	+	-	-	+	-	-
11	*Temora turbinata*	-	+	+	-	+	+	-	+	+	-	-	+
12	*Corycaeus danae*	-	+	+	+	+	+	+	+	+	+	+	+
13	*Corycaeus catus*	+	+	+	+	+	+	+	+	+	+	+	+
14	*Oithona brevicornis*	-	-	-	+	+	+	+	+	-	+	+	+
15	*Oithona rigida*	-	+	+	-	-	+	-	+	+	-	-	+
16	*Oithona similis*	+	+	+	+	+	+	+	+	+	+	+	+
17	*Oncaea venusta*	-	-	+	+	+	-	+	-	-	-	-	-
18	*Clytemnestra scutellata*	-	-	+	+	+	+	-	+	-	-	-	+
19	*Euterpina acutifrons*	+	+	+	+	+	+	+	+	+	+	+	+
20	*Longipedia* sp.	-	+	+	-	+	+	+	-	+	+	-	-
21	*Macrosetella* sp.	+	+	+	-	+	+	+	+	+	-	+	+
22	*Microsetella* sp.	+	+	-	+	-	+	+	+	+	-	-	+

23	*Favella brevis*	+	−	+	−	+	−	+	−	−	+	+	−
24	*Favella philippinensis*	−	+	−	+	−	−	−	+	+	−	−	−
25	*Tintinnopsis tocantinensis*	+	−	+	−	+	−	+	−	+	−	−	−
26	*Tintinnopsis tubulosa*	−	−	−	+	−	+	−	+	−	+	−	−
27	Sagitta sp	+	−	+	+	+	+	+		+	+	−	−
28	Barnacle nauplii	−	−	+	−	−	+	+	+	+	+	−	+
29	Crustacean nauplii	+	−	−	+	+	+	+	+	+	+	+	−
30	Copepod nauplii	+	+		+	+	−	+	+	+	+	+	+
31	*Globigerina*sp.	+	+	+	+	+		+	+	+	+	+	−
32	*Globigerina bulloides*	−	−	−	−	−	+	+	+	+	+	−	−
33	Bivalve veliger	+	+	+	+	−	+	+	+	+	+	+	+
34	Gastropod veliger	+	+	+	+		+	+	+	+	+	+	+
35	*Lucifer hanseni*	+	−	+	+	+	−	−	+	+	+	−	−
36	Polychaete larvae	+	−	+	+	+	+	+	+	+	+	+	−

Footnote: (+: Present; -: Absent)

4.6. Benthos

4.6.1. Macro-benthos

During the present investigation, six groups of benthic organisms namely Polychaetes, Bivalves and Gastropods of organisms were recorded in various stations in Tiruvottiyur kuppam coastal waters. Among them, polychaetes constituted the dominant group followed by bivalves and gastropods. Altogether, 41 species of macro fauna were recorded from the surveyed stations. Of these, polychaetes topped the list with 29 species. Bivalves and Gastropods were found to be the next dominant group in the order of abundance with 6 species each was also recorded during the present study.

Among the polychaetes *Armandia lanceolata, Capitella capitata, Cirratulus filiformis, Cossura coasta, Euclymene annandalei, Glycera unicornis, Goniada emerita, Lumbrineris inflate, Magelona cincta, Nephtys dibranchis, Onuphis eremita, Pista indica, Prionospio cirrifera, Prionospio pinnata, Scoloplos armiger, Syllis gracilis* and *Terebellides stroemi* were found to be the most commonly occurring species in the samples collected in surveyed stations. Coming to bivalves *Donax incarnates, Gafrarium tumidum, Seapharca inaequivalves, Siliqua radiate, Circe scripta* and *Volachilamys traquebarica* and in Gastropods, *Fusinus longicaudatus, Cerithedia cingulata, Turridella attenuate, Duplicaria duplicate* and *Nassarius stolatus* were found to be the common species in the collection.

Population density

The population density varied from 450 to 975 No m^{-2} with maximum was at TMS-9 and minimum TGS-1 (Fig. 49).

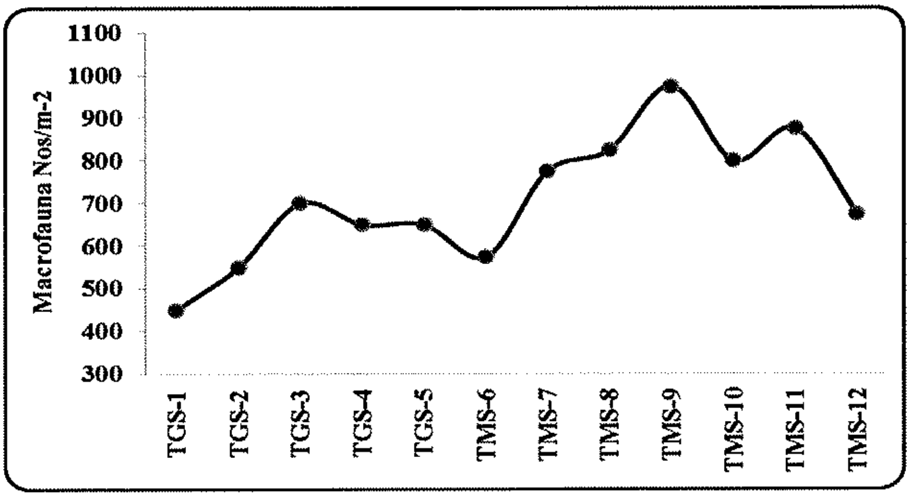


Fig. 49. Population density of Macro benthos in various stations of Tiruvottiyur kuppam coastal waters

Percentage composition

When the results of percentage composition of benthic fauna were viewed, polychaetes constituted the maximum with 73% to the total benthic organisms. Bivalves and Gastropods contributed to 15% and 12% respectively to the total benthic faunal community (Fig. 50).

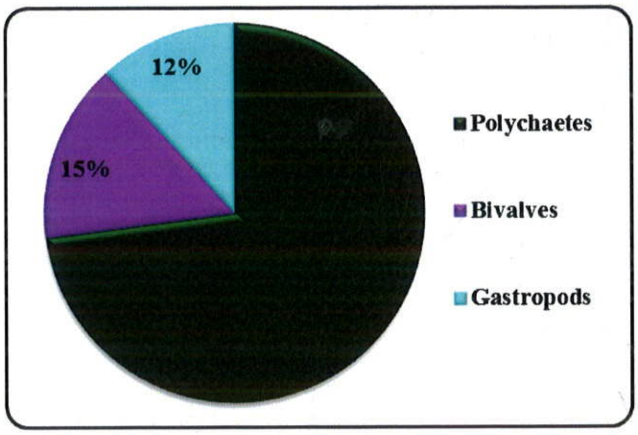


Fig. 50. Percentage composition of macro benthos in various stations of Tiruvottiyur kuppam coastal waters

Diversity Indices:

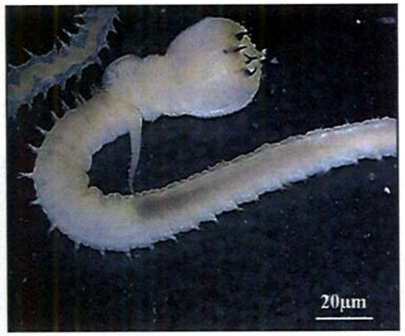
The macro-benthic species diversity (H') varied from 2.705 to 3.631 with maximum was in TGM-10 and minimum in TGS-1. The species richness (d) ranged between 4.372 and 6.687 withmaximum in TGS-3 and minimum in TMS-10. The species evenness varied from 0.639 to 0.874 with the maximum in TMS-9 and minimum in TGS-2 (Table 10).

Table 10. Diversity indices Shannon diversity (H'); Margalef richness (d) and Pielou'sevenness (J') calculated for macro benthos in Tiruvottiyur kuppam coastal waters

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
TGS-1	2.705	5.944	0.642
TGS-2	3.044	6.184	0.639
TGS-3	2.940	6.697	0.653
TGS-4	2.824	5.913	0.647
TGS-5	3.089	6.344	0.692
TMS-6	2.942	4.752	0.754
TMS-7	2.990	4.880	0.812
TMS-8	3.374	4.681	0.869
TMS-9	3.084	4.836	0.874
TMS-10	3.631	4.527	0.835
TMS-11	3.214	5.065	0.791
TMS-12	3.041	5.129	0.807

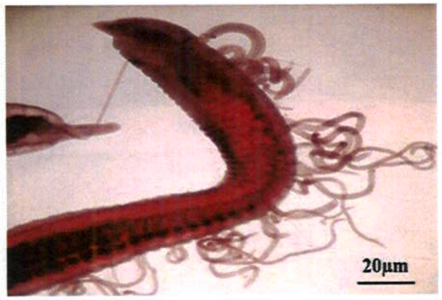
PLATE-III MACRO BENTHOSPOLYCHAETES

Diopatra sp.

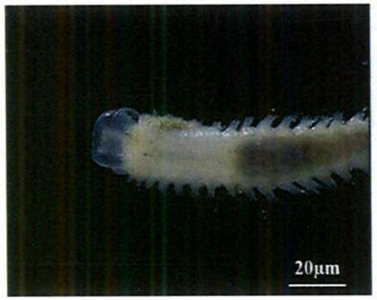


Goniada sp.

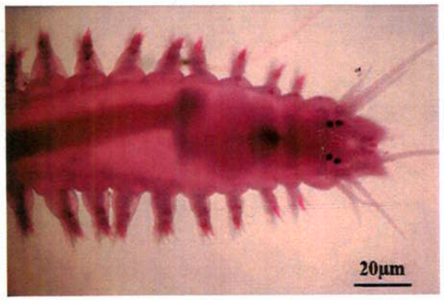
Capitella capitata



Cirratulus filiformis

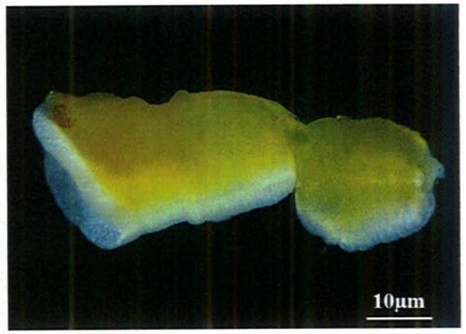


Nephtys dibranchis



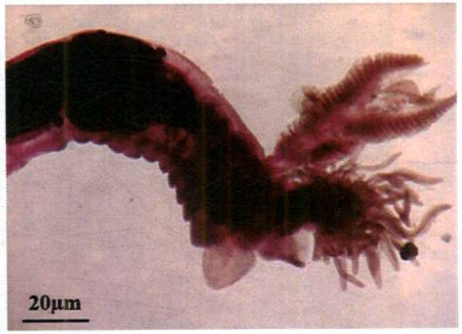
Nereis sp.

Prionospio cirrifera



Sabaco sp.

Spionidae sp.



Terebellides stroemi

BIVALVES

Scapharca inaequivalvis

Circe scripta

Donax incarnatus

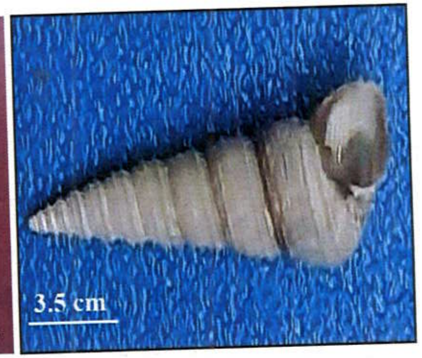
Siliqua radiata

GASTROPODS

Nassarius stolatus

Cerithedia cingulata

Fusinus longicaudatus



Turridella attenuata

Table 11. Check list of macrofauna species recorded from various stations of Thiruvottriyur kuppam coastal waters

S. No	Macrofauna	TGS-1	TGS-2	TGS-3	TGS-4	TGS-5	TMS-6	TMS-7	TMS-8	TMS-9	TMS-10	TMS-11	TMS-12
	Polychaetes												
1	*Armandia lanceolata*	-	+	-	-	-	+	-	+	-	-	+	-
2	*Capitella capitata*	+	+	-	-	+	+	+	+	-	-	+	-
3	*Cirratulus filiformis*	-	+	+	+	+	-	-	+	-	+	+	-
4	*Cossura coasta*	-	+	+	-	-	+	-	+	-	+	+	+
5	*Diopatra* sp.	-	-	+	+	+	+	-	-	+	+	-	+
6	*Euclymene annandalei*	+	-	-	+	+	-	+	-	+	-	-	+
7	*Eunice* sp.	-	-	+	-	+	-	-	+	-	+	+	+
8	*Glycera* sp.	-	+	-	-	-	+	-	+	+	-	+	-
9	*Glycera unicornis*	-	-	-	+	-	-	+	+	-	+	+	+
10	*Goniada emerita*	-	+	-	-	+	+	+	-	-	-	+	-
11	*Goniada* sp.	+	+	+	-	-	-	-	-	+	+	-	+
12	*Lumbrineris inflata*	-	+	-	-	+	-	-	+	-	-	+	+
13	*Magelona cincta*	-	-	+	-	+	-	-	-	-	+	-	+
14	*Maldane* sp.	-	-	-	-	-	-	-	+	+	-	-	-
15	*Nephtys dibranchis*	-	-	+	+	-	+	-	-	+	+	-	+
16	*Nephtys* sp.	+	+	-	-	+	-	+	+	+	-	+	+
17	*Nereis* sp.	+	+	+	-	+	-	+	-	+	+	+	+
18	*Onuphis eremita*	-	+	-	-	+	+	+	+	-	-	+	+
19	*Pista indica*	+	-	-	+	-	+	-	+	-	+	-	-
20	*Pista* sp.	-	-	+	-	-	+	-	-	+	+	+	+

21	*Prionospio cirrifera*	-	+	-	+	+	+	+	+	-	-	+	+
22	*Prionospio pinnata*	+	-	+	+	-	+	+	-	-	+	+	-
23	*Sabaco* sp.	+	+	-	+	-	+	+	+	+	-	+	-
24	*Scoloplos armiger*	-	-	+	-	-	-	-	+	+	+	-	-
25	*Sigalion* sp.	-	-	-	-	-	-	+	-	+	-	+	-
26	*Spionidae* sp.	+	+	+	+	-	+	-	+	-	+	-	+
27	*Syllis gracilis*	+	-	-	-	+	-	+	+	-	-	+	+
28	*Terebella* sp.	-	+	-	-	+	-	+	-	+	+	-	+
29	*Terebellides stroemi*	-	+	+	+	-	+	+	-	-	+	+	-
	Bivalves												
30	*Donax incarnatus*	+	-	-	+	-	+	-	-	+	-	+	+
31	*Gafrarium tumidum*	-	+	+	-	+	-	+	+	-	+	-	-
32	*Seapharca inaequivalves*	-	-	+	+	+	+	+	-	+	+	+	+
33	*Siliqua radiata*	-	-	+	-	+	-	-	+	-	+	+	+
34	*Circe scripta*	-	+	-	+	+	-	+	+	+	-	+	-
35	*Volachilamys traquebarica*	+	-	+	-	+	-	-	+	+	+	-	-
	Gastropoda												
36	*Fusinus longicaudatus*	-	+	-	+	-	+	-	+	+	-	-	-
37	*Cerithedia cingulata*	+	-	+	-	+	+	+	-	-	+	+	-
38	*Agaronia* sp.	+	+	-	-	+	+	-	+	+	-	-	+
39	*Turridella attenuata*	-	-	+	+	-	-	+	-	-	+	+	-
40	*Duplicaria duplicata*	+	+	-	-	-	-	-	-	+	-	+	-
41	*Nassarius stolatus*	-	-	-	+	+	-	+	+	+	+	-	+

Footnote: (+: Present; -: Absent) Meio-benthos:

In the present study, as many as 45 species belonging to four groups of Meio-benthic organisms namely Foraminiferans, Nematodes, Ostracodes and Harpacticoids were recorded. Among them, Foraminiferans topped the list with 27 species. Nematodes were found to be the next dominant group in the order of abundance with 8 species and Ostracods came next with 6 species and Harpacticoids with 4 species.

Among the foraminiferans, *Ammonia beccarii, A. tepida, Bolivina compacta, Discorbinella bertheloti, Elphidium texanum, Lagena lacunata, L. semistriata, Nonion depressulus, Operculina ammonoidea, Q. apicula, Q. bicarinata, Rosalina globularis, S. angulosa, Spiroloculina depressa, Thurammina cariosa* and *Trochammina inflate* were found commonly in various stations. With respect to nematodes, *Epsilonema steiner, Daptonema conicum, Astomonema jenneri, Draconema cephalatum, Neochromadora craspedota, Enoplolaimus abnormis, Halalaimus filum* and *Oxystomina clavicauda* were found to be the common species in the samples collected in various stations. The Ostracodes species such as *Basslerites liebaui, Neocytherideis senescens, Keijella reticulata, Basslerites liebaui, Paijenborchella cymbula, Eucythere argus* and in Harpacticoids, *Macrosetella gracilis, Laophonte thoracica, Cylindropsyllus laevis* and *Leptastacus mocronyx* were found to be common species in the surveyed stations.

Population density

The population density of Meio-benthic fauna varied from 158 to 276 Nos.10cm^{-2} with maximum was recorded at TMS-10 and minimum at TGS-2 (Fig. 51).

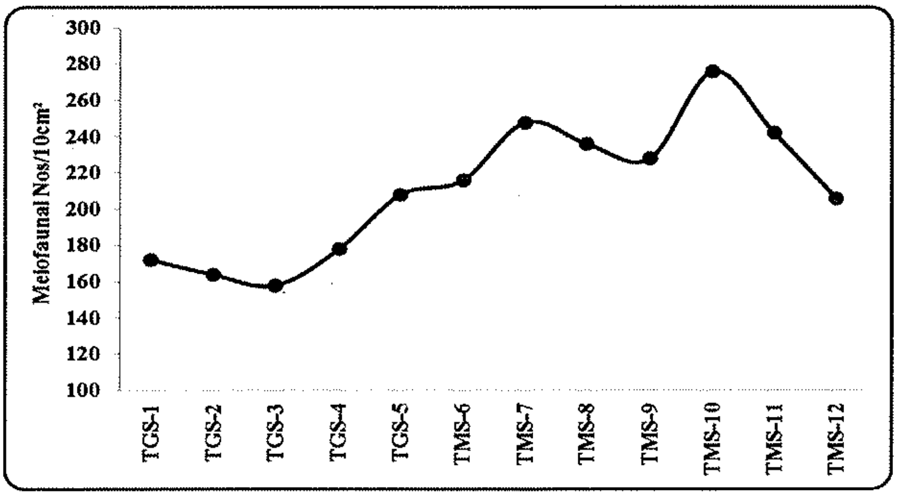


Fig. 51. Population density of Meio-fauna recorded in various stations of Tiruvottiyur kuppam coastal waters

Percentage composition:

The results of percentage composition of Meio-fauna revealed that Foraminiferans constituted maximum with 70% of the total Meio-benthic organisms. Nematodes, Ostracodes and Harpacticoids contributed with 13%, 12% and 5% respectively to the total Meio-benthic samples collected (Fig. 52).

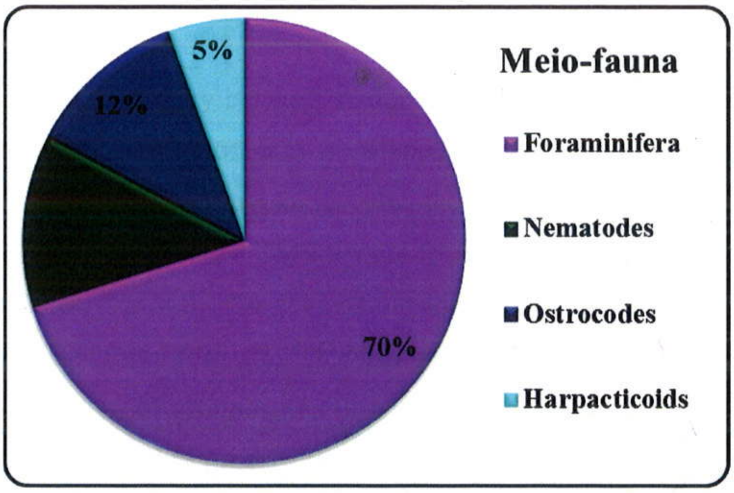


Fig. 52. Percentage composition of Meio-benthos in various stations of Tiruvottiyur kuppam coastal waters

Diversity Indices

The Meio-benthic species diversity (H') varied from 2.863 to 3.478 with maximum wasin TGS-9 and minimum in TGS-2 and similarly the species richness (d) ranged between 4.495 and 6.135 with maximum in TGS-2 and minimum in TMS-10. The species evenness varied from0.715 to 0.914 with the maximum in TMS-9 and minimum in TGS-1 (Table 12).

Table 12. Diversity indices Shannon diversity (H'); Margalef richness (d) and Pielou'sevenness (J') calculated for Meio-benthos in Tiruvottiyur kuppam coastal waters

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')
TGS-1	2.982	5.872	0.715
TGS-2	2.863	6.153	0.744
TGS-3	3.011	5.057	0.726
TGS-4	2.928	5.895	0.805
TGS-5	2.941	5.392	0.718
TMS-6	3.279	5.679	0.874
TMS-7	3.265	4.567	0.853

TMS-8	3.398	4.723	0.865
TMS-9	3.478	4.509	0.914
TMS-10	3.092	4.495	0.805
TMS-11	3.151	5.325	0.797
TMS-12	3.279	5.518	0.762

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 withinGroyne TMS-7, TMS-6, TMS-8, TMS-10, TMS-11, TMS-12, and TMS-9 were forming cluster separately based on the species composition and abundance. Similarly, the stations outside groyne TGS-1, TGS-2, TGS-3, TGS-5 and TGS-4 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 (0.14), 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).

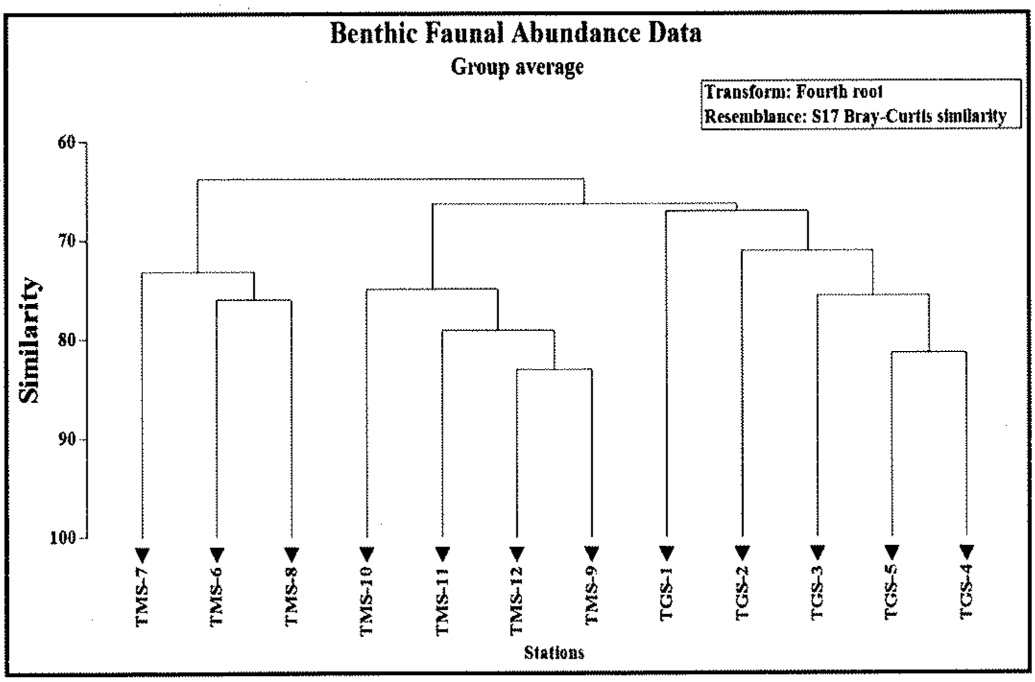


Fig. 53. Dendrogram for the benthic fauna abundance data collected in Tiruvottiyurkuppam coastal waters

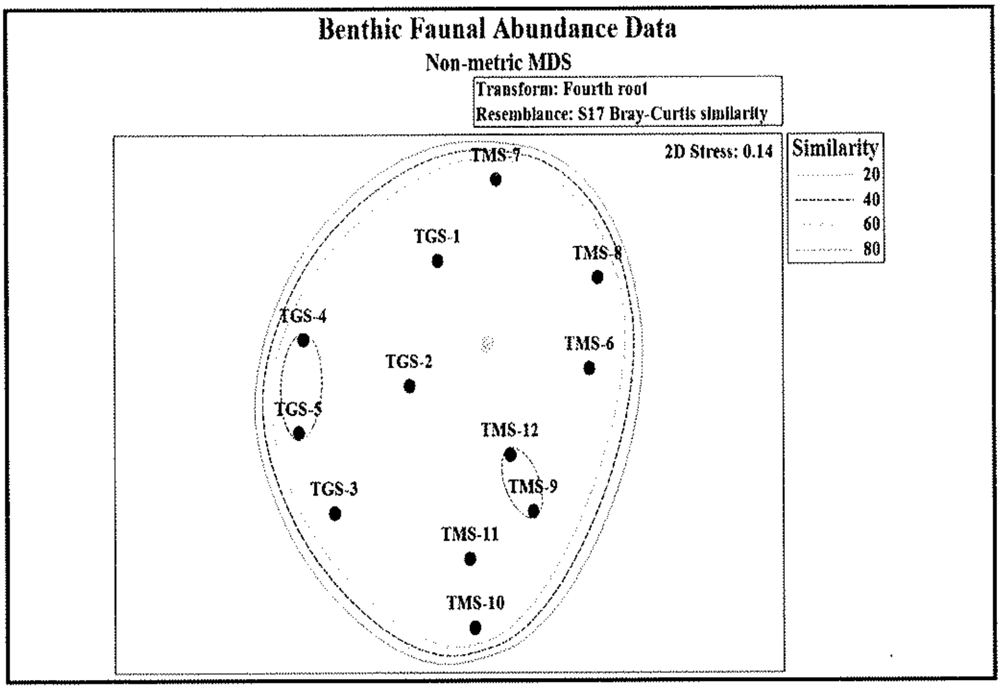


Fig. 54. MDS drawn for the benthic faunal abundance in various Tiruvottiyur kuppam coastal waters

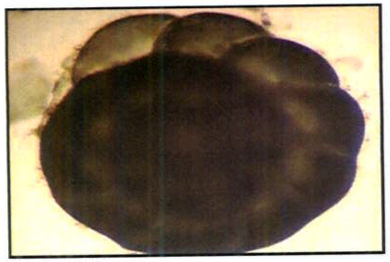
BIO-ENV (Biota-Environment matching)

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, eight environmental variables (Temperature, Salinity, Silt, Sand, Clay, DO, TOC S. pH, Evenness and Diversity) were allowed to match the biota. The results revealed that, a combination of eight environmental parameters (pω = 0.918) namely Salinity, Dissolved Oxygen, S. pH, Sand, Diversity, Evenness, Clay and TOC got manifested as best match in determining benthic faunal distribution followed by DissolvedOxygen, Clay, S. pH, TOC, Salinity, Sand, Diversity (pω = 0.873) which also got manifested as second best variable combinations, in determining the faunal distribution in the Tiruvottiyur kuppam coastal waters (Table 13).

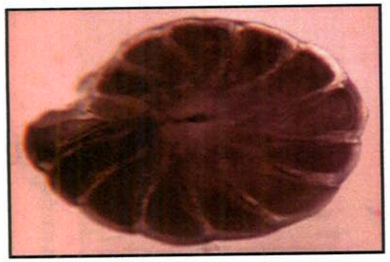
Table 13. Harmonic rank correlations (ρω) between benthic faunal (both Macro-benthos and Meio-benthos) abundance against environmental variables in Tiruvottiyur kuppam coastal waters

S. No.	No. of variables	Best variable combinations	Correlation (ρω)
1.	8	Salinity – Dissolved Oxygen – S. pH – Sand – Diversity – Evenness – Clay – TOC	0.918
2.	7	Dissolved Oxygen - Clay – S. pH – TOC - Salinity – Sand - Diversity	0.873
3.	6	Sand - TOC – Evenness – S. pH – Salinity - Dissolved Oxygen	0.841
4.	5	Clay - TOC – S. pH - Dissolved Oxygen - Salinity	0.805
5.	5	Salinity – S. pH – Clay – TOC - Evenness	0.764

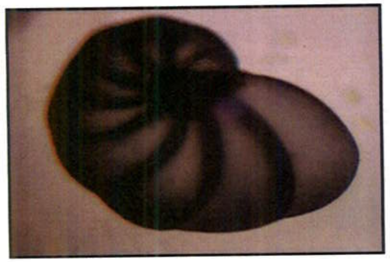
PLATE-IV MEIO-BENTHOS- FORAMINIFERANS



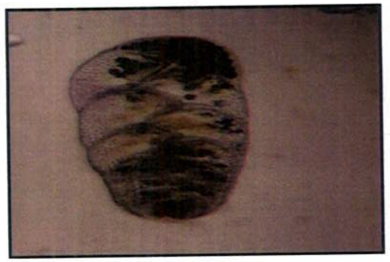
Ammonia tepida



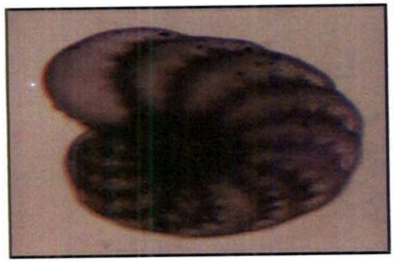
A. beccarii



Nonion depressulus



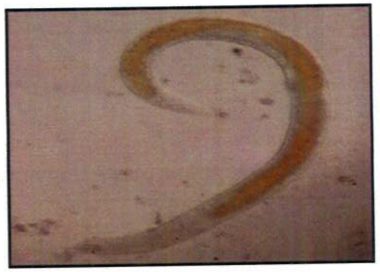
Bolivina compacta



Elphidium advenum

Spiroloculina angulosa

NEMATODES

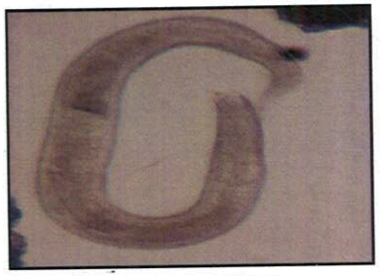


Daptonema conicum

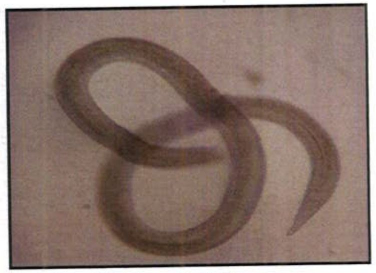
Epsilonema steiner

Neochromadora craspedota

Halalaimus filum

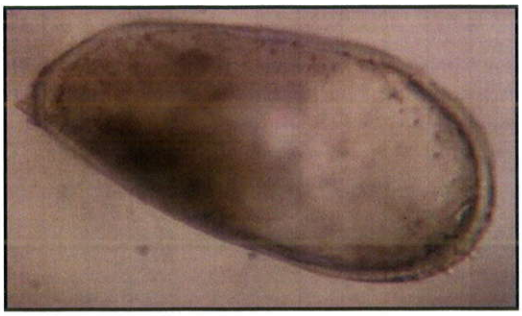


Draconema cephalatum

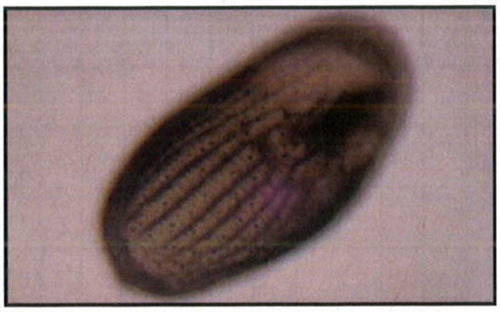


Pandolaimus latilaimus

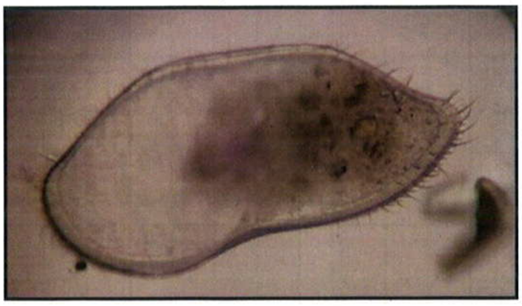
HARPACTICOIDS



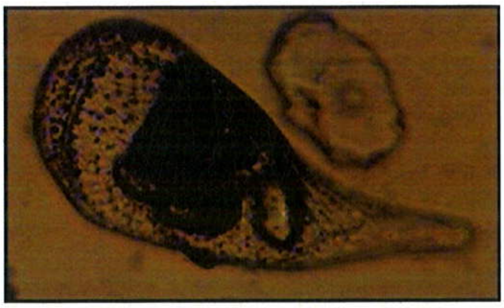
Keijella reticulata



Basslerites liebaui

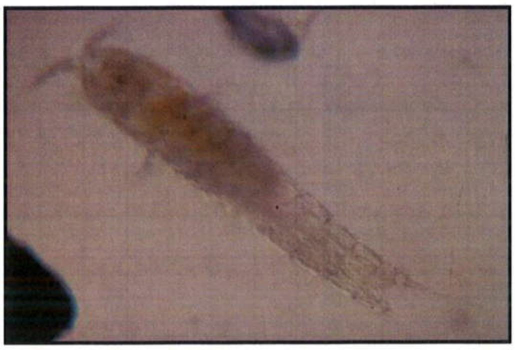


Bairdoppilata scaura



Paijenborchella cymbula

OSTRACODES



Laophonte thoracica

Cylindropsyllus laevis

Table 14. Check list of meiofaunal species recorded from various stations of Thiruvottriyur kuppam coastal waters

S. No.	Meiofauna Benthos	TGS-1	TGS-2	TGS-3	TGS-4	TGS-5	TMS-6	TMS-7	TMS-8	TMS-9	TMS-10	TMS-11	TMS-12
	Foraminifera												
1	*Ammonia beccarii*	+	+	+	+	+	+	+	+	+	+	+	+
2	*Ammonia tepida*	+	-	-	-	+	+	-	+	+	+	+	+
3	*Bolivina compacta*	-	+	+	+	+	+	+	+	+	-	+	+
4	*Bolivina hantkeniana*	+	+	+	+	+	+	+	+	+	+	+	+
5	*Cristellaria helicinoides*	-	-	-	-	+	+	+	-	+	+	+	+
6	*Cymbaloporetta bradyi*	+	+	+	+	-	+	+	-	+	+	+	+
7	*Discoanomalina semipunctata*	-	+	-	+	+	+	+	+	+	+	+	+
8	*Discorbinella bertheloti*	-	-	-	-	-	+	+	-	+	-	+	+
9	*Elphidium advenum*	+	+	-	+	+	-	+	+	-	+	+	+
10	*Elphidium subevolutum*	+	+	+	+	-	+	+	+	+	-	+	+
11	*Globigerina aequilateralis*	-	+	-	-	+	+	-	+	+	+	-	+
12	*Labrospira jeffreysi*	-	-	+	+	+	-	+	-	+	+	+	+
13	*Lagena lacunata*	+	+	+	+	+	-	+	+	+	+	+	+
14	*Lagena quadrata*	-	+	-	-	+	+	+	+	+	+	+	+
15	*Lagena semistriata*	-	+	-	+	-	-	+	-	+	-	+	-
16	*Miliolinella semicostata*	-	-	-	+	+	+	+	+	-	+	+	+
17	*Nonion depressulus*	-	+	-	+	+	+	+	+	+	-	+	+
18	*Operculina ammonoidea*	+	+	-	-	+	-	+	+	+	+	+	+
19	*Quinqueloculina apicula*	+	-	+	+	+	+	+	+	+	+	+	+
20	*Quinqueloculina bicarinata*	+	+	-	-	+	+	+	+	+	+	+	+
21	*Rosalina globularis*	+	+	+	+	+	+	+	+	+	+	+	+
22	*Rotalia cubana*	-	+	-	-	-	+	-	+	+	-	-	-
23	*Spiroloculina angulosa*	+	+	+	-	+	+	+	+	-	+	+	+
24	*Spiroloculina depressa*	+	-	+	-	+	+	+	+	+	+	+	-
25	*Textularia foliacea*	+	+	-	+	-	-	+	-	+	+	-	+
26	*Thurammina cariosa*	+	+	+	-	+	+	+	+	+	+	+	+

27	*Trochammina inflate*	+	+	+	+	+	+	+	+	-	+	+	-
	Nematodes												
28	*Epsilonema steiner*	+	+	-	-	+	-	-	+	-	+	+	-
29	*Daptonema conicum*	+	+	+	+	-	+	-	+	+	+	+	-
30	*Astomonema jenneri*	-	-	-	+	+	-	+	-	-	-	-	-
31	*Draconema cephalatum*	-	-	+	-	-	+	-	-	+	+	+	+
32	*Pandolaimus latilaimus*	+	-	-	+	+	+	+	-	-	-	+	-
33	*Neochromadora craspedota*	+	+	+	+	+	+	+	+	+	-	-	-
34	*Halalaimus filum*	+	-	+	-	-	+	+	+	-	+	+	-
35	*Oxystomina clavicauda*	+	+	+	+	+	+	+	-	+	-	+	-
	Ostrocodes												
36	*Basslerites liebaui*	-	+	+	+	-	-	-	+	+	-	+	-
37	*Neocytherideis senescens*	+	-	+	-	+	+	+	-	-	+	+	+
38	*Keijella reticulata*	-	+	+	+	+	+	+	+	+	-	+	+
39	*Basslerites liebaui*	-	-	+	-	-	-	-	+	-	+	-	+
40	*Paijenborchella cymbula*	+	+	-	+	-	-	+	-	+	+	-	+
41	*Eucythere argus*	+	+	+	+	-	+	+	-	+	+	+	+
	Harpacticoids												
42	*Macrosetella gracilis*	+	-	-	+	+	-	-	+	-	+	+	-
43	*Laophonte thoracica*	-	+	+	-	+	+	-	+	-	+	-	+
44	*Cylindropsyllus laevis*	+	-	+	+	-	+	-	+	+	+	-	+
45	*Leptastacus mocronyx*	-	+	+	+	+	+	+	+	+	+	+	-

Footnote: (+: Present; -: Absent)

4.7. Marine Underwater SCUBA survey

The present underwater marine survey was conducted on four locations around the Tiruvottiyur kuppam fishing harbour by the help of Pacific Blue Subsea services (P) Ltd. (collaborative study). The locations were selected based on the environment such as following:

1. Near to fishing boat channel path – 13° 9'55.34"N; 80°18'44.32"E
2. Fishing harbour groynes channel path – 13° 9'50.30"N; 80°18'50.41"E
3. Inside the fishing harbour – 13° 9'38.59"N; 80°18'54.27"E
4. Outside the fishing harbour – 13° 9'50.09"N; 80°19'20.13"E

During SCUBA dives at the four stations, the water temperature, salinity, and depth were recorded. Benthic photography and video recording were conducted in four locations, including the midpoint of the fishing boat's path at the harbour mouth, 500 meters away from the mouth, and both inside and outside the fishing harbour, at depths ranging from 6 to 16 meters, in order to analyse the habitat and ecological condition of the chosen harbour.

A muddy and sandy bottom with a few scattered patches of mixed seagrass, dead gastropod shells, including *Turritella* sp., and some common fish, including flathead mullet, herring, and milkfish, were also spotted during the study. Besides, tube worms, a few small fish, an octopus egg sac, small gastropods, plastic litters, one jellyfish, rock oysters, tube-dwelling worms, ascidians, and turf algae, were seen beyond the fishing harbour. The majority of the diverse marine life was spotted beyond the fishing harbour, where boat access is scarce. The common visuals taken during under water using SCUBA is shown below:

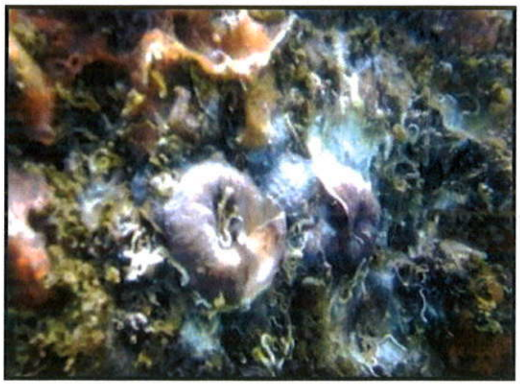
Underwater SCUBA Survey

Muddy sandy bottom

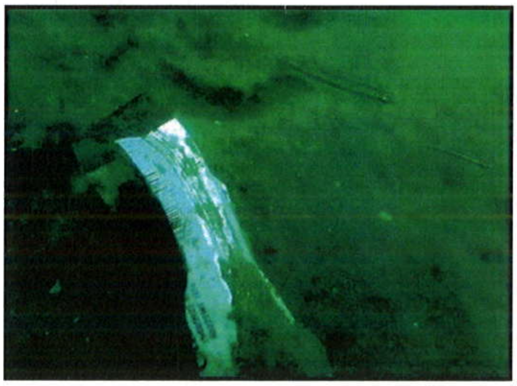
Dead shells marine bottom

Turritella sp. Gastropod

Flathead mullet fish



Tube-dwelling Worms attached groyne



Plastic litter in bottom

4.8. Other ecologically sensitive groups

4. 8. 1. Mangroves

No mangroves were recorded from the surveyed coastal stations.

4. 8. 2. Corals

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

4. 8. 3. Turtles

During the survey near Tiruvottiyur kuppam coastal waters, no organized turtle nesting ground was noticed in the sampled area.

4. 8. 4. Other Endangered Species

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

4. 8. 5. Avifauna

In the project region, no significant bird population is observed.

4. 8. 6. Seaweeds

The following seaweed species patches were found away from the surveyed stations are *Sargassumilicifolium* and *S. polycystum*

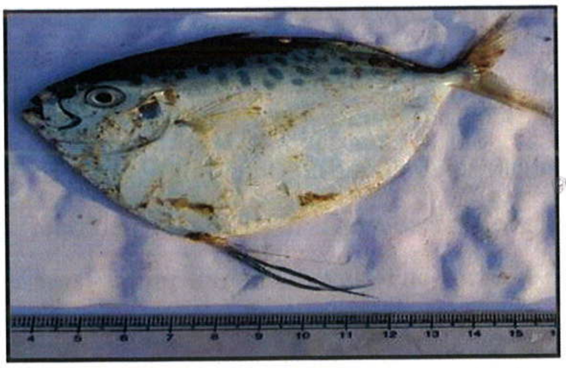
4. 8. 7. Sea grasses

During the survey scattered patches of *Syringodium isoetifolium* was found

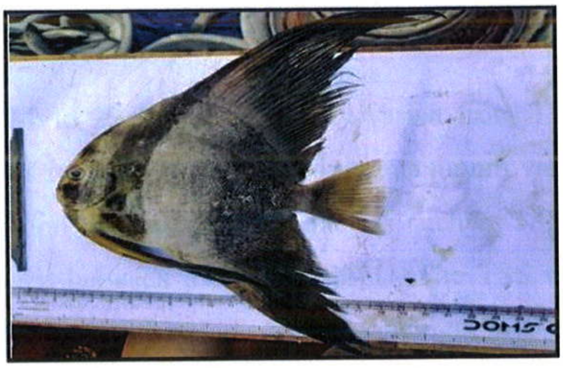
4. 8. 8. Fisheries

Selaroides leptolepis, Ariomma indicum, Coryphaena hippurus, Lethrinus nebulosus, Antennarius indicus, Mene maculate, Platax orbicularis, Xanthichthys ringens, Rhabdosargus sarba, Lates calcarifer, Trachinotus blochii, Hilisa keele, Chanos chanos, Plotosus canius, Platycephalus indicus, Leiognathus daura, Sillago sihama, Caranx sem, Lutjanus sp., *Mugil cephalus, Epinephelus tauvina, Siganus canaliculatus, Euthynnus affinis, Hemirampus far, Sardinella* sp., and *Lates calcarifer* caught using gillnets, purse-seines & bag nets. The crustacean resources like prawns, lobsters & crabs formed an important commercial catch for the local fishing community.

COMMERCIALLY IMPORTANT FISHES

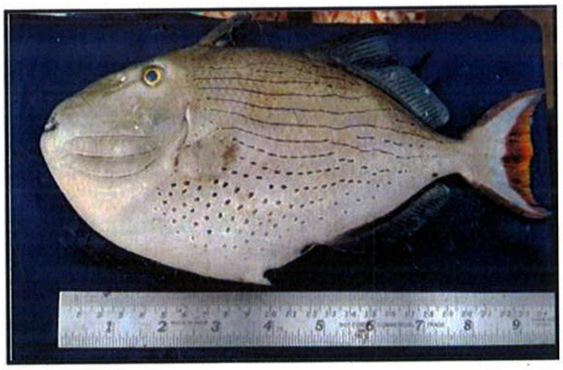


Mene maculate



Platax orbicularis

Rhabdosargus sarba



Xanthichthys ringens

Lates calcarifer

Trachinotus blochii

5. SUMMARY AND CONCLUSION

In the present survey, which lasted for two days, the physico-chemical and biological parameters were analyzed both in the water and sediment samples from predetermined (12 stations) locations of Tiruvottiyur Kuppam coastal waters. The results of various parameters are summarized below:

The surface water temperature varied from 27.2 to 29.5°C. The salinity varied from 33.5 to 35.5PPT. Hydrogen ion concentrations in surface waters remained alkaline and the maximum value of 8.3 was recorded at TMS-10. The observations made on the key physical factors such as TSS and turbidity was within the safe level. The turbidity ranged between 3.8 and 8.4NTU. The TSS values fluctuated from 71.20 and 135.20 mg/l. The maximum TSS and turbidity values were at TGS-2 and minimum at TMS-9. 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 4.495 and 6.265mg/l, with the maximum DO level was recorded at TMS-10 and the minimum was recorded at TGS-2. The DO concentration remained fairly well within the prescribed limit of water quality. The BOD level was found to be ranged from 1.03 and 2.38mg/l with the maximum BOD was observed at TMS-10 during this survey.

In the present investigation, the ammonia concentration ranged between 0.035 to 0.111mg/l. The concentration of nitrite fluctuated from 0.099 to 0.32mg/l. The nitrate values ranged from 0.18 and 0.56mg/l and the total nitrogen varied between 1.51 to 2.23mg/l. The inorganic phosphate ranged from 0.056 and 0.078mg/l. The observed total phosphorus values ranged between 0.193 to 0.361mg/l. The silicate concentration ranged from 7.20 and 9.49mg/l. The particulate organic carbon values ranged from 0.07 and 0.13 mg/l respectively.

In the present survey, Petroleum Hydrocarbon in water varied between 0.000306 and 0.000498mg/l. with higher concentration at station TGS-2. The total organic carbon content varied from 6.35 and 9.76mgC/g with the maximum was at TGS-4 and minimum at TMS-8. The present survey showed that the Petroleum hydrocarbon relatively higher in sediment than the water and the values ranged from 0.468 to 0.889mg/kg. The maximum was recorded at TGS-2 andthe minimum was recorded at TMS-9 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 (1166.23 to 1965.20µg/g) compared to iron concentration in water (0.010 to 0.117mg/L). The maximum was recorded at TGS-2 and the minimum was recorded at TMS-9. 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 theinter-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, sand and Mn got correlated with stations TGS-5, TGS-3 TGS-2, TGS-1, TMS-6, TMS-8 and TMS-9 while the rest of the parameters showed strong correlation with stations TMS-10, TMS- 11, TMS-12, TMS-7 and TGS-4 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 1.053 to 2.804 mg/m^3, with maximum at TGS-3 and minimum at TMS-12. The Phaeopigments content varied from 1.107 to 2.475 mg/m^3 with maximum was at TGS-3 and the minimum was observed at TMS-9. The Total biomass values varied from 1.968 to 5.803 ml/100m^3, with maximum at TGS-4 and minimum at TMS-10. The primary productivity was measured using the dark and light reaction method. The values ranged from 114.15 to 168.72mgCm^{-3}d^{-1}. The maximum value was recorded at TGS-5 and minimum value at TMS-

10. Density of phytoplankton varied from 6,905 to 20972 Cells/l with maximum was at TGS-4 and minimum at TGS-2. In the present study, as many as 42 phytoplankton species belonging to three major groups namely Bacillariophyceae (Diatom), Dinophyceae (Dinoflagellates) and Cyanophyceae (Cyanobacteria) were recorded in Thiruvottiyur kuppam coastal area. Of these, Bacillariophyceae were found to be the dominant group with 30 species, Dinophyceae formed next group with 11 species and Cyanophyceae with one species.

The phytoplankton species diversity (H') varied from 2.988 to 3.643 with maximum at TMS-8 and minimum at TGS-2. The species richness (d) ranged between 4.824 and 6.233 with maximum at TGS-2 and minimum at TMS-9. The species evenness varied from 0.545 to 0.892 with the maximum at TGS-3 and minimum at TMS-9.

The zooplankton density varied from 4,225 to 6,682Nos/m^3 with maximum at TGS-5 and minimum at TSG-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 11 species. Cyclopoid copepod was recorded with 6 species and Harpacticoid copepod came as next dominant group with 5 species and Oligotrichea with 4 species. The Other Crustacean forms were observed with 3 species, Foraminifera and Mollusca were found 2 species from each group, Chaetognatha, Decapoda and Annelida were recorded with 1 species each of total zooplankton abundance.

With regard to diversity indices, the zooplankton species diversity (H') varied from 2.626 to 3.763 with maximum was in TGS-5 and minimum in TGS-1. The species richness (d) ranged between 4.192 and 5.684 with maximum in TGS-2 and minimum in TMS-8. The species evenness varied from 0.652 to 0.897 with the maximum in TGS-9 and minimum in TGS-2.

The abundance data of phytoplankton and zooplankton were amalgamated and subjected to classification and ordination methods. The resulting dendrogram revealed that the stations within the groynes TGS-1, TGS-2, TGS-4, TGS-5 and TGS-3 were forming a cluster based on the species composition and abundance. Similarly, the stations outside groynes TMS-6, TMS-12,TMS-7, TMS-9, TMS-8, TMS-11 and TMS-10 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 stress value (0.16), 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. 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 Dissolved Oxygen, Total phosphate, Total Nitrogen, Chlorophyll 'a', Silicate, Primary productivity and Total biomass were featured as the major variables explaining the best match (□□= 0.896) with plankton (both phytoplankton and zooplankton) distributions. The other parameters such as Total Nitrogen, Silicate, Salinity, Chlorophyll 'a', Dissolved Oxygen and Primary productivity (□□= 835) which also got manifested in the next best variable combinations in determining the plankton distribution in Tiruvottiyur kuppam 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 estuarineenvironments (Juggins, 1992; Hassan *et al.*, 2007).

The population density varied from 450 to 975 No m-2 with maximum was at TMS-9 and minimum TGS-1. During the present investigation, six groups of benthic organisms namely Polychaetes, Bivalves and Gastropods of organisms were recorded in various stations in Tiruvottiyur kuppam coastal waters. Among them, polychaetes constituted the dominant group followed by bivalves and gastropods. Altogether, 41 species of macro fauna were recorded from the surveyed stations. Of these, polychaetes topped the list with 29 species. Bivalves and Gastropods were found to be the next dominant group in the order of abundance with 6 species each was also recorded during the present study.

The macro-benthic species diversity (H') varied from 2.705 to 3.631 with maximum in TGM-10 and minimum in TGS-1. The species richness (d) ranged between 4.372 and 6.687 with maximum in TGS-3 and minimum in TMS-10. The species evenness varied from 0.639 to 0.874 with the maximum in TMS-9 and minimum in TGS-2.

Regarding meiobenthic organisms, the population density of Meio-benthic fauna varied from 158 to 276 Nos.10cm^{-2} with maximum was recorded at TMS-10 and minimum at TGS-2. Inthe present study, as many as 45 species belonging to four groups of Meio-benthic organisms namely Foraminiferans, Nematodes, Ostracodes and Harpacticoids were recorded. Among them, Foraminiferans topped the list with 27 species. Nematodes were found to be the next dominant group in the order of abundance with 8 species and Ostrocods came next in the order with 6 species and Harpacticoids with 4 species.

The Meio-benthic species diversity (H') varied from 2.863 to 3.478 with maximum was in TGS-9 and minimum in TGS-2 and similarly the species richness (d) ranged between 4.495 and 6.135 with maximum in TGS-2 and minimum in TMS-10. The species evenness varied from 0.715 to 0.914 with the maximum in TMS-9 and minimum in TGS-1.

The cluster/dendrogram revealed that the stations within groyne TMS-7, TMS-6, TMS-8, TMS-10, TMS-11, TMS-12, and TMS-9 were forming cluster separately based on the species composition and abundance. Similarly, the stations outside groyne TGS-1, TGS-2, TGS-3, TGS-5 and TGS-4 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 (0.14), 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 procedure indicated that the combination of eight environmental parameters ($p\omega = 0.918$) namely Salinity, Dissolved Oxygen, S. pH, Sand, Diversity, Evenness, Clay and TOC got manifested as best match in determining benthic faunal distribution followed by Dissolved Oxygen, Clay, S. pH, TOC, Salinity, Sand, Diversity ($p\omega = 0.873$) which also got manifested as second best variable combinations, in determining the faunal distribution in the Tiruvottiyur kuppam 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 under water survey, only dead molluscan shells and a few dead Sea grass species were recorded. During survey, not even single pieces of corals were noticed in the project location.

With respect to ecologically sensitive groups, the occurrence of Corals, Turtle nesting ground and any endangered species like Sea horse, *Olive ridley* turtle, Indian otter, Salt water crocodile etc., were not noticed from the surveyed stations.

As regards fish population, *Mene maculate, Xanthichthys ringens, Trachinotus blochii, Hilisa keele, Chanos chanos, Sillago sihama, Euthynnus affinis, Mugil cephalus & Lates calcarifer* were the most frequently landed commercial fishes, and they were captured using gillnets, purse-seines, and bag nets. The crustacean resources like prawns, lobsters & crabs also formed an important commercial catch for the local fishing industry. There is no national park, wildlife sanctuary and biosphere reserve within 10 km radius of the proposed project site.

Further, diversity indices calculated for the plankton and benthic data in the present studyclearly indicated the fairly undisturbed nature of the environment since diversity values of plankton and benthos were found to be more than 3.05 in the study area as have been stated by the ecologist Sanders (1968).

Further, the results of physico-chemical and biological parameters indicated that thewater 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 sedimentsamples 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 marine Biodiversity survey made during 23rd to 25th February 2023 in Thiruvottiyur kuppam coastal waters and careful perusal of available secondary information suggested that the water quality parameters are within the safe level and did not indicate any alarming effect on the existing biological components. The observations on other ecologically sensitive organismsreflected the patchy occurrence of a few groups especially sea grass and seaweeds from the nearby regions, which is away from the proposed site.

From the ecological point of view, the proposed structure will have very marginal impact on biota during both pre-operational and operational phase but such impacts are confined to a limited period and a confined region, as most of the marine organisms are capable of recouping themselves quickly to its original state and thus there will not be any pronounced change/variations to the biotic community. Therefore, based on the biodiversity survey conducted and also under water SCUBA survey, the proposed facility can be initiated. At the same time, the present marine survey was done only short period, continuous monitoring is needed even after commissioning of this proposed facility by the reputed Marine Biology Institute like Centre of Advanced Study in Marine Biology, Annamalai University with a view to ascertain the temporal variations in the Physico-chemical and biological components of this environment and thereby a suite of mitigation measures could be suggested.

IMPACT, MITIGATIONAND MANAGEMENT PLAN

Based on the primary data and also appending with secondary data, the Comprehensive Marine Environmental Impact Assessment (CMEIA) has come to the conclusion that:

Coastal habitats may be silted due to groyne construction and land reclamation,

Variation in surface water quality may occur during both the construction and operation phases,

Oil pollution is one of the environmental hazards resulting from port/harbour and shipping operations. This includes bilge oil released from commercial trawlers handling non-oil cargo as well as the more common threat from oil tankers.

Parameters	Impact	Mitigation
Turbidity	Murky waters might lead to lesser intertidal faunal population	With due course of time post construction, turbidity levels will come to normal level
Oil spill due to harbour operation	Oil spills can cause barrier between surface water and atmosphere and inflammable in nature	Oil Spill control measures as per International Convention for the Prevention of Pollution from Ships (MARPOL) 1974/1978, Consolidated Edition, IMO, 1991, including 1992 amendments to Annex 1 and 2002 amendments.
Dredging	Disturbances in floral and faunal habitat	As most of the benthic organisms are capable of recouping themselves quickly, the diversity will come back to normalcy
Substrate loss	Shoreline decrease	Implementation of Shoreline Protection Techniques such as sand by passing
Nutrients and Heavy metals	High nutrients leading to bloom; metals leading to toxicity	Minimalistic amount; will ward off with due course of time; metal concentrations will be dispersed within 2 months post construction.

WATER QUALITY MAINTENANCE AND PROTECTION TO MARINE ORGANISMS

→ Turbidity levels will be maintained as to the baseline data by continuous monitoring and proper care by way of stopping the activities whenever there is increase in turbidity

→ Oil Spill control measures will be adopted.

→ Marine environmental monitoring as per environmental monitoring programme

→ Dredge Management Programme (DMP) together with the Environmental Monitoring and Management Plan (EMMP), and the Biosecurity Management Plan (BMP), shall include measures to avoid entrapment of macro marine fauna.

→ Regular Interactions shall be initiated with the fishing community and conflicts, if any with fishing community shall be amicably resolved in all cases.

→ Shoreline Protection Techniques such as Sand by passing if any will be carried.

→ The fluctuations in the parameters are due the construction and shall ward off in due course of time. However the immediate spike in the values won't affect the present biodiversity conditions of the shoreline as already the construction is being carried out in the intertidal/ splash zone.

→ The present marine survey was done only for a short period, seasonal monitoring (post-monsoon, summer, pre-monsoon and monsoon) is a pre-requisite even after commissioning of this proposed facility. This will ascertain the temporal variations in the Physio-chemical and biological components of this environment and thereby further suites of mitigation measures could be suggested.

BIOSECURITY MANAGEMENT (BMP) SOP

→ Understanding the site.

→ Identifying activities which risk introducing invasive non-native species.

→ Biosecurity control measures.

→ Short and accessible Contingency plan.

→ Reviewing the implementation of the plan.

IN-SHORE OIL SPILL MANAGEMENT SOP

→ Eliminate source of spill by closing leakage, up righting containers that might cause spills, closing valves or similar actions.

→ Prevent further spread of the spill by creating suitable barriers all around the spill.

→ Use absorbents immediately to absorb majority of the spill starting at the periphery and gradually proceeding towards the centre of the spill.

→ Use skimmers to eliminate further remnant of the spill

→ In case the spill seeps to the bottom, excavating of the bottom substrate and replacing it with similar substrate is recommended.

TAMIL NADU BIODIVERSITY BOARD
(A statutory, autonomous & regulatory body of the Government of Tamil Nadu)

Dr. Shekhar Kumar Niraj, IFS.,
Principal Chief Conservator of
Forests & Secretary

TBGP Campus, II Floor
Velachery-Tambaram Main Road
Nanmangalam, Medavakkam Post
Chennai-600 100, Tamil Nadu
Tel: 044-22782730
Email: secy.tnbb@tn.gov.in
Website: https://www.tnbb.tn.gov.in

Ref. No. TNBB/799/2023/B1, Dated: 25.08.2023

To,
Mr.M.Murugesan, M.Tech., MBA.,
Executive Engineer,
Fishing Harbour Project Division,
Chennai – 35.

Sir,

Sub: TNBB – Fisheries and Fishermen Welfare – Construction of Tuna Fishing Harbour at Thiruvottriyurkuppam in Thiruvallur District – Conducting Detailed Marine Biodiversity Management Plan – Report submission – reg.

Ref: Your letter No. DB/D1/C.25(1)/2021 dated: 17.07.2023

******

With respect to the report- Marine Biodiversity for Tuna Fishing Harbour Thiruvottiyur Kuppam, Tiruvallur district, Chennai Central Team, Tamil Nadu (report by Centre of Advanced Study in Marine Biology) from the Fishery Department on Ennore project. You are requested to clarify the following points to this office in order to take further action to issue necessary clearance from Tamil Nadu Biodiversity Board.

1. The biodiversity study is based on two days of data collection which appears inadequate for an assessment on the biodiversity.
2. Two-day-alone data collection does not reflect the seasonality pattern which is so important for understanding the wildlife movement pattern.
3. Current status of the project
4. Raw data have not been provided which the Board would want in order to understand the analysis and interpretation.

Yours faithfully,

Principal Chief Conservator of Forests & Secretary,
Tamil Nadu Biodiversity Board.

ANNEXURE 6

COMPREHENSIVE REPORT (Three Seasons) ON THE MARINE BIODIVERSITY SURVEY FOR TUNA FISHING HARBOUR AT THIRUVOTTRIYURKUPPAM, THIRUVALLUR DISTRICT, CHENNAI, TAMIL NADU

Research Team

Dr. P. MURUGESAN

Associate Professor & Principal Investigator

Annamalai University

Research Scholars

Dr. R. Punniyamoorthy

Dr. K. Manimaran

Mr. P. Chandrasekaran

Ms. Sasmita Swain

Mrs. R. Raguna

ANNAMALAI UNIVERSITY

Centre of Advanced Study in Marine Biology

Faculty of Marine Sciences

Parangipettai - 608 502

Tamilnadu

February 2024

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Dr. P. MURUGESAN, M.Sc., Ph.D
ASSOCIATE PROFESSOR
C.A.S. in Marine Biology
Faculty of Marine Sciences
Annamalai University
Parangipettai - 608 502
Tamil Nadu, India

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Centre of Advanced Study in Marine Biology
Faculty of Marine Sciences
Parangipettai - 608 502
Tamilnadu

February 2024

MARINE BIODIVERSITY SURVEY FOR TUNA FISHING HARBOUR
THIRUVOTTRIYUR KUPPAM, THIRUVALLUR DISTRICT, CHENNAI, TAMIL NADU

1. Preamble

The coastal area, adjoining the north of the Chennai Port has been adversely affected by continued erosion due to the development of the port. Since several developmental activities such as advent of industries, improvement of fisheries, etc. a groyne field was constructed stretching from Royapuram to northwards and the sea wall stretch of about 10 km length lying parallel to Ennore High Road to combat the erosion problems. A proposal was further mooted to expand existing groynes to form a fishing harbor. Accordingly, the Fisheries Department, Govt. of Tamilnadu requested the Department of Ocean Engineering, IIT Madras to revise/revive the proposed layout and perform numerical model studies to validate the same. Therefore, the layout was revised and subjected to tranquility and shoreline evolution studies. Thiruvallur District is historically known for its fishery resources and community living and presently it has a fishermen population of around 50,000 in the stretch of 25 Km that includes North Chennai. The project location is historically known for fishery resources and a strong fishermen settlement and more precisely, with a fishery harbor at about 3.5Km south as a landmark facility of Chennai since long time

The proposed Tuna Fishing Harbour is a flag ship program of Government of Tamil Nadu which intended to create exclusive facilities to enhance Tuna catch and processing the same to add value to benefit the fishing community of the project location, Thiruvottriyur Kuppam, Chennai. The proposed fishing harbour facility is intended principally to ease out the congested Chennai Fishing Harbour as it is overflowing with more traffic and fishing activities. At times, there is an acute shortage of space to anchor the boats inside the harbour. The proposed

Harbour location is about 3.5Km North from the Chennai Fishing Harbour which will provide location advantage and flexibility in harbour operation and fishing activities. Accordingly, the Department of Fisheries was mandated to enhance the harbour facilities. The project is much needed to improve the socio economic status of the local fishing community of more than a lakh in the North Chennai Zone of Tamil Nadu.

The project location is historically used by the local fishermen community and only in the recent past the coastline got eroded and it was then provided with groynes which were subsequently extended as a field with 13 numbers of groynes. It is evident that the project shoreline of about 10km stretch has been stabilized and with sand by passing over groynes over the years, the beach line has been restored and now, the project coastline is showing features of stabilization with accretion of sand and restored shoreline. The proposed harbour, as it is very close to Chennai Fishing Harbour, will serve as an extended harbour facility of it and intended to promote Tuna catch & processing. At present, from the Chennai Fishing Harbour, there are about 300 boats are operating exclusively to venture deep into the Bay of Bengal to catch tuna and bring in about 1,000 tonnes every month. Under these circumstances, the project proponent has been mandated to study marine biodiversity potential of the project site by a reputed Institute/University.

During Environmental Clearance by the Ministry of Environment, Forests & Climate Change, it was insisted that the physico-chemical and biological parameters of the Coastal environs bordering the Tuna fishing harbour, Thiruvottriyurkuppam have to be monitored continuously at least seasonal intervals so as to understand the impact of port activities on the biodiversity potential of the area, if any, and also to have time series data on the same, by a reputed University/Institute.

Accordingly subject Experts from the Centre of Advanced Study in Marine Biology, Annamalai University, Tamilnadu was engaged to carry out seasonal Marine Ecological feasibility survey during 23rd to 25th February 2023 representing post-monsoon season; 27th to 28th July 2023 representing summer season and during 18th to 19th December 2023 representing monsoon season at Thiruvottiyur kuppam coastal waters and altogether three seasonal sampling was made. During survey, sea water, sediment and biological samples (plankton, benthos, microbiological and other ecologically important flora and fauna, if any) were collected from 12 different stations from the proposed sites. In addition to marine biodiversity survey, under water SCUBA survey was done by engaging Pacific Blue Subsea services (P) Ltd. The results of three seasons are given in a comprehensive and comparative manner. The latitude and longitude of the sampling stations are given in Table 1 and also in Map (Fig.1).

Table 1. Sampling stations and their geographical Co-Ordinates in Thiruvottiyur kuppam coastal waters

S. No.	Stations Code	Latitude	Longitude
1.	TGS-1	13°9'58.80"N	80°18'39.15"E
2.	TGS-2	13°9'52.98"N	80°18'35.17"E
3.	TGS-3	13°9'41.92"N	80°18'36.69"E
4.	TGS-4	13°9'48.90"N	80°18'42.45"E
5.	TGS-5	13°9'55.34"N	80°18'44.32"E
6.	TMS-6	13°10'3.92"N	80°18'42.96"E
7.	TMS-7	13°9'58.41"N	80°18'53.14"E
8.	TMS-8	13°9'50.30"N	80°18'50.41"E
9.	TMS-9	13°9'50.09"N	80°19'20.13"E
10.	TMS-10	13°9'38.59"N	80°18'54.27"E
11.	TMS-11	13°9'31.19"N	80°18'41.43"E

12.	TMS-12	13°9'34.84"N	80°18'31.45"E

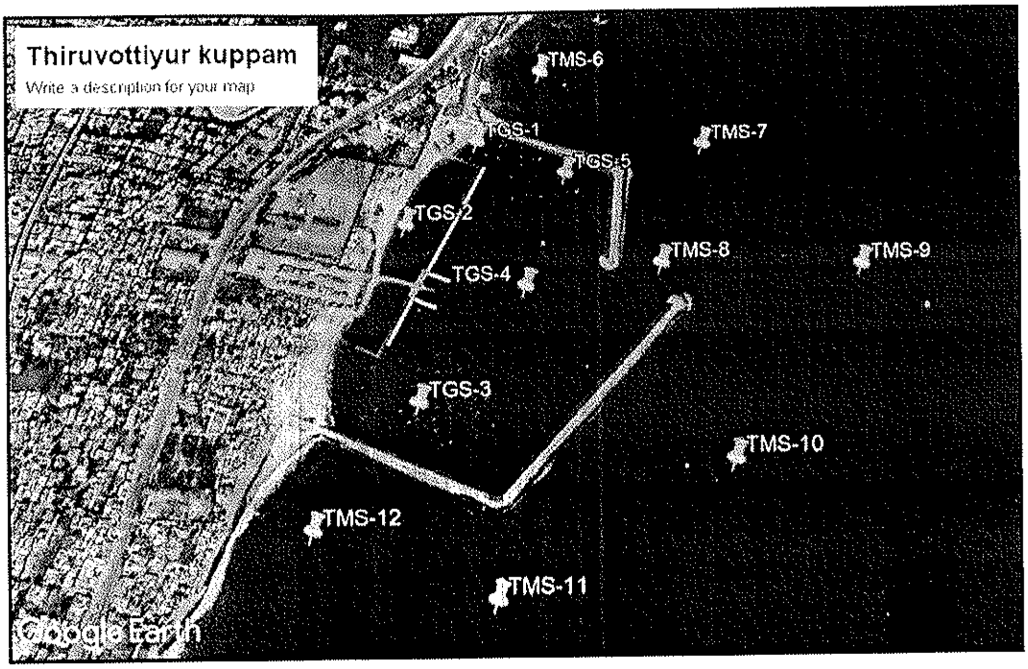


Fig. 1. Map showing the stations in Thiruvottiyur kuppam coastal waters

RESEARCH TEAM

MATERIALS AND METHODS

Water and Sediment Sampling

For collecting water and sediment samples, the Standard sampling methodologies were adopted during three seasons and the details of the sampling protocol for both physico-chemical and biological parameters are given below:

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 andrepeat 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 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.

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.

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.

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 analyzed 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 mol ofNitrogen/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 Hydrocarbons

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

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.

Microbiology methods

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 sterilized 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.

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 24 to 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 petridishes and re-streaked in appropriate nutrient agar plates thrice before a pure culture was established in agar slants.

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.

Pigments concentration

Chlorophyll 'a':

The samples were filtered through Whatman GF/C filter papers and the chlorophyll was extracted into 90% acetone. The resulting coloured 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.

Plankton community

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).

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.

Benthic Community:

Macro fauna

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 Muruganantham *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).

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).

Cluster Analysis

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)

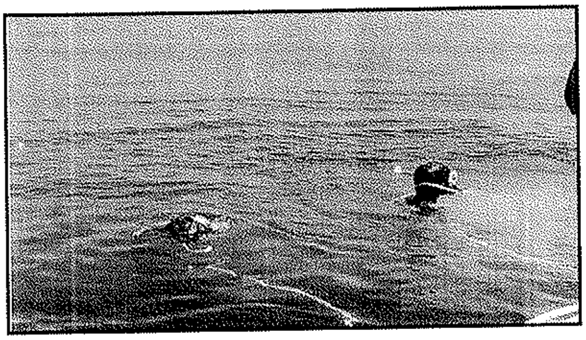
This method was proposed by Shepard (1962) and Kruskal (1964). To confirm the clustering pattern, this was used to find out the similarities (or dissimilarities) between each pair of entities to produce a 'map', which would ideally show the interrelationships of all.

BIO-ENV procedure

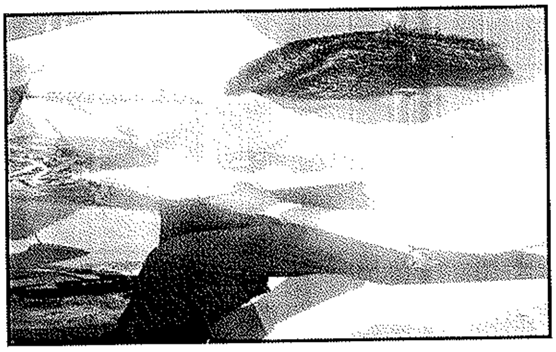
In the present study, to ascertain the relationship between biological and environmental variables, the BIO-ENV procedure (Clarke and Ainsworth, 1993) was employed. The basic principle behind this is to measure the agreement between the rank correlations of the biological (Bray-Curtis similarity) and 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 AND ACTIVITIES

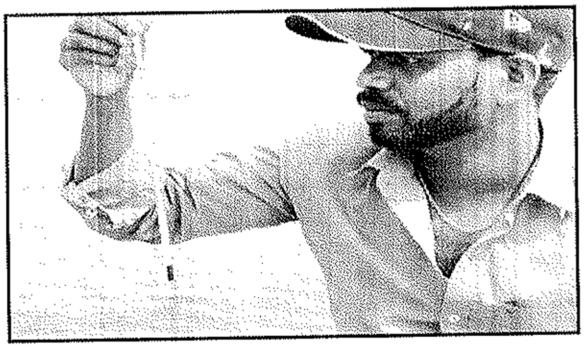
Near Thiruvottriyur Kuppam Fishing Harbor



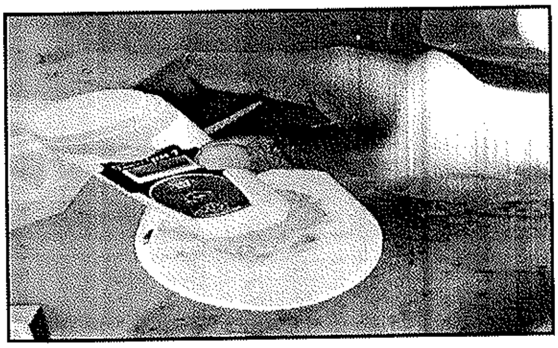
Biological sample collection by SUBA diving method



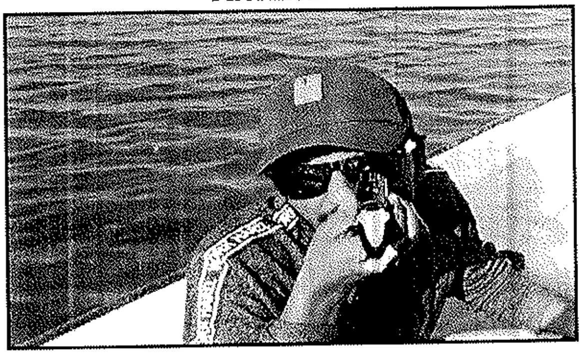
Locating sampling points by using GPS



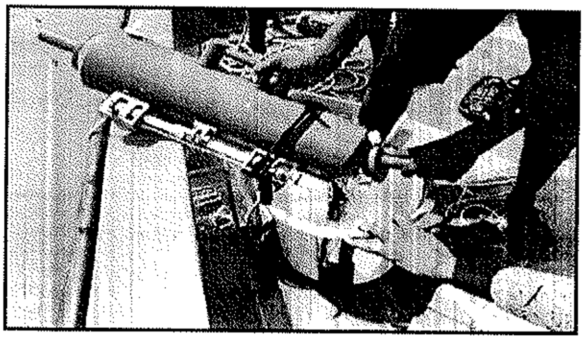
Temperature measurement by using Thermometer



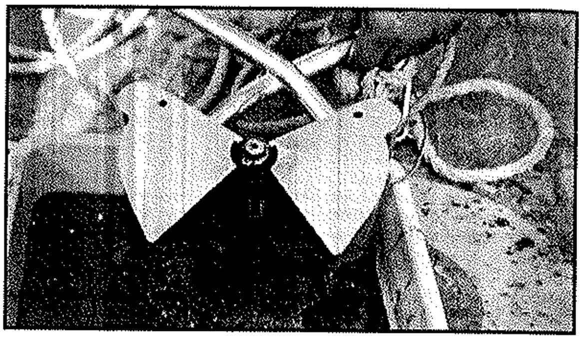
pH measurement by using pH pen



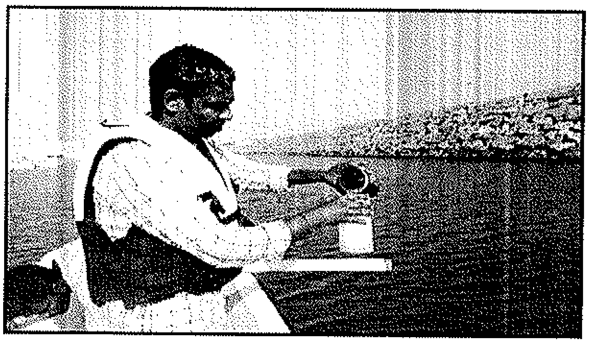
Salinity measurement by using Refractometer



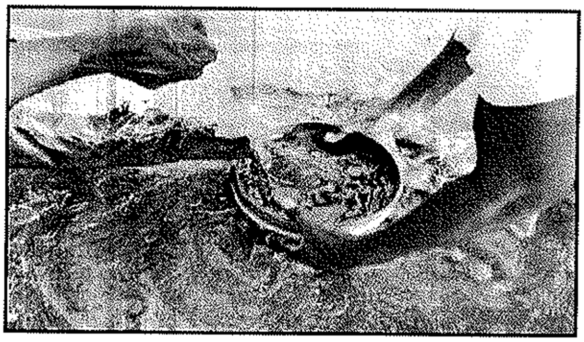
Sub-surface water sample collection by using Niskin water sampler



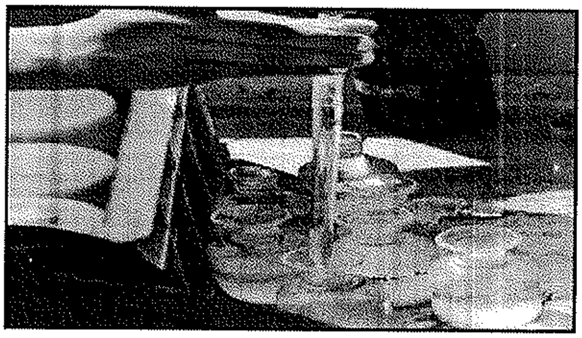
Sediment sample collected using Van-Veen Grab



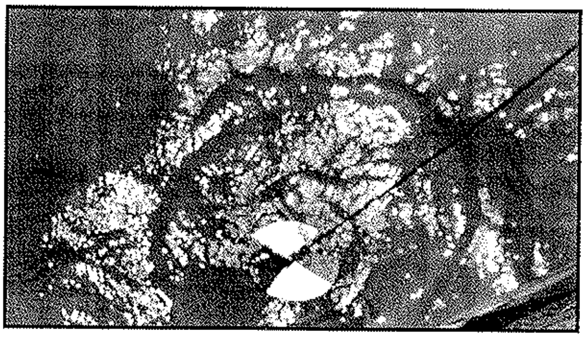
Plankton sample collection by using plankton net



Sieve retains-benthic samples



DO estimation by following Winkler's method



Vertical transparency measurement by using Secchi disc

OBSERVATIONS

Physical parameters

In the present survey, which was done in three seasons during 23rd – 25th February 2023 (post-monsoon season); during 27th – 28th July 2023 (summer season) and during 18th – 19th December 2023 (monsoon season) at Kattupalli coastal waters, the physico-chemical and biological parameters were analyzed both in the water and sediment samples collected from 12 stations at Thiruvottriyur Kuppam coastal waters. The physico-chemical parameters studied did not fluctuate much except a few parameters which showed only marginal variations. The results of various parameters are summarized below: The surface water temperature varied from 27.2 (pre-monsoon) to 30.7°C (post-monsoon) and the salinity varied from 32.08 (monsoon) to 35.5PSU (summer). Hydrogen ion concentrations in surface waters remained alkaline and the maximum value of 8.3 was recorded at stations near marine zone (TMS-10) during summer. Among the seasons, the level of temperature, salinity and pH showed peak during summer and trough during monsoon. The observations made on the prime physical factors such as TSS and turbidity was within the permissible level. The turbidity ranged between 3.8 (post-monsoon) and 14.84 NTU (monsoon). The TSS values fluctuated from 48.8 and 142.4 ppm with maximum values was recorded at stations near shore (TGS-4) and minimum at TMS-9 during monsoon season. The variation noticed between the stations is only marginal, which might be due to seasonal, geographical location and tidal influence.

Chemical parameters

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 4.009 to 6.67 mg/l, with the maximum DO level was recorded at stations near outside groyne region (TMS-9) during monsoon and the minimum was recorded at station within the inside groynes region (TGS-2) during summer. The DO concentration remained fairly well within the prescribed limit of water quality. The BOD level was found to vary from 1.02 to 3.54 mg/l with the maximum value was observed at near shore station (TGS-2) during post monsoon and minimum at groyne inside region during monsoon.

With respect to nutrients, the level of total nitrogen (25.29μmol/l), total phosphorus (4. 81μmol/l), silicate (27.28μmol/l) and particulate organic carbon (142.46μgC/l) were found maximum at near groyne inside stations (TGS-1) during monsoon and the minimum at stations near marine zone (TMS-9) during post monsoon season. Petroleum Hydrocarbon in water sample varied between 0.306 and 0.962μg/l with higher concentration at station within the groyne inside station (TGS-1) during monsoon and the minimum was at stations near marine zone (TMS-9) during post-monsoon season. The total organic carbon content varied from4.18 to 9.97mgC/g with the maximum at near groyne inside station (TGS-5) during monsoon and minimum at outside groyne station (TMS-9) during summer.

Heavy metal concentration

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 sedimentary iron was found to be high (1028.98 to 1965.24μg/g) compared to that of water (10.43 to 21.73μg/L). The maximum values were recorded at station within the groynes inside stations (TGS-1) during post-monsoon and the minimum was recorded at station near groynes outside region (TMS-9) during monsoon. 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 Clay and Sand percentage was higher during this survey. 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.

Principle component analysis

The PCA plot drawn indicated that water parameters such as DO, Salinity, pH, BOD, W.PHC, TSS, Turbidity, Nutrient parameters namely NO_2, NO_3, TN, SiO_3 and POC showed significant correlation with the surveyed stations. The stations TGS-5, TMS-8, TMS-10, TMS-9 TMS-12, TMS-11, TMS-7 and TMS-6 got strong correlation with parameters such as Temperature, salinity, pH, DO, BOD, IP, NO_2, SiO_3, TN, POC, TP, water PHC and water Pb during summer and post-monsoon season while the stations TGS-1, TGS-2, TGS-3 and TGS-4 had negative correlation with other parameters during monsoon season.

Phytopigments and plankton

In the present study, the chlorophyll '*a*' in water sample varied from 1.014 to 3.468 mg/m^3, with maximum was at stations groyne outside region (TGS-4) during summer and minimum at station (groyne inside region) (TGS-1) during monsoon. The Phaeopigments content (1.107 to $3.836 mg/m^3$) showed maximum at TGS-3 during summer and minimum at TMS-9 during post monsoon. Total biomass (1.573 to 6.218) was found maximum at stations near marine zone (TGS-4) during monsoon and the minimum was observed in station within groyne outside station (TMS-10) during summer. The primary productivity values ranged from 114.15 to $172.49 mgCm^{-3}d^{-1}$ and the maximum value was recorded at stations near groyne inside station

(TGS-4) during monsoon and minimum value at stations near groyne outside region (TMS-10) during post-monsoon.

Phytoplankton

With respect to phytoplankton, the population density varied from 3,964 to 20,972Nos/l with maximum at near groyne inside station (TGS-4) during post-monsoon and minimum at near groyne inside station (TGS-2) during monsoon. In the present study, species belonging to three groups namely diatoms, dinoflagellates and blue greens were recorded. Altogether, a total of 71 species has been recorded during three seasons and of this, monsoon season registered the maximum species (55) followed by post-monsoon (46) and pre-monsoon (42) season. Among three groups of organisms, diatoms were found to be the dominant group with 48 species in various stations. Dinoflagellates formed next group with 19 species and blue green algae came last in the order with 4 species in various stations.

Statistical analysis

Univariate techniques

The data collected on phytoplankton species were subjected to various diversity indices. The species diversity (H') varied from 2.203 to 3.743 with maximum at stations near groyne outside region (TMS-10) during summer and minimum at stations near groyne inside station (TGS-2) during monsoon. The species richness (d) ranged between 4.372 and 6.879 with maximum at stations near groyne inside station (TGS-1) during summer and minimum at stations near groyne outside station (TMS-8) during monsoon. The species evenness varied from 0.545 to 0.957 with the maximum at stations near groyne outside station (TMS-10) during summer and minimum at stations near groyne inside region (TGS-4) during monsoon.

Zooplankton

Coming to zooplankton, the density varied from 322 to 6,682 Nos/m^3 with maximum at stations near marine zone (TMS-9) during post-monsoon and minimum at stations within the groyne inside region (TGS-2) during monsoon. During the study period, 3 groups of macro zooplankton namely, calanoids, cyclopoids, and harpacticoids and 2 groups of micro zooplankton namely, spirotricha and larval forms and group "others" were recorded.

Overall, a total of 45 species has been recorded during three seasons. Among the seasons, postmonsoon registered maximum number of species (38) followed by summer (34) and monsoon (32) seasons. Of the above said groups, Calanoida were found to be the dominant group with 17 species. Spirotricha and Larval forms came as next dominant groups with 7 species each. Cyclopoida, group "Others" and harpacticoida came next in the order with 5, 5 and 4 species respectively.

Statistical analysis

Univariate technique

As done for phytoplankton, the zooplankton species diversity (H') varied from 2.301 to 3.763 with maximum at stations near groyne outside region (TMS-10) during summer and minimum at stations groyne inside region (TGS-3). The species richness (d) ranged between 3.592 and 6.658 with maximum in stations near groyne inside region (TGS-4) during monsoon and minimum in stations near groyne outside region (TMS-10) during summer. The species evenness varied from 0.613 to 0.976 with the maximum in station near groyne outside region (TMS-9) during summer and minimum in stations near groyne inside region (TGS-3) during monsoon season.

Multivariate technique

Cluster & MDS analysis (Phytoplankton and Zooplankton-Combined)

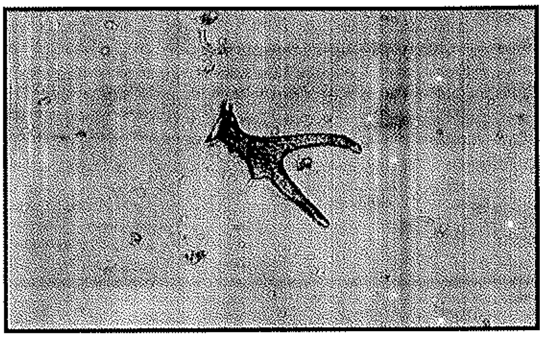
The abundance data of phytoplankton and zooplankton were amalgamated and subjected to classification and ordination methods. The resulting dendrogram revealed that the stations outside groynes TMS-11, TMS-9, TMS-10, TMS-7, TMS-8, TMS-6 and TMS-12 were forming a cluster based on the species composition and abundance. Similarly, the stations within the groynes TGS-1, TGS-4, TGS-5, TGS-3 and TGS-2 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 stress value (0.16), 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.

BIO-ENV (Biota-Environment matching)

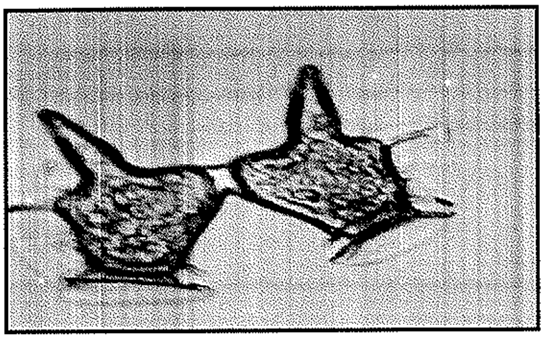
The BIO-ENV procedure was adopted to measure the agreement between the rank correlations of the biological (Bray-Curtis similarity) and environmental (Euclidean distance) matrices. To achieve this, twelve environmental variables (Primary productivity, Total nitrogen, Nitrite, Nitrate, Dissolved oxygen, Salinity, Chlorophyll 'a', Silicate, Inorganic phosphate, Total phosphate, ammonia, pH and Temperature) were allowed to match the biota.

In this case, the Salinity, Dissolved Oxygen, Total phosphate, Total Nitrogen, Chlorophyll 'a', Silicate, Primary productivity and Total biomass were featured as the major variables explaining the best match ($\rho\omega = 0.915$) with plankton (both phytoplankton and zooplankton) distributions. The other parameters such as Total Nitrogen, Total phosphate, Silicate, Salinity, Chlorophyll 'a', Dissolved Oxygen and Primary productivity ($\rho\omega = 872$) which also got manifested in the next best variable combinations in determining the plankton distribution in Tiruvottiyur kuppam coastal waters.

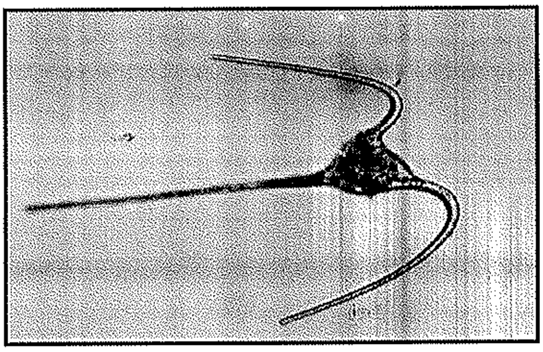
PLATE -I COMMON PHYTOPLANKTON SPECIES



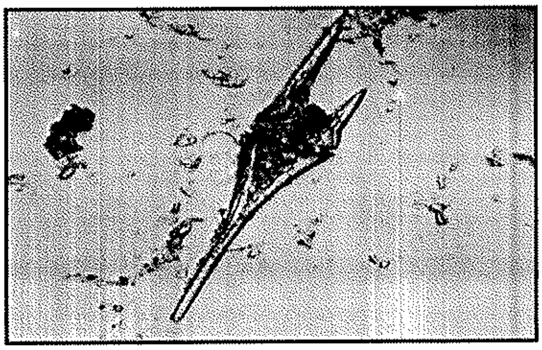
Dinophysis puncata



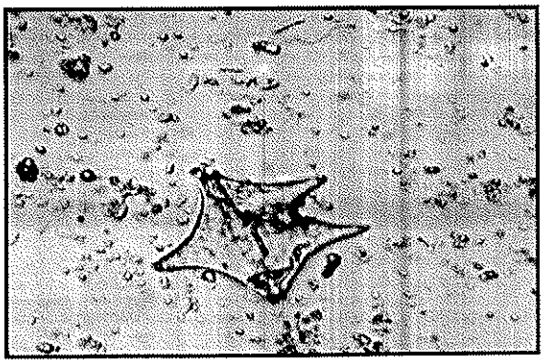
D. caudata



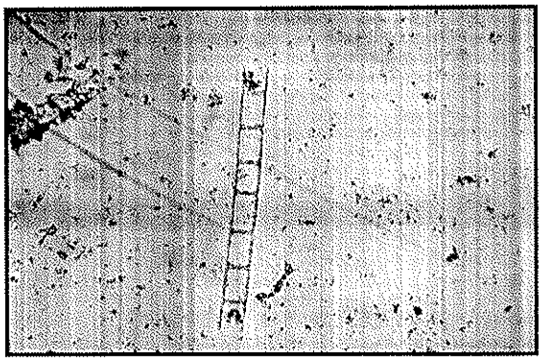
Ceratium macroceros



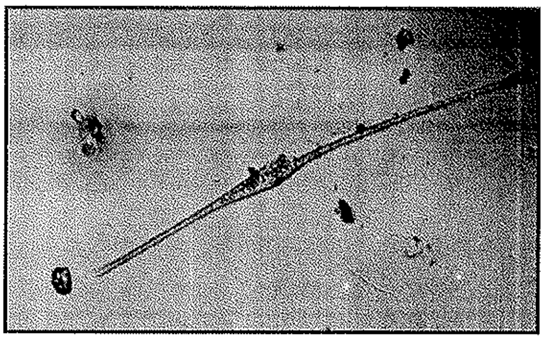
C. furca



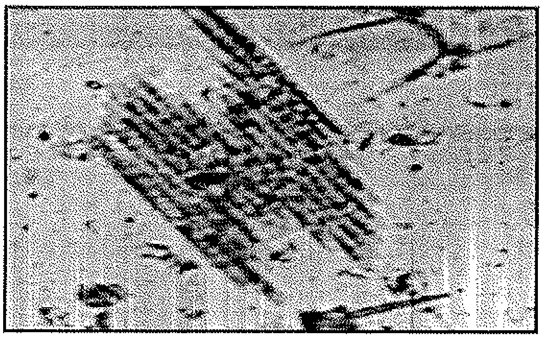
Protoperidinium divergens



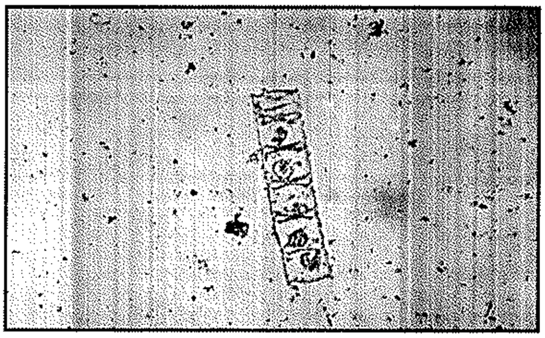
Leptocylindrus danicus



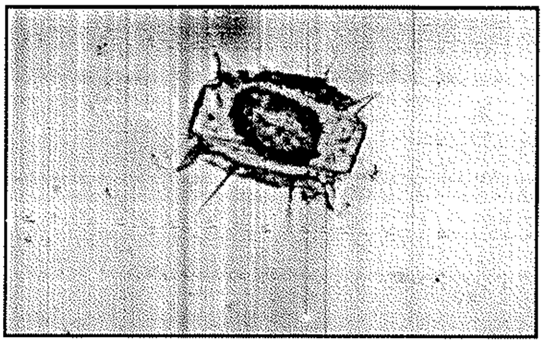
Nitzschia closterium



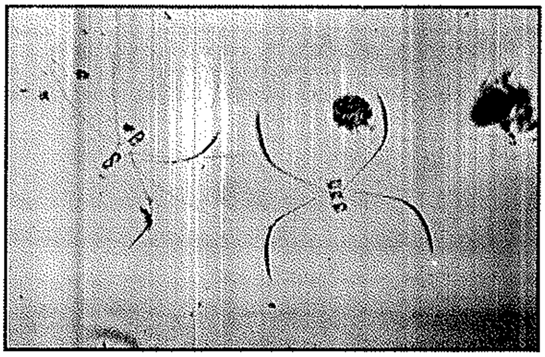
Bacillaria paradoxa



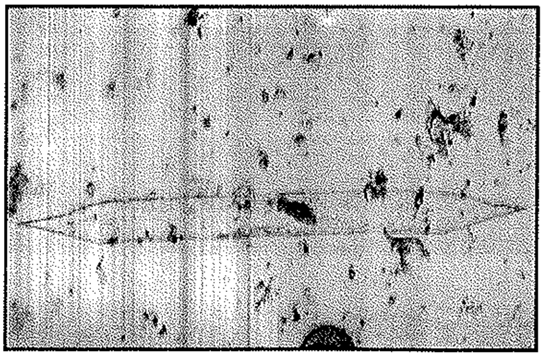
Bellerochea malleus



Biddulphia biddulphina

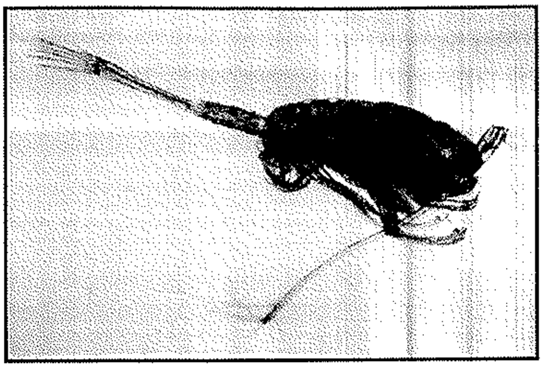


Chaetoceros diversus

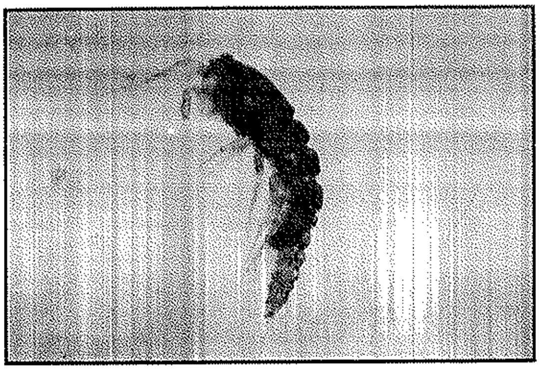


Rhizosolenia alata

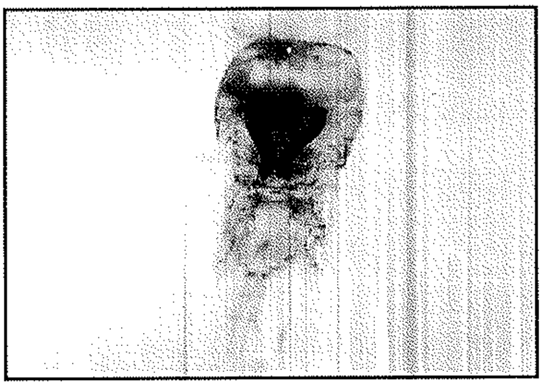
PLATE -II COMMON ZOOPALNKTON RECORDED



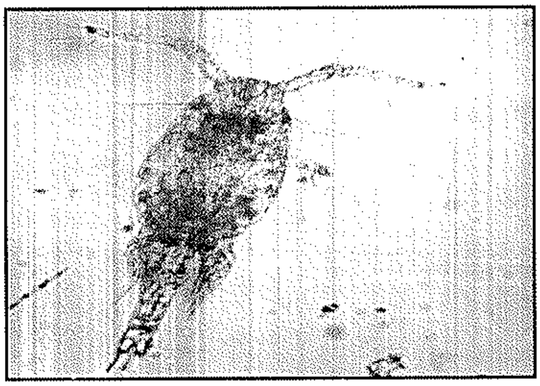
Tortannus barbatus



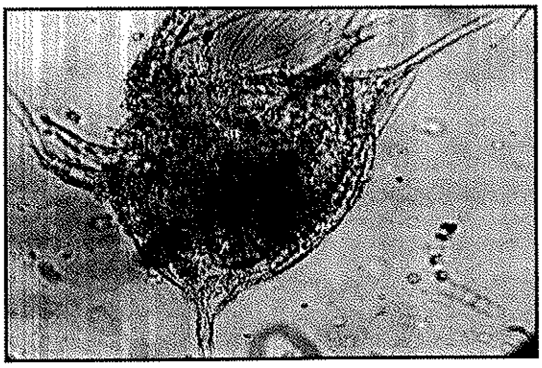
Clytmnestra scutellata



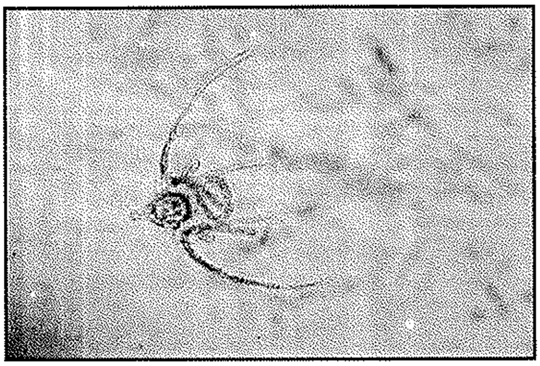
Corycaeus catus



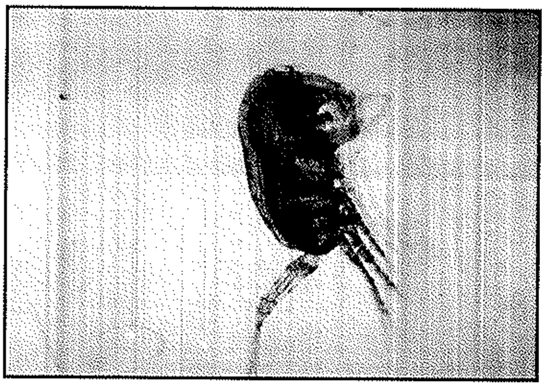
Oithona brevicornis



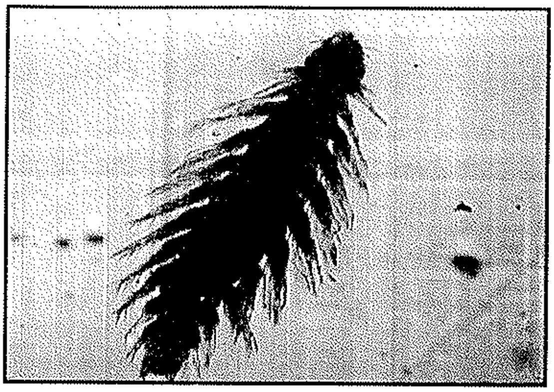
Barnacle nauplii



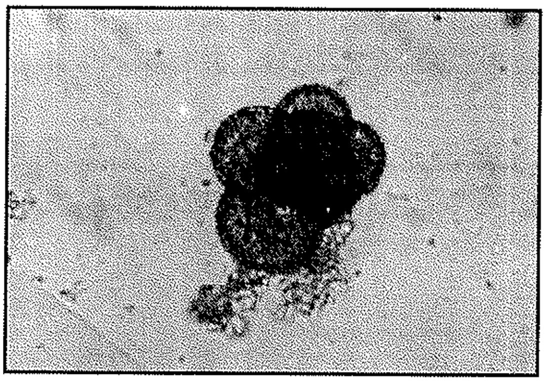
Ophiothrix larva



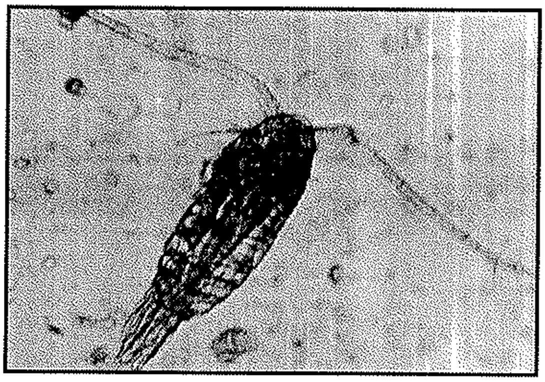
Pseudodiaptomus serricaudatus



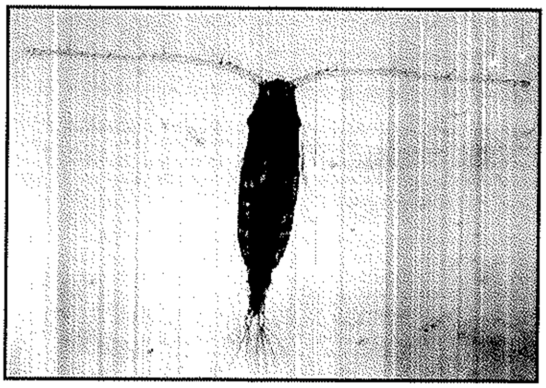
Polychaete larva



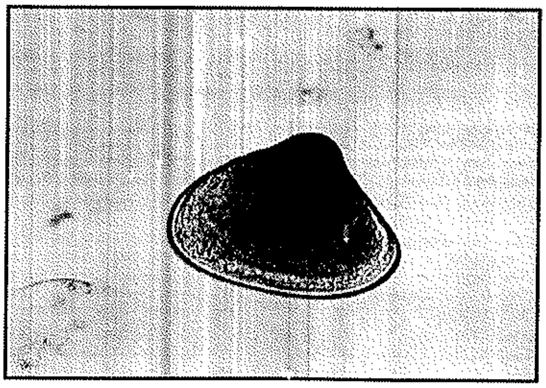
Globigerina rubescense



Paracalanus parvus



Acartia spinicauda



Bivalve veliger

Macrobenthos

The macro-benthic faunal population density varied from 450 to 1525 Nos/m^{-2} with maximum in stations near outside groyne region (TMS-9) during monsoon and minimum at stations near inside groyne region (TGS-1) during summer.

Altogether, 62 species has been recorded in three seasons of survey. Among the three seasons, summer season registered maximum number of species (53) and followed by postmonsoon (44) and monsoon (41) season. Of the various groups, polychaetes topped the list with 33 species and bivalves and gastropods were found to be the next dominant groups in the order of abundance with 9 and 7 species respectively. Crustaceans were found to be the least dominant group in the order of abundance with 5 species of the total benthic organisms collected. Group "Others" (2 species) meagerly contributed to the total samples collected.

Statistical analysis

Univariate technique

The macro-benthic species diversity (H') varied from 2.385 to 3.970 with maximum at station near outside groynes region (TMS-9) during summer and minimum in stations near inside groynes region (TGS-4) during monsoon. The species richness (d) ranged between 4.006 to 7.945 with maximum in stations near inside groyne region (TGS-3) during postmonsoon and minimum at stations near marine zone (TMS-10) during summer. The species evenness varied from 0.515 to 0.874 with maximum value at station near marine zone (TMS-9) during post-monsoon and minimum at stations near inside groyne region (TGS-2) during monsoon.

Meio-benthos

Regarding meio-benthic organisms, the population density of meio-benthic fauna varied from 146 to 282$Nos/10cm^{-2}$ with maximum at stations near marine zone (TMS-9) during summer and minimum at stations near inside groyne region (TGS-1) during monsoon.

Altogether, a total of 58 species has been recorded in three seasons, postmonsoon season registered maximum number of species (45) followed by summer with 44 species and monsoon with 41. Among them, Foraminiferans topped the list with 34 species. Nematodes and Ostracods were found to be the next dominant groups in the order of abundance with 10 and 9 species respectively and Harpacticoids came next with 5 species.

Statistical analysis

Univariate technique

The Meio-benthos species diversity (H') varied from 2.327 to 3.793 with maximum in stations near marine zone (TMS -9) during summer and minimum at stations near inside groyne region (TGS-4) during monsoon and similarly the species richness (d) ranged between 4.495 and 7.975 with maximum in stations near inside groyne (TGS-3) during monsoon and minimum in near outside groyne station (TMS-9) during monsoon. The species evenness varied from 0.579 to 0.917 with the maximum in near outside groyne station (TMS-10) during summer and minimum in at near inside groyne station (TGS-4) during monsoon.

Multivariate technique

Cluster & MDS analysis (Macro and Meio-benthos- combined)

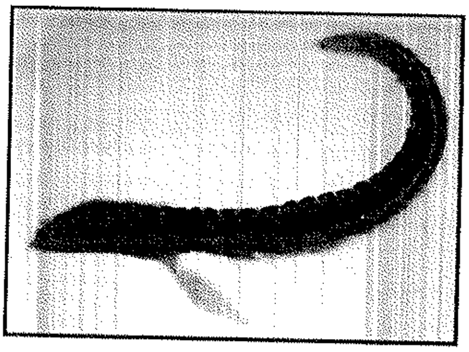
To find out the similarity/dissimilarity between stations, as done for plankton data, the benthic faunal abundance data (macrofauna and meiofauna) were amalgamated and subjected to classification and ordination methods. The resulting dendrogram revealed that the stations within Groyne TGS-3, TGS-2, TGS-5, TGS-4 and TGS-1 T were forming cluster separately based on the species composition and abundance. Similarly, the stations outside groyne MS-7, TMS-6, TMS-9, TMS-8, TMS-10, TMS-12, and TMS-11 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.

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, eight environmental variables (Temperature, Salinity, W. pH, Silt, Sand, Clay, DO, TOC, S. pH,) were allowed to match the biota. The results revealed that, a combination of eight environmental parameters namely Salinity, Dissolved Oxygen, S. pH, Sand, Clay and TOC got manifested as best match ($\rho_\omega = 0.948$) in determining benthic faunal distribution followed by Salinity, S. pH, Dissolved Oxygen, Clay, TOC, Sand, ($\rho_\omega = 0.891$) which also got manifested as second best variable combinations, in determining benthic faunal distribution in the Tiruvottiyur kuppam coastal waters.

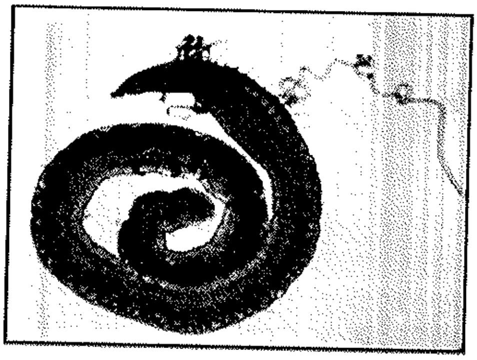
PLATE-III COMMON MACROBENTHIC SPECIES

POLYCHAETES

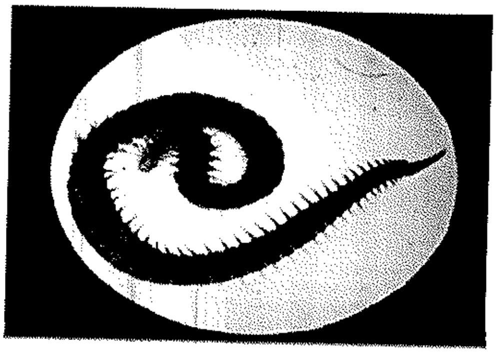


***Bhavania* sp.**

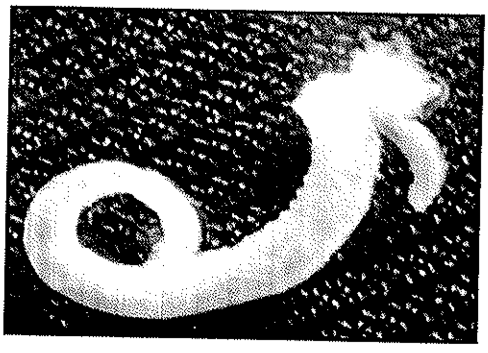
Capitella capitata



Cirratulus sp.



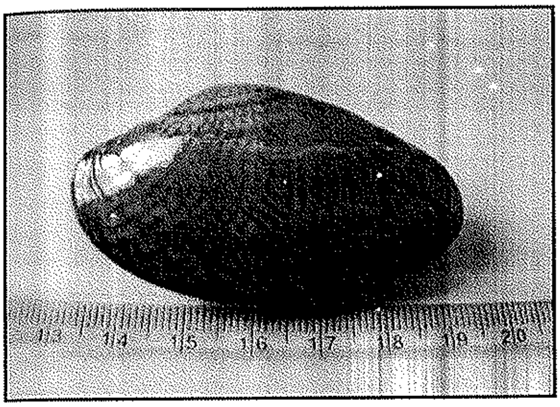
Goniada emerita



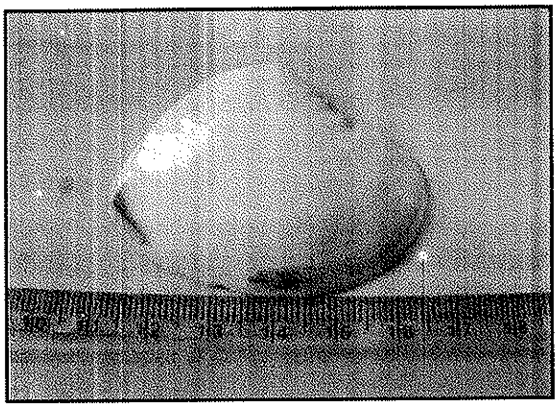
***Terebelides* sp.**

Prionospio japonica

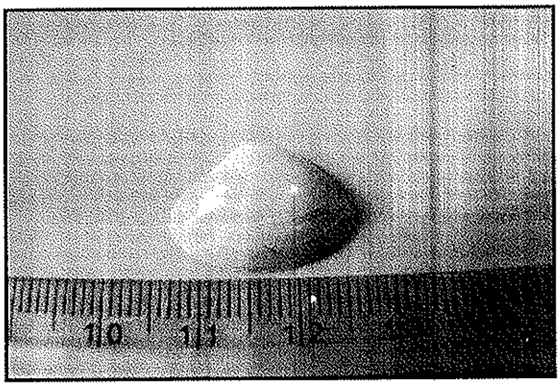
BIVALVES



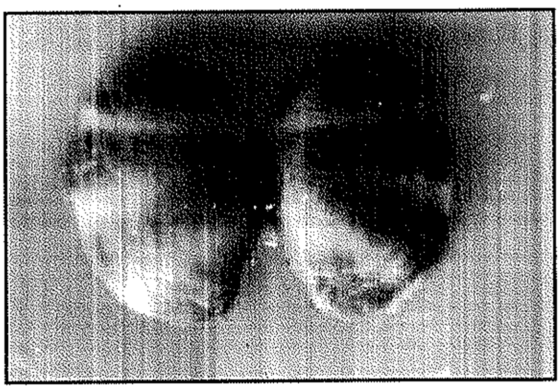
Sunettta meroe



Meretrix meretrix

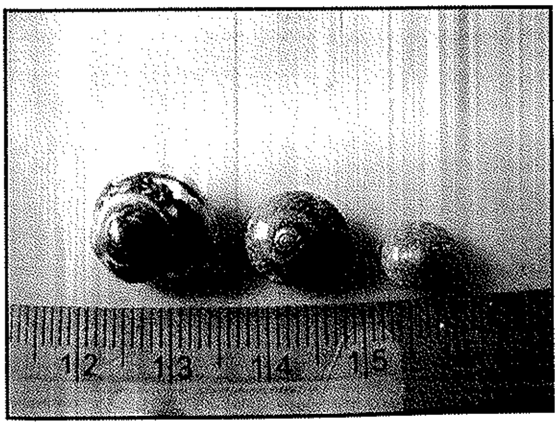


Donax incartinatus

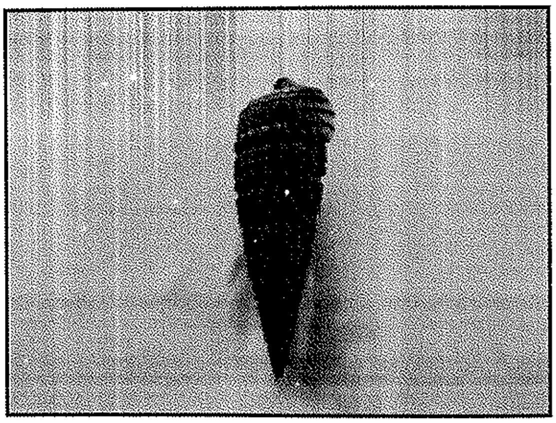


Siliqua radiate

GASTROPODS



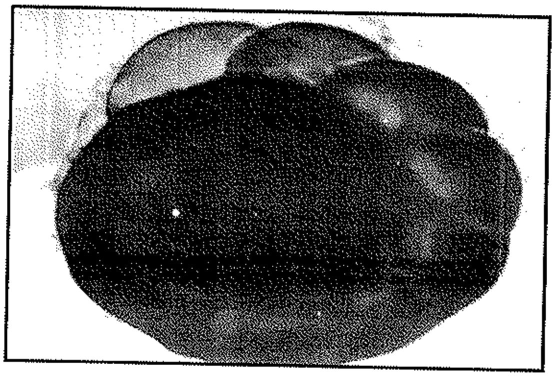
Umbonium vestiarium



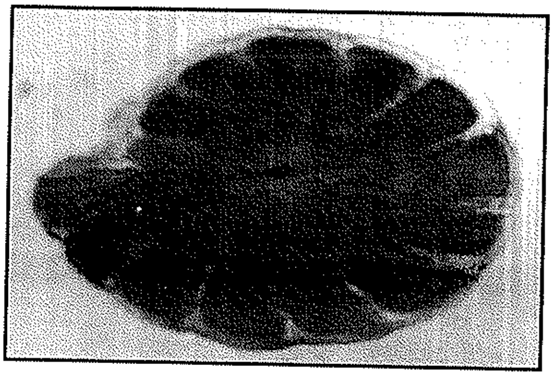
Cerithiacea cingulate

PLATE-IV COMMON MEIOBENTHIC SPECIES

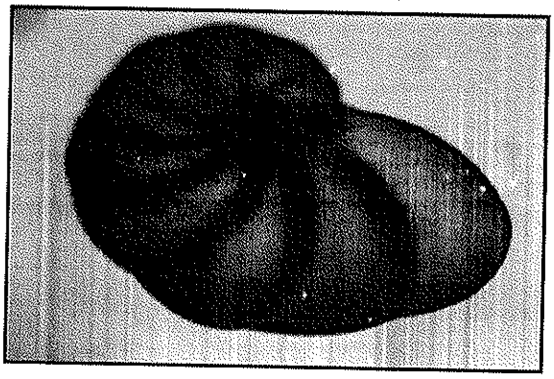
FORAMINIFERANS



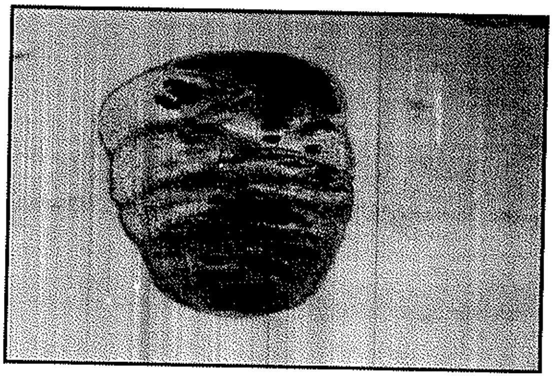
Ammonia tepida



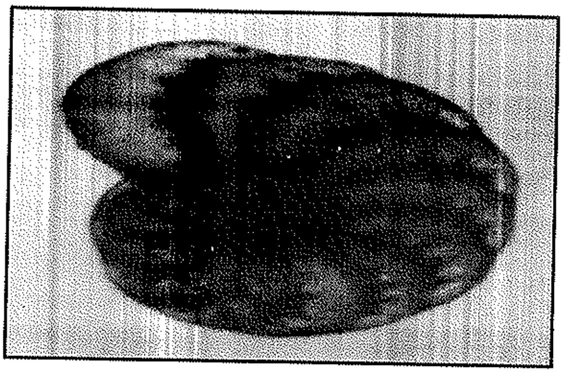
A. beccarii



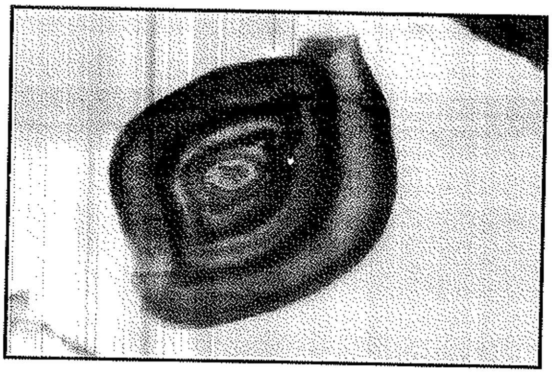
Nonion depressulus



Bolivina compacta

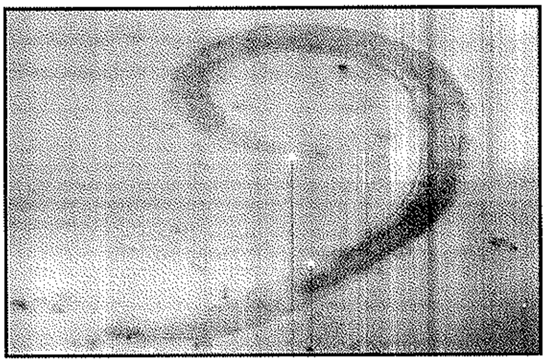


Elphidium advenum



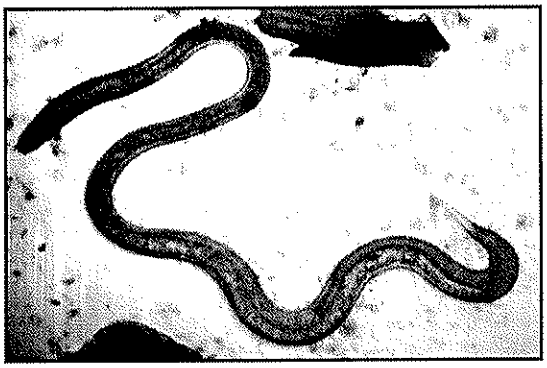
Spiroloculina angulosa

NEMATODES

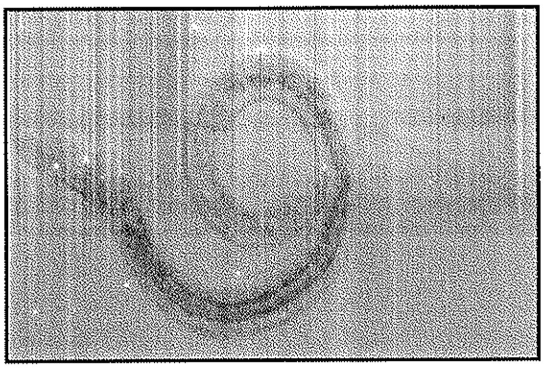


Daptonema conicum

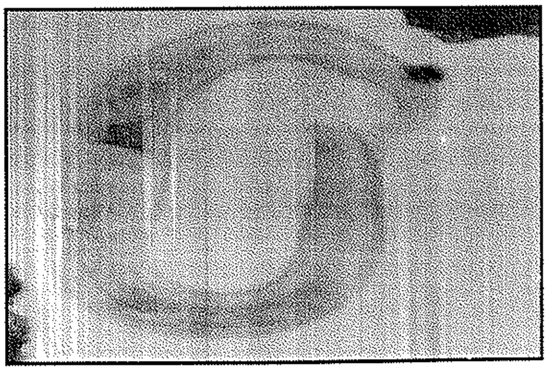
Epsilonema steiner



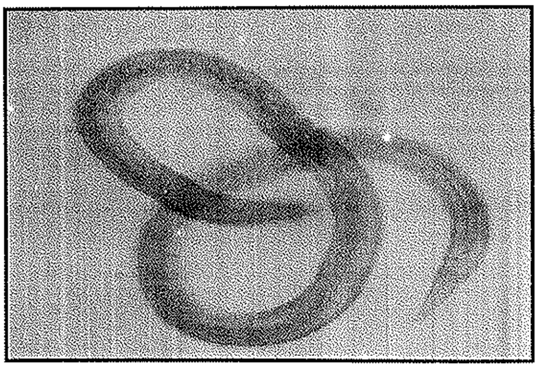
Neochromadora craspedota



Halalaimus filum

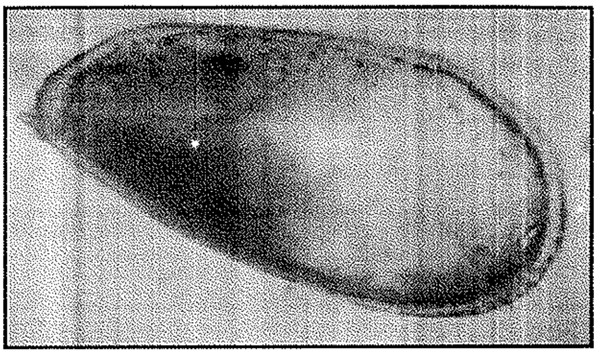


Draconema cephalatum

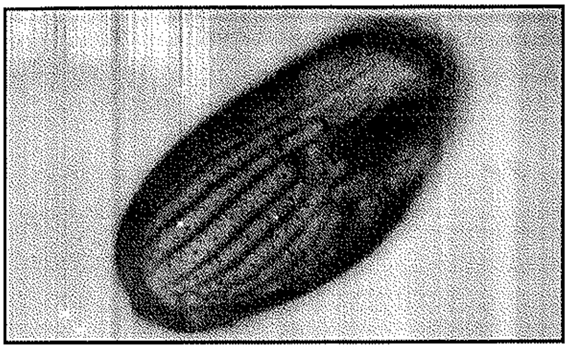


Pandolaimus latilaimus

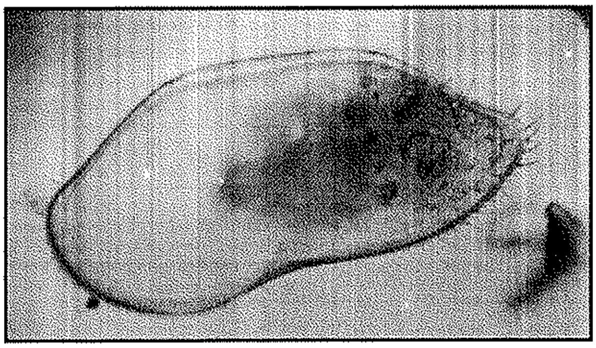
HARPACTICOIDS



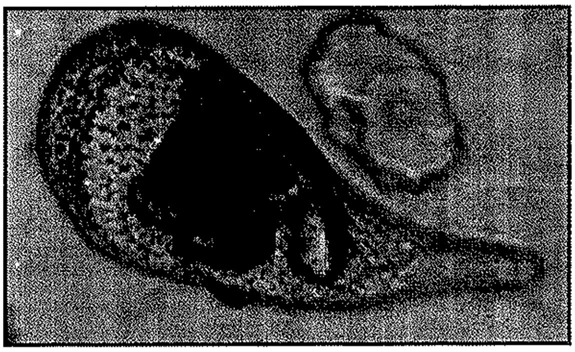
Keijella reticulata



Basslerites liebaui

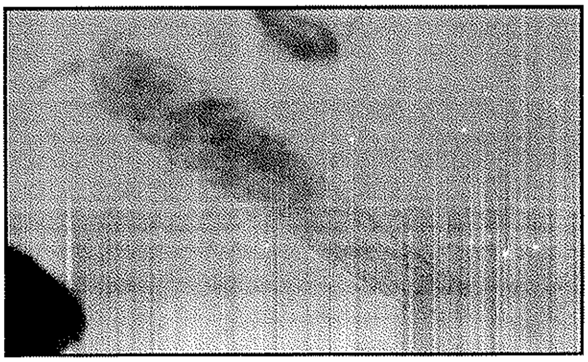


Bairdoppilata scaura

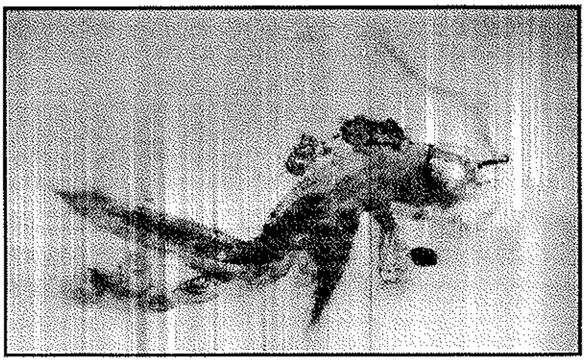


Paijenborchella cymbula

OSTRACODES



Laophonte thoracica



Cylindropsyllus laevis

Underwater SCUBA survey

The present underwater marine life survey was conducted in four locations around the Tiruvottiyurkuppam fishing harbour by engaging Pacific Blue Subsea services (P) Ltd. (collaborative study). The locations were selected based on the environment such as following:

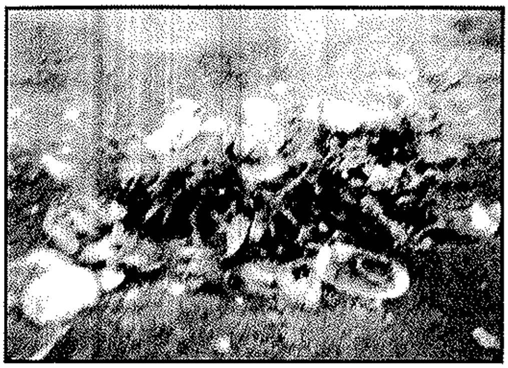
1. Near to fishing boat channel path – 13° 9'55.34"N; 80°18'44.32"E
2. Fishing harbour groynes channel path – 13° 9'50.30"N; 80°18'50.41"E
3. Inside the fishing harbour – 13° 9'38.59"N; 80°18'54.27"E
4. Outside the fishing harbour – 13° 9'50.09"N; 80°19'20.13"E

During SCUBA dives at the four stations, the water temperature, salinity, and depth were recorded. Benthic photography and video recording were done in four locations, including the midpoint of the fishing boat's path at the harbour mouth, 500 meters away from the mouth, and both inside and outside the fishing harbour, at depths ranging from 6 to 16 meters, in order to analyse the habitat and ecological condition of the chosen harbour.

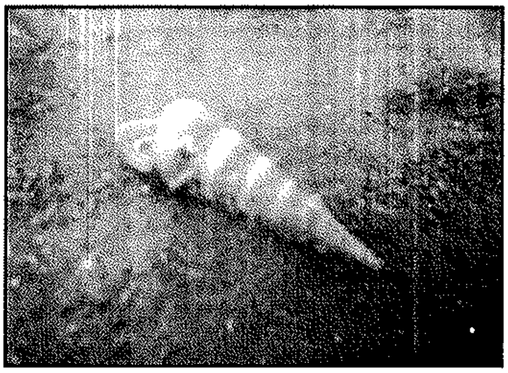
The exercise revealed muddy and sandy bottom with a few scattered patches of mixed seagrass, including *Oceana serrulata* and *Syringodium isoetifolium*, were observed. Dead shells, some gastropods, including *Turritella* sp., and some common fish, including flathead mullet, herring, and milkfish, were also spotted during the study. Besides, a few small fish, an octopus egg sac, small gastropods, plastic litters, one jellyfish, rock oysters, sponges, tube-dwelling worms, ascidians, and turf algae, were seen beyond the fishing harbour. The majority of the diverse marine life was spotted beyond the fishing harbour, where boat access is scarce.

PLAT – IV UNDERWATER SCUBA SURVEY

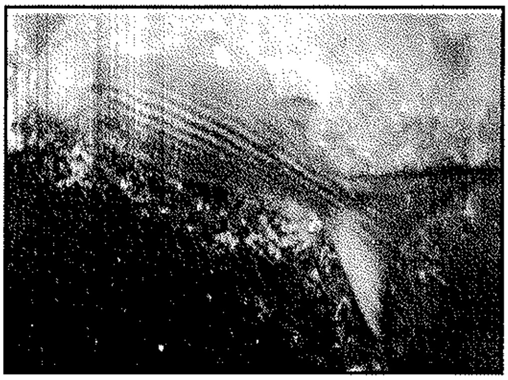
Muddy sandy bottom



Dead shells marine bottom



***Turritella* sp. Gastropod**



Flathead mullet fish

Tube-dwelling Worms attached groyne

Plastic waste in bottom

Ecologically sensitive groups

Mangroves

No mangroves were seen from the surveyed coastal stations.

Corals

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

Turtles

During the survey near Tiruvottiyurkuppam coastal waters, no organized turtle nesting ground was noticed in the sampled area. There are few reports which indicated occurrence of turtles but no nesting has been observed during survey. We visited sites mentioned above and tried to collect as much information as possible to ensure correct study of nesting pattern.

Other Endangered Species

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

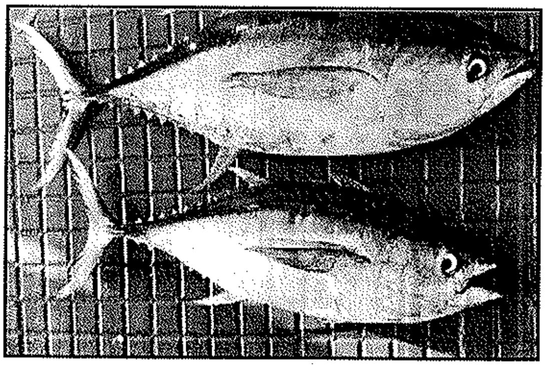
Avifauna

In the project region, a few common bird species were recorded. They are Pacific golden plover, Marsh sandpiper, Common redshank and little stint.

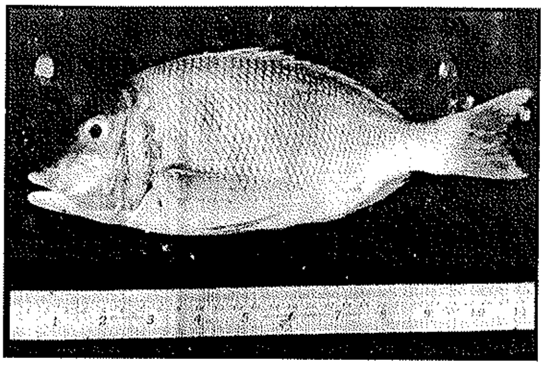
Seaweeds and Sea grasses

A patchy occurrence of the following seaweed and sea grass species were found near the surveyed stations: *Sargassum padina* and *Ulva* sp. and *Oceana serrulata*

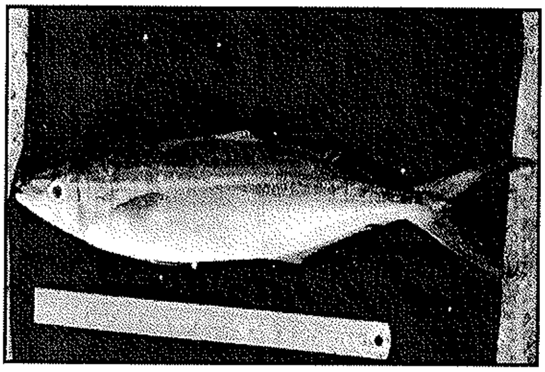
PLATE – VI COMMERCIALLY IMPORTANT FISHES FROM THE STUDY AREA



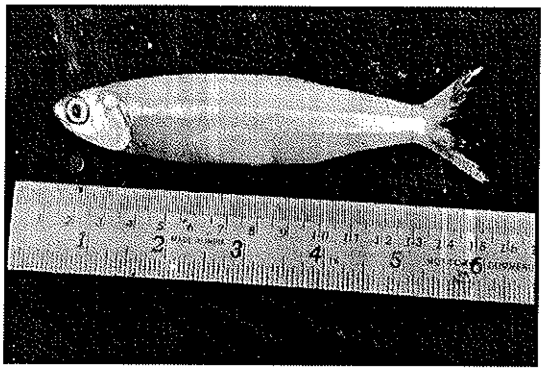
Thunnus albacares



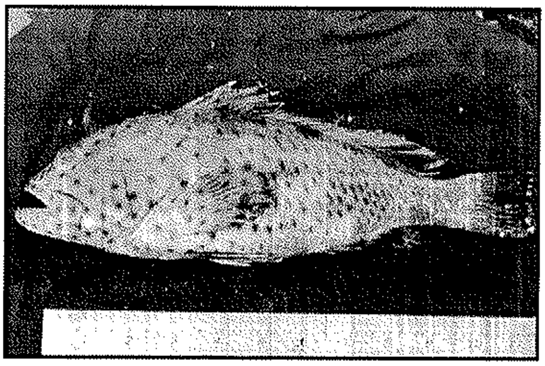
Lethrinus nebulosus



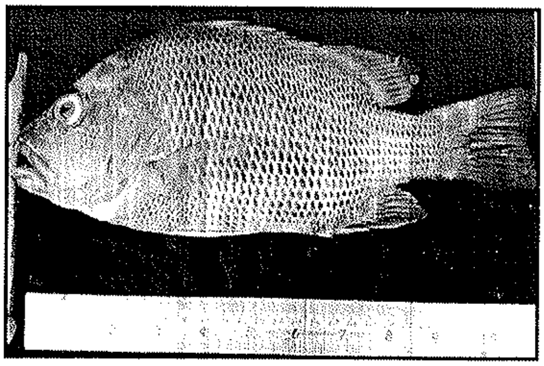
Elagatis bipinnulata



Stolephorus indicus



Epineohelus longispinis



Summary and Conclusion

The results of the Primary and secondary surveys undertaken during three seasons indicated that the physico-chemical and biological parameters did not vary much except a few parameters which showing typical seasonal variations. The surface water temperature, salinity, pH, TSS and turbidity were within the permissible level as suggested by Dept. of Oceanography, SOEST, Hawaii (2012). The variation noticed between the stations was only marginal and it might be due to seasonal changes, geographical location and sampling time. The range of ecologically sensitive chemical parameters such as Oxygen, BOD, nutrients was also at the optimal concentration corresponding to the seasonal variation as suggested by Khadanga (2012). Similarly, the level of Heavy metals (sediment and water) was also within the permissible limit as per the limits suggested by USA Environmental Protection Agency (2009). The sand, silt and clay fraction at each of the stations along with their textural classification indicated that the sand and silt percentage was higher during this survey. The microbial population showed general trend in water and sediment samples during this survey. The maximum colony count was observed in sediment compared to the water samples.

With regard to biological entities, the phytoplankton species predominantly belonging to three major groups namely Bacillariophyceae (Diatom), Dinophyceae (Dinoflagellates) and Cyanophyceae (Cyanobacteria). Six groups of macro zooplankton namely, Calanoid copepod, Cyclopoid copepod, Harpacticoid copepod, Oligotrichea, Foraminifera and Other Crustacean forms and four groups of micro zooplankton namely, Mollusca, Chaetognatha, Decapoda and Annelida were recorded. Of the above said groups, calanoida were found to be the dominant group.

Among the macro benthic organisms, five groups are recorded and among these polychaetes topped the list. Bivalves and gastropods came next in the order of abundance. Crustaceans and groups 'Other' contributed meagerly to the total benthic organisms collected. The four groups of meio-benthic organisms were recorded, which were dominated by foraminiferans followed by nematodes, ostracodes and harpacticoids.

Ecologically sensitive areas like Biosphere Reserves, National Parks, Wildlife Sanctuaries and other protected areas (PA) are not located within 10 km radius of the project site. The primary data collected during comprehensive survey period as well the secondary data collected did not reflect the existence of any critical flora and fauna in the study area as well as project area.

In short, the marine ecological survey made during 23rd – 25th February 2023 (representing postmonsoon season); during 27th – 28th July 2023 (representing late summer season) and 18th – 19th December 2023 (representing monsoon) in Thiruvottriyur Kuppam coastal waters and careful perusal of the available information suggests that the water quality parameters are within the safe level and did not indicate any alarming impact on the existing biological components. Further, the results of physico-chemical and biological parameters indicate that the water is well oxygenated and nutrients are adequate supporting fairly good plankton population, the base in the food chain. The other parameters like benthos and fisheries are also appeared to be normal.

The analysis on other ecologically sensitive organisms reflected the patchy occurrence of a few groups especially Seaweeds and seagrass from the nearby regions. The discharges accruing 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 rapid survey was done only three seasons, a long term intensive survey of this kind, after commissioning of the proposed structure, is warranted in order to pin point the changes in the biotic community arising out of proposed project.

IMPACT, MITIGATIONAND MANAGEMENT PLAN

Based on the primary data and also appending with secondary data, the Comprehensive Marine Environmental Impact Assessment (CMEIA) has come to the conclusion that:

Coastal habitats may be silted due to groyne construction and land reclamation,

Variation in surface water quality may occur during both the construction and operation phases,

Oil pollution is one of the environmental hazards resulting from port/harbour and shipping operations. This includes bilge oil released from commercial trawlers handling non-oil cargo as well as the more common threat from oil tankers.

Parameters	Impact	Mitigation
Turbidity	Murky waters might lead to lesser intertidal faunal population	With due course of time post construction, turbidity levels will come to normal level
Oil spill due to harbour operation	Oil spills can cause barrier between surface water and atmosphere and inflammable in nature	Oil Spill control measures as per International Convention for the Prevention of Pollution from Ships (MARPOL) 1974/1978, Consolidated Edition, IMO, 1991, including 1992 amendments to Annex 1 and 2002 amendments.
Dredging	Disturbances in floral and faunal habitat	As most of the benthic organisms are capable of recouping themselves quickly, the diversity will come back to normalcy
Substrate loss	Shoreline decrease	Implementation of Shoreline Protection Techniques such as sand by passing
Nutrients and Heavy metals	High nutrients leading to bloom; metals leading to toxicity	Minimalistic amount; will ward off with due course of time; metal concentrations will be dispersed within 2 months post construction.

WATER QUALITY MAINTENANCE AND PROTECTION TO MARINE ORGANISMS

→ Turbidity levels will be maintained as to the baseline data by continuous monitoring and pro care by way of stopping the activities whenever there is increase in turbidity

→ Oil Spill control measures will be adopted.

→ Marine environmental monitoring as per environmental monitoring programme

→ Dredge Management Programme (DMP) together with the Environmental Monitoring Management Plan (EMMP), and the Biosecurity Management Plan (BMP), shall inc measures to avoid entrapment of macro marine fauna.

→ Regular Interactions shall be initiated with the fishing community and conflicts, if any fishing community shall be amicably resolved in all cases.

→ Shoreline Protection Techniques such as Sand by passing if any will be carried.

→ The fluctuations in the parameters are due the construction and shall ward off in due cour time. However the immediate spike in the values won't affect the present biodiversity condi of the shoreline as already the construction is being carried out in the intertidal/ splash zone.

→ The present marine survey was done only for a short period, seasonal monitoring (post-mon summer, pre-monsoon and monsoon) is a pre-requisite even after commissioning of proposed facility. This will ascertain the temporal variations in the Physio-chemical biological components of this environment and thereby further suites of mitigation mea could be suggested.

BIOSECURITY MANAGEMENT (BMP) SOP

→ Understanding the site.

→ Identifying activities which risk introducing invasive non-native species.

→ Biosecurity control measures.

→ Short and accessible Contingency plan.

→ Reviewing the implementation of the plan.

IN-SHORE OIL SPILL MANAGEMENT SOP

→ Eliminate source of spill by closing leakage, up righting containers that might cause closing valves or similar actions.

→ Prevent further spread of the spill by creating suitable barriers all around the spill.

→ Use absorbents immediately to absorb majority of the spill starting at the periphery and gradually proceeding towards the centre of the spill.

→ Use skimmers to eliminate further remnant of the spill

→ In case the spill seeps to the bottom, excavating of the bottom substrate and replacing it with similar substrate is recommended.

ANNEXURE 7

ANTICIPATED IMPACT ON MARINE ENVIRONMENT DUE TO ACCIDENTAL OIL SPILL IN TIRUVOTTIYUR FISHING HARBOUR

GOVERNMENT OF TAMILNADU

TRUTH ALONE TRIUMPHS

DEPARTMENT OF FISHERIES
GOVERNMENT OF TAMIL NADU

JULY 2024

IMPACT ON MARINE ENVIRONMENT DUE TO OIL SPILL

Petroleum products released into the environment are subjected to differential processes of weathering that immediately begin altering its original physical and chemical characteristics. As a result, samples of oil from exactly the same source can be very different in composition after being subjected to a differing mix of environmental influences.

Impact on offshore waters

Most oils float on the sea surface where they are spread over a wide area by currents, wind and waves. Depending on the type of oil, it may disperse into the top few metres of the water column. The types of organisms that are commonly impacted in an open sea spill include plankton, fish, seabirds and marine mammals and reptiles.
The oil environmental impact on water in damaging in a variety of ways. When there are oil spills in the sea, it does not blend with the water. Over a very short period of time, the oil spreads out into a very thin layer across the surface of the water. This can block sunlight from reaching oceanic environments, which can severely impact producers and, thus, the entire food chain of an ecosystem. As a result, the potential environmental impacts of oil in open waters are generally confined to this upper area of the water column although, on occasion, some types of oil will sink and environmental impacts may be observed on the seabed. The environmental effects of oil spills are less known with respect to small scale spills of oil which are common in port and harbour areas.

Biological impacts

The range of biological impacts after an oil spill can encompass.

- Physical and chemical alteration of natural habitats.
- Physical smothering effects on flora and fauna.
- Lethal or sub-lethal toxic effects on flora and fauna.
- Changes in biological communities resulting from oil effects on key organisms

Marine animals and plants tend to be tolerant to low level concentrations of oil in sediments from chronic or small discharges, however this is not always the case.

- Prolonged exposure to major or minor oil spills can lead to mass mortality of plankton, benthic communities, fish, mammals and birds.
- Contamination of sediments with oil may modify chemical, physical and biological processes.
- Contaminants can be trapped in the sediments and later released as a result of disturbance such as erosion or dredging.

- In sediments, as it is organic, oil will be broken down relatively quickly by microorganisms which may result in the localized removal of oxygen from the sediments and surrounding water with possible effects on marine life.

- The persistent toxic constituents of oil, such as heavy metals, can become stored in the sediments, and taken up into the food chain. This will have devastating effect on the ecosystem.

Open waters of the oceans and the associated pelagic and seabed communities have rarely shown any impacts from oil spills. The high dilution potential that this habitat provides is a major mitigating factor.

Impact on Plankton

Even though laboratory research has shown that planktonic organisms which live in surface waters can be variously affected by oil, no long-term effects have been demonstrated due to their huge regenerative potential, as well as immigration from outside the affected area. This regenerative potential is fundamental to the important role the plankton plays in the food chains of the world's seas and oceans.

Planktonic life, whether phytoplankton or zooplankton tends to be fairly sensitive to even low levels of hydrocarbons in water, in the range of parts per billion (ppb) to a few parts per million (ppm) of dissolved hydrocarbons. It is unlikely, however, that the planktonic component in marine environment would significantly be affected by oil pollution because of high rate of recruitment from non-affected areas, assured by the wide distribution and large population sizes of plankton.

Impact on Benthos

The benthic invertebrate biota is an important component of coastal waters providing an energy base for fish and seabirds. It responds to disturbances and represents an ideal monitoring system. Bivalves and echinoderms show behavioral changes to hydrocarbon contamination, which may limit their survival, such as emergence from sediments in mussels and clams and narcosis in many species. This can occur after acute, post-spill exposure as well as after long term chronic contamination in parts per billion range. Other invertebrate fauna behave similarly. Benthic invertebrates are able to accumulate hydrocarbons to high levels from the surrounding medium, suggesting bio-transfer as a possible concern. Sessile and sedentary marine organisms are very sensitive to oil spill residues.

Impacts on Corals

Coral reefs are important nurseries for shrimp, fish, and other animals as well as recreational attractions for divers. Coral reefs and the marine organisms that live within and around the reefs are at risk from exposure to the toxic substances within oil as well as smothering.

Spill impacts vary in severity with the specific conditions at a given spill, including oil type and quantity, species composition, and the nature of oil exposure. Oil can kill corals, depending on species and exposure. Longer exposure to lower levels of oil may kill corals as well as shorter exposure to higher concentrations. Chronic oil toxicity impedes coral reproduction, growth, behaviour, and development.

Impacts on Fish and Shellfish

Concerns are often expressed about the effects of spills on fish and shellfish eggs and larvae which are found in the plankton, especially as their sensitivity to oil pollution has been demonstrated in laboratory toxicity tests. However, there is no definitive evidence that oil induced mortalities of fish and shellfish eggs and larvae in the open sea have resulted in significant effects on future adult populations. This is not surprising because oil-induced mortalities of eggs or young life stages are often of little significance compared with huge natural losses each year through predation, temperature changes, storms etc.

Fish may ingest large amounts of oil through their gills. Fish that have been exposed to oil may suffer from changes in heart and respiratory rate, enlarged livers, reduced growth, fin erosion and a variety of effects at biochemical and cellular levels. If this does not kill them more or less directly, the oil may affect the reproductive capacity negatively and/or result in deformed fry.

Contamination with hydrocarbons will make shellfish, taste and smell bad and thus make it impossible to use them for food.

Impact on Fisheries

An oil spill can have a number of direct and indirect effects on fisheries. Commercially exploited animals and plants may be killed as a result of oil smothering and toxicity. Catches and cultivated stock may become physically contaminated or may acquire an objectionable oil-derived taste known as 'tainting'.

Valuable fishing and shellfish areas may be closed for fishing for shorter or longer periods because of the risks of the catch being tainted by oil. Concentrations of petroleum contaminants in fish and crab tissue, as well as contamination of shellfish, could pose a significant potential for adverse human health effects, and until these products from nearshore fisheries or aquaculture have been cleared by the health authorities, they could be banned from human consumption.

Impacts on Seabirds

Oil vapors can cause damage to an animal's central nervous system, liver, and lungs. Animals are also at risk from ingesting oil, which can reduce the animal's ability to eat or digest its food by damaging cells in the intestinal tract. Some studies show that there can also be long-term reproductive problems in animals that have been exposed to oil.

If a bird gets smeared with oil, it may clog the bird's feathers making it impossible for it to fly. The bird may also loose it buoyancy (its ability to float on the water surface) and actually drown.

Oil may also affect the reproductive success of the birds as oil from feathers of a bird that is laying on eggs may pass through the pores in the eggshells and either kill the embryos or lead to malformations.

Impacts on Marine Mammals

Toxic effects due to ingestion of oil or inhalation of oil droplets/ vapours, on marine mammals include congested lungs, damaged airways, liver and kidney damage, eye and skin lesions from continuous exposure to oil; decreased body mass due to restricted diet; and stress due to oil exposure and behavioral changes.

Whales, dolphins, Dugong dugong are very vulnerable to oil pollution because they need to surface to breathe. Exposure to oil during surfacing and inhaling oil could lead to damage of mucous membranes, injuries in airways or even cause death.

A stressed or panicking dolphin would move faster, breathe more rapidly and therefore surface more frequently into oil which would increase exposure. Dolphins eyesight may also be affected by oil. Habitat loss and diminishing food resources constitute indirect effects on the mammals.

Impact on Microbes

It has been determined that the composition of microbial community changes with exposure to hydrocarbons, generally in favour of hydrocarbon degraders - the oleoclasts. Such changes may be faster in tropical oceans.

Impact on Sea Plants (seaweeds and seagrass)

Sea plants (Seaweeds and Seagrass) are very important for the survival of marine animals. Without this, there would be no life in the sea. When an oil spill happens there will be no entry of oxygen in the sea. This will lead to the death of sea plants due to lack of oxygen. Additionally, the lack of oxygen means there will be no photosynthesis

Impacts on Sea bottom

Oil contamination of the seabed may cause serious long- and short-term effects on bottom-dwelling organisms (animals, algae and microorganisms). Filtering organisms such as oysters and mussels and clams which filter large volumes of water to get their food are especially likely to accumulate oil or oil components. In addition, if tar-like clumps of oil sink to the bottom, they may destroy living conditions for bottom-living organisms, as well as nursing grounds for fish and shellfish.

Impact on sediment quality

Some portion of the spill will be adsorbed by the suspended particulate matter and these particles on settling may increase the load of hydrocarbon in sediment. Moreover, residue remaining after the evaporation of lighter fractions will be broken down in lumps which may also sink or deposited on the shores. The residue may be transported over long distances by current and sinking will spread unevenly on the bed. Hence, sediment levels of hydrocarbon may be found abnormal in such plains. The residue deposited on the bed will be mixed with the sediment by natural physical processes as well as by bioturbation perhaps up to a depth of 5 cm and may remain for several years. The Microbial degradation of hydrocarbons is slow in the sediments since dissolved oxygen becomes a serious limitation. Scouring of the bed material by monsoon flow is prevalent in these areas which may transport the contaminated sediment to other downstream areas.

The sedimentation of weathered residue may have profound effect on benthic animals in shallow waters because of their sedimentary habits depending on the quantum of oil deposited. The sensitivity of benthic animals to crude oil varies among major groups and sometimes within species.

Longer exposure to sublethal concentrations of crude residue may bring in physiological, morphological, biochemical and reproductive changes in the benthic organisms of localized areas.

Impacts on Mangroves

Mangrove forests are home to a diversity of plant and animal life. Mangroves are highly susceptible to oil exposure. Mangrove trees have long roots, called prop roots, that stick out well above the water level and help to hold the mangrove tree in place. A coating of oil on these prop roots can be fatal to the mangrove tree, and because they grow so slowly, replacing a mangrove tree can take decades. The amount of oil reaching the mangroves and the length of time spilled oil remains near the mangroves are key variables in determining the severity of effect. Trade-offs include potential increased toxicity to adjacent communities, and increased penetration of dispersed oil to mangrove sediments. Increased weathering generally lowers oil toxicity.

Impacts on Tidal Flats

Inter tidal zone usually containing rich plant, animal, and bird communities. Deposited oil may seep into the muddy bottoms of these flats, creating potentially harmful effects on the ecology of the area especially on the benthic organisms.

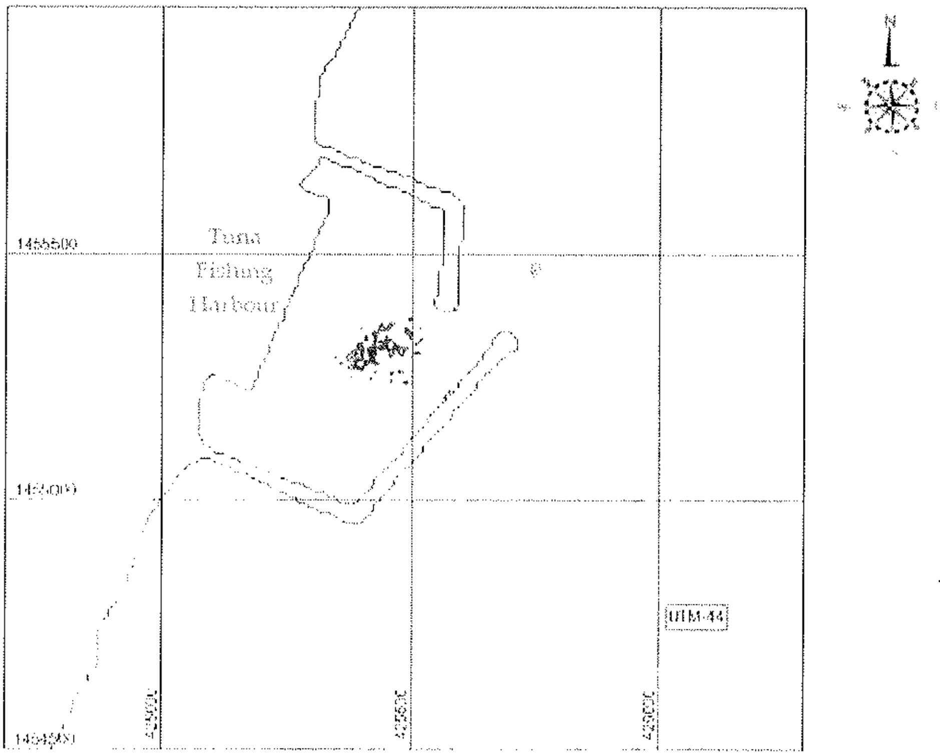
Modelling of oil spill

In order to understand the nature of oil spillage inside the fishing harbour, oil spill modelling has been undertaken for the worst case scenario.

The movement of oil slick with tide induced currents is simulated by forcing the hydrodynamic conditions. The spread of the oil slick on the sea surface due to tide influenced flow after 1 hour, 2 hours. 3 hours, 4 hours, 5 hours and 6 hours after the accidental release of oil in the sea is shown in **Figs. 1 to 3.** The simulation shows that the total oil slick thickness above 0.6 mm extends to 150 m x 115 m along the north westerly direction at 1 hour. After 1.0 hour, the slick thickness remains to 0.06 mm spread over an area of 120 m x 80 m which remains at north westerly. After 2 hours, the slick thickness reduces to 0.04 mm spread over an area of 90 m x 60 m which moves predominantly towards east. After 3 hours, the slick thickness remains at 0.04 mm spread over an area of 90 m x 60 m which moves predominantly towards east. After 4 hours, the slick thickness reduces to 0.04 mm spread over an area of 60 m x 40 m which moves predominantly towards east. Finally, after 5 hours the oil slick starts to decay completely, and the surface spread of oil disappears. During flood tide, the currents of the order of 0.3 m/s, for nearly 6 hours after the release of the accidental spill; and after 1.5 hours the slick gets disappeared. From the model simulations carried out, it is evident that the oil slick spread due to accidental spillage is minimum.

Thereby, the oil slick gets advected with flood currents and dissipates faster. So, the necessary contingency plan should be taken to contain the oil slick within the proposed harbour and should not allow drifting of oil slick towards the wharf neither to the sea.

1 Hour



2 Hour

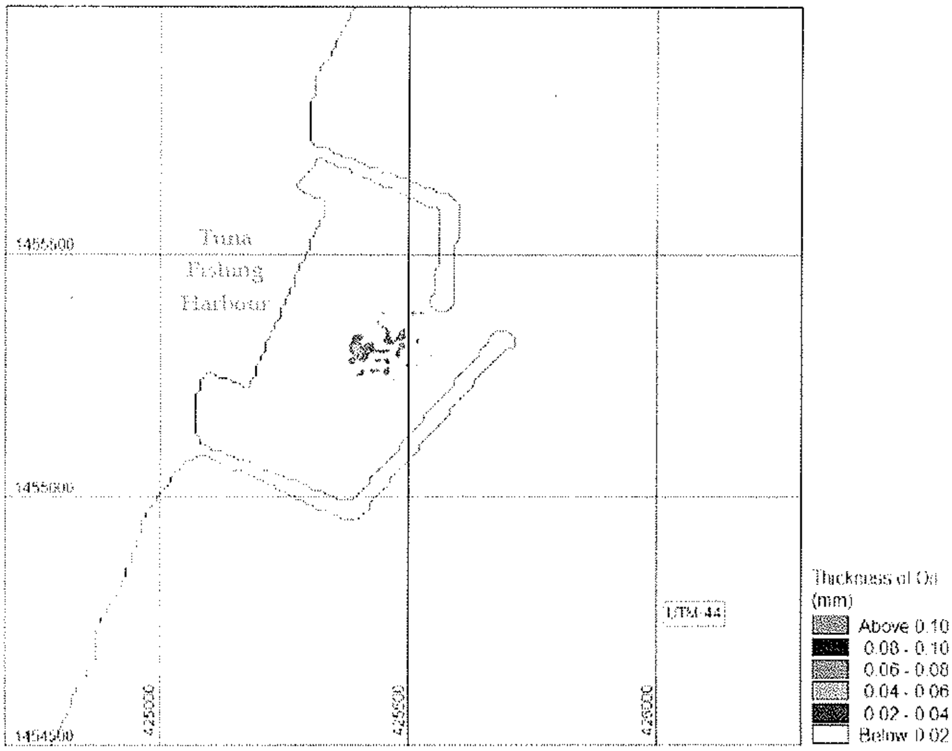
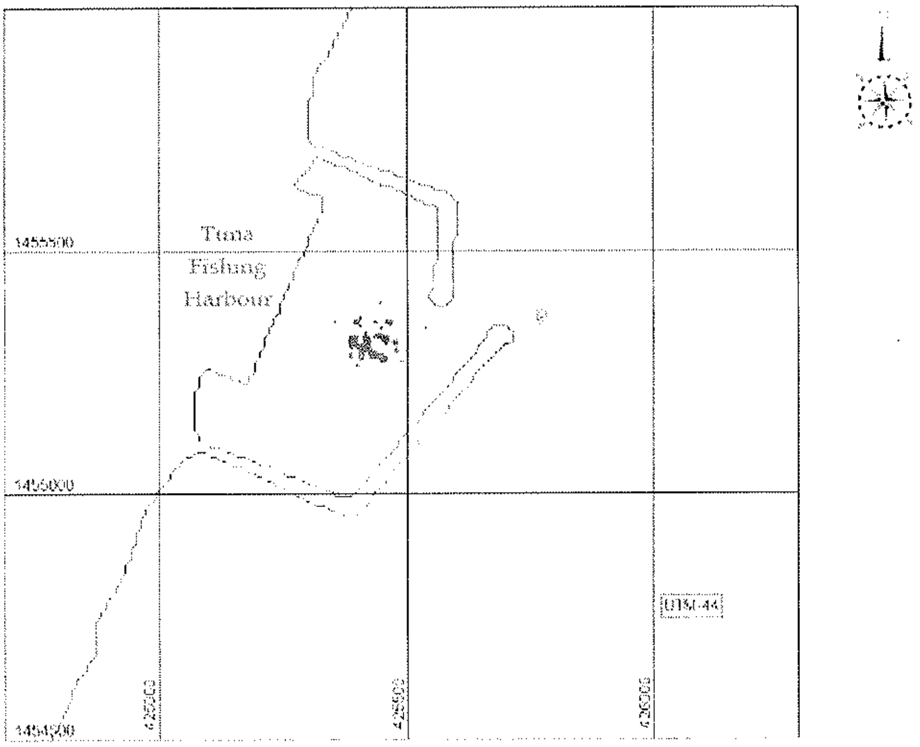


Fig. 1. Movement of oil slick during 1st hour and 2nd hour

3 Hour



4 Hour

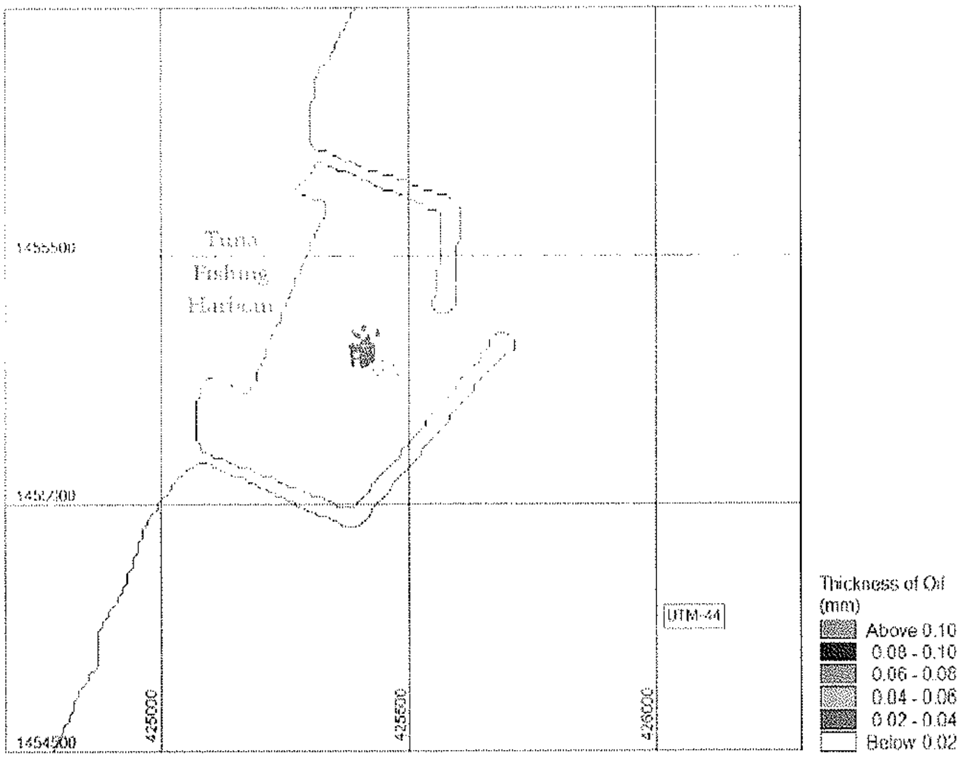
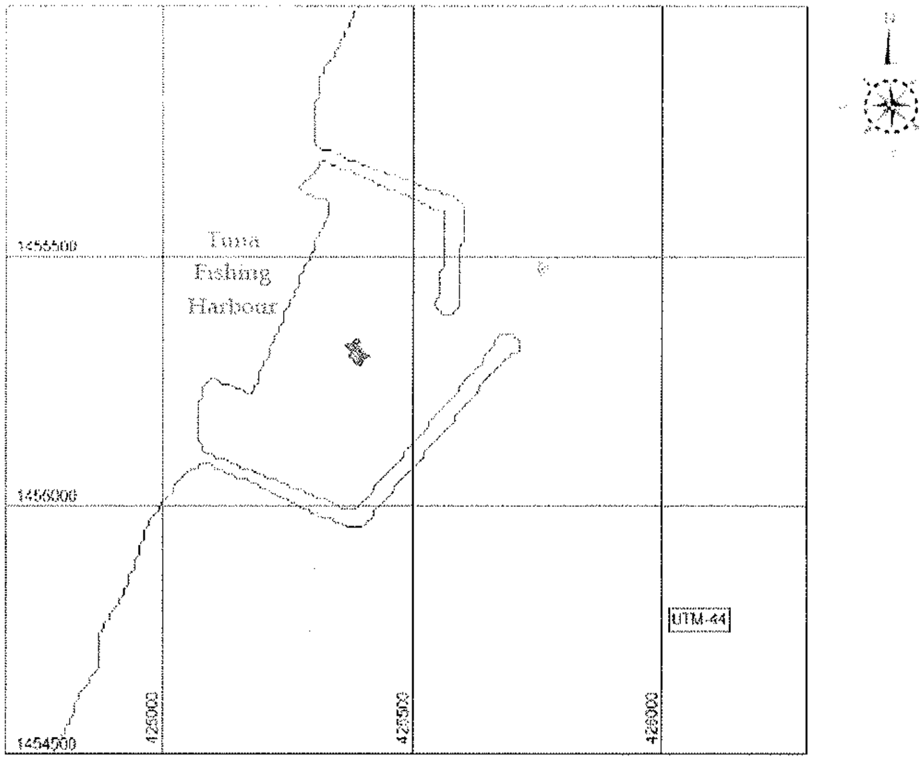


Fig. 2. Movement of oil slick during 3rd hour and 4th hour

5 Hour



6 Hour

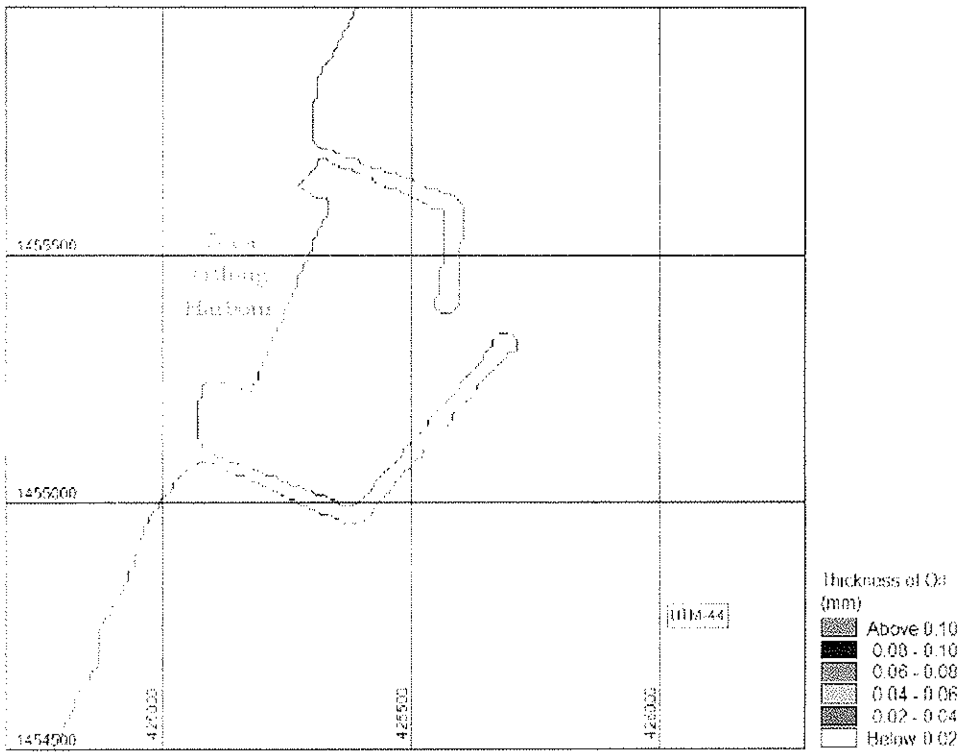


Fig. 3. Movement of oil slick during 5th hour and 6th hour

Conclusion

The proposed fishing harbor is devoid of seaweed, seagrass, corals, mangroves, and marine mammals. The impact on benthos and plankton due to fuel spills in the harbor basin is minimal because the fuel handled on boats is in low quantities. Consequently, there will not be any noticeable impact on the marine environment due to the fuel spill in the Tiruvottiyur fishing harbor.

ANNEXURE 8

TUNA Fishing Harbor at Thiruvottriyur Kuppam

Report Submitted to

Fisheries Department
Tamil Nadu.

By,
Prof. V. Sundar
Prof. S.A. Sannasiraj

Department of Ocean Engineering
Indian Institute of Technology Madras
Chennai 600 036, India.

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1.0 INTRODUCTION

The coastal area, adjoining the north of the Chennai Port has been adversely affected by continued erosion due to the development of the port. Since several developmental activities such as advent of industries, improvement of fisheries, etc. a groyne field was constructed stretching from Royapuram to northwards and the sea wall stretch of about 10 km length lying parallel to Ennore High Road to combat the erosion problems. A proposal was further made to expand existing groynes to form a fishing harbor. The Fisheries Department, Chennai requested the Department of Ocean Engineering, IIT Madras to revise/revive the proposed layout and perform numerical model studies to validate the same. Therefore, the layout was revised and subjected to tranquility and shoreline evolution studies, which is detailed in this report.

2.0 SCOPE AND OBJECTIVES

The main objective of the study is to revise the layout of the proposed fishing harbor The scope of the study includes,

- To prevent erosion of shoreline and ascertain development of fisheries related activities along the coast.
- To suggest suitable extension for groynes to form a pair of breakwaters and predict the shoreline behavior in view of the proposed groins through numerical modeling.
- Numerical model study for the wave transformation/tranquility due to the extension of the existing shore connected structures, and to determine the operability of vessels.

3.0 WAVE CHARACTERISTICS

3.1 General

The National Institute of Oceanography (1990) published a wave atlas for Arabian Sea and Bay of Bengal (Latitude: $0^0 - 25^0$ N and Longitude: $60^0 - 95^0$ E) compiling the ship observed data for 19 years from 1968 to 1986. The coastal region around India is divided into 10 grids, each of size 5^0 latitude and 5^0 longitudes as shown in **Fig. 2.** The grids 1 to 4 falls in the Bay of Bengal on the east coast, grids 5 to 7 fall in Indian Ocean in the south and grids 8 to 10 all in the Arabian Sea on the west coast. The present study area comes under the grid located at $5 - 10^0$ N and $75 - 80^0$ E in the wave atlas, representing grid number six. The wave data (wave height, wave period and wave direction) from wave atlas given for deep-waters were used for the present study.

3.2 Wave height

The monthly distribution of deep-water wave heights in terms of percentage of occurrence derived from wave rose diagrams are projected in **Figs. 3 to 6.** The class interval adopted for the calculations is 0.5m. It is observed from the results, that the most frequently occurring wave height is about 1.5m with a percentage of occurrences of 20 to 30% for the months January and November. From the above referred figures, it is also observed that the most frequently occurring wave height is 1.0m with a percentage of occurrences of 20 to 35% during the months of February, March, April, May, October and December. The most frequently occurring wave height is 2m with a percentage of occurrences between 25 to 35% for the months June to September.

3.3 Wave periods

The monthly distribution of wave periods in terms of percentage of occurrence derived from the wave atlas is projected in **Figs. 7 to 10**. The class interval adopted for the presentation is 1sec. From the above figure, it is observed that the maximum percentage of occurrence is the waves associated with periods ranging between 5 and 6 seconds.

3.4 Wave direction

The monthly distribution of wave directions with respect to geographic north in terms of percentage of occurrence obtained from the wave atlas is projected in **Figs. 11 to 14**. The class interval adopted for the presentation is 20^0. The average wave characteristics given as the input to the numerical model is as per given in **Table 1.** The shore-normal angle for the present study was arrived to be 218° with respect to geographic north.

Table 1: Wave characteristics for the present study

Month	**Deep water Wave direction w.r.t North (θ°)**	**Wave height (m)**	**Wave period (sec), T**	**Wave direction from shore normal (θ°) in**
January	60^0	1.5	5	49^0
February	60^0	1.0	5	49^0
March	90^0	1.0	5	19^0

April	150^0	0.5	5	-41^0
May	180^0	1.0	5	-71^0
June	180^0	2.0	5	-71^0
July	180^0	1.0	5	-71^0
August	180^0	2.0	5	-71^0
September	180^0	1.0	6	-71^0
October	60^0	1.0	5	49^0
November	60^0	1.0	6	49^0
December	30^0	2.0	6	79^0

4.0 LITTORAL DRIFT ESTIMATE

4.1 Distribution of Sediment Transport

The wave atlas data has been analyzed to obtain the monthly averaged wave height, wave period and wave direction. These are offshore wave climate and are transformed to the near shore location of Thiruvottriyur Kuppam coast using Snell's law. The average breaking wave characteristics were derived from the available wave data. The monthly distribution of mean breaker wave height for the study area is shown in **Fig. 15(a).** The results indicate that the mean breaker height varies from about 0.87m to 1.57m. The breaker height is observed to be a maximum during June and July. The monthly distribution of the mean breaker wave angle with respect to shore normal is shown in **Fig. 15(b).** From the results it is seen that for the study area, the breaker angle with respect to shore normal and long shore current velocity are directed towards South from October to February. The average surf width in which the long shore drift is predominant is further estimated from the breaker wave height for the given bathymetry and is projected in **Fig.15(c)** for the different months. It shows that the maximum surf width of about 95m occurs during the months of June and July. Further, the derived wave characteristics were used to calculate the long shore sediment transport. Three different methods CERC (1984), Komar (1976a), and by integrating the distribution across the surf zone (Komar, 1976b) have been adopted to calculate the alongshore sediment transport rate. The average sediment transport rate for the different months is shown in

Fig.16. All the three methods have yielded similar order sediment transport rate. The net drift is found to be about 400000m^3 per annum and directed towards the North.

5.0 PROPOSED SCHEME

In view of promoting fisheries in the vicinity of the coast of Thiruvottriyur Kuppam, the existing groynes are planned to be extended to form a pair of breakwaters, thereby proving calm tranquil conditions for landing of fishing boats. The northern breakwater extends for about 510 m unitl -6 m water depth and the southern breakwater extends upto -7.5m water depth. An opening width of 90 m is provided between the base of northern and southern breakwater for movement of fishing boats. The layout is shown in **Plate 1**.

The tranquil conditions within the fishing harbour basin were studied for operability. Furthermore, the proposed coastal protection scheme has been further examined for shoreline evolution using numerical modeling techniques, which supplements our understanding of the shoreline behavior.

6.0 NUMERICAL MODELLING FOR SHORELINE EVOLUTION

6.1 General

Structures in the near shore environment are built for different purposes. These may be for the formation of artificial harbors, shore protection measures, seawater intake systems, disposal of effluent, etc. There are several configurations of such structures with respect to the shoreline, among which, structures normal to the shore is most common. The construction of a shore-connected structure often leads to changes in the shoreline. This warrants a study on the shoreline due to presence of the shore-connected structures. Such a study is very much essential in planning stage; so as to assess the impact of shore connected structures on the adjacent shoreline.

Numerical models offer the capability to study the effect of the wave characteristics, structure dimensions and other associated parameters in providing reasonable estimates of the shoreline response. As the ocean waves approaches the near shore it undergoes transformations like shoaling, refraction, diffraction and breaking. The phenomena of wave breaking throw sediments to the surface due to the turbulence generated. The sediments in suspension are then driven by the wave-induced currents. Since the direction of waves in the near shore is oblique, the currents induced by them have two components. One along the shore called long shore current mainly responsible for the long shore sediment transport, which plays an important role in the shoreline changes especially due to the shore connected structures. The other component is in the direction normal to the shore, in which case, the mode of sediment transport is called onshore-offshore sediment transport. When a structure normal to the shoreline is constructed, it will intercept the free passage of long shore sediment transport, which results an imbalance in the quantity of sediment in the near shore especially near the structure. This leads to accretion on the updrift side and erosion on the downdrift side of the structure.

6.2 Methodology

KRAUS and HARIKAI (1983) proposed a numerical scheme to solve the one line model using Crank Nicholson implicit finite difference method. The non-dimensional equation of shoreline

$$y^*_{n,t^*+1} = B\{Q^*_{n,t^*+1} - Q^*_{n+1,t^*+1}\} + C_n \qquad (1)$$

$$where\ B = \frac{\delta t^*}{2\times\delta x^*}\ and\ C_n = B\{Q^*_{n,t^*} - Q^*_{n+1,t^*} + 2\delta x^* q^*_{n,t^*}\} + y^*_{n,t^*} \qquad (2)$$

The non-dimensional shoreline is divided into 'n' grid points at equal non-dimensional interval, δx^*. Then shoreline changes over a non-dimensional time, δt^* is calculated using Crank-Nicholson finite difference scheme. The schematic diagram for finite difference scheme is shown in **Fig. 17.**

In this method, Q^* at the time interval (t^* +1) is expressed in terms of the shoreline co-ordinate of y*, first isolating the term involving α_{sp} (angle of shoreline normal to x-axis) using trigonometric identities. One of the term involving α_{sp} is then expressed as first order quantities in y* at time step (t*+1).

$$Q^* = K_D^2 \cos(\alpha_o)\sin(\alpha_b) \qquad (3)$$

Where, $\alpha_o = \alpha - \alpha_{sp}$ and α is wave direction with respect to x-axis. The definition sketch showing the angles is shown in **Fig. 18.**

The elliptical form of mild slope equation, which deals with combined refraction-diffraction,

$$Q' = K_D^2 \cos(\alpha - \alpha_{sp}) \sin(\alpha_b) \quad (4)$$

$$Q' = K_D^2 \sin(\alpha_b) \{\cos(\alpha)\sin(\alpha_{sp}) \cot(\alpha_{sp}) + \sin(\alpha) \sin(\alpha_{sp})\} \quad (5)$$

$$Q' = E_n \{y_{n-1,t'+1} - y'_{n,t'+1}\} + F_n \quad (6)$$

$$Where\ E_n = K_D^2 \{\cos(\alpha)\sin(\alpha_{sp,t'})\sin(\alpha_{b,t'})\} / \delta x^* \ and \quad F_n = K_D^2 \{\sin(\alpha_{sp,t'})\sin(\alpha_{b,t'})\}$$

By substituting above equations, give the final equation as given below

$$BE_n Q^*_{n-1,t'+1} - (1+2BE_n)Q^*_{n,t'+1} + BE_n Q^*_{n+1,t'+1} = E_n[C_n - C_{n-1}] - F_n \quad (7)$$

The above equations represent a set of (N-1) linear equation for (N-1) unknowns. The end values are specified as boundary conditions, that is, $Q^*_1 = 0$ and $Q^*_{N+1} = Q^*_N$. The above equation results into a tridiagonal form which is solved for Q^*. This process is repeated for the entire duration and non-dimensional quantity is converted into real quantities using the corresponding scale factors. The program has been validated with published results.

6.3 Input and Output from the numerical model

The coastal line is discretized into number of grids with an equal spacing of 5m. The co-ordinates of the existing shoreline were provided. The length of the structure andgrain size of the sediments (0.2mm) required for the calculation of active depth of the sediment transport and water depth at the tip of the structure are the inputs given to the model. In addition to these, the monthly wave characteristics and the number of years over which the shoreline change is desired to be mentioned.

The output shows the predicted shoreline changes after a period of 1, 5, 10, 15, 20& 25 years. The upstream of the structures shows advancement of the shoreline position, while, the downstream end shows the erosion.

6.4 Results and discussion

The numerical model to predict the shoreline evolution due to the shore-connected structures has been used to predict the shoreline changes due to the proposed groins. The wave characteristics given as the inputs to the numerical model is as per given above table.In addition, the length of the groins, water depth at the end of the groins and the present status of the shore are also to be given as the inputs to the numerical model.

The numerical model was executed for the most frequently occurring wave characteristics for the different months as stated earlier. The result on the predicted shoreline variations over years are projected in **Fig. 19**. The shoreline prediction has been made at the end of 1 year, 5 years, 10 years, 15 years, 20 years and 25 years after the construction of the groins and has been presented by superimposing the shoreline patterns. The results also show that no significant erosion is observed on either side of the proposed shore protections measure.

7.0 WAVE TRANQUILLITY STUDY

7.1 Offshore wave characteristics

The wave characteristics such as significant wave height, mean wave period and mean wave direction at a deep-water location (13°15'0.00"N, 80°30'0.00"E) off Thiruvottiyur Kuppam have been extracted from the ECMWF (European Centre for Medium-Range Weather Forecasts) including the wind-wave modeling hind-cast studies. The data are sampled at every 6 hours. Basically, the wave field follows the wind pattern. It is noted that the spatial variability is closely related, the maximum of H_s are associated with maximum wind speeds. The offshore wave climate for an annual year is presented in **Fig.20**.The joint distribution tables of significant wave height vs. wave direction, Mean wave period vs. mean wave direction and significant wave height vs. mean wave period are presented in **Tables 2, 3** and **4** respectively.The waves are predominantly observed in 6s to 8s period with the significant wave height ranges between 0.5m to 1.5m. However, larger wave heights were also observed.

Table 2. Wave height vs Mean direction joint distribution

Wave direction	Wave Height (m)										Total
	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	
N-NNE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
NNE-NE	0.00	0.07	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.41**
NE-NEE	0.00	2.06	1.44	0.21	0.00	0.00	0.00	0.00	0.00	0.00	**3.70**
NEE-E	0.00	7.68	6.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**14.67**
E-SEE	0.00	5.83	2.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**8.36**
SEE-SE	0.07	3.36	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**4.73**
SE-SSE	0.00	10.14	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**11.24**
SSE-S	0.00	24.13	16.38	0.34	0.00	0.00	0.00	0.00	0.00	0.00	**40.85**
S-SSW	0.14	6.99	4.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**11.85**
SSW-SW	0.00	1.23	0.82	0.07	0.00	0.00	0.00	0.00	0.00	0.00	**2.12**
SW-SWW	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.75**
SWW-W	0.07	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.21**
W-NWW	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.48**
NWW-NW	0.07	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.21**
NW-NNW	0.00	0.27	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.34**
NNW-N	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.07**
Total	**0.34**	**63.26**	**35.77**	**0.62**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**100.00**

Table 3. Wave Period vs Mean direction joint distribution

Wave direction	Wave Period (s)										
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	16-18	18-20	20-22	22-24
N-NNE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NNE-NE	0.00	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE-NEE	0.00	0.00	3.22	0.34	0.14	0.00	0.00	0.00	0.00	0.00	0.00
NEE-E	0.00	0.07	13.16	1.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E-SEE	0.00	0.00	6.37	1.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SEE-SE	0.00	0.00	1.92	2.54	0.27	0.00	0.00	0.00	0.00	0.00	0.00
SE-SSE	0.00	0.00	3.02	7.54	0.69	0.00	0.00	0.00	0.00	0.00	0.00
SSE-S	0.00	0.00	13.71	21.45	5.41	0.27	0.00	0.00	0.00	0.00	0.00
S-SSW	0.00	0.00	6.17	4.66	0.75	0.00	0.00	0.00	0.00	0.00	0.00
SSW-SW	0.00	0.00	2.06	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SW-SWW	0.00	0.07	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWW-W	0.00	0.07	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W-NWW	0.00	0.21	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NWW-NW	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NW-NNW	0.00	0.14	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NNW-N	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.00**	**0.75**	**51.68**	**40.03**	**7.27**	**0.27**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Table 4. Wave height vs mean period joint distribution

Hs (m)	Tm (s) 2	4	6	8	10	12	14	16	18	20	22	24	Total
0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1	0.14	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.75**
1.5	0.07	35.44	15.90	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**51.61**
2	0.14	25.02	14.80	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**40.10**
2.5	0.00	2.47	4.59	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**7.27**
3	0.00	0.00	0.21	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.27**
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Total	**0.34**	**63.54**	**35.50**	**0.62**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**100.00**

7.2 Numerical modelling

The study aims at providing an depth analysis on the wave tranquility near the proposed groyne field at Thiruvottiyur Kuppam. A suitable numerical model is required in order to carry out this task. For the present simulation, the well known CGWAVE model has been used.

The nonlinear wave propagation associated with most of the observed phenomenon in offshore region (e.g., wave reflection, refraction and diffraction) is generally represented by the shallow water mild slope equation.

$$\nabla.\left(C_p C_g \nabla \eta\right) + k^2 C_p C_g \eta = 0 \qquad (8)$$

Where, C_p and C_g are the wave celerity and group celerity respectively. η is the water surface elevation. k is the wave number. For the computation of near shore wave field, this model

(Eqn. (8)) is subjected to the proper boundary conditions. This is provided by the bathymetry and the shore line.

The computational domain roughly approximates a semi circle of radius 2.8 km. **Fig.21** shows the domain where the computations are actually performed. The direction of the incident monochromatic wave is defined with respect to the geometric northern direction.

A numerical method is required to solve the above Eqn. (8) for wave elevation. In this study, Finite Element Method (herein after abbreviated as FEM) is employed. This requires creating a mesh structure in the given computational domain. Upon creation of such a mesh, the domain is represented by nodal points which are connected with each other through the created mesh. The numerical solution of Eqn. (8) is sought in those nodes. This mesh has been generated using the commercial package GAMBIT. The mesh is shown in **Fig. 22.**

7.3 Detail of the mesh structure

The CGWAVE model utilizes triangular mesh units in the computational domain. Due to the complexity in the shoreline geometry (as can be seen in **Fig.21**) which includes the proposed groyne, an unstructured mesh is desired. Hence a triangular unstructured mesh is generated in GAMBIT, mesh generation software. In such a mesh the nodal spacing is optimized so as to adapt to the nearby portion of the shoreline boundary. The outer semi circular periphery is modeled by 1265 nodes with a spacing of 5 m and the inner shoreline is modeled by nodes with a spacing of 5 m. Then an unstructured mesh is created with an average spacing of 5m inside the domain. This leads to a total number of 147455 nodes with 393820 numbers of triangular elements.

7.4 Results and discussion

A total number of three wave directions have been simulated in order to investigate the wave tranquility inside the proposed breakwater. The wave directions are chosen such that these represent an annual year. The wave period of the computations is given as 8s to observe the wave climate. The incident wave angle is varied to simulate different wave directional scenarios.

The wave climates representing typical wave directions are presented. **Fig.23** to **Fig.27** present the wave phase diagram and the wave height distribution for the three cases representing the wave crest propagation for the wave approach angles 45^0 , 90^0, 135^0, 155^0 and 180^0 respectively.

8.0 RECOMMENDATIONS

The optimized revised harbour layout for the fishing harbour at Thiruvottriyur kuppam is given in Plate 1 by satisfying the tranquility requirements inside the breakwaters and, the simulation from the shoreline change study indicates the erosion on the north. However, the series of groynes on the north would mitigate the erosion. Hence, the Proposed revised layout is recommended.

Prof. S.A. Sannasiraj **Prof. V. Sundar**

9.0 REFERENCES

1. ~~**Berkhoff**(1972)Computation of combined Refraction and –Diffraction.~~
2. **CERC** (1984) Shore Protection Manual. Coastal Engineering Research Centre, US.
3. **Coastal Engineering Manual**, 2006. Part VI
4. **Goda,Y.** (1985) Random seas and design of maritime structures.
5. **Kressener**(1928)Tests with scale models to determine the effect of currents and breakers upon a sandy beach, and the advantageous installation of groins.
6. **Owen and Allsop** (1983), Hydraulic modelling of rubble mound breakwaters, Proceedings of the conference organized by Institute of Civil Engineers, London.
7. **Sundar, V.** (2005) Behaviour of groins. Fifth international symposium on wave measurement and analysis, WAVES 2005, Madrid, Spain, 3-7 July.
8. **US Army Engineer District, Willington (1973)** Hurricane-Wave protection-Beach-Erosion control Brunswick country, N.C., Beach projects, Yaupon beach and long beach segments.
9. **Komar, P.D.(1976a),** *Beach process and sedimentation, Prentice –Hall Englewood Cliffs,* N.J., 429p.
10. **Komar,P.D.(1976b),** *Longshore currents and sand transport on ocean Eng. III,* ASCE,333-354.

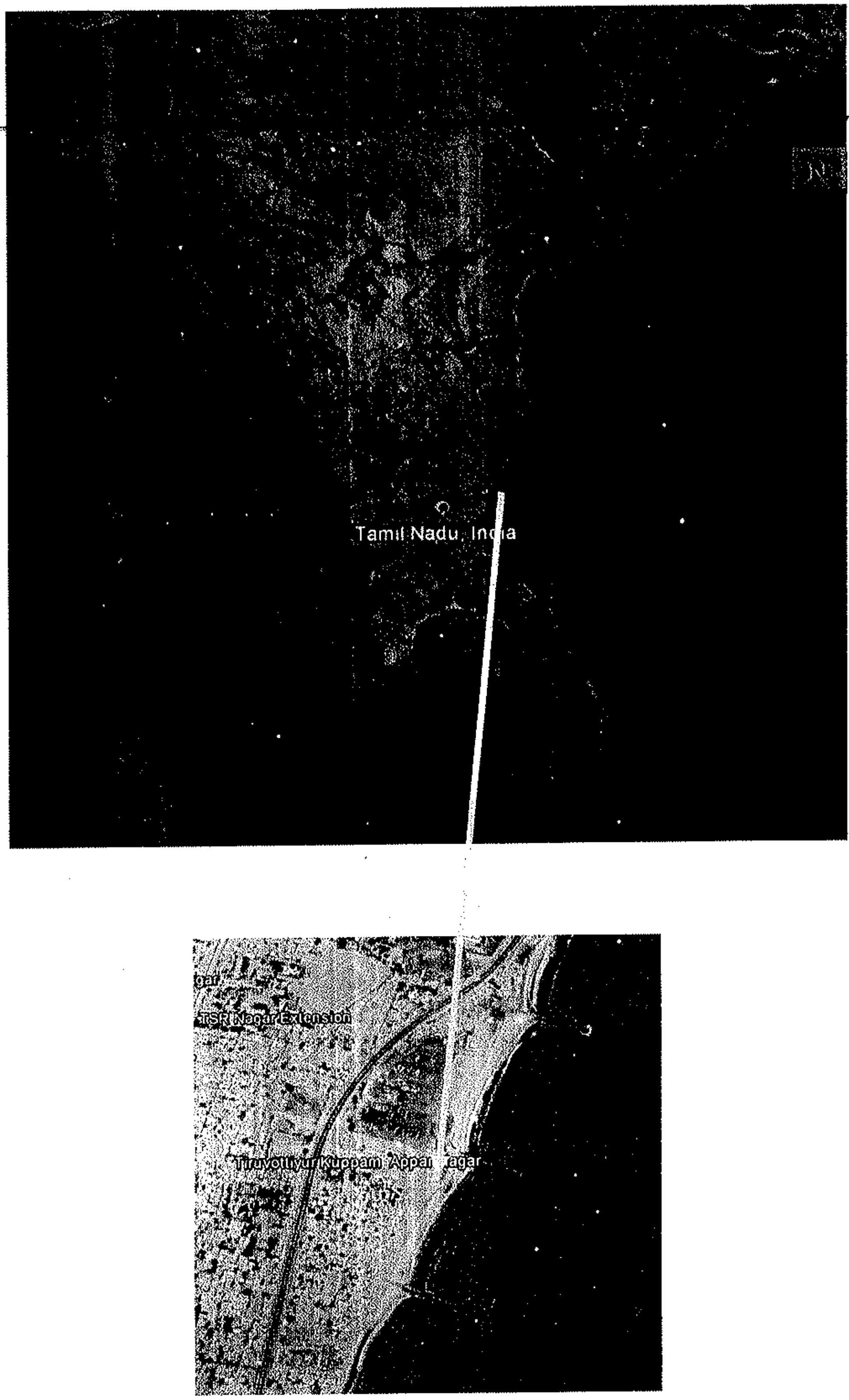


Fig.1 Aerial view of Thiruvottriyur Kuppam

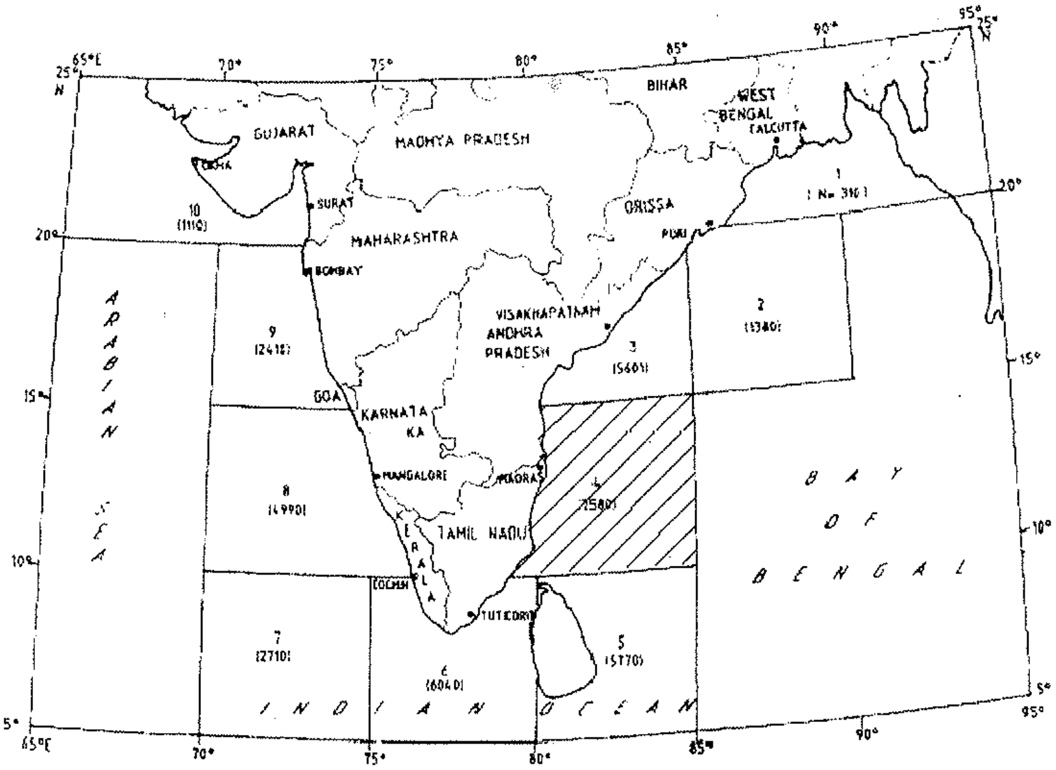


Fig.2 Grid on wave atlas for study area

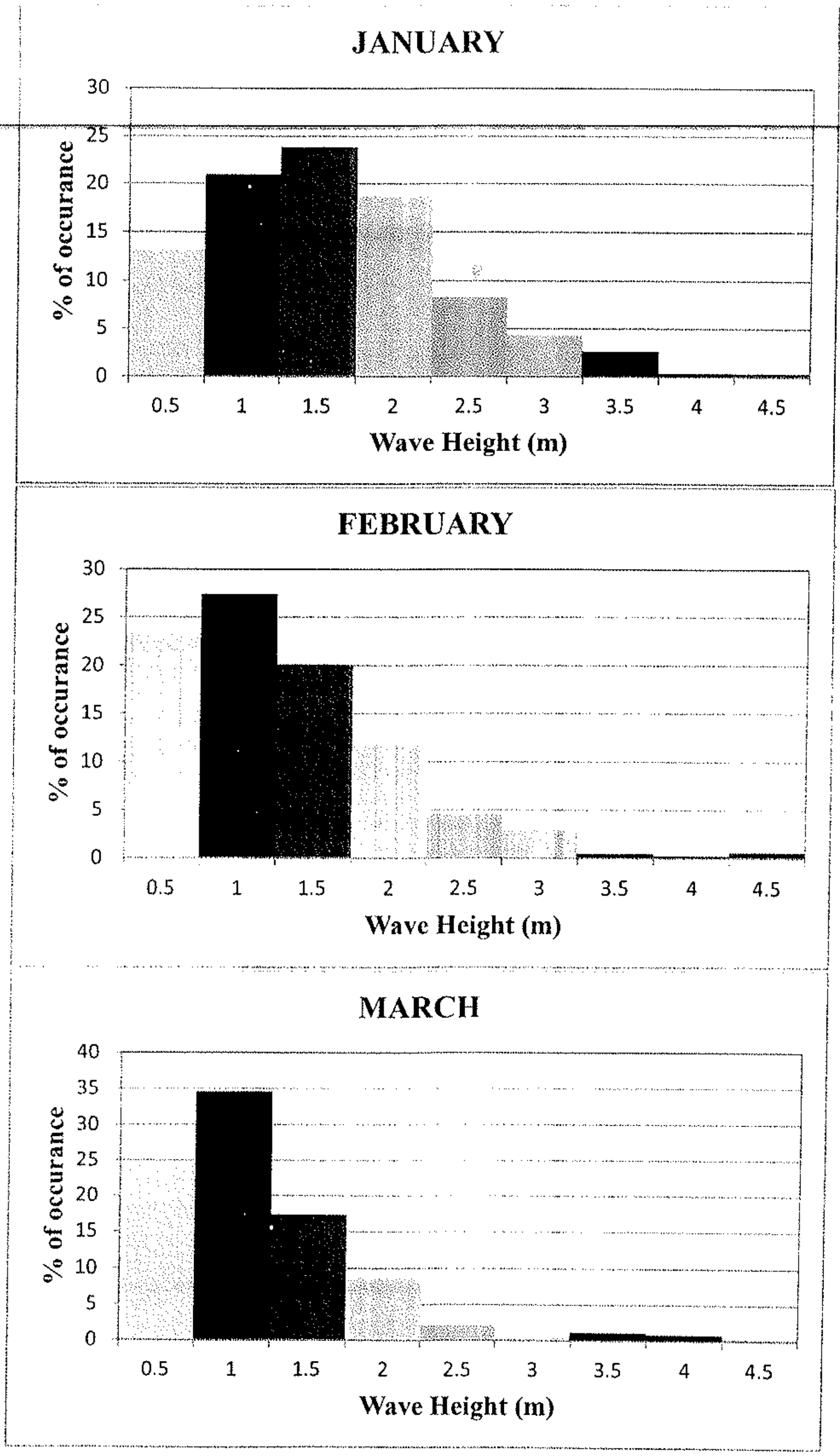


Fig.3 Monthly distribution of wave heights (Jan-Mar)

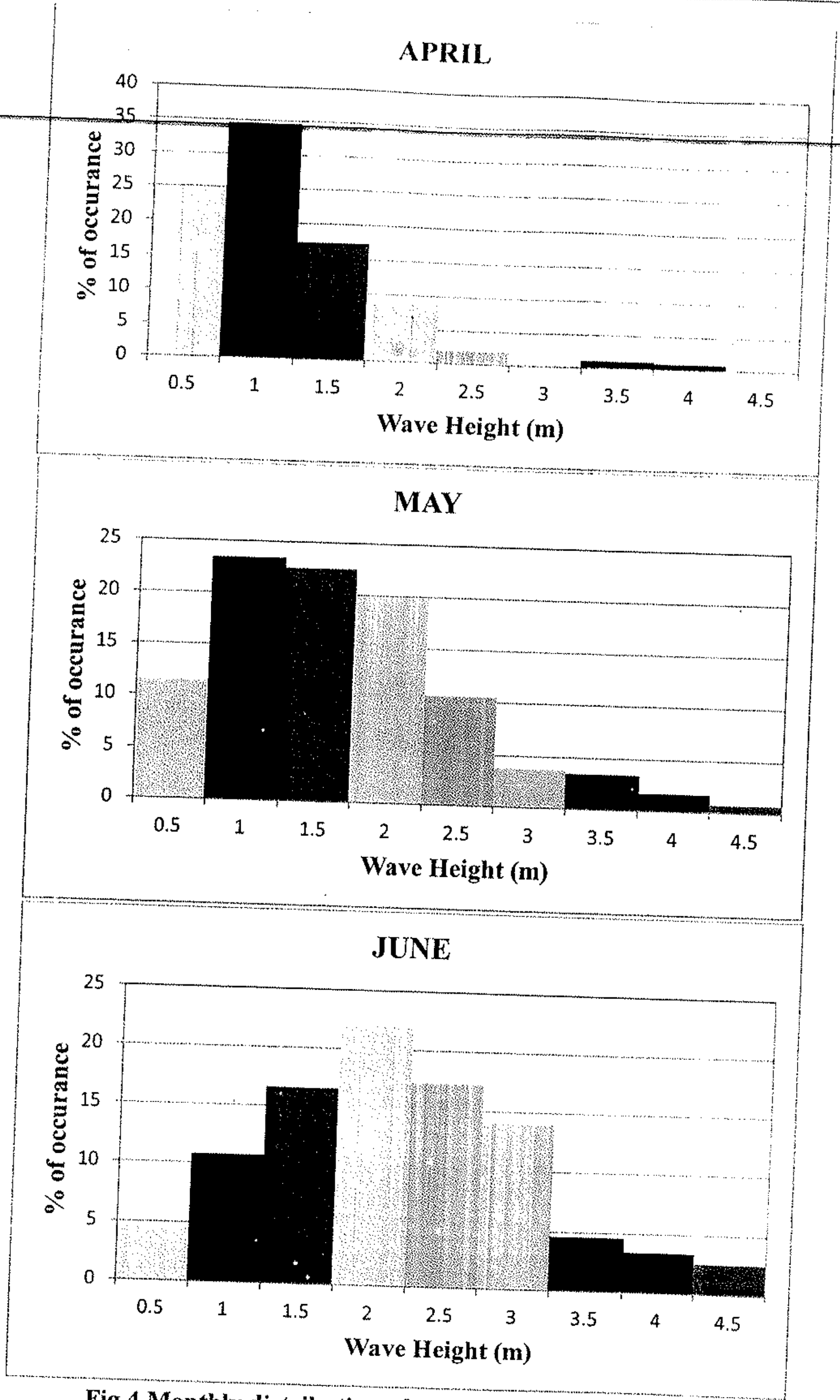
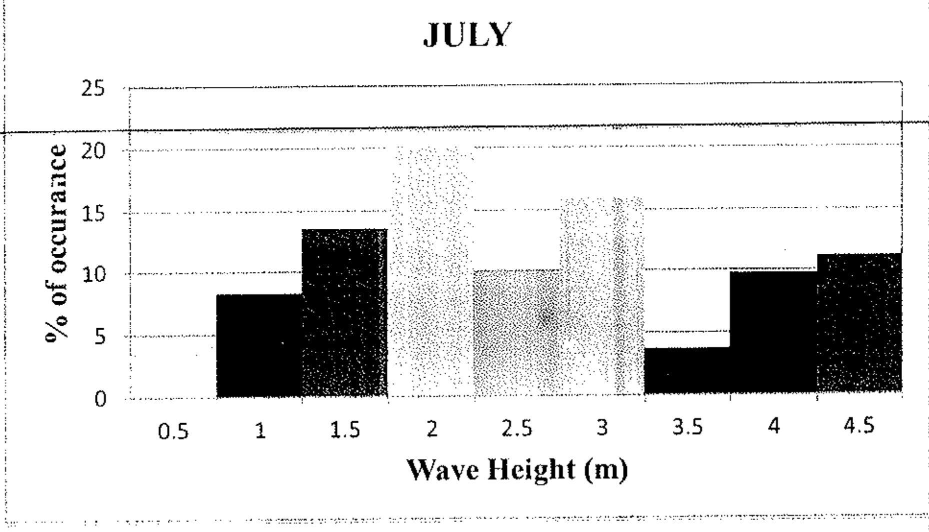
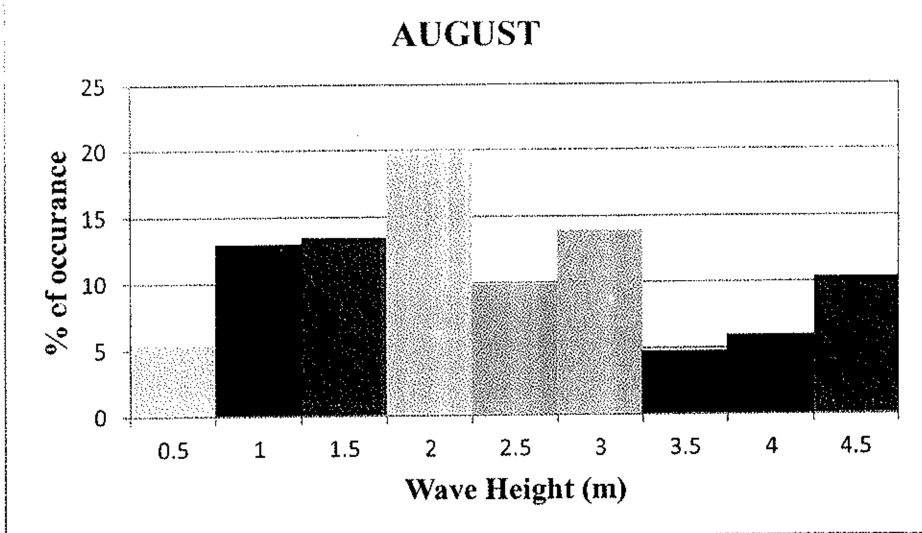


Fig.4 Monthly distribution of wave heights (Apr – June)





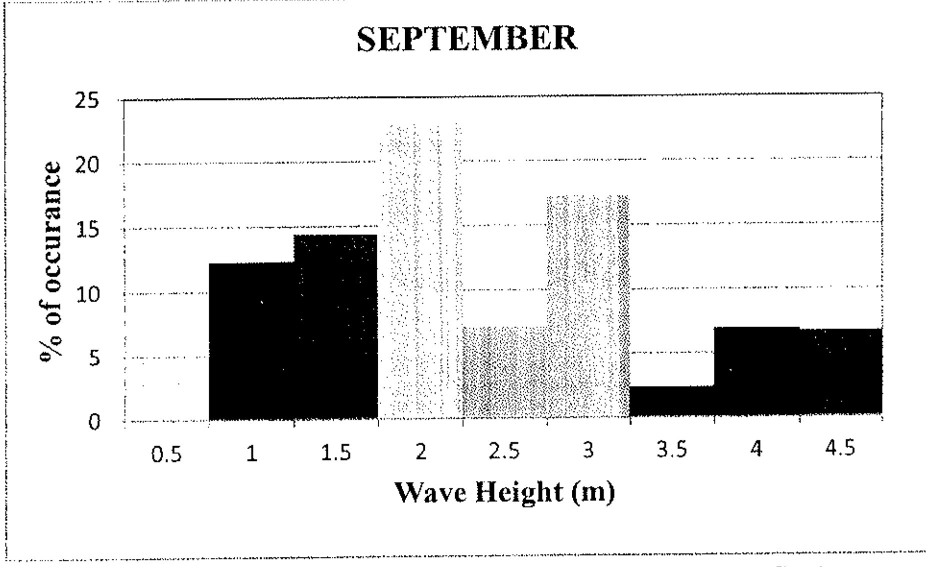
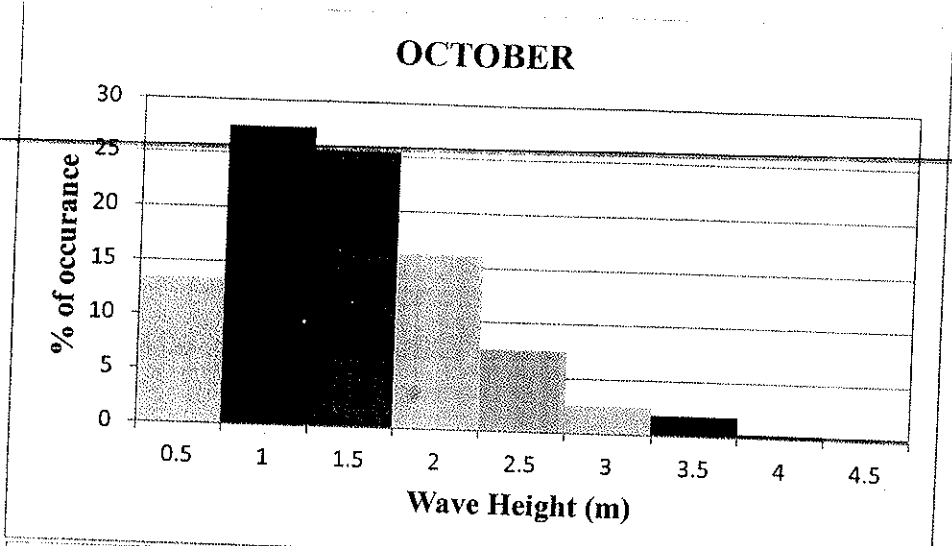
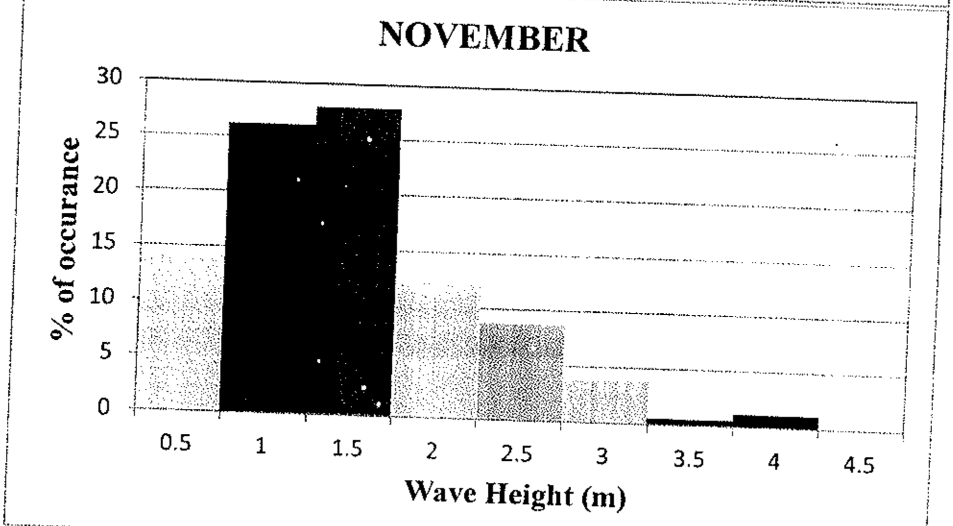


Fig.5 Monthly distribution of wave heights (July – Sep)





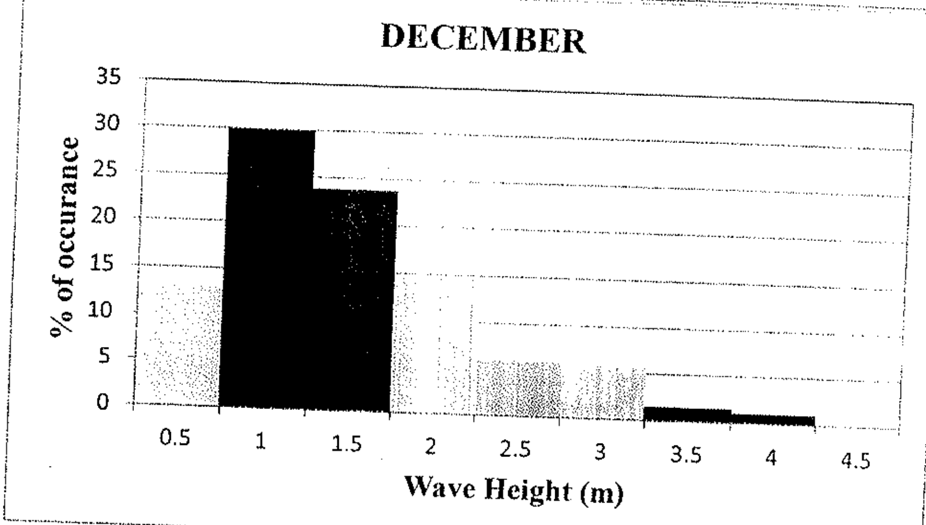


Fig.6 Monthly distribution of wave heights (Oct – Dec)

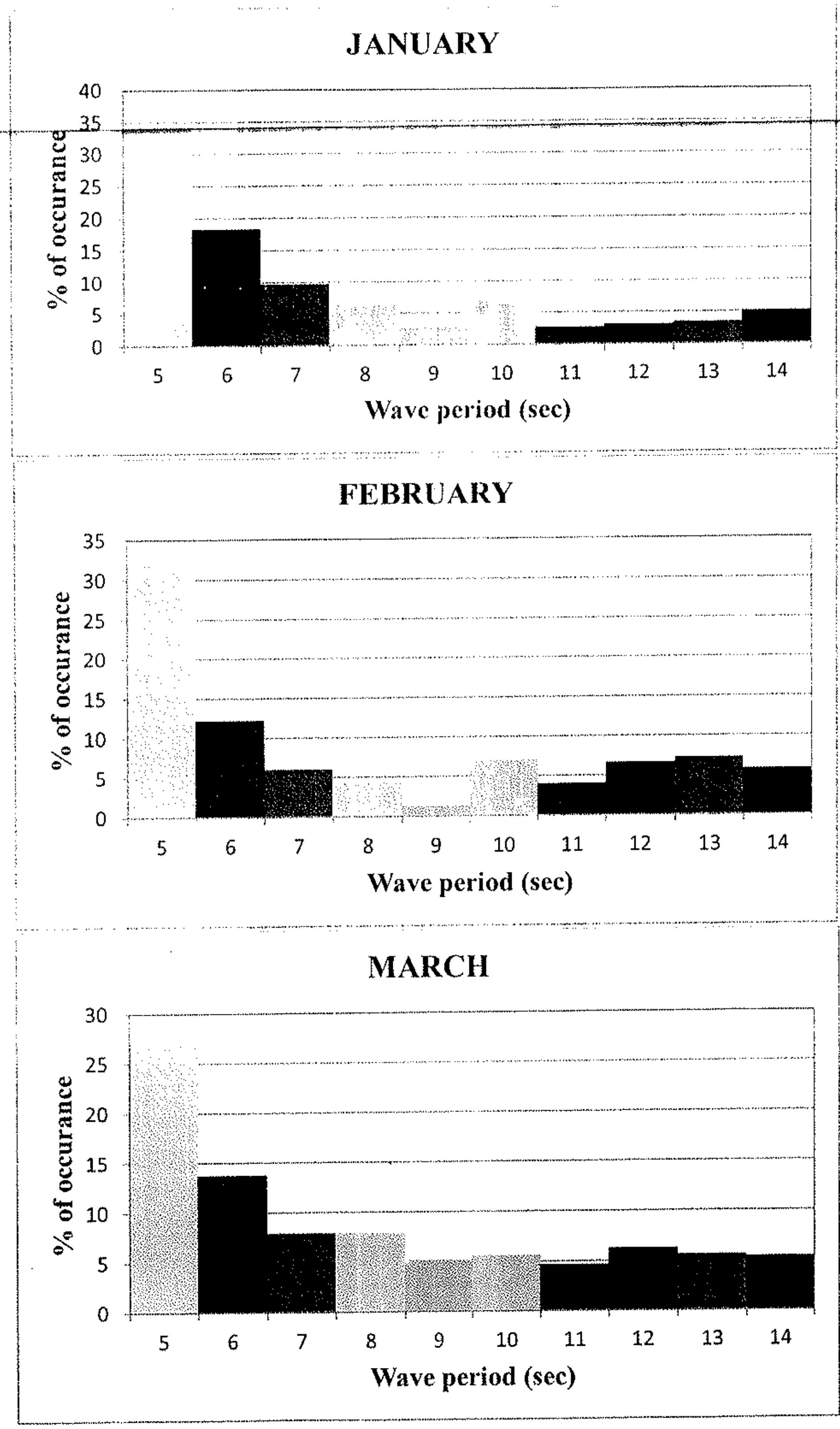


Fig.7 Monthly distribution of wave periods (Jan- Mar)

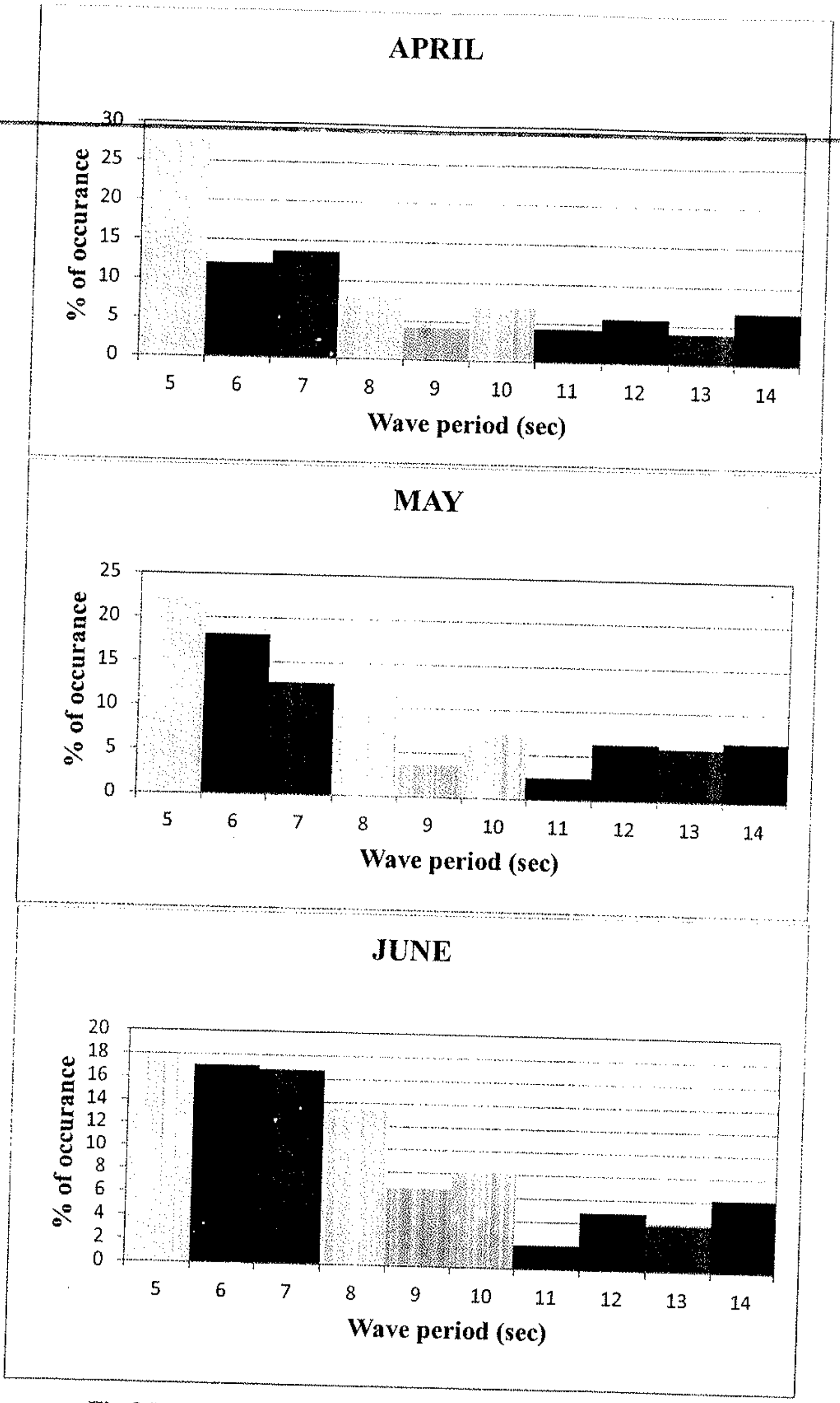


Fig.8 Monthly distribution of wave periods (Apr- June)

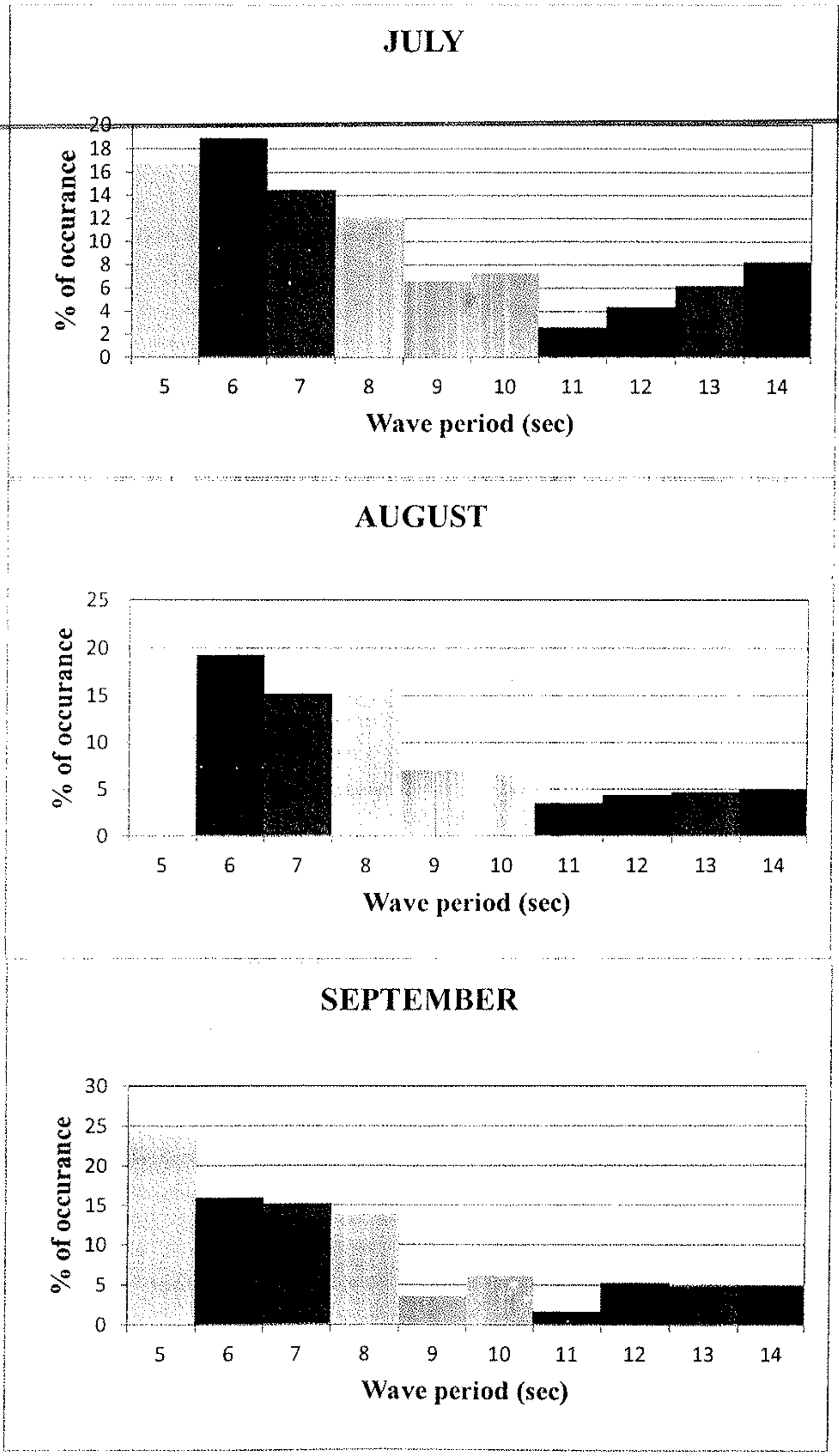
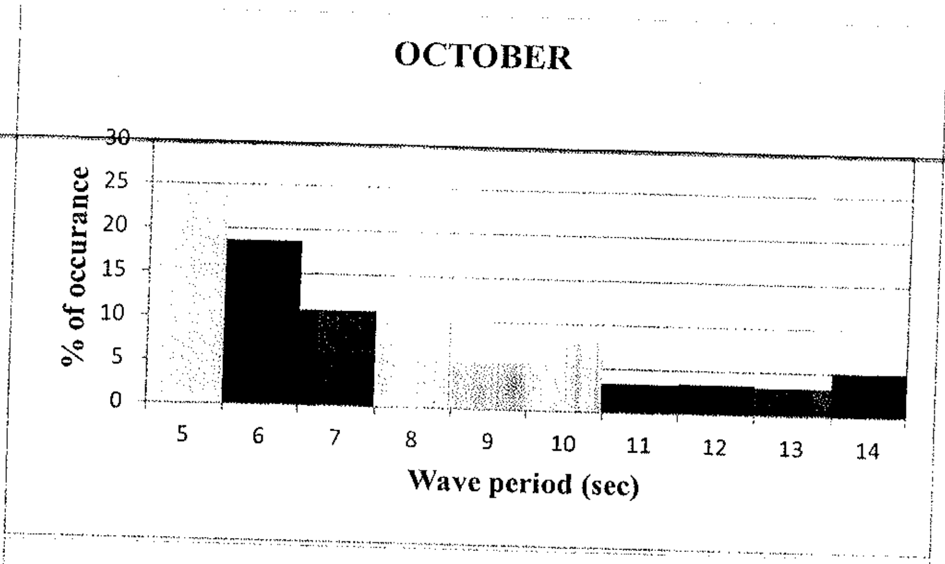
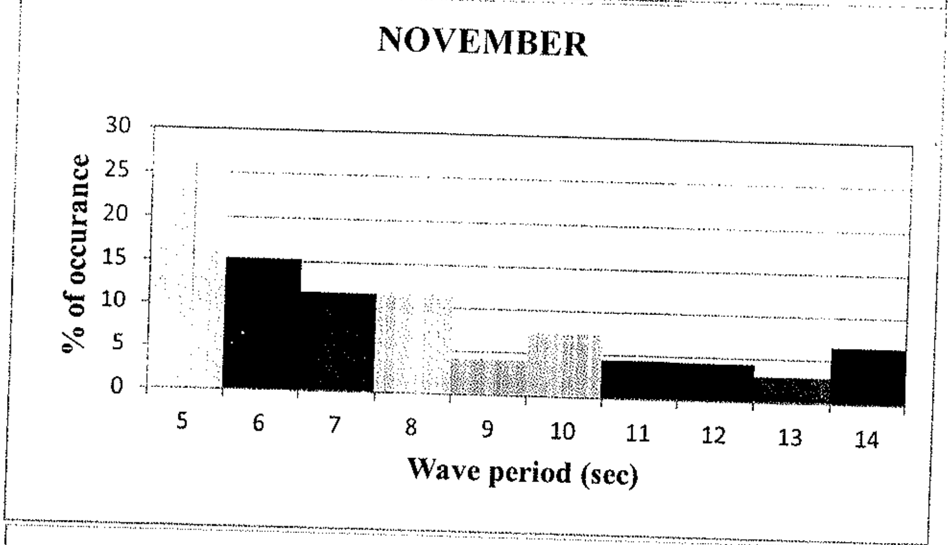


Fig.9 Monthly distribution of wave periods (July – Sep)





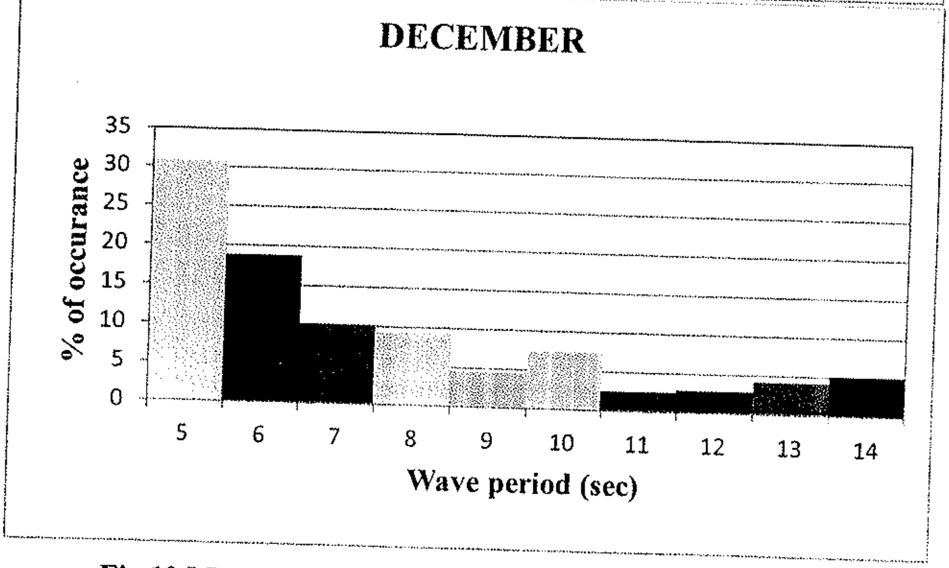
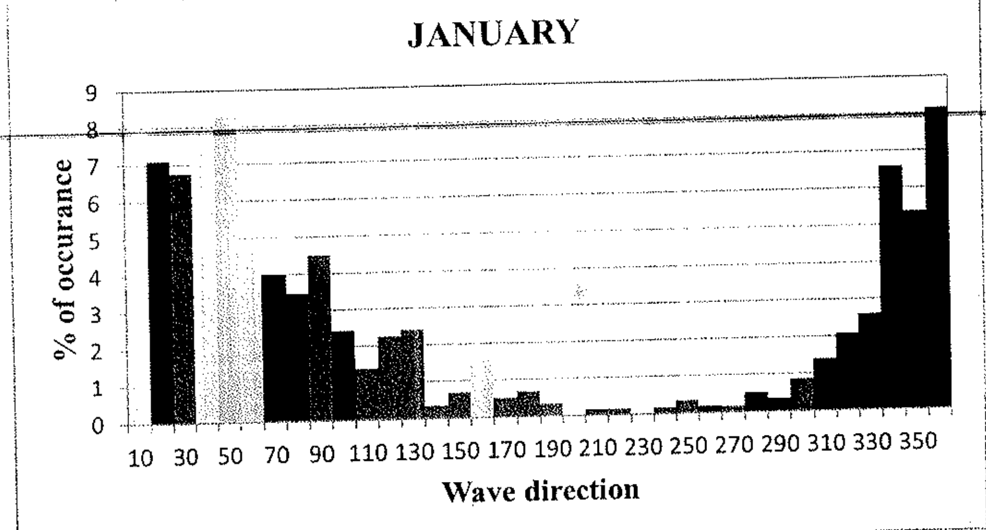
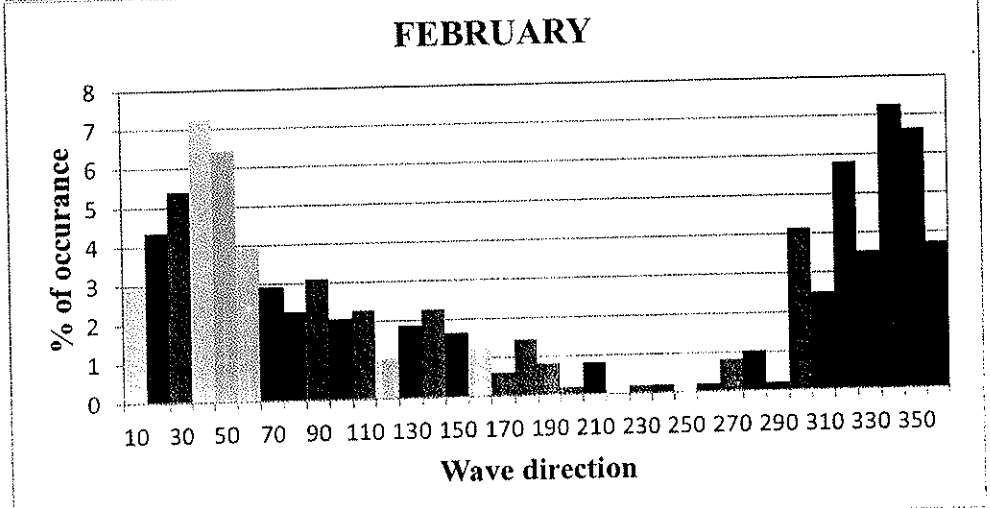


Fig.10 Monthly distribution of wave periods (Oct – Dec)





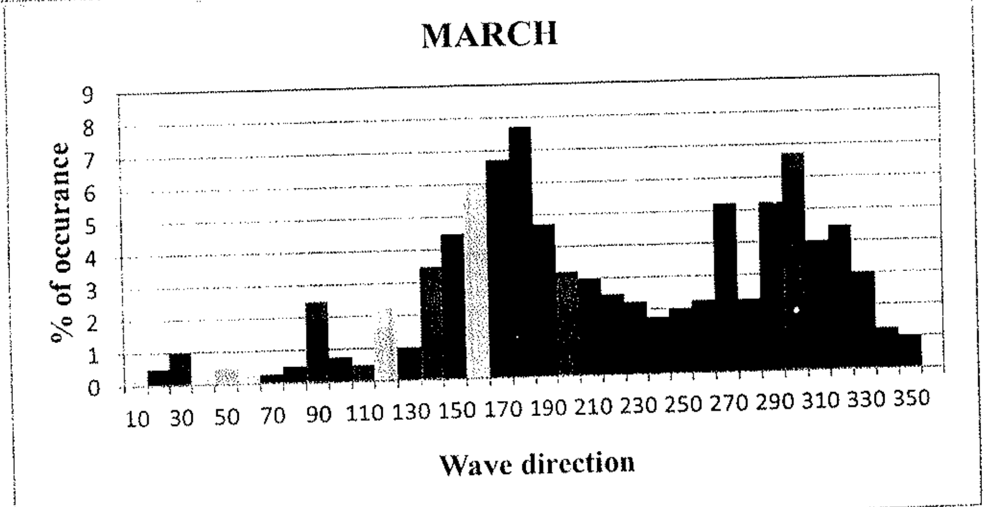


Fig.11 Monthly distribution of wave directions (Jan – Mar)

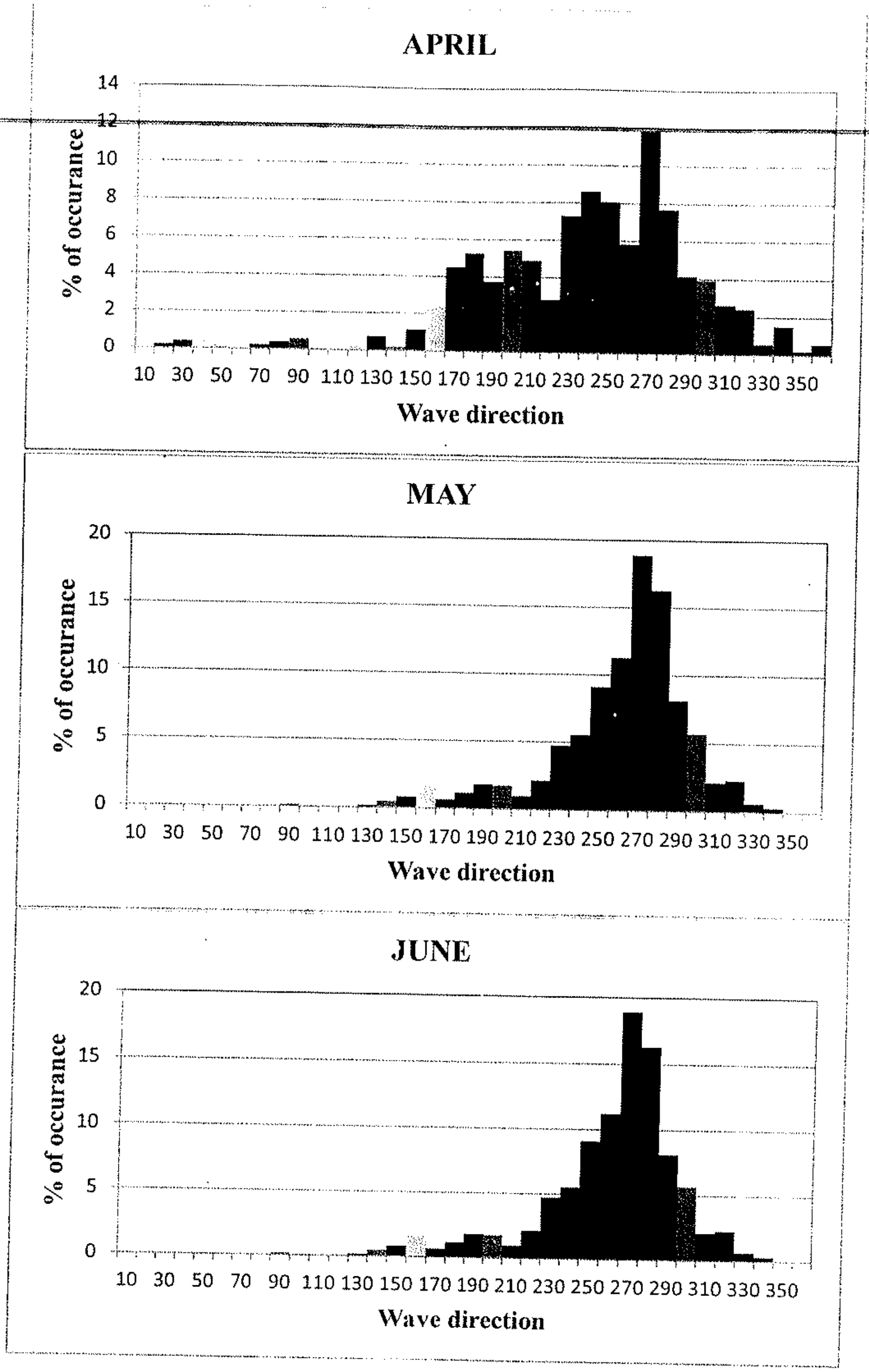


Fig.12 Monthly distribution of wave directions (Apr – June)

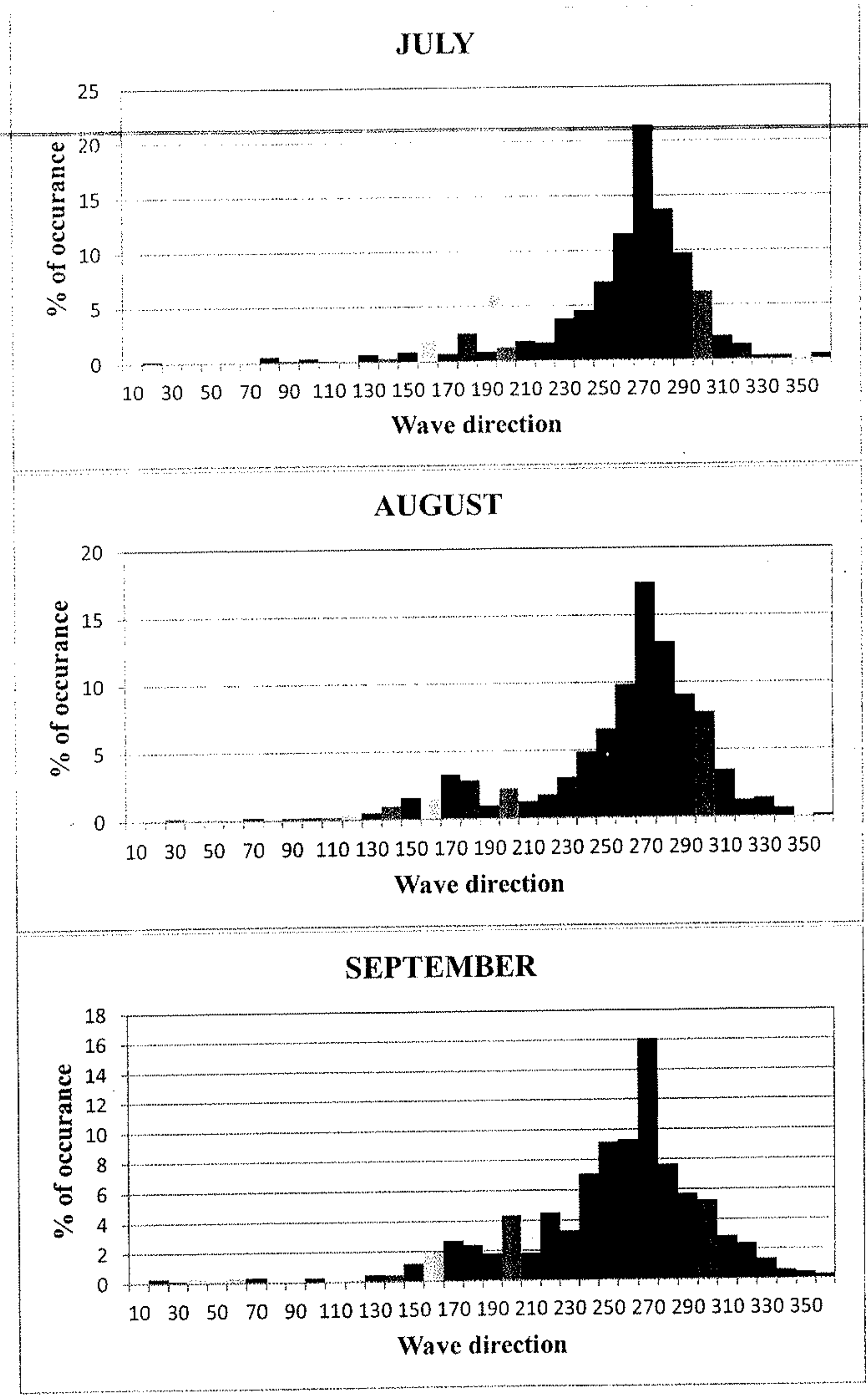


Fig.13 Monthly distribution of wave directions (July – Sep)

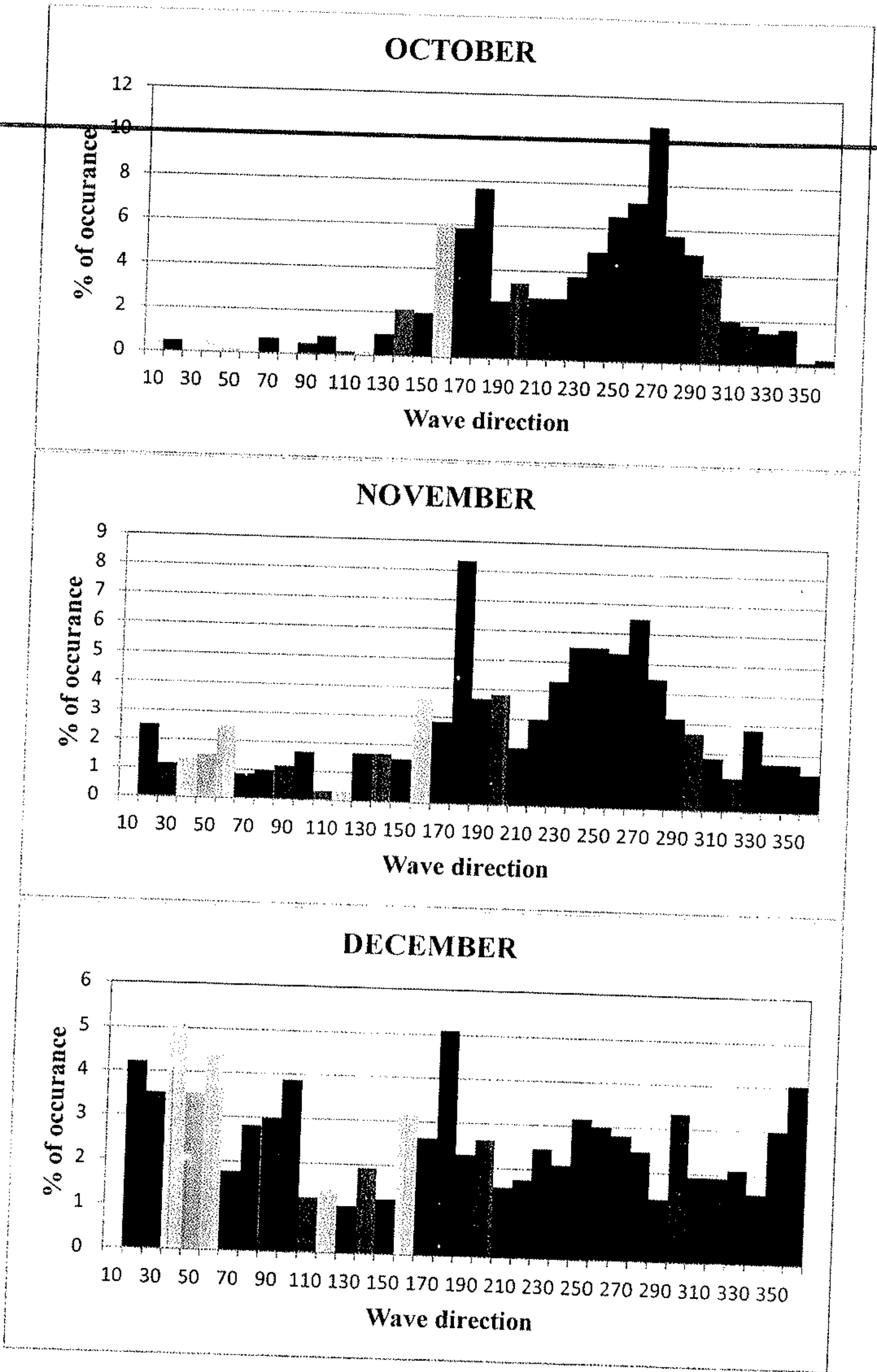


Fig.14 Monthly distribution of wave directions (Oct – Dec)

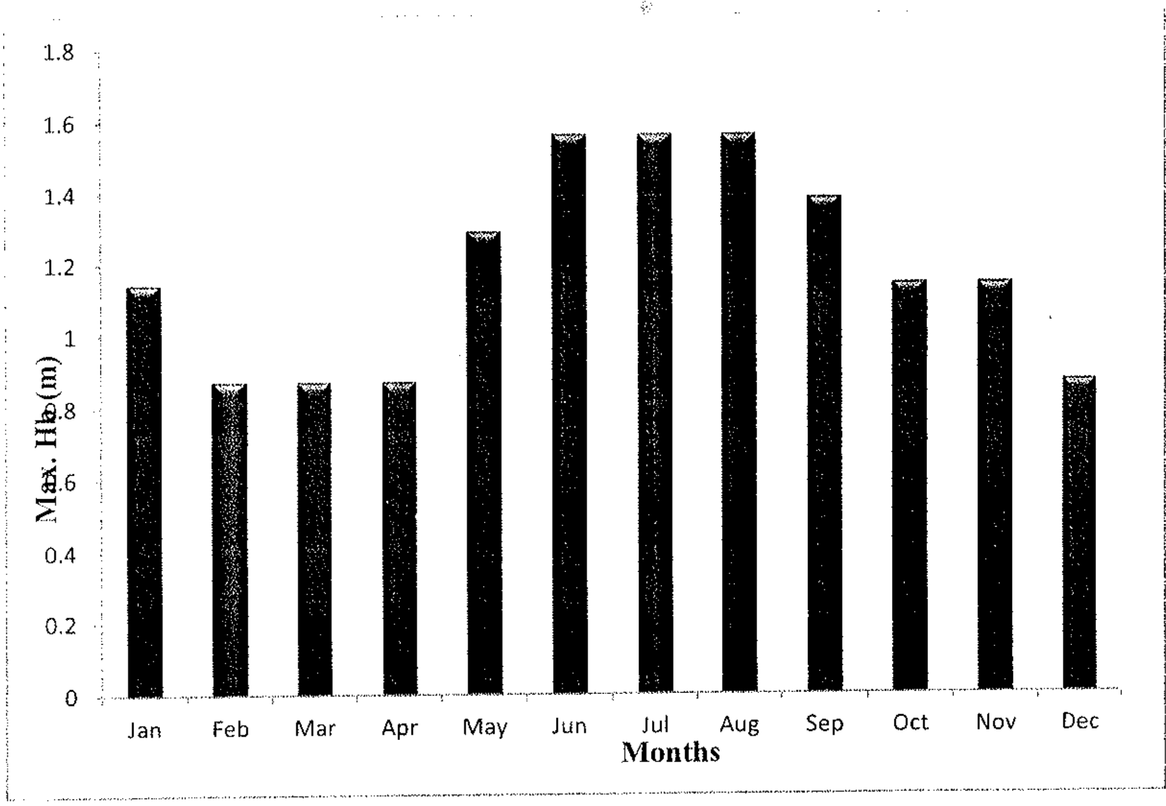


Fig.15(a) Mean Breaker Height for all months

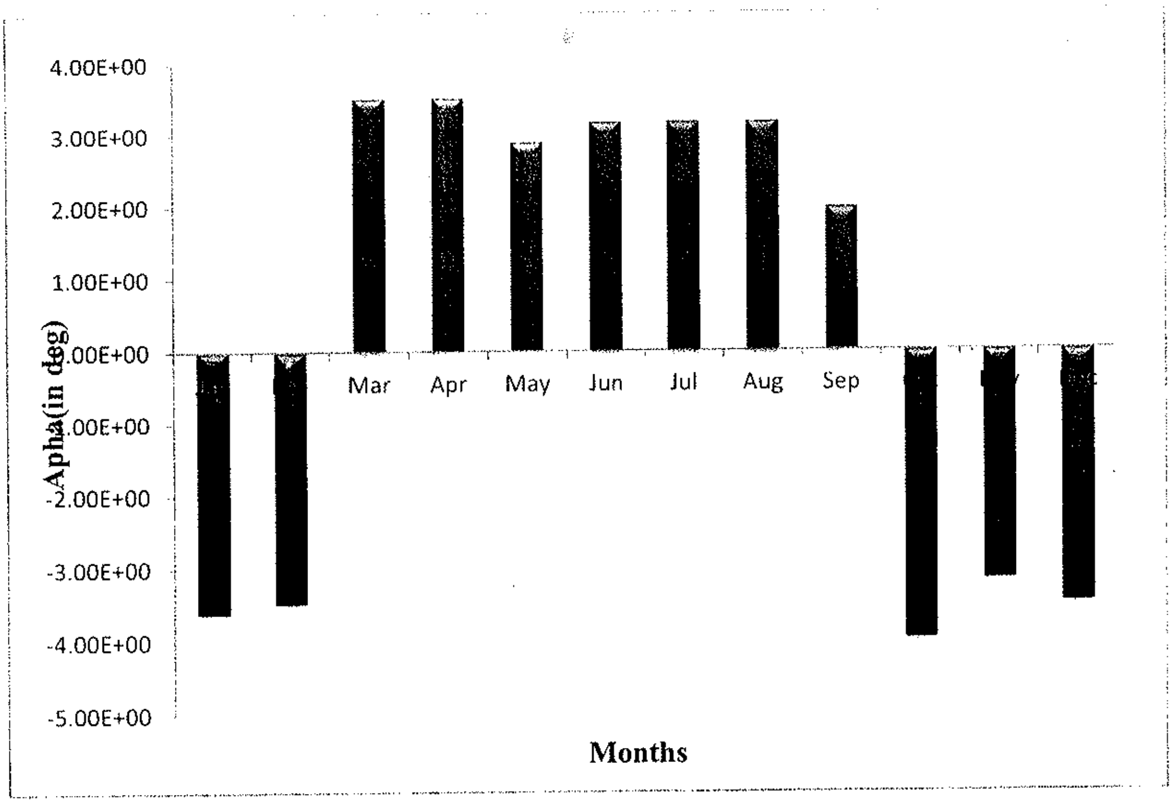


Fig.15(b) Mean Breaker Angle for all months

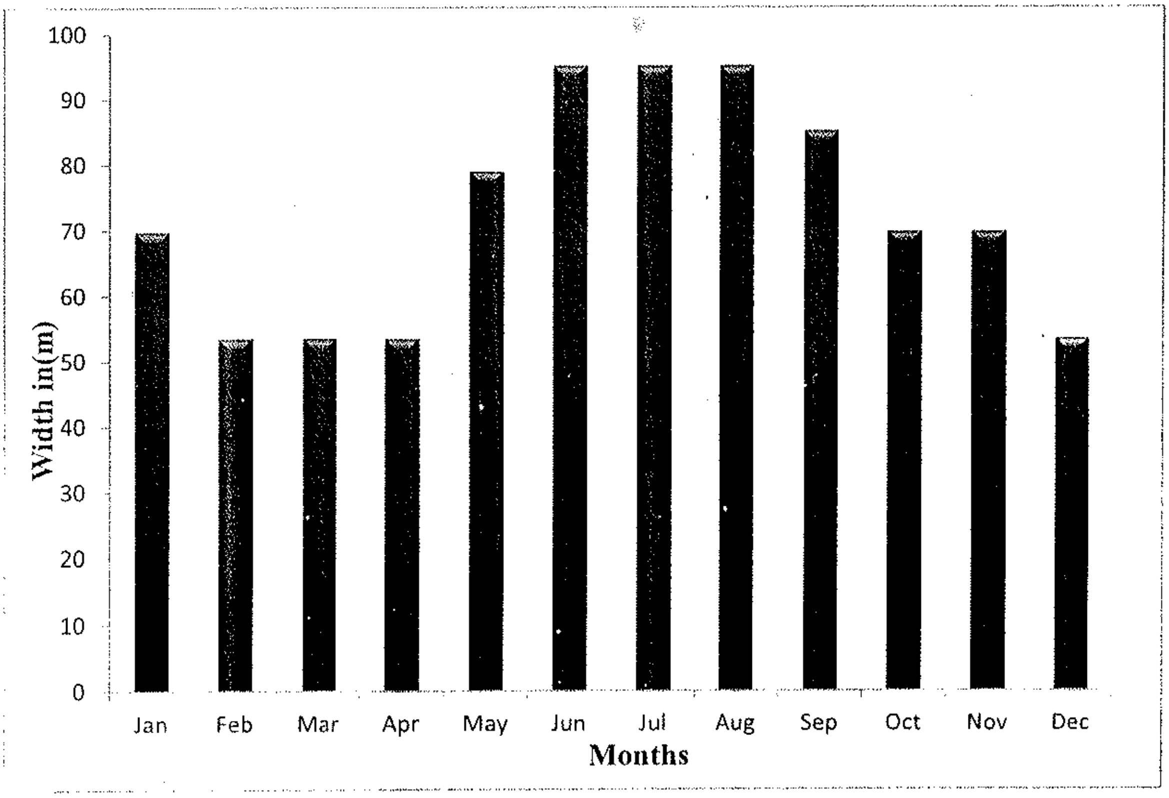


Fig.15(c) Mean Surf Zone Width for all months

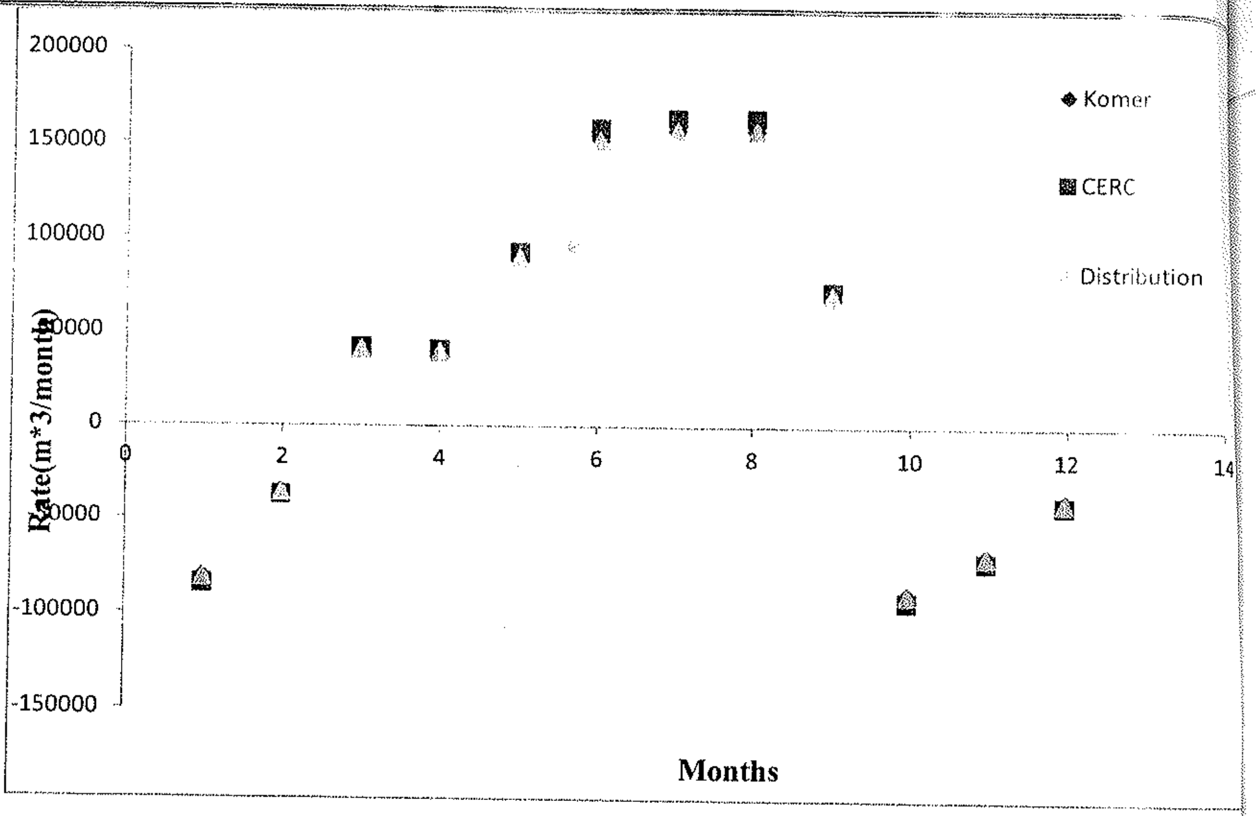


Fig.16 Long shore sediment transport rate

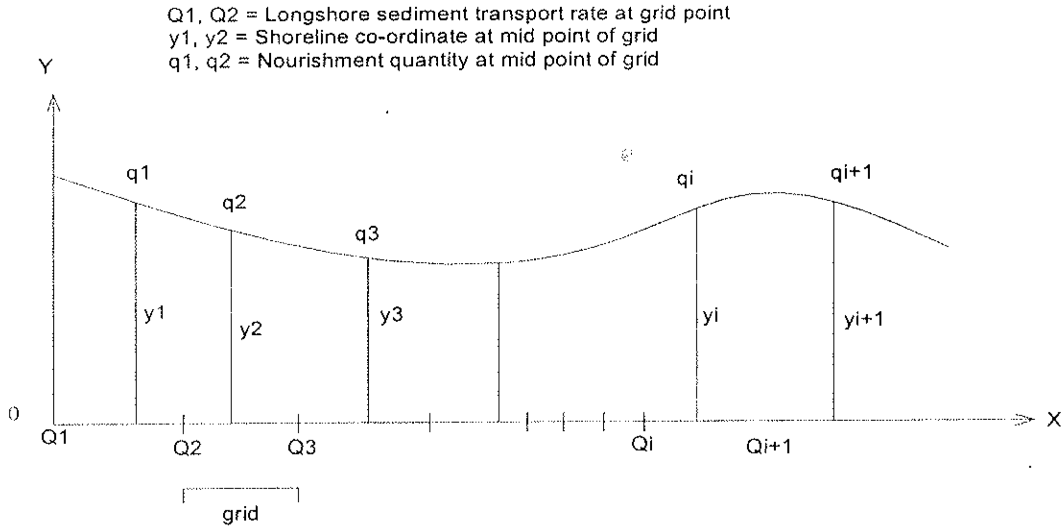


Fig.17 Schematic diagram for finite difference scheme

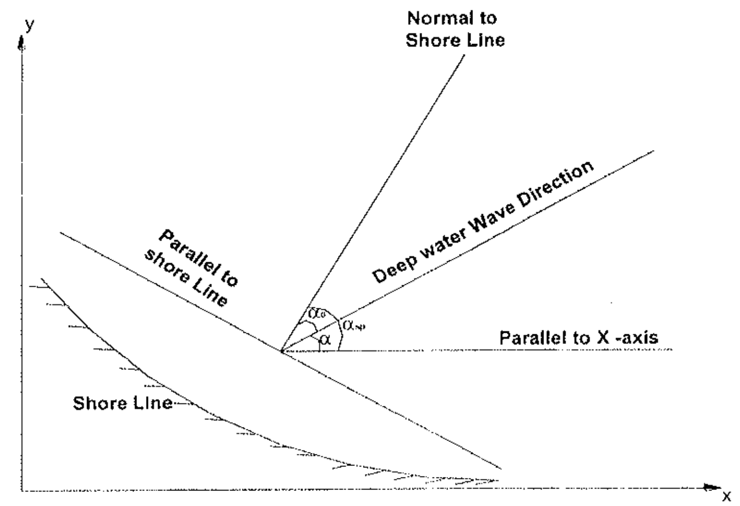


Fig.18 Definition sketch of angles considered

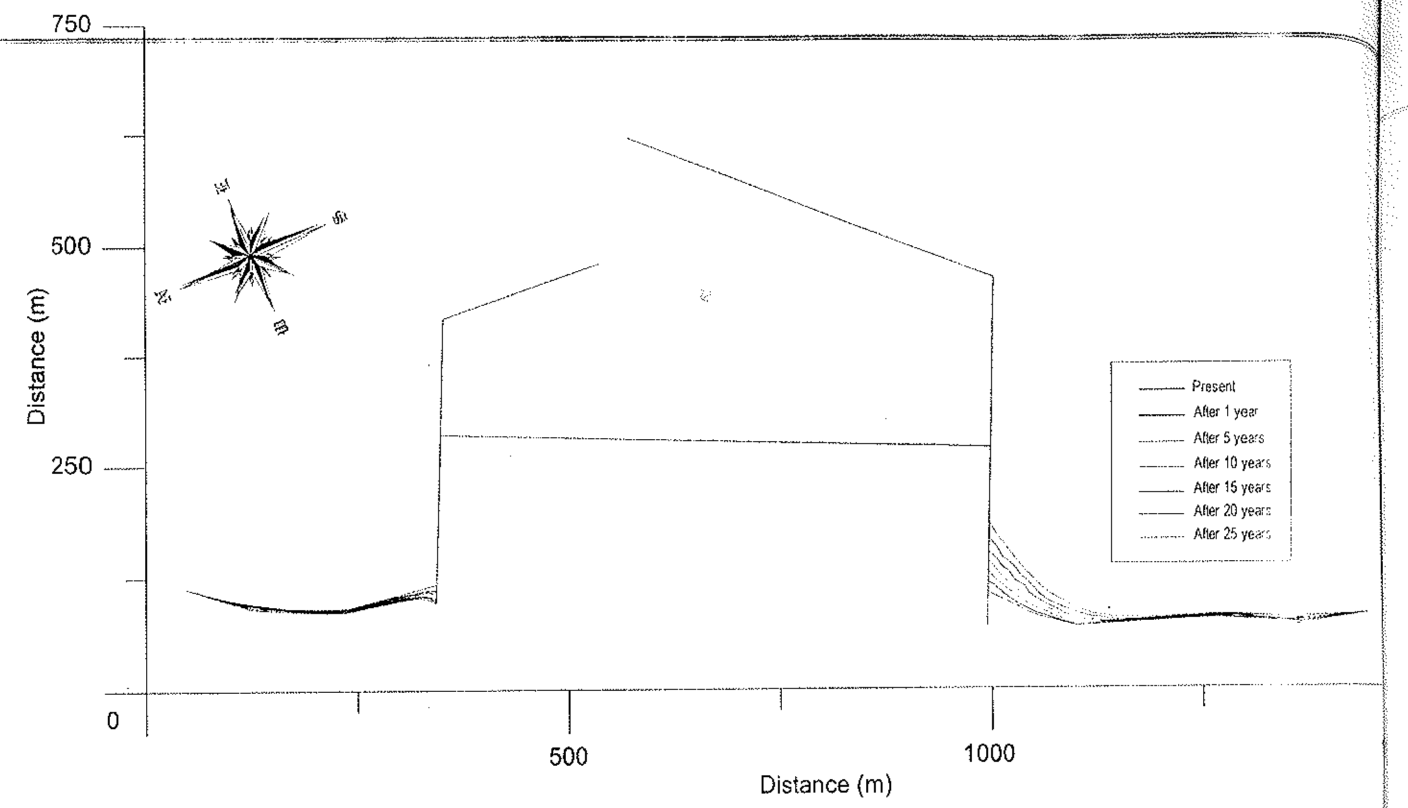


Fig.19 Shoreline evolution

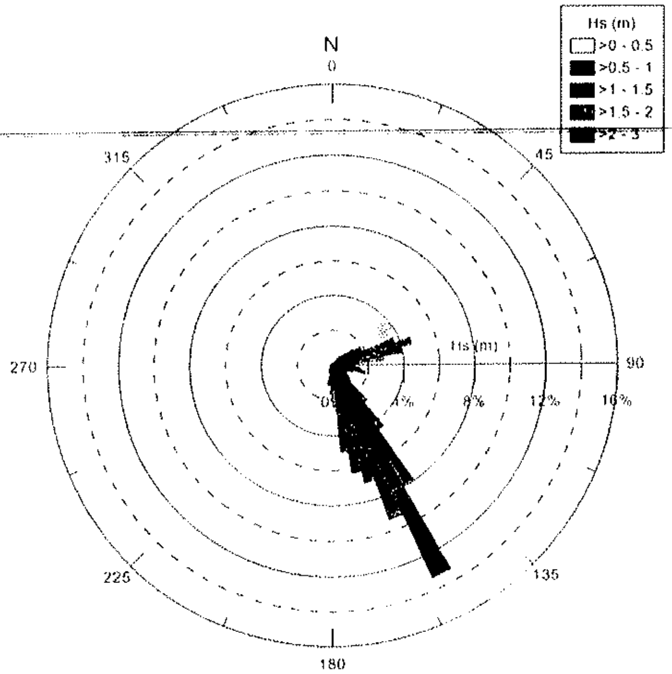


Fig.20 Wave rose diagram representing the significant wave height (m) along the particular direction for an annual year

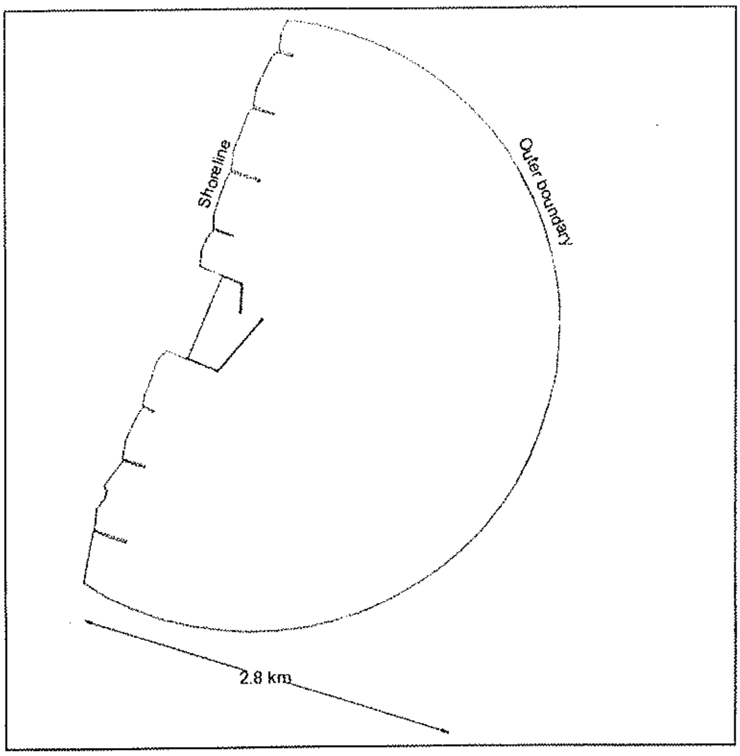


Fig.21 Computational domain for tranquility studies for Thiruvottriyur Kuppam

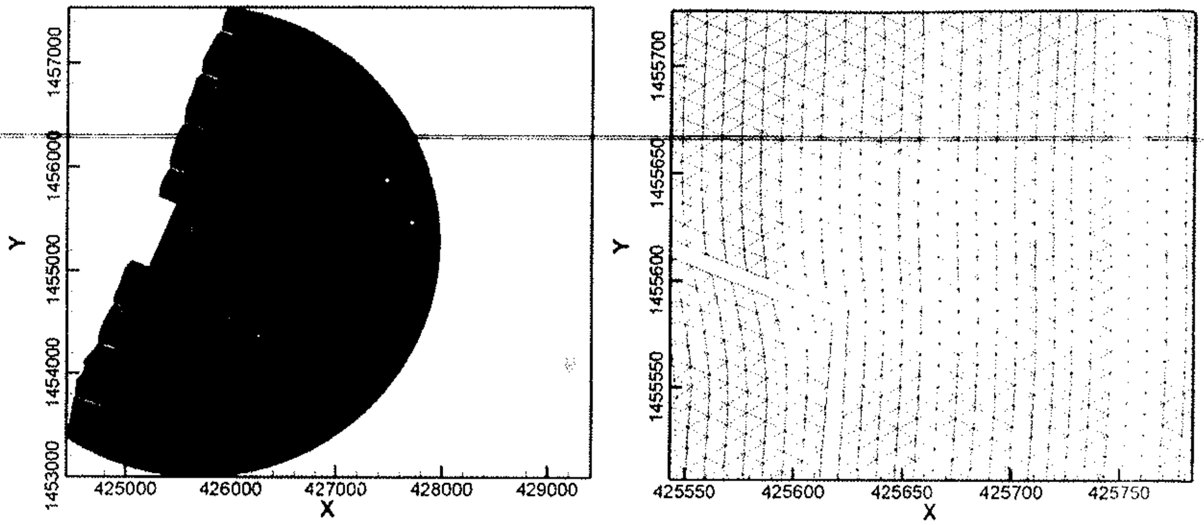
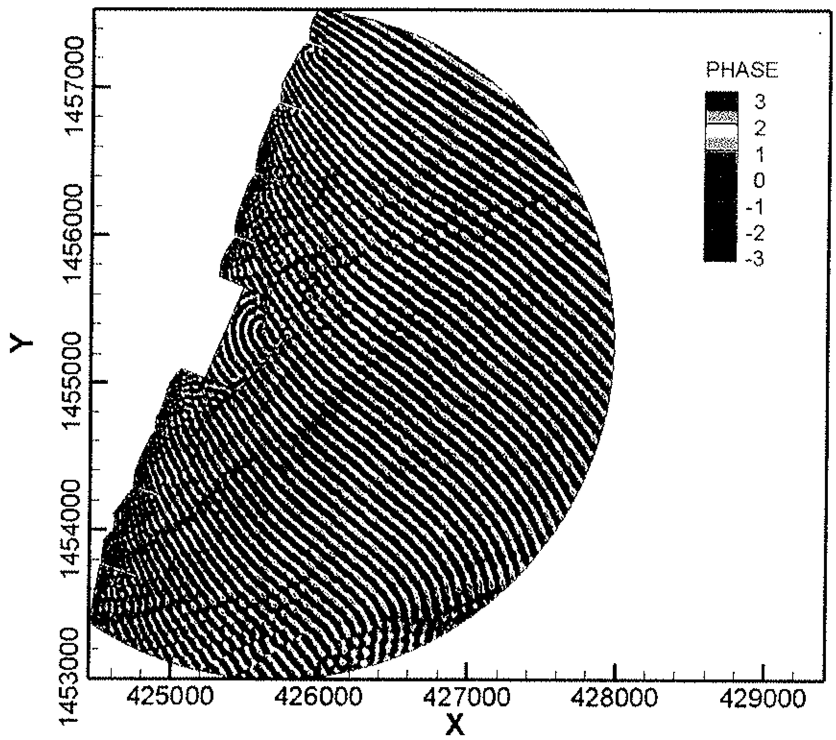


Fig.22 Mesh Structure adopted for the wave propagation modeling



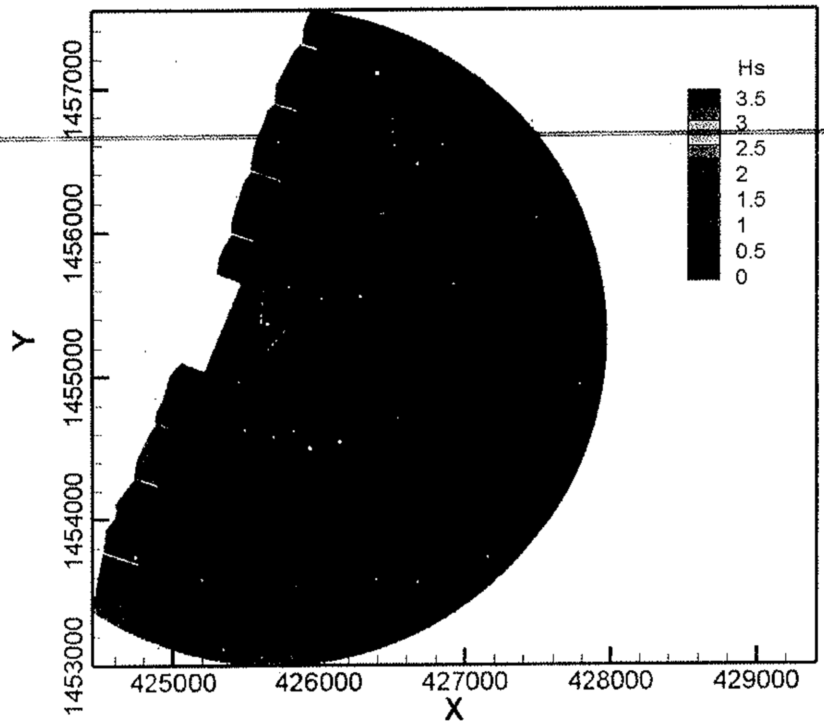
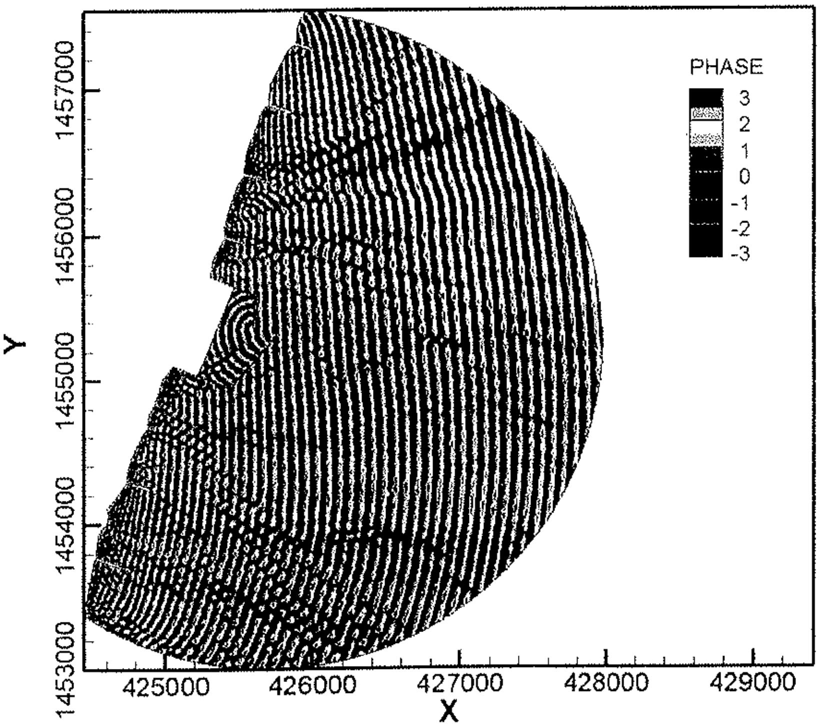


Fig.23 Phase distributions and Wave height distribution for the wave approach angle from 45^0



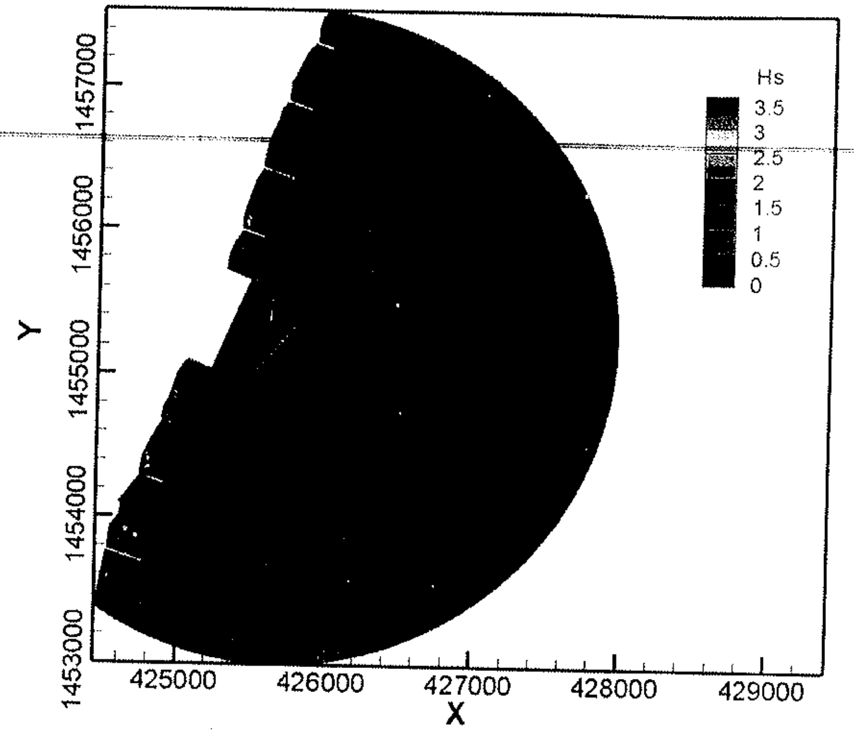
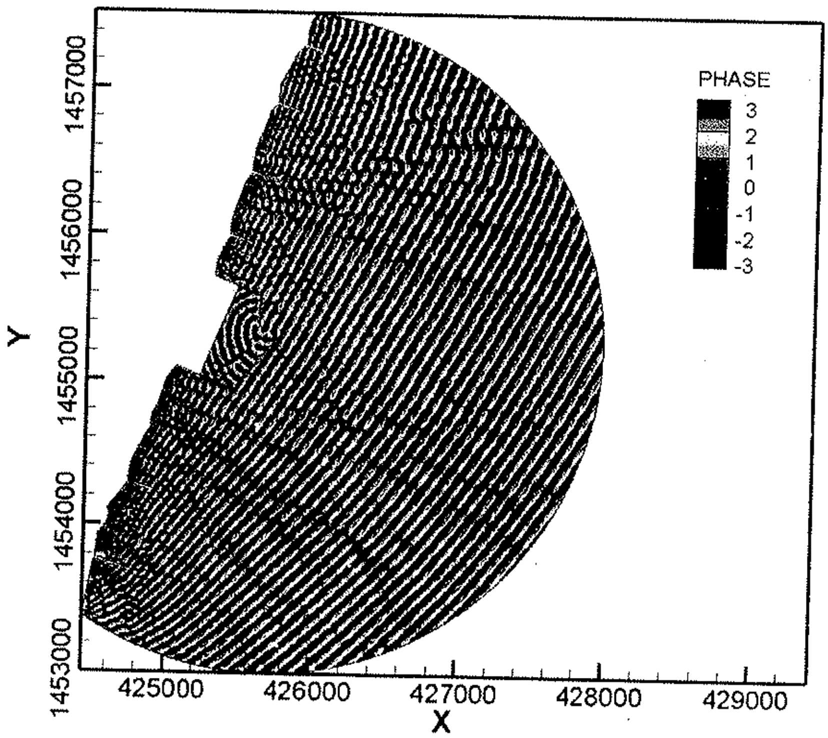


Fig.24 Phase distributions and Wave height distribution for the wave approach angle from 90^0



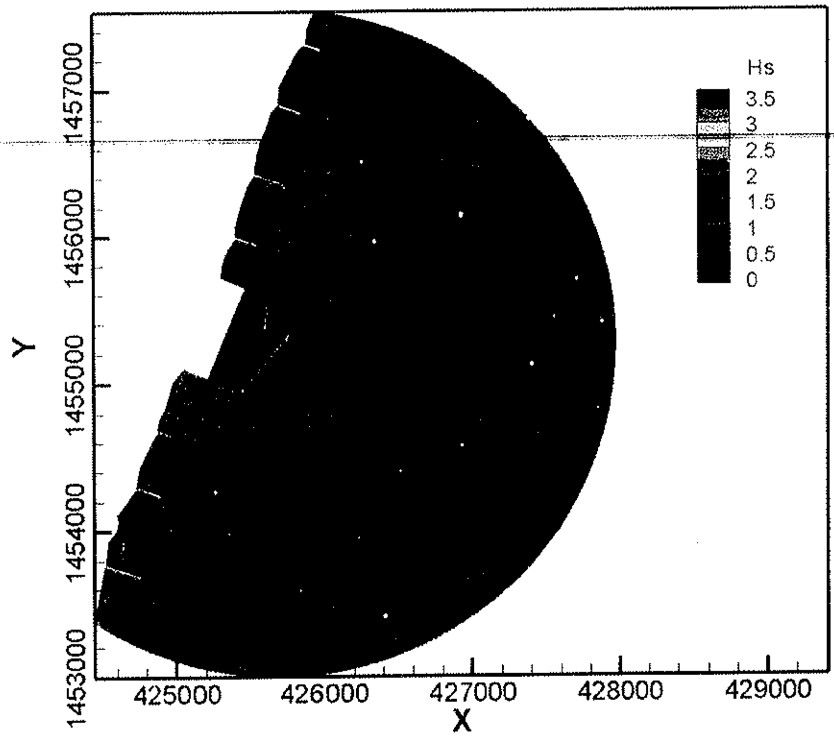
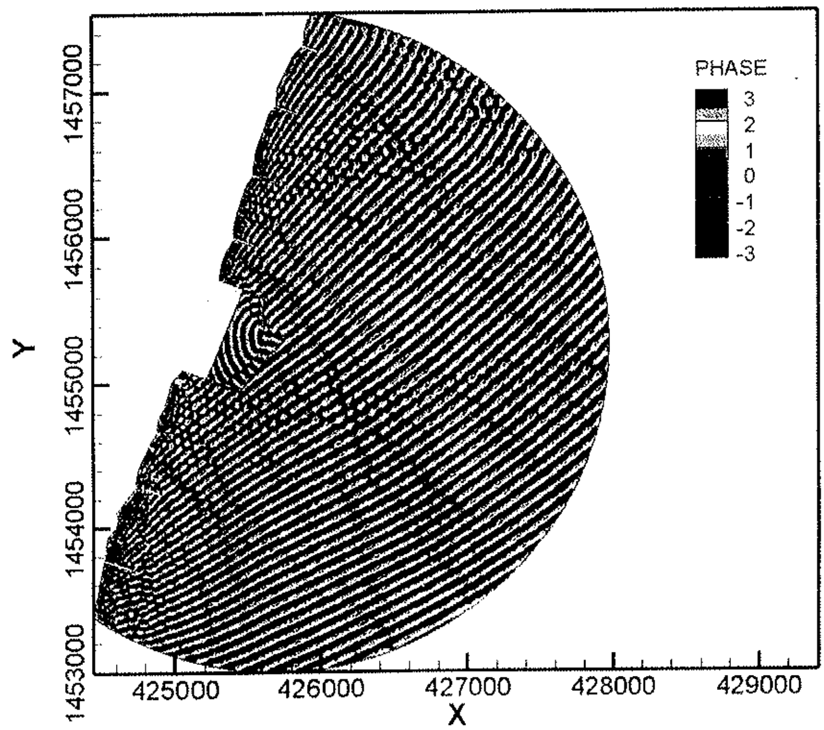


Fig.25 Phase distributions and Wave height distribution for the wave approach angle from 135^0



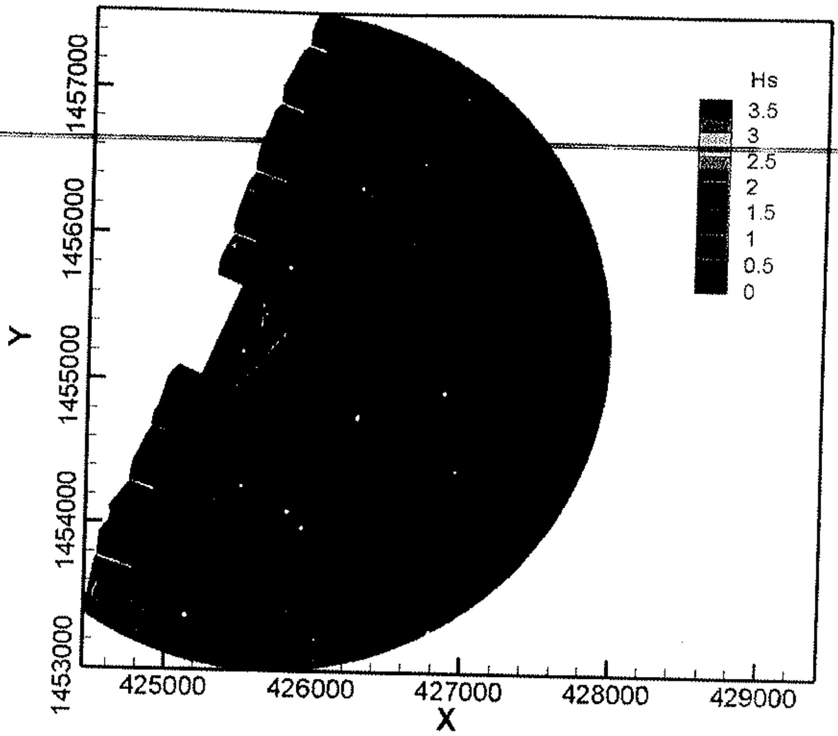
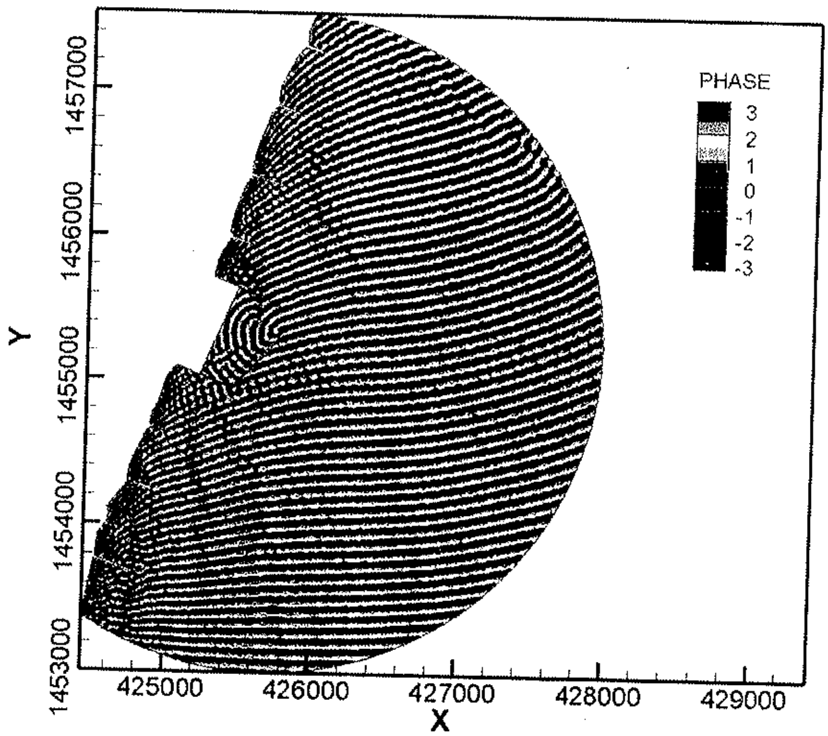


Fig.26 Phase distributions and Wave height distribution for the wave approach angle from 155^0



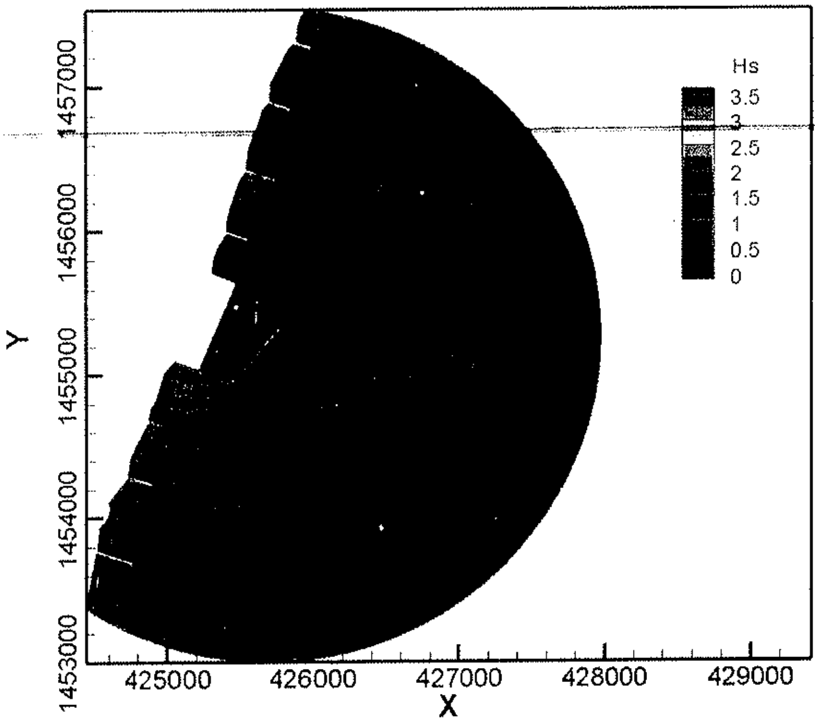
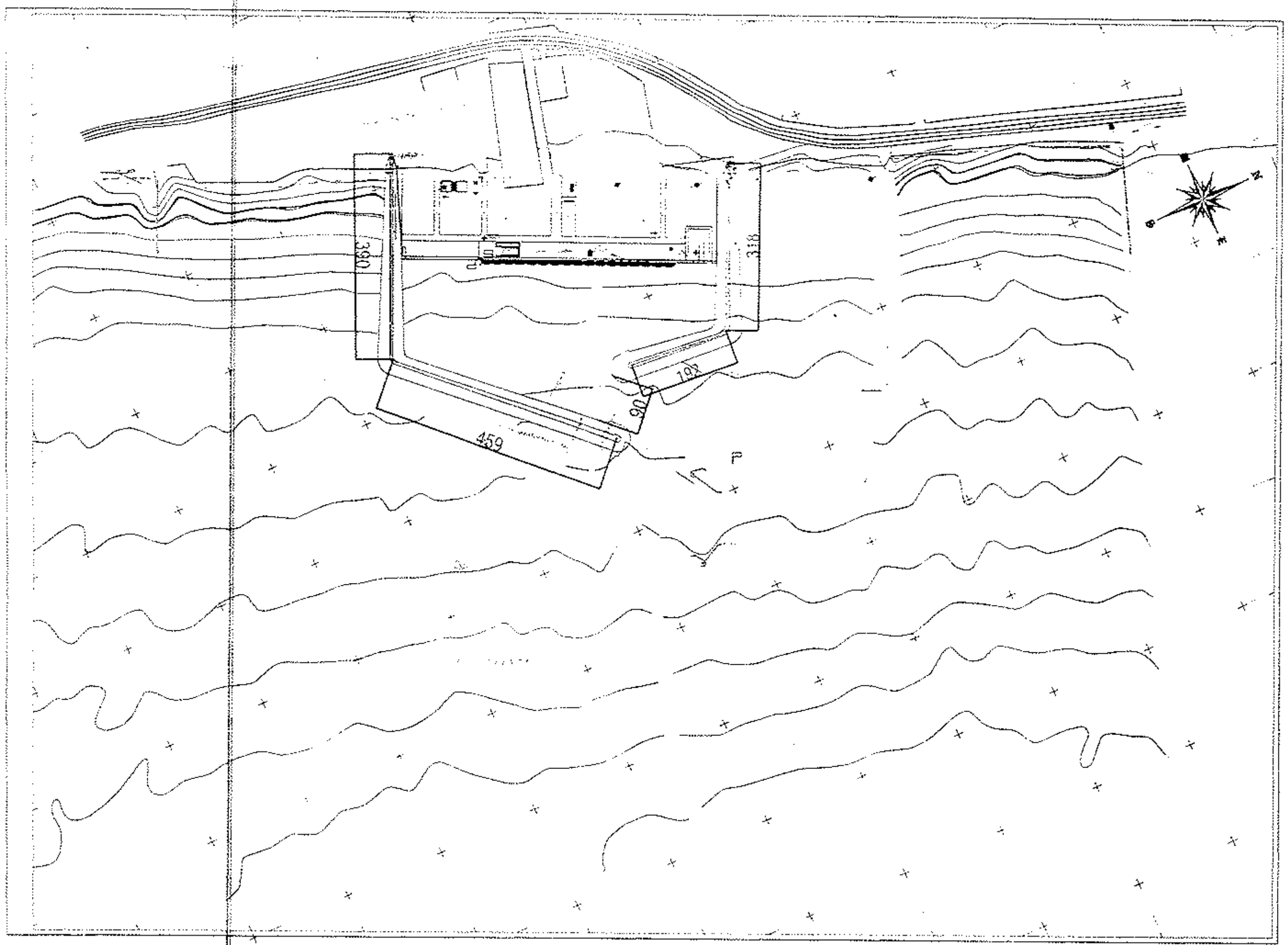


Fig.27 Phase distributions and Wave height distribution for the wave approach angle from 180^0



ALL DIMENSIONS ARE IN 'm'

DEPARTMENT OF OCEAN ENGINEERING
IIT MADRAS

CLIENT:
FISHERIES DEPARTMENT, TAMIL NADU

PROJECT:
TUNA FISHING HARBOR AT THIRUVOTTRIYUR KUPPAM

PLATE 1 :
PROPOSED REVISED LAYOUT OF THE FISHING HARBOR

(Prof. V. SUNDAR) (Prof.S.A.SANNASIRAJ)
DEPARTMENT OF OCEAN ENGINEERING

DRAWING NO.:IITM\DOE\01	DATE: 15.07.2019	REV:00

THIRU. A.R. RAHUL NADH, I.A.S.
MEMBER SECRETARY

STATE LEVEL ENVIRONMENT IMPACT
ASSESSMENT AUTHORITY-TAMILNADU
3rd Floor, Panagal Maaligai,
No.1, Jeenis Road, Saidapet,
Chennai - 600 015.
Phone No. 044-24359973
Fax No. 044-24359975

AMENDMENT IN ENVIRONMENTAL CLEARANCE

Letter No. SEIAA-TN/F.No.6440/EC/7(e)/75/2020/Amendment/2024 dated:30.09.2024

To

M/s. Fishing Harbour Project Division
Executive Engineer
Chennai

Sir/Madam,

Sub: SEIAA-TN – Amendment in Environmental Clearance for the Proposed construction of Tuna Fishing Harbour with net fish handling capacity of 69,000 TPA at S.F.No. 7/4, 39, 40, 41, 42 & 49, Thiruvottiyur Kuppam Village, Ennore Taluk, Thiruvallur District, Tamil Nadu by Department of Fisheries, Government of Tamil Nadu, Fishing Harbour Project Division – under Category "B1" and Schedule Sl. No. 7(e) - Ports, Harbour Projects under the EIA Notification, 2006 as amended – Amendment in Environmental Clearance – Issued – Regarding.

Ref:
1. Earlier EC issued by SEIAA-TN vide Letter No. SEIAA-TN/F.No.6440/EC/7(e)/75/2020 dated: 05.08.2020.
2. The Hon'ble NGT judgment in Original Application No.28/2020 as well as the Appeal No.28/2020 dated: 28.09.2022.
3. Minutes of the 383rd SEAC meeting held on 15.06.2023.
4. Minutes of the 385th SEAC meeting held on 22.06.2023.
5. Minutes of the 392nd SEAC meeting held on 14.07.2023.
6. Recommendation from Tamil Nadu Biodiversity Board vide Ref. No. TNBB/799/2023/B1, Dated: 05.06.2024
7. Reply by the Project Proponent Dated: 09.08.2024.

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8. Minutes of the 494th SEAC meeting held on 05.09.2024.
9. Minutes of the 496th SEAC meeting held on 12.09.2024.
10. Minutes of the 759th SEIAA meeting held on 30.09.2024

- - - - -

Environmental Clearance was accorded vide Letter No. SEIAA-TN/F.No.6440/EC/7(e)/75/2020 dated: 05.08.2020 to Department of Fisheries, Government of Tamil Nadu, Fishing Harbour Project Division for the Proposed construction of Tuna Fishing Harbour with net fish handling capacity of 69,000 TPA at S.F.No. 7/4, 39, 40, 41, 42 & 49, Thiruvottiyur Kuppam Village, Ennore Taluk, Thiruvallur District, Tamil Nadu under Category "B1" and Schedule Sl. No. 7(e) - Ports, Harbour Projects.

Based on the Hon'ble National Green Tribunal (NGT) Original Application No.28/2020 as well as the Appeal No.28/2020 dated: 28.09.2022 directions vide ref 2nd cited & Study reports furnished by PP, the following Amendment in EC Issued was processed.

Remarks of SEAC

Proposed construction of Tuna Fishing Harbour with net fish handling capacity of 69,000 TPA at S.F.No. 7/4, 39, 40, 41, 42 & 49, Thiruvottiyur Kuppam Village, Ennore Taluk, Thiruvallur District, Tamil Nadu by Department of Fisheries, Government of Tamil Nadu, Fishing Harbour Project Division – For Amendment in Environmental Clearance. (SIA/TN/MIS/43388/2015, dated: 27.09.2019)

The proposal was placed in this 496th meeting of SEAC held on 12.09.2024. The details of the project furnished by the proponent are available on the PARIVESH web portal (parivesh.nic.in).

The SEAC noted the following:

1. The SEIAA has issued the Terms of Reference (ToR) to carryout Environment Impact Assessment (EIA) and Public hearing meeting, vide their Letter No.SEIAA-TN/F.No. 6440/SEAC-C/7(e)/ToR-301/2017 dated: 22.01.2018.
2. SEIAA has granted Environmental Clearance (EC) vide their Letter No. SEIAA-TN/F.No.6440/EC/7(e)/75/2020 dated: 05.08.2020.

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SEIAA-TN

3. In the meantime, anticipating the Environmental Clearance and considering the importance of Welfare schemes, only casting of Tetra pods and placing of Granite stones on the existing groynes were started by the PP.
4. Subsequently, in Hon'ble NGT an Original Application OA No.28/2020 was filed by the Meenava Thanthai K.R. Selvaraj Kumar, Meenava Nala Sangam rep. by its President M.R. Thiyagarajan against the Construction of Tuna Fishing harbour in CRZ Zone at Thiruvottriyur, Thiruvallur District. The Application was filed before the National Green Tribunal as the Department of Fisheries, is alleged commenced the works without getting permissions.
5. The Hon'ble National Green Tribunal (NGT) in OA No.28/2020 has given the directions. As per the Hon'ble court direction the work was stopped from 10.02.2020. The Tamil Nadu Environmental Impact Assessment Authority granted Environmental Clearance (EC) on 05.08.2020. Based on the Hon'ble NGT direction work has been resumed from 21.09.2020 and now the work has been completed 94% and as per court order further onshore works are in progress.
6. After so many hearings, the Hon'ble NGT judgment in Original Application No.28/2020 as well as the Appeal No.28/2020 dated: 28.09.2022 are as follows,
   a. The claim of the appellant that the baseline data collected prior to the ToR and the consideration of the project after three years of the collection of baseline data which will vitiate and not conducting the public hearing after further details submitted by the project proponent as directed by the SEAC – Tamil Nadu in its 141st meeting will vitiate the issuance of Environmental Clearance (EC) are rejected for the reasons discussed above in the Judgment.
   b. There is no necessity to set aside the Environmental Clearance (EC) as claimed by the appellant, but suspending the Environmental Clearance (EC) to the extent of directing the project proponent not to commission the project but permitting to undertake the project work in onshore area only till such time further studies are completed and further conditions are to be imposed, if any, by the SEIAA – Tamil Nadu will be sufficient and for that purpose, following directions are issued:
      i. The project proponent is directed to conduct a study of sediment deposit and sediment erosion including predicting the locations and suitable

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environment management plan for reducing the same on the basis of the ToR issued and the directions issued by the SEAC – Tamil Nadu in their 141st meeting.

ii. The project proponent is also directed to conduct a study on impact of spillage of fuel or engine oil, lubricant from the construction site and source of other pollution and impacts and suitable precautionary methods to be taken to avoid pollution and trap the spillage should be conducted.

iii. A detailed marine biodiversity management plan prepared through NIOT or any other institute of repute on marine, brackish water and freshwater ecologically and biodiversity and must be submitted to and implemented to the satisfaction of the State Biodiversity Board and the CRZ authority. The report shall be based on the study of the impact of the project activities on intertidal biotopes, corals and coral communities (if any) in the area, molluscs, sea grasses, sea weeds, sub-tidal habitats, fishes and other marine and aquatic micro, macro and mega flora and fauna including benthos, planktons, turtles, birds, etc. as also the productivity. The data collection and impact assessment shall be as per standards survey methods and include underwater photography in tune with the recommendations made by the SEAC – Tamil Nadu while recommending the project.

iv. The study must be conducted by the project proponent and prepare a biodiversity management plan and in consultation with biodiversity board and the CRZ authority.

v. After conducting studies and getting report through accredited agency, then the same shall be placed before the SEAC – Tamil Nadu for consideration and on receipt of the same, the SEIAA– Tamil Nadu shall place the same before the SEAC – Tamil Nadu and they shall consider the sufficiency or otherwise of the same and on that basis, if any, further conditions are to be imposed to protect the marine environment then they shall impose the same and recommend the project or pass appropriate findings and forward the same with recommendation / findings to the SEIAA – Tamil Nadu and on receipt of the same, the SEIAA – Tamil Nadu shall appraise the same and

MEMBER SECRETARY
SEIAA-TN

take appropriate decision imposing additional conditions or otherwise on the basis of the findings of the SEAC – Tamil Nadu and incorporate the same in the Environmental Clearance (EC) granted.

c. The project proponent is directed to complete the studies within a period of 6 (Six) months and on submission of the report by the project proponent, the SEAC / SEIAA – Tamil Nadu are directed to complete the process of further appraisal as directed by this Tribunal within a further period of 3 (Three) months and issue necessary further conditions or modifications or findings in accordance with law.
d. Once the SEIAA – Tamil Nadu imposed further conditions, then the project proponent is directed to carry out those conditions as well while proceeding with the project.
e. The Environmental Clearance (EC) granted will be subject to the further orders to be passed by the SEAC and SEIAA – Tamil Nadu as directed by this Tribunal.

Considering the circumstances, parties are directed to bear their respective costs in the respective cases.

7. This proposal was placed in the 383rd meeting of SEAC held on 15.06.2023. Based on this Appeal No.28/2020 (SZ) the marine biodiversity management plan prepared through Centre of Advanced Study in Marine Biology Faculty of Marine Sciences, Parangipettai - Annamalai University and submitted by the PP.

   During the meeting, SEAC decided to defer the proposal and take it up in the ensuing meeting.
8. The proposal was again placed in the 385th SEAC Meeting held on 22.06.2023. Based on the presentation made by the proponent SEAC decided to defer the proposal, since the PP has requested more time to furnish the additional details.
9. This proposal was again placed in the **392nd SEAC Meeting held on 14.07.2023.** During the meeting, the representatives from TN Fisheries Department and Annamalai University gave a detailed presentation. Based on the deliberations and documents furnished, SEAC noted that Hon'ble NGT vide order dated.28.09.2022 has stated that

   "...A detailed marine biodiversity management plan prepared through NIOT or any other institute of repute on marine, brackish water and freshwater ecologically and biodiversity and must be submitted to and implemented to the satisfaction of the ***State***

MEMBER SECRETARY
SEIAA-TN

Biodiversity Board and the CRZ authority...."

This is also part of the recommendation made by SEAC earlier. Hence, the SEAC decided that the Biodiversity Management Plan (BMP) prepared shall be presented before the State Biodiversity Board, obtain their remarks, revise the BMP and submit the details to SEAC for further consideration.

10. The project proponent vide letter dated 09.08.2024 submitted the following study reports.
    i. Sediment Deposition and Sediment Erosion Study by Department of Ocean Engineering, Indian Institute of Technology Madras
    ii. Marine Biodiversity Survey for Tuna Fishing Harbour, Thiruvottriyur Kuppam, Thiruvallur District, Chennai, Tamil Nadu by Annamalai University, Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences, Parangipettai.
    iii. Anticipated Impact on Marine Environment due to Accidental Oil Spill in Tiruvottiyur Fishing Harbour by M/s. Indomer Coastal Hydraulics (P) Ltd., Chennai
11. Regarding detailed marine biodiversity management plan, the project proponent has obtained the recommendation from Tamil Nadu Biodiversity Board vide Ref. No. TNBB/799/2023/B1, Dated: 05.06.2024.
12. The proposal was placed in this 494th meeting of SEAC held on 05.09.2024. During the meeting, the SEAC asked the PP to make the presentation by the experts who prepared the reports. Since, the experts were not present during the meeting, PP requested additional time to make the presentation. Hence, SEAC deferred the proposal and asked the PP to make the presentation before the committee on 12.09.2024 by the experts who prepared the reports.

Now, the proposal was placed in this **496th meeting of SEAC held on 12.09.2024.** Based on the presentation and the study reports furnished by the project proponent, the SEAC decided to recommend the following amendment in the EC issued vide Letter No. SEIAA-TN/F.No.6440/EC/7(e)/75/2020 dated: 05.08.2020, subject to the additional conditions below.

Sediment Deposition and Sediment Erosion:

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A report on shoreline evaluation was submitted by M/s Fisheries Department, conducted by IIT-M, and a presentation was made before SEAC. The conclusion of the report indicated that there will be no significant sediment erosion due to the Fishing Harbour. The report prepared by IIT-M has also stated that the area of study covers upto Ennore Creek.

Marine Biodiversity:

The PP has carried out a marine biodiversity through Annamalai University, Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences, Parangipettai. Dr.Anurag Sen, Project Scientist made a presentation before SEAC. The report was also examined by Tamil Nadu Biodiversity Board. The Tamil Nadu Biodiversity Board has observed as follows:

1) The Local Biodiversity Management Committee (BMC) may be involved in implementation of the management plan.
2) The present marine rapid survey was done for three seasons; however, it is recommended that a long-term intensive survey may please be continued even after commissioning of the proposed structure to pin point the changes in the biotic community arising out of proposed project.

Oil spill:

The PP has submitted the report prepared by NABET accredited consultant Indomer Coastal Hydraulics (P) Ltd., on anticipated impact on marine environment due to accidental oil spill in harbour and a presentation was made before SEAC. The conclusion of the report is as follows

1. The proposed fishing harbour is devoid of seaweed, seagrass, corals, mangroves and marine mammals.
2. The impact on benthos and plankton due to fuel spills in the harbour basin is minimal because the fuel handle on boats is in low quantities.
3. Oil slick spread is minimal, and dissipation is rapid.

Further, the study suggested that necessary contingency plan should be prepared to contain oil slick within the harbour and prevent it from drifting towards the wharf or open sea.

The SEAC examined the reports and also presentation made by the experts who prepared the reports and decided to recommend that the **following additional conditions** may be added to the EC conditions already imposed.

1) The PP shall carry out a study through IIT-M to monitor the conditions of groynes and shoreline protection structures on the northern side of the Fishing Harbour up to Ennore

MEMBER SECRETARY
SEIAA-TN

Creek in order to ensure the following;

- To evaluate sediment deposition and erosion in the northern portion of the Fishing Harbour.
- To suggest mitigation measures, if any weakness of the above aforesaid structures are noticed.
- This study must be carried out annually for the first two years, and for every two years thereafter.

2) The Local Biodiversity Management Committee (BMC) should be involved in implementation of the environment management plan.
3) The PP shall carry out a long-term intensive marine survey after commissioning of the proposed structure to pin point the changes in the biotic community arising out of proposed project. While making long term study, the population of diatoms should specifically studies as their health determines the helath of the entire food chain.
4) PP shall study the turbidity levels around the Fishing Harbour on a continuous monitoring basis through reputed institutions / accredited labs spanning twice in a year namely pre-monsoon & post-monsoon.
5) In order to prevent paint related pollution, the PP shall ensure that no painting activities are permitted within Fishing Harbour.
6) PP shall prepare and enforce a 'Code of Conduct' among all the users of the harbour. The Code should reward good behaviour while penalising harmful behaviour.
7) The PP shall prepare oil spill contingency plan and monitor the quality of water inside the harbour for presence of oil particles on a weekly basis or more frequently, if required. Boat movements in and out of slipway should be watched carefully for oil spillage.
8) The PP shall place the action taken report on the compliance of the EC conditions in the Harbour Management Committee every year and copies of action taken report along with the response of the Harbour Management Committee shall be submitted to SEIAA.

All other conditions and validity mentioned in the EC vide Letter No. SEIAA-TN/ F.No.6440/EC/7(e)/75/2020 dated: 05.08.2020 shall remain unchanged and unaltered.

MEMBER SECRETARY
SEIAA-TN

Discussion of SEIAA:

The subject was appraised in the 496th meeting of SEAC held on 12.09.2024. The SEAC examined the reports and also presentation made by the experts who prepared the reports and recommend the amendment in the EC issued with the **additional conditions** stated therein.

Now the subject was placed in the 759th Authority meeting held on 30.09.2024. The authority noted that the subject was appraised in the 496th meeting of SEAC held on 12.09.2024.

In view of the above, the Authority accepted the SEAC's decision and decided to grant amendment in the EC issued vide Letter No. SEIAA-TN/F.No.6440/EC/7(e)/75/2020 dated: 05.08.2020 in addition to the following conditions:

1. The PP shall ensure that there is no impact on Mangrove Vegetation.
2. The PP shall ensure that there is no impact on coastal marine diversity.
3. The Project activity should not impact the livelihood of fishermen.
4. The Project activity should not create any hindrance to human settlement.
5. The Project activity should not disturb coastal margin & lead to erosion & intrusion of salt water.
6. The Project activity should not result in coastal line changes.
7. The Project activity should not impact the land use patterns.
8. The Project activity should not disturb the migratory patterns of birds & marine life.
9. The project activity shall ensure that the biological waste is disposed properly, for maintaining the hygiene in the local community.
10. The PP shall ensure that the post construction monitoring shall be strictly adhered for the cleanliness.
11. **All other conditions and validity mentioned in the EC vide Letter No. SEIAA-TN/ F.No.6440/EC/7(e)/75/2020 dated: 05.08.2020 shall remain unchanged and unaltered.**

MEMBER SECRETARY
SEIAA-TN

Copy to:

1. The Principal Secretary to Government, Environment, Climate Change and Forests Department, Govt. of Tamil Nadu, Fort St. George, Chennai - 9.
2. The Chairman, Central Pollution Control Board, Parivesh Bhavan, CBD Cum-Office Complex, East Arjun Nagar, New Delhi - 110032.
3. The Chairperson, Tamil Nadu Pollution Control Board, 76, Mount Salai, Guindy, Chennai-600 032.
4. The APCCF (C), Regional Office, Ministry of Environment & Forest (SZ), 34, HEPC Building, 1st & 2nd Floor, Cathedral Garden Road, Nungambakkam, Chennai - 34.
5. Monitoring Cell, I A Division, Ministry of Environment & Forests, Paryavaran Bhavan, CGO Complex, New Delhi - 110003.
6. The District Collector, Thiruvallur District.
7. Stock File.

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ANNEXURE 9

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04 FEB 2019

மீன்வளத்துறை, சென்னை

ABSTRACT

Fisheries – Construction of Tuna Fishing Harbour at Thiruvottriyur Kuppam in Tiruvallur District at a cost of Rs.200.00 crore – Administrative sanction - Accorded – Orders - Issued.

Animal Husbandry, Dairying and Fisheries (FS-1) Department

G.O.(Ms).No.14

Dated 01.02.2019
திருவள்ளுவர் ஆண்டு – 2050
விளம்பி, தை – 18

Read:

1. Government letter No.9216/FS1/2018-2, Animal Husbandry, Dairying and Fisheries (FS1) Department, Dated 20.08.2018.
2. Government D.O.letter No.16425/FS1/2018-1, Animal Husbandry, Dairying and Fisheries (FS1) Department, Dated 30.11.2018 addressed to the Secretary to Government of India, Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture and Farmers Welfare, New Delhi.
3. From the Government of India, Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture and Farmers Welfare, Letter No.33015-3/2017-Fy(H) Vol.I, dated 03.12.2018.
4. Government letter No.9216/FS1/2018-3, Animal Husbandry, Dairying and Fisheries (FS1) Department, Dated 7.12.2018.

ORDER :

The Hon'ble Chief Minister has announced on the floor of the Legislative Assembly on 6.6.2018 under Tamil Nadu Legislative Assembly Rule 110 that a Tuna Fishing Harbour would be constructed at Thiruvottriyur Kuppam, Tiruvallur District at an estimated cost of Rs.200.00 crore (Announcement No.13).

2. Subsequently, the Hon'ble Chief Minister of Tamil Nadu in his letter dated 16.6.2018 addressed to the Hon'ble Union Minister of Agriculture and Farmers Welfare has requested to sanction Rs.750.00 crore for Tamil Nadu under Fisheries and Aquaculture

Infrastructure Development Fund (FIDF) for the development of Fisheries Infrastructure in Tamil Nadu over a period of 3 years.

3. In the letter first read above, the Detailed Project Report for Construction of Tuna Fishing Harbour at Thiruvottriyur Kuppam in Tiruvallur District at a cost of Rs.200.00 crore was forwarded to the Government of India seeking financial assistance under Fisheries and Aquaculture Infrastructure Development Fund (FIDF). The General Abstract of the project is tabulated below:-

Sl. No.	Description	Unit	Amount (Rs.)
1	Breakwaters		
	i) Northern Breakwater	Rm	408,209,169
	ii) Southern Breakwater	Rm	787,678,379
2	Dredging and Disposal	Cum	25,092,220
3	Reclamation with borrowed earth (good earth or gravel)	Cum	29,375,123
4	Diaphragm Wall	Rm	137,654,420
5	Jetty	Rm	159,040,000
6	Road with Storm water drainage arrangements	Sqm	44,122,419
7	Fish Handling and Auction Hall	Sqm	23,803,600
8	Fishery Administrative Office	Sqm	3,765,000
9	Fishermen gear sheds (1Nos.x176.87 Sqm)	Sqm	2,783,530
10	Net mending sheds (1Nos.x258.10 Sqm)	Sqm	2,613,700
11	Fishermen rest shed (1Nos.x218.00 Sqm)	Sqm	3,579,935
12	Boat repair shop (1 Nos.x100.45 Sqm)	Sqm	1,856,121
13	Restaurant	Sqm	2,468,537
14	Dormitary	Sqm	6,375,599
15	RC sloping yard for Tuna Boats	Sqm	49,280,304
16	Security/guard House	Sqm	746,154
17	Compound wall	Rm	3,430,713
18	Radio Communication Tower	Sqm	3,973,820
19	Public Toilet (2Nos.x35.86)	Sqm	1,665,803
		Sub Total	1,697,514,546
20	Navigational and radio-communication equipment	LS	500,000

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21	Electric power supply and distribution including electric substation and general lighting	LS	5,000,000
22	Fresh water storage, supply and distribution with ground water sumps, pump house and overhead tank	LS	5,000,000
23	Seawater supply and distribution with shallow water tube well, pump house and overhead tank	LS	1,500,000
24	Sewerage system with STP arrangements	LS	5,000,000
25	Greeneries and landscaping in front of main gate and at other places	LS	500,000
26	Fire extinguishers, fire hydrants and other equipment	LS	500,000
27	Consultancy charges for Subsoil investigations, Numerical model studies	LS	2,000,000
28	Environmental impact assessment, mitigation measures and monitoring	LS	2,000,000
		Sub Total	1719514546
29	Add 12% for GST		206341746
30	Add 2 % for Contingencies		34390291
31	Add 1% for Price Escalation charges		17195145
32	Add 1% for Labour welfare Fund		17195145
33	Advertisement and documentation charges	.	5363126
		Total	2000000000 (Rs.200.00 crore)

4. In the D.O. letter second read above, the Government of India has been requested to accord 'In-Principle' approval for financial assistance for this project, under Fisheries and Aquaculture Infrastructure Development Fund (FIDF).

5. The Government of India, in the letter third read above, had approved the creation of Fisheries and Aquaculture Infrastructure Development Fund (FIDF) along with the stipulated of scheme.

6. In the letter fourth read above, the detailed project profile in respect of the Construction of Tuna Fishing Harbour at Thiruvottriyur Kuppam in Tiruvallur District has been forwarded to Government of India on 07.12.2018 in a revised format to accord administrative

approval for the Construction of Tuna Fishing Harbour at Thiruvottriyur Kuppam in Tiruvallur District at a cost of Rs.200.00 crore with financial assistance to the tune of Rs.180.00 crore (90% of project cost) under Fisheries and Aquaculture Infrastructure Development Fund (FIDF) and the remaining 10% to be met by State Government. The Government of India has also been requested to place this proposal in the first meeting of the Central Approval and Monitoring Committee (CAMC) and also to arrange for a loan assistance which has been pending.

7. The Government after careful examination, accord Administrative sanction for the Construction of Tuna Fishing Harbour at Thiruvottriyur Kuppam in Tiruvallur District at a cost of Rs.200.00 crore (Rupees two hundred crore only) under Fisheries and Aquaculture Infrastructure Development Fund (FIDF), pending approval of the project by Central Approval and Monitoring Committee (CAMC), Department of Animal Husbandry, Dairying and Fisheries, Government of India and Environmental Clearance.

8. This order issues with the concurrence of the Finance Department vide its U.O.No.4761/Finance(AHD&F)/2019, dated 01.02.2019.

(By Order of the Governor)

K.GOPAL
Principal Secretary to Government

To
The Director of Fisheries, Chennai-35.
The Joint Secretary (Fisheries), Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture and Farmers Welfare, New Delhi-1.
The Chief Engineer, Fisheries Department, Chennai-35.
The General Manager, National Bank for Agriculture and Rural Development, Chennai-34.
The Principal Accountant General(E&RSA), Chennai-18.
The Resident Audit Officer,
Office of the Principal Accountant General(G&SSA), Chennai-9.
The Pay and Accounts Officer (South), Chennai-35.

Copy to:
Office of the Hon'ble Chief Minister, Chennai-9.
The Senior Personal Assistant to Hon'ble Deputy Chief Minister, Chennai-9.

The Senior Personal Assistant to Hon'ble Minister (Fisheries and Administrative Reforms), Chennai-9.
The Finance(AHD&F/ Res-II) Department, Chennai-9.
The Private Secretary to Principal Secretary to Government, Animal Husbandry, Dairying and Fisheries Department, Chennai-9.
Stock file/spare copies.

//Forwarded By Order//

K. Anbu 01/02/19
Section Officer
1/2/19