# Anthropogenic Impact on the Biogeochemistry of Coastal Environment

*MAJOR RESEARCH PROJECT*
**(ENVIRONMENTAL SCIENCE)**

**Awarded by**
**UNIVERSITY GRANTS COMMISSION**
**NEW DELHI – 110 002**


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ज्ञान-विज्ञान विमुक्तये

Annexure-I

## **PART – A**

| | | |
|---|---|---|
| 1. Broad Subject | : | **Environmental Science** |
| 2. Area of Specialization | : | **Environmental Biogeochemistry** |
| 3. Duration | : | **Three years** |
| 4. Principal Investigator | | |
| i. Name | : | **Dr. A. RAJENDRAN** |
| ii. Sex: M/F | : | Male |
| iii. Date of Birth | : | 7$^{th}$ May 1945 |
| iv. Category | : | OBC |
| v. Qualification | : | Ph.D., D.Sc., |
| vi. Designation | : | Professor & Coordinator (Retired) |
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5. Co - Investigator

| | | |
|---|---|---|
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| iii. Date of Birth | : | 29th January 1968 |
| iv. Category | : | OBC |
| v. Qualification | : | Ph.D |
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6. In case of a retired teacher, please give the following information:

| | | |
|---|---|---|
| i. Date of Superannuation | : | 31st May 2010 |
| ii. Age at the time of Superannuation | : | 65 years |
| iii. Whether employed or not | : | Not Employed |

7. Name of the Institution where the project will be undertaken:

| | | |
|---|---|---|
| i. Department | : | **Department of Marine Science** |
| ii. University | : | **Bharathidasan University,**<br>**Tiruchirapalli – 620 024** |
| iii. Whether the institute is located in rural /backward area | : | Yes. It is situated in rural areas |

8. Whether the University is approved under Section 2 (f) and 12 (B) of the UGC Act?

**Yes**

9. Teaching and Research Experience of Principal Investigator (PI):

| | | |
|---|---|---|
| a. Teaching experience | : | 10 years |
| b. Research experience | : | 35 years |

c.1. Year of award of Doctoral degree: 1975

c.2. Title of thesis for doctoral (Ph.D) degree:

Chemistry and microbiology of nutrient regeneration in tropical estuary

d.1. Year of award of D.Sc degree : 2001

d.2. Title of thesis for D.Sc degree:

Carbon and carbon components in the Arabian Sea

e. Publication:

| | | |
|---|---|---|
| i. Papers Published | : | Seventy |
| ii. Accepted | : | Nil |
| iii. Communicated | : | One |
| iv. Book(s) Published | : | One under preparation |

(Please enclose the list of papers and books published and/or accepted during last five years)

**PULICATIONS: Principal Investigator**

1. Vignesh, S., Hans-Uwe Dahms., Kumarasamy, P., **Rajendran. A**, Jeon, H.J and James*, R.A. (2015). "Microbial effects on geochemical parameters in a tropical river basin, southern India", <u>*Environmental Processes*</u> Vol.2, pp.125-144 (Springer; IF 0.2)

2. Kumarasamy, P., Vignesh, S., Muthukumar, P., **Rajendran. A**. and James*, R.A. (2009). "*Enumeration and identification of pathogenic pollution indicators in Cauvery river, South India*", <u>Research Journal of Microbiology</u>, Vol. 4(12), pp.540-549.

3. Kumarasamy, P., Vignesh, S., James*, R.A., and **Rajendran. A**. (2009). "*Approaches on phytopathogenic fungi transformation of thymol to phenol, 2-(1, 1-dimethylethyl) and 1-dodecene by Curvularia lunata and Colletotrichum capsici*" , <u>Current Biotica</u>, Vol.3, No.3, pp. 345-352

4. James, R.A., and **Rajendran A**. (2009) "GIS for water resources management", GIS and Disaster Management Vol.1, pp.25-35.

5. Rajasekar, A. Ganesh Babu T. Karutha Pandian, S. Maruthamuthu, S. Palaniswamy N. and. **Rajendran A** (*2007)*. "Biodegradation and corrosion behaviour of Bacillus cereus ACE4 in diesel transporting pipeline" Corrosion Science, Vol. 49, pp.2694-2710.

6. Rajasekar, A. Ganesh Babu, T. Karutha Pandian, S. Maruthamuthu, S. Palaniswamy, N. and **Rajendran, A**.(2007). "Role of Serratia marcescens on diesel degradation and its influence on corrosion" Journal of Industrial Microbiology and Biotechnology, No.34(9) pp.589-598.

7. Rajasekar, A. Maruthamuthu, S. Palaniswamy, N. and **Rajendran, A**. (2007). "Role of corrosion inhibitor degradation and its influence on corrosion" Microbiological Research, Vol.162 pp.355-368

8. Arun, S., **Rajendran, A**. and Subramanian, P (2006). "Sub cellular/tissue distribution and responses to oil exposure of the cytochrome P450-dependent monooxygenase system and glutathione S-transferase in freshwater prawns (Macrobrachium malcolmsonii, M. lamarrei lamarrei)", Ecotoxicology, Vol. 15, pp.341-346.

9. Palanichamy,S., Ragumaran, S and **Rajendran, A**. (2004) Heavy metal concentrations in some marine algae from the Gulf of Mannar, Southeast Coast of India, Seaweed Res. Utiln**,** Vol. 26: pp107-110

10. Palanichamy, S., Maruthamuthu, S., Manickam, S. T. and **Rajendran, A**. (2002). Microfouling of Manganese-oxidising bacteria in Tuticorin harbour, Current Science**,** Vol.82, No.7,pp.865 -869.

11. Palanichamy, S., Raghumaran, S. and **Rajendran, A**. (2002) Impact of thermal power plant discharges of the Coastal environment of Tuticorin Thermal Ecology Vol.1, pp.142-149

## PART – B

## Research Output

### i) ANTHROPOGENIC IMPACT ON THE BIOGEOCHEMISTRY OF COASTAL ENVIRONMENT

In the earth's surface, 18% is represented by coastal zone, which provides space for 60% of the world's human population. 70% of the world cities with population exceeding 1.6 million are located in this zone. Interestingly, 90% of the world fish catch is obtained from coastal zone. The coastal zone is only 8% in the hydrosphere, but responsible for 18-33% of the total primary production. The biological wealth of this zone is very high as it serves as feeding, nursery and spawning grounds with rich biodiversity. It was once thought that human being, living only on one-third of the portion of globe, cannot pollute this vast amount of water, as the marine ecosystems are capable of serving as sink for all the pollution caused by us. However, in reality this is not true. We have come to realize that our waste, even in small quantities, have huge effects on ocean communities and species. Moreover, it is difficult to believe that something so massive and seemingly resilient can really be adversely affected by our activities.

Environmental pollution of the coast, inshore water and Deep Ocean is one of the important topical issues in the context of human health and global warming. The major pollutants like oil, sewage, garbage, toxic chemicals, pesticides, heavy metal, radioactive waste, thermal pollution, and eutrophication in coastal and marine environments, their characteristics and principal impacts are discussed in detail. The concept of anthropogenic impact is extremely important for analyzing the ecology of coastal and shelf zone. Various activities that are in progress in this narrow area on the shoreline provide 50% and more of the gross national product of many countries. All of these activities usually affect the shelf ecology directly and hazardously.

At present, the anthropogenic disturbances of the shelf zone are found on a global scale. In many areas, they have reached critical limits. This is the prize for the unjustifiably rapid economic growth and shortsighted environmental policy (or rather for its absence). Underestimation of the striking complexity of anthropogenic impact on the water ecosystems and the use of a single-factorial approach to analyze their state, focusing on some single aspect of human activity, generally lead to a distorted picture of the consequences of such activity. Simultaneous impacts of several factors can cause synergistic effects whereas the consequences can exceed the mere sum of the effects caused by each factor separately. Such situations are quite possible, for example, when radioactive and thermal impacts are combined.

**ii a) Origin of the research problem**

Environmental degradation is an acute problem in many parts of the world and is brought by the changing pattern of land and water use. The nature and specifics of environmental degradation vary from place to place. The study of critical areas and processes becomes necessary to better understand the causes and effects on global scale. The quality of aquatic system is reliable indicator of the ongoing environmental changes (Ittekkot and Subramanian, 1999). Land use change is currently extremely rapid and its consequences are more evident in the tropical regions, in part because of the disproportionate share of human population growth that is taking place in the tropics. Land clearing and conversion causes substantial loss of carbon and nitrogen and a lesser loss of sulfur and phosphorus from cleared sites in most regions.

Climate change and increased nutrient deposition from the atmosphere will affect soils, plant productivity and the biogeochemical cycles. The overall emphasis of the biogeochemistry is the terrestrial regulation of element pools, transformation, gains and losses as they are altered by components of global change. In addition, there are a number of regions, in which land use and atmospheric composition and anticipated climate change are likely to alter the biogeochemistry of terrestrial ecosystems significantly and consequently cause significant change on the marine biogeochemistry. In many parts of the humid tropics, the conversion of forests to agricultural use has an impact on the biogeochemical cycles of carbon, nitrogen and phosphorus.

The impact occurs in two phases: i) the initial clearing of forests, the techniques of which are important in determining the short term alterations to biogeochemical cycles and ii) the type and intensity of the subsequent agricultural use, which are critical in determining the long term effects. It is estimated that between 1970 and 2000 non-agricultural land use in India has expanded from 16.2 to 26 million hectares, an increase of 60%. Globally, during 1900-1990, the annual loss of forest area was 17-20 million hectares and for India it was 1.3 million hectares. The organic matter derived from land sources such as agricultural runoff, soil erosion, land conversion and flooding enter the natural waterways such as rivers and estuaries and finally into the coastal oceans. Hence the detailed study on the harbor waters, the coastal ecosystem with immense human activities, is ideal to investigate the nutrient cycle and biogeochemistry of trace metals that effect the environmental hazards within the coastal ecosystem.

**ii b) Review of research and development**

***ii b1. Biogeochemistry***

Harbor waters are the representatives of the present day ecotoxic chemical processes involving constant mobility of materials such as water, sediment and dissolved salts in the ocean. Many organisms serve as indicators of marine pollution. For example, the ecological shift in the succession of phytoplankton communities from diatoms to dinoflagellates due to thermal pollution. Usually the pollutants exceeding threshold limits combined with environmental variables such as temperature, salinity, pH, dissolved oxygen, hydrogen sulphide etc., give stress to the organisms. While the migratory organisms such as fishes might have avoided the polluted area, the sedentary organisms exposed to the pollutants experience the higher stress conditions. For example the crustaceans and molluscs experience the following pollution stress conditions. a) Disoriented movements, b) Abnormal muscle opacity, c) Retardation of moulting, d) Disease in carapace & exoskeleton – white spots, e) Black gills, f) Attachment of filamentous bacteria and protozoan as epidictic biofoulents on external surfaces and g) Increased number of bacteria in haemolymph.

In thermal pollution, the normal temperature of marine source water column is increased to 7-8°C from the ambient temperature. Mostly the power generating plants along the ocean coastlines use the marine waters for cooling purposes, which leads to heated water expelled into the marine environment. The excess temperature usually gets reduced by various ways. As the water has higher specific heat, it takes prolonged time for cooling unless there is an external mechanism to accelerate this. The dilution by surrounding water, evaporation and precipitation may accelerate cooling within a reasonable time. Thermal pollution seems to affect the communities immediately adjacent to the discharge. In continuous discharge the exposure time is also continuous, which generally result in community shift, for example more heat tolerant species may replace the normal biota.

The longtime exposure to the heat conditions may be detrimental to the normal biota. Many studies on the effects of thermal pollution on the marine environment have been carried out. Thermal discharge is most noted in the tropical areas, where organisms are near their thermal maximum. For example, mangrove trees in a thermal heated bay no longer reproduce and no new seedlings can be found in the lagoon. Carbon (C), nitrogen (N) and phosphorus (P) are essential elements found either as dissolved or particulate fraction in harbor waters. The exchange and transformation of these elements are responsible for the growth and decay of living organisms. The biogeochemical cycle of carbon, nitrogen and phosphorus at the earth surface depend on the rates of the process that control storage in and transfer between various external reservoirs. The coupling of these cycles and numerous possible feedback mechanisms complicates the dynamics and thus, the response of the biogeochemical cycles to human intervention. For example, enhanced primary productivity in coastal environments resulting from higher human-induced riverine fluxes of the nutrient elements - nitrogen and phosphorus may increase the deposition of organic matter in sediments along the continental margins.

Thus, in order to identify and quantify the processes that control the cycling of C, N and P, basic data set is needed that includes not only a proper inventory of the elements at the earth's surface, but also accurate estimates of present-day fluxes between the various external reservoirs. The distribution of C, N and P in environment that has been significantly disturbed by humans such as polluted rivers and coastal environment, which may act as essential reservoirs, needs to be monitored (Purvaja and Ramesh, 2000). The primary objective of this study is to determine the spatial and temporal variation of nutrients (nitrogen, phosphorus and silica) in water and of total carbon, nitrogen and phosphorus in sediments of the coastal ecosystems so as to understand the human impact on their cycling in relation to the biogeochemistry of certain essential trace elements such as Iron and Manganese.

### *ii b2. Anthropogenic input of Pesticides into Coastal Systems*

The environmental contaminations by pesticide residues are of great concern due to their toxicity, bioaccumulation and persistent nature. Organochlorine pesticides such as HCH (hexachlorocyclohexane) and DDT (dichlorodiphenyl-trichloroethane), Endrin, Lindane and Aldrin are among the most persistent and globally distributed organic pollutants. These pesticides are long-lived organic compounds that become concentrated as they move through the food chain and have toxic effects on reproduction and immunological function. Since the introduction of organochlorine pesticides in late 1930s the residues of these compounds have been found in many parts of the World (Hattula et al., 1978). Along with other chlorinated micro pollutants, persistent pesticides such as HCH, DDT, Endrin, Lindane and Aldrin have become widely distributed around the planet. Pesticides are unique in that they are purposefully released in to the environment to control the selected species. The chlorinated pesticides are now largely banned chemicals, which may still pose a threat to human health as well as the wider environment.

In India, the organochlorine insecticides, DDT and HCH were used extensively for agriculture and other public health programs accounting for ~ 77% of the total consumption (Gupta, 1986). The pesticide transport can occur in three ways, i) movement in the vapor phase, ii) surface runoff and iii) leaching. The tropical warm temperatures favor evaporation from earth's surface. Among them surface runoff can contribute maximum load from the non-point source through streams and canals. Hence the logic is to dictate that the concentration will be highest near the point of release and decline with distance. Relatively mobile organochlorine compounds have the exception with the distance because of their tendency to partition for easy movement. In spite of their persistence nature, organochlorine insecticides were reported in major world rivers (Oliver and Nicol, 1984; Ramesh et al., 1990; Agnihotri et al., 1994; Rajendran and Subramanian, 1997; Yamashita et al., 1997; Wu et al., 1999 and Guzzella et al., 2005).

A comparison of published levels of organochlorine from the surface waters of sea, river and lake water gives a good indication of the typical contamination that might be expected in different water types. Very little information exists with respect to contamination of surface seawater, although it is acknowledged that the gas-phase exchange of the semi-volatile organochlorines from the atmosphere will probably influence their occurrence more than direct riverine discharges. Recent studies (Schreitmuller and Ballschmiter, 1995) suggest that global distribution will be largely controlled by gas-phase equilibrium between the ocean and the atmosphere. A logical extension of this is the probability that the ocean will become a different source of such compounds for many years as increasing restriction reduces their release. Recent reports on HCH levels in the atmosphere have indicated a net source of this compound in the northern hemisphere (Iwata et al., 1993).

***ii b3. Geographical Information System***

Geographical Information System (GIS) is a computer-based tool developed for handling spatially referenced data. Normally, it integrates database functions with analytical tools and techniques for geographic analysis and computerized cartography (Bartlett, 1993). Bloemer et al., (1986), defined major requirements and functions of GIS and mentioned spatial data handling tool for solving complex geographical problems. Angermeier and Bailey (1991) used GIS as a conservation tool for rivers. The essential question addressed in this study through GIS is whether the distribution of biogeochemical elements and pesticides in the river basin are simply dependant on sediment size due to the physical adsorption on fine sediment surface or are mainly affected by the discharge from agricultural and industrial outfalls.

**iii a) Objectives**

This study will focus on the influence of various changes, like natural and anthropogenic forcing factors affecting biogeochemical cycles in the Coastal waters, with the following objectives:

- A systematic survey and mapping of the usage pattern for the past decade or so, will be carried out for the harbor and coastal regions of Tuticorin, a representative coastal ecosystem, using both field survey with GPS.

- A detailed study on siltation problem and Port handling pattern will be carried out in high and lower end to assess the impact of these aspects on nutrient load and consequently on the biogeochemical processes.

- The distribution of nutrients such as N (nitrate, nitrite and ammonia), P (ortho phosphate and total dissolved phosphorus) and silica in the water and sediments of the harbor basin and their role on the cycling of trace elements such as Iron and Manganese.

- To evaluate the residue levels of organochlorine pesticides in water and sediments of this basin in order to study the input of the handling of pesticides.

- To suggest an optimal handling usage plan for the Tuticorin harbor region using the geographic information system (GIS).

- A compact water quality model will be carried out with the water quality data using suitable modeling software package.

- Environmental Impact Assessment for the Tuticorin harbor based on the above dataset by quality controlled analysis using X and S control chart.

### iii b) Study area

The Tuticorin harbor is one of the most important nonstop cargo handling system after Chennai in Tamil Nadu. This basin is located in the southern part of the state and more precisely, lies between the latitude 8°10' N and 9°13'N and longitude 77°10' E and 78°10' E (Fig. 1). Tuticorin harbor and Coastal waters are selected as study area because of the huge amount of human activities for example cargo and coal handlings in the port, fishing activities and essentially lot of effluents by Chemical Industries. The harbor basin is intensively used for a variety of purposes including domestic and industrial uses throughout its course in addition to dockyard. Several small and large-scale industries, for example, Thermal power station, textile, chemical industries, cement factories etc., are also surrounded in the visinity. The Tuticorin harbor serves as a nonstop source of transport for multiple activities in this region.

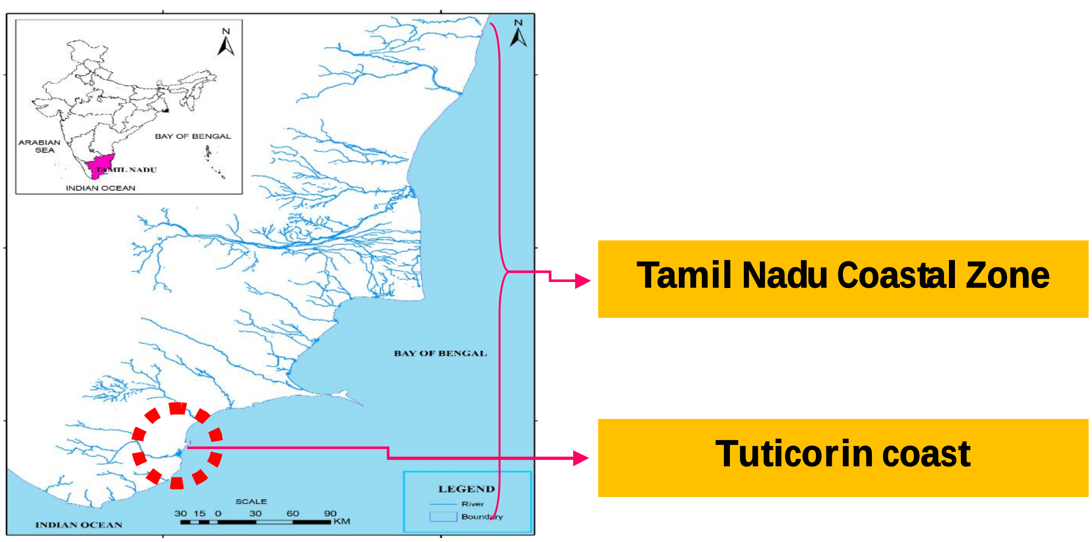


**Fig.1 Study area**

## iv) Methodology

### *iv a) Sampling and Analysis*

Surface water, suspended and bed sediment samples for at least four seasons (summer, premonsoon, monsoon and postmonsoon) were collected from the Tuticorin harbor and coastal environment. The collected samples were preserved by adding appropriate preservatives ($HNO_3$ and $H_2SO_4$) according to analysis and transported through iceboxes (4°C) from the field and were immediately filtered through a 0.45-µm filter (Sartorius, cellulose-nitrate type) on arrival to the laboratory. Then, the filtered water samples were analyzed for nutrients [$NO_3^{-2}$, $NO_2^-$, $NH_4^+$, $PO_4^{-3}$, dissolved silica ($H_4SiO_4$) total dissolved phosphorus (TDP)] using standard procedures (APHA 2007, Grasshoff, 2000). The bed and suspended sediments were analyzed for major and trace elements using standard procedures. Pesticide residues were extracted from the water and sediment samples according to the method described by Ramesh et al., 1990. On other hand, about 10 litres of surface water samples have been collected in a pre-cleaned polyethylene bottles and is passed through pre-washed, air dried Amberlite XAD-II resin packed in a glass column of 10 mm inner diameter and about 100 mm in length. Then it was stored at 4° C until analysis. The organochlorine insecticides adsorbed to the Amberlite XAD-II resin were eluted with 150 ml ethanol into a separatory funnel containing 100 ml hexane and 750 ml hexane-washed water and thoroughly shaken for 10 minutes. After partitioning, the hexane layer was collected and concentrated to 5 ml in a Kuderna-Danish (KD) concentrator. The concentrate was cleaned with 5% fuming sulfuric acid and then with hexane-washed water. The identification and quantification of organochlorine pesticides were carried out in a Gas Chromatograph fitted with an Electron Capture Detector (ECD) (Nucon 5765, India).

### *iv b) Application of GIS*

The study area have been divided mainly into three regions such as zone A, middle (B) and C areas. The preparation of various spatial themes such as geology, geomorphology, wetlands, cargo handling pattern, land use and land cover etc., has been prepared. Also, the slope, relief and soil maps has been prepared using the Survey of India topography sheets. These parameters were integrated with the field data into the Geographic Information System to identify the potential areas for environmental protection and other developmental activities. The GIS technique application has three main stages: i.e., i) digitisation ii) GIS manipulation and iii) GIS analysis. First the study area map, the sampling points will be digitised manually using the windows based ARC-GIS software. All the features of each digitised lines are taken as x, y co-ordinates and the value (concentration) of each point will be coded as z. The digitised points were stored as vector file of polygon format and finally transformed into raster format. Interpolation of the selected rasterised maps of individual parameters were stored in vector files of point format would carried out. True geographical information systems provide a large set of tools aimed at retrieving information through i) the geometric component of each geographical entity and ii) the attribute component of each geographical entity. In other words, the retrieval operation is a selection of specified data for direct application or subsequent manipulation (Nasr et al., 1997).

**v) Project result**

Based on the quality oriented result,

- Interrelationship between geological, geomorphological and biogeochemical processes with reference to harbor water was framed. Based on the detailed assessment programme, the correct system forecast is derived with reference to spatial and temporal variation.
- Most of the samples were found to have higher physiochemical, indicator bacteria and pesticides levels than those prescribed by WHO (1998), BIS (2009) and TNPCB (2000). This study also suggests that the study area was heavily contaminated with pathogens and pesticides, which were crossed the permissible limits and is an alarming situation. Most of the parameters were found high in monsoon and summer, moderate in premonsoon and lowest in post monsoon.

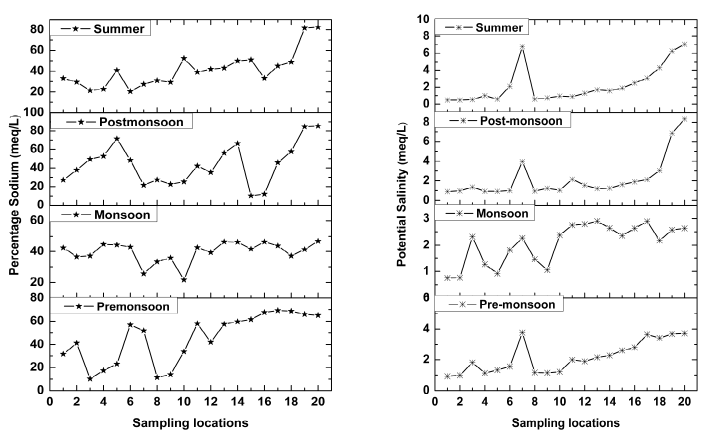


**Fig.2 Seasonal variations major ion distribution**

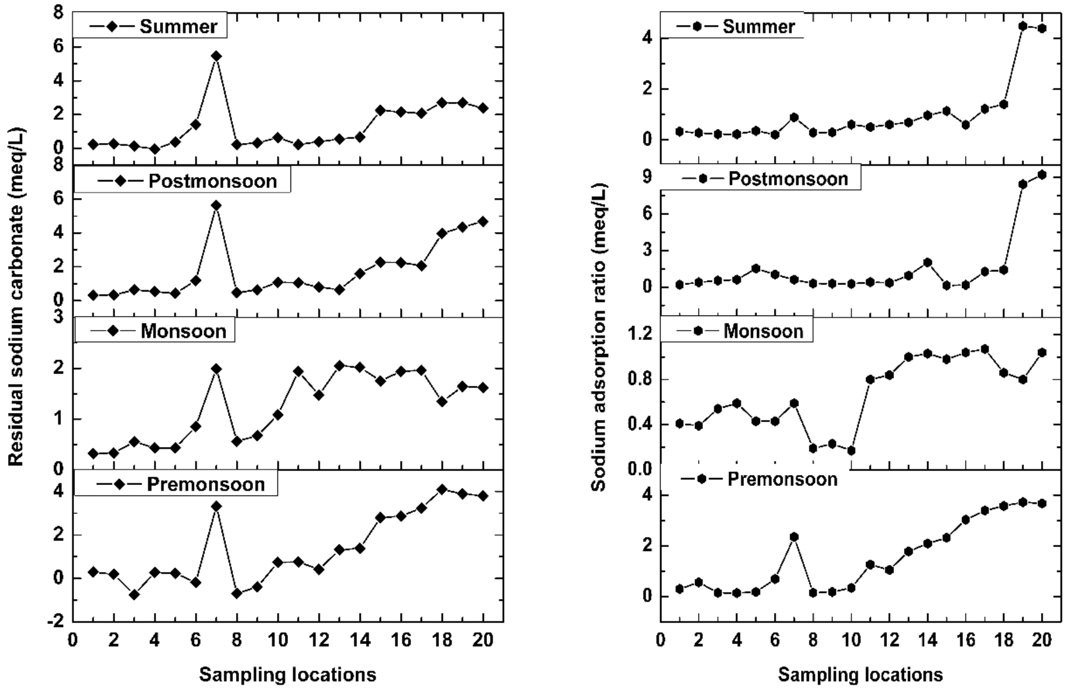


**Fig.3 Seasonal variations major ion distribution**


**Fig.4a and 4b shows the plastic pollution in coastal area**

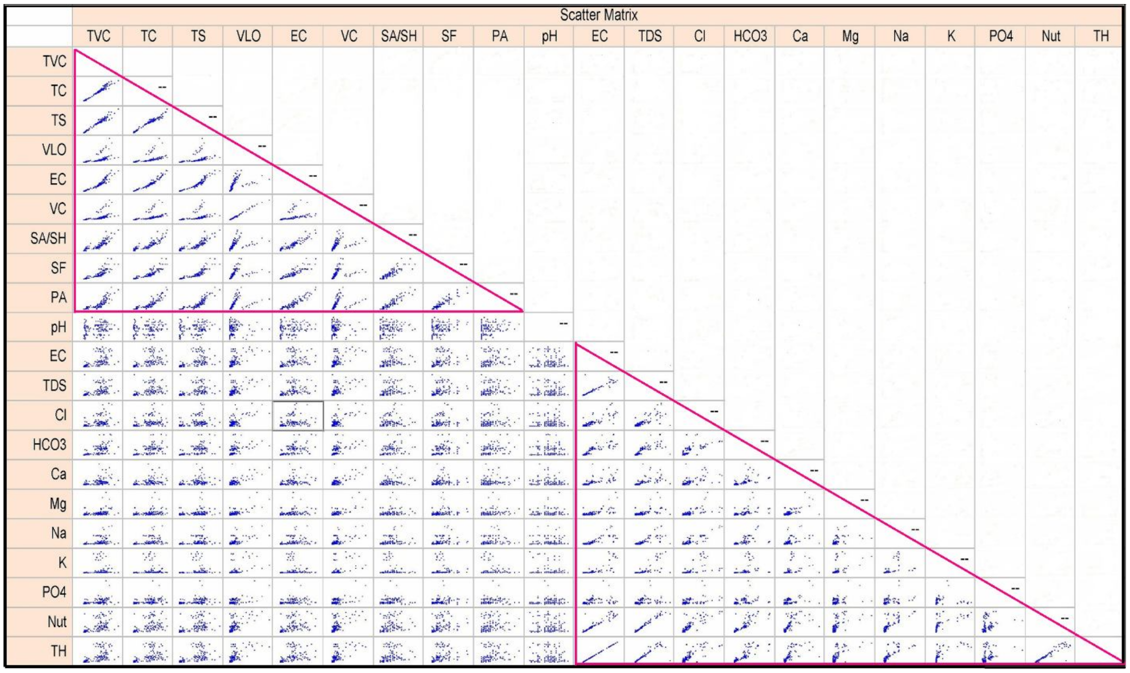


**Fig.5 Inverse relationship between biogeochemical parameters and microbial community**

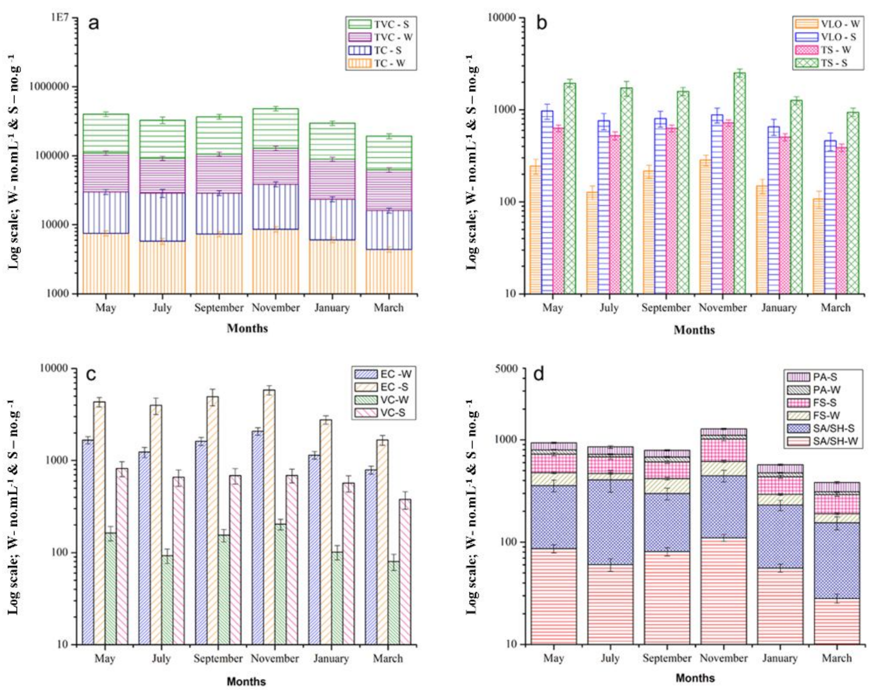


**Fig.6 Pollution indicators in the study area**

Table 1. Coefficient correlation between microbial and physiochemical parameters

| | TVC | TC | TS | VLO | EsC | VC | SA/ SH | SF | PA | pH | EC | TDS | Cl | $HCO_3$ | Ca | Mg | Na | K | $PO_4$ | Nut | TH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TVC** | 1 | | | | | | | | | | | | | | | | | | | | |
| **TC** | 0.98 | 1 | | | | | | | | | | | | | | | | | | | |
| | *0* | | | | | | | | | | | | | | | | | | | | |
| **TS** | 0.98 | 0.98 | 1 | | | | | | | | | | | | | | | | | | |
| | *0* | *0* | | | | | | | | | | | | | | | | | | | |
| **VLO** | 0.60 | 0.57 | 0.52 | 1 | | | | | | | | | | | | | | | | | |
| | *1.4E-14* | *8.8E -13* | *1.6E-10* | | | | | | | | | | | | | | | | | | |
| **EsC** | 0.94 | 0.96 | 0.95 | 0.52 | 1 | | | | | | | | | | | | | | | | |
| | *0* | *0* | *0* | *1.2E-10* | | | | | | | | | | | | | | | | | |
| **VC** | 0.60 | 0.56 | 0.52 | 0.99 | 0.51 | 1 | | | | | | | | | | | | | | | |
| | *1.6E-14* | *1.3E-12* | *1.5E-10* | *0* | *2.3E-10* | | | | | | | | | | | | | | | | |
| **SA/SH** | 0.87 | 0.88 | 0.88 | 0.48 | 0.94 | 0.47 | 1 | | | | | | | | | | | | | | |
| | *0* | *0* | *0* | *2.8E-9* | *0* | *7.3E-9* | | | | | | | | | | | | | | | |
| **SF** | 0.85 | 0.88 | 0.89 | 0.45 | 0.91 | 0.45 | 0.89 | 1 | | | | | | | | | | | | | |
| | *0* | *0* | *0* | *2.9E-08* | *0* | *4.4E-08* | *0* | | | | | | | | | | | | | | |
| **PA** | 0.85 | 0.87 | 0.87 | 0.44 | 0.94 | 0.43 | 0.93 | 0.93 | 1 | | | | | | | | | | | | |
| | *0* | *0* | *0* | *9.5E-08* | *0* | *2.6E-07* | *0* | *0* | | | | | | | | | | | | | |
| **pH** | 0.27 | 0.30 | 0.30 | 0.06 | 0.28 | 0.06 | 0.25 | 0.33 | 0.28 | 1 | | | | | | | | | | | |
| | *0* | *3.3E-4* | *3.6E-4* | *0.47* | *9.0E-04* | *0.47* | *0* | *7.4E-05* | *0* | | | | | | | | | | | | |
| **EC** | 0.56 | 0.52 | 0.51 | 0.61 | 0.45 | 0.62 | 0.36 | 0.38 | 0.37 | 0.03 | 1 | | | | | | | | | | |
| | *2.6E-12* | *1.3E-10* | *2.6E-10* | *3.3E-15* | *5.1E-08* | *8.8E-16* | *1.5E-05* | *5.3E-06* | *8.1E-06* | *0.68* | | | | | | | | | | | |
| **TDS** | 0.49 | 0.45 | 0.44 | 0.56 | 0.39 | 0.57 | 0.31 | 0.33 | 0.32 | 0.05 | 0.91 | 1 | | | | | | | | | |
| | *1.9E-09* | *3.7E-08* | *6.2E-08* | *1.4E-12* | *2.2E-06* | *4.2E-13* | *2.1E-04* | *8.8E-05* | *1.3E-04* | *0.5* | *0* | | | | | | | | | | |
| **Cl** | 0.46 | 0.40 | 0.39 | 0.70 | 0.33 | 0.72 | 0.27 | 0.30 | 0.25 | 0.05 | 0.78 | 0.74 | 1 | | | | | | | | |
| | *2.6E-08* | *1.3E-06* | *3.5E-06* | *0* | *8.3E-05* | *0* | *0* | *3.3E-04* | *0* | *0.54* | *0* | *0* | | | | | | | | | |
| **$HCO_3$** | 0.65 | 0.63 | 0.62 | 0.52 | 0.62 | 0.53 | 0.51 | 0.53 | 0.56 | 0.08 | 0.85 | 0.78 | 0.66 | 1 | | | | | | | |
| | *0* | *2.2E-16* | *8.8E-16* | *1.4E-10* | *2.0E-15* | 5.6E-11 | *2.1E-10* | *5.2E-11* | *2.4E12* | *0.33* | *0* | *0* | *0* | | | | | | | | |
| **Ca** | 0.45 | 0.40 | 0.38 | 0.72 | 0.35 | 0.72 | 0.27 | 0.25 | 0.28 | **-0.02** | 0.66 | 0.60 | 0.61 | 0.62 | 1 | | | | | | |
| | *3.2E-08* | *1.2E-06* | *5.2E-06* | *0* | *2.8E-05* | *0* | *0* | *0* | *8.1E-04* | *0.77* | *0* | *2.1E-14* | *6.0E-15* | *1.1E-15* | | | | | | | |
| **Mg** | 0.35 | 0.31 | 0.28 | 0.75 | 0.27 | 0.75 | 0.25 | 0.25 | 0.27 | 0.08 | 0.59 | 0.52 | 0.63 | 0.47 | 0.68 | 1 | | | | | |
| | *2.8E-05* | *2.0E-04* | *7.7E-04* | *0* | *0* | *0* | *0* | *0* | *0* | *0.32* | *5.0E-14* | *1.0E-10* | *2.2E-16* | *7.1E-09* | *0* | | | | | | |
| **Na** | 0.44 | 0.39 | 0.37 | 0.61 | 0.32 | 0.62 | 0.27 | 0.33 | 0.27 | 0.05 | 0.80 | 0.76 | 0.87 | 0.61 | 0.51 | 0.48 | 1 | | | | |
| | *1.0E-07* | *2.1E-06* | *7.9E-06* | *5.3E-15* | *1.5E-04* | *1.7E-15* | *0* | *8.6E-05* | *0* | *0.52* | *0* | *0* | *0* | *2.8E-15* | *3.2E-10* | *3.6E-09* | | | | | |
| **K** | 0.21 | 0.18 | 0.18 | 0.49 | 0.09 | 0.49 | 0.04 | 0.08 | 0.03 | **-0.09** | 0.74 | 0.69 | 0.60 | 0.38 | 0.43 | 0.45 | 0.48 | 1 | | | |
| | *0.01* | *0.03* | *0.03* | *2.4E-09* | *0.30* | *1.3E-09* | *0.60* | *0.31* | *0.70* | *0.29* | *0* | *0* | *1.1E-14* | *4.8E-06* | *1.8E-07* | *1.8E-14* | *2.6E-09* | | | | |
| **$PO_4$** | 0.41 | 0.38 | 0.35 | 0.62 | 0.34 | 0.61 | 0.25 | 0.28 | 0.26 | 0.14 | 0.31 | 0.27 | 0.43 | 0.33 | 0.55 | 0.42 | 0.38 | 0.00 | 1 | | |
| | *9.8E-07* | *4.8E-06* | *0.3E-05* | *8.8E-16* | *6.3E-05* | *6.4E-15* | *0* | 0 | *0* | *0.09* | *2.6E-04* | *0* | *2.0E-07* | *7.2E-05* | *3.6E-15* | *3.9E-07* | *4.5E-06* | *0.30* | | | |
| **Nut** | 0.54 | 0.50 | 0.49 | 0.61 | 0.44 | 0.63 | 0.36 | 0.38 | 0.37 | 0.06 | 0.94 | 0.98 | 0.81 | 0.85 | 0.64 | 0.57 | 0.81 | 0.67 | 0.32 | 1 | |
| | *1.4E-11* | *5.7E-10* | *1.3E-09* | *2.4E-15* | *6.2E-08* | *0.4E-16* | *1.8E-05* | *5.3E-06* | *9.7E-06* | *0.49* | *0* | *0* | *0* | *0* | *0* | *9.1E-13* | *0* | *0* | *1.2E-04* | | |
| **TH** | 0.56 | 0.52 | 0.51 | 0.61 | 0.45 | 0.62 | 0.36 | 0.38 | 0.37 | 0.03 | 1 | 0.91 | 0.78 | 0.85 | 0.66 | 0.59 | 0.80 | 0.74 | 0.31 | 0.94 | 1 |
| | *2.5E-12* | *1.2E-10* | *2.5E-10* | *3.3E-15* | *4.9E-08* | *8.8E-16* | *1.4E-05* | *5.1E-06* | *7.9E-06* | *0.67* | *0* | *0* | *0* | *0* | *0* | *5.0E-14* | *0* | *0* | *2.6E-04* | *0* | |

Significant levels are shown in Italic form; Negative correlation value shown in bold form; Positive (high = >0.60) correlation values are underlined

Table 2. Average concentration of OCPs (ng $l^{-1}$) in water and sediment samples

| **Pesticides** | **Premonsoon** | | **Monsoon** | | **Post monsoon** | | **Summer** | |
|---|---|---|---|---|---|---|---|---|
| | **Range** | **Mean ±S.D** | **Range** | **Mean ±S.D** | **Range** | **Mean ±S.D** | **Range** | **Mean ±S.D** |
| **Water** | | | | | | | | |
| α-HCH | <0.01 | - | <0.01 | - | <0.01 | - | <0.01- 0.15 | 0.24 ± 0.00 |
| HCB | <0.05 | - | <0.04- 0.25 | 0.24 ± 0.00 | <0.05 | - | <0.05- 0.21 | 0.19 ± 0.13 |
| Aldrin | <0.02 | - | <0.01 - 1.66 | 0.34 ± 0.59 | <0.02 - 1.20 | 0.55 ± 0.44 | <0.02 - 0.30 | 0.14 ± 0.09 |
| p,p'-DDE | <0.01 - 0.04 | 0.04 ± 0.00 | <0.01 - 0.27 | 0.22 ± 0.09 | <0.01 | - | <0.01 - 0.11 | 0.09 ± 0.03 |
| o,p'-DDD | <0.02 - 0.07 | 0.07 ± 0.00 | <0.02 - 0.35 | 0.06 ± 0.12 | <0.02 - 0.22 | 0.10 ± 0.05 | <0.02 - 0.03 | 0.04 ± 0.01 |
| Endrin | <0.02 | - | <0.02 - 65.0 | 58.002 ± 0.00 | <0.02 | - | <0.02 - 3.20 | 2.62 ± 0.77 |
| o,p'DDT | <0.01 | - | <0.01 - 0.33 | 0.31 ± 0.00 | <0.01 - 0.15 | 0.12 ± 0.00 | <0.01 - 0.20 | 0.09 ± 0.08 |
| Mirex | <0.01 - 0.7 | 0.27 ± 0.22 | <0.01 - 0.50 | 0.39 ± 0.14 | <0.01- 0.18 | 0.18 ± 0.06 | <0.01 - 0.17 | 0.10 ± 0.05 |
| **Sediment** | | | | | | | | |
| α-HCH | <0.01 | - | <0.01 | - | <0.01 | - | <0.01 | - |
| HCB | <0.05 | - | <0.05 | - | <0.05 | - | <0.05 -21.5 | 21.50 ± 0.00 |
| Aldrin | <0.02 | - | <0.02 - 591.4 | 384.65 ± 247.10 | <0.02 | - | <0.02 - 20.4 | 17.40 ± 0.00 |
| p,p'-DDE | <0.01- 4.5 | 3.60 ± 0.00 | <0.01 - 85.77 | 78.70 ± 0.00 | <0.01-16.7 | 16.55 ± 1.63 | <0.01 | - |
| o,p'-DDD | <0.02 - 18.4 | 14.72 ± 9.61 | <0.02 - 55.2 | 32.55 ± 22.79 | <0.02 - 58.2 | 38.95 ± 18.58 | <0.02 - 14.8 | 16.24 ± 3.10 |
| Endrin | <0.02 | - | <0.02 | - | <0.02 | - | <0.02 | - |
| o,p'DDT | <0.01 - 12.4 | 13.60 ± 0.00 | <0.01 - 231.7 | 178.13 ± 90.92 | <0.01 - 20.4 | 14.40 ± 0.00 | <0.01 - 19.3 | 21.20 ± 2.84 |
| Mirex | <0.01 - 26.9 | 24.82 ± 5.14 | <0.01- 70.9 | 65.58 ± 7.24 | <0.01 - 74.5 | 43.19 ± 20.39 | <0.01- 66.7 | 54.35 ± 40.58 |

BDL - Below detectable limit

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