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Spatial and temporal variations in the water quality parameters of Pulicat Lake, Tamil Nadu, India

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Abstract
The spatial and temporal variations in water quality were assessed in Pulicat lake during 2011 and 2012 to evaluate the status of the estuarine water. Among the physical parameters studied, only turbidity recorded high values. Chemical parameters exhibited variations between stations among the two years of study. There was an increase in the values of BOD, COD, TDS and TH. These indicate that there was an increase in pollutants reaching the estuary, probably due to the discharge of three seasonal rivers that open in to the lake and the Buckingham canal that brings in industrial and domestic waste.

Keywords: Physicochemical parameters, pollution, estuary, Pulicat lake.

1. Introduction
Industrial developments has led to an increased discharge of chemical effluents into the aquatic ecosystem, leading to damage of marine habitats. Rivers plays a major role in assimilation of municipal and industrial waste water and runoff from agricultural lands. When river water mixes with sea water, large numbers of physical and chemical processes take place which may influence water quality [1]. The estuary is an integral part of the coastal environment. It is the outfall region of the river, making the transitional zone between the fluvial and marine environs. They are complex and dynamic environmental components which receive large amounts of contaminants from urban and industrial sites [2]. The health status and the biological diversity of the Indian estuarine ecosystems are deteriorating day by day through man-made activities and dumping of enormous quantities of sewage into the estuaries which has caused considerable ecological imbalance thereby resulted in the large-scale disappearance of their flora and fauna.
India has an extensive coastline of about 8,129 km and of this nearly 6,000 km is formed into enriched prosperous estuaries, creeks, brackish water lagoons and lakes, forming an important nursery and breeding grounds for the marine organisms. The Southeast coast of India is an important stretch of coastline, where many major rivers drain into the Bay of Bengal and are rich in marine fauna [3]. Water quality plays a significant role in safeguarding a well-balanced environment. Estuaries determine the fate of physicochemical parameters of continental origin to the ocean. The net flux of riverine inputs to the open ocean depends on their biogeochemical behaviours in the estuary [4]. Therefore, the present study was carried out to monitor this important estuarine lake for physicochemical changes.

2. Materials and methods
2.1. Study area
Pulicat lake (latitude 13º 24' and 13º 43'N and longitude 80º 03' and 80º 18E') is the second largest coastal lake in India located 40 km north of Chennai city, Tamil Nadu, India. The lake is about 60 km in length and 0.2 to 17.5 km in breadth and separated from the Bay of Bengal by an inland split called the Sriharikota Island. The main source of freshwater is land runoff through three small seasonal rivers that open into the lake *viz*., Arani, Kalangi and Swarnamukhi. The Buckingham canal, which runs parallel to the Bay of Bengal, brings in the industrial and domestic wastes to the lake and eventually to the Bay of Bengal [5]. The hydrology of the Pulicat lake is influenced by local climate, the regime of the inflowing rivers, the Buckingham canal that enters the lake, in addition to the effect of the neritic waters of the Bay of Bengal. Pulicat lake, harbours many euryhaline species and serves as a nursery for several marine species and a very few secondary freshwater fishes. The industries located

around Pulicat lake are discharging effluents indirectly into the lake and the point sources of pollution mainly comes from North Chennai thermal power plant, Ennore port activities, Manali petrochemical industries, other nearby industries and untreated urban wastes from Chennai metropolitan city [5].

2.2. Collection of samples and analysis

Water samples were collected from four stations in the Pulicat lake which are suspected sites of possible local and point source pollution. The water samples were collected undisturbed from the surface water in the study area as the depth of water was very less (< 5m) during early morning throughout the study period. Samples were collected from January 2011 to December 2012 on a monthly basis to study the effects of seasonal variation. The water samples were collected in two litre polyethylene cans which were previously cleaned, rinsed and washed with deionized water and then rinsed with samples several times.

Temperature was recorded at the collection sites by using a mercury-in-glass thermometer. Salinity was measured using an Atago Master-PM hand held Refractometer. The collected water samples were brought to the laboratory and preserved. The various physicochemical parameters like temperature (^{o}C), pH, turbidity (NTU), salinity (ppt), DO (mg/L), BOD (mg/L), COD (mg/L), alkalinity total (as $CaCO_3$) (mg/L), chloride (as Cl) (mg/L), flouride (as F) (mg/L), Total dissolved solids (TDS) (mg/L), Total hardness (TH) (as $CaCO_3$) (mg/L), calcium (as Ca) (mg/L), magnesium (as Mg) (mg/L), sodium (as Na) (mg/L), potassium (as K) and iron (as Fe) (mg/L) were analyzed by adopting the standard methods of examination of water and waste water [6].

3. Results and discussion

The values for physical and chemical parameters of Pulicat lake during the study period from January 2011 to December 2012 are presented in Tables 1 and 2.

3.1. Temperature (°C)

In 2011 the temperature varied between 27.4 and 31.7°C among the four seasons. In 2012 it varied between 28.4 and 30.2°C. In both the years the highest temperature was recorded during summer and lowest during monsoon. Temperature is an important limiting factor, which regulates the biogeochemical activities in the aquatic environment. Generally, the surface water temperature is influenced by the intensity of solar radiation, evaporation, fresh water influx and cooling and mix up with ebb and flow from the adjoining neritic waters. The water temperature during monsoon was low because of strong land breeze and precipitation and the recorded high value during summer could be attributed to high solar radiation. Temperature also controls behavioural characteristics of organisms and also the solubility of gases and salts in water [7]. Similar observations have been reported in Uppanar estuary, in Ennore [8], in Sarada and Varaha estuarine complex, East Coast of India [9] and in Pulicat lake [10]. Thus the present findings are similar to the temperature reports of other estuarine systems.

3.2. pH

The pH ranged between 7.6 and 7.7 during post monsoon and summer in 2011. In 2012, the pH ranged between 7.3 and 7.5 during pre-monsoon and post monsoon. The fluctuations in pH was not comparable during the two years. Generally, temporal fluctuations in pH could be attributed to factors like removal of carbon dioxide by photosynthesis through bicarbonate degradation, dilution of sea water by freshwater influx, low primary productivity, reduction of salinity and temperature besides decomposition of organic matter [11]. The recorded high pH values during summer might be due to the influence of seawater penetration and high biological activity. pH of water is an important environmental factor and is generally considered as an index for suitability of the environment. Increased pH appears to be associated with increased use of alkaline detergents in residential areas and alkaline material from wastewater in industrial areas [12].

3.3. Turbidity

In 2011 the turbidity varied between 2.7 and 6.1NTU among the four seasons. In 2012 it varied between 4.6 and 6.1NTU. In the present study, high turbidity was observed during post monsoon in 2011 whereas in 2012 it was high during summer. High turbidity may be due to input of sediments brought by fresh water inflow and tidal movements. Turbidity was affected by salinity; salts settle sediments and hence the presence of salt in estuaries had the effect of reducing turbidity. Increased turbidity decreases light penetration, plant growth and oxygen production in the water. Therefore, breeding and survival of fish and other aquatic animals were reduced. Suspended particles absorb heat which causes water temperature to increase and it holds less oxygen than cold water [13].

3.4. Salinity

The salinity ranged between 31.3 and 31.8ppt during monsoon and post monsoon in 2011. In 2012 the salinity ranged between 30.9 and 31.1ppt during monsoon and post monsoon. Salinity is one of the important factors which profoundly influence the abundance and distribution of the animals in estuarine environment. High salinity may be due to high temperature which decreases freshwater inflow and land drainage. Low salinity was recorded during monsoon in both the years. Similar observations were recorded from Uppanar estuary [14] and in Pulicat [10]. Salinity acts as a limiting factor in the distribution of living organisms and its variation caused by dilution and evaporation which influence the characteristic change of fauna in the intertidal zone. Most species in the estuarine environment live under stress either due to low or high salinity depending on their origin from fresh or marine areas [15].

3.5. Dissolved oxygen

In 2011 and 2012 the DO varied between 2.3 and 2.4mg/L among the four seasons. High values were recorded during pre-monsoon and monsoon in both the years. DO in seawater plays a very important role with respect to marine life. A decrease in salinity or temperature causes an increase in the solubility of gases. The high concentration of oxygen during monsoon was due to the monsoon and floods and turbulence of water caused by the mixing of freshwater with seawater as suggested by Zingde *et al*. [16]. Any increase in BOD and COD will indicate decreased DO. Higher concentration of dissolved oxygen was also observed when there was a higher pH suggesting the abundant growth of phytoplankton and zooplankton leading to high biological activity. The low DO during summer could be related to lesser input of freshwater and also due to the biochemical oxidation of organic matter and the combined effects of temperature, salinity and photosynthetic activity [10].

3.6. Biochemical oxygen demand
The BOD ranged between 38.6 and 50.6mg/L during pre-monsoon and post monsoon during 2011. In 2012 the BOD ranged between 44.7 and 107.6mg/L during post monsoon and monsoon. BOD estimation is a vital aspect in assessing the organic pollution of aquatic ecosystem [10]. BOD is the measure of quantity of oxygen required by bacteria and other microorganisms under aerobic condition in order to biochemically degrade and transform organic matter present in the water bodies. High BOD limits the presence of aquatic organisms and type of material present in water can impact the BOD [17]. The consequences of high BOD include aquatic organisms becoming stressed, suffocating and eventually death [18].

3.7. Chemical oxygen demand
In 2011 the COD varied between 291.1 and 352.3mg/L among the four seasons. In 2012 it varied between 252.5 and 288.4mg/L. Maximum COD was observed during the summer season in both the years. This may be due to decrease in freshwater inflow, land drainage, domestic sewage, industrial inputs, increase in salinity, temperature, phytoplankton productivity and microbial utilization of oxygen at the time of decomposition. Low COD may be due to the presence of heavy river run-off, decreased mixing of agricultural and domestic wastes, land drainage into the estuary and decreased biological activity due to decreased salinity and temperature. The elevated levels of COD indicate an increased load of organic and inorganic pollution that require more oxygen to oxidize under increased thermal conditions [19].

3.8. Alkalinity total
The alkalinity total ranged between 135.6 and 147.9mg/L during summer and post monsoon in 2011. In 2012 the alkalinity total ranged between 159.9 and 176.2mg/L during summer and post monsoon. In both the years, the highest alkalinity total was recorded during post monsoon and lowest during summer. Alkalinity of water is a measure of weak acid present in it and the cations balanced against them. Total alkalinity is the total concentration of bases in water usually bicarbonates and carbonates. Total alkalinity depends on the concentration of the substance which would raise the pH of the water. High levels of alkalinity indicate the presence of strongly alkaline industrial waste water and sewage in the estuary. The degradation of plants, living organisms and organic waste in the estuary might also be one of the reasons for increase in carbonate and bicarbonate levels, thereby showing an increase in alkalinity [20].

3.9. Chloride
In 2011 the chloride varied between 10991.9 and 12782.2mg/L among the four seasons. In 2012 it varied between 12434.5 and 13515.2mg/L. The possible reason for lower concentration of chloride may be due to the lesser input from the industrial activity while, higher concentration of it may be due to seawater intrusion coupled with huge influx of sewage and industrial wastewater. The high chloride concentration in water indicates the presence of large amount of organic matter. The higher concentration of chloride in water is an index of pollution of animal origin and there is a direct correlation between chloride concentration and pollution levels. Excess chloride in the form of human excreta and industrial wastes would reduce the DO content of water, which turns harmful for aquatic organisms [21].

3.10. Flouride
The flouride ranged between 0.4 and 0.5mg/L both during summer and post monsoon in 2011 and also in 2012. Minimum fluoride concentrations were recorded during pre-monsoon whereas maximum during monsoon and summer. Similar observations were recorded by Ravaniah and Murthy [10] at Pulicat lake.

3.11. Total dissolved solids
In 2011 the TDS varied between 21337.2 and 26084.5mg/L during the four seasons and in 2012 it varied between 22428.0 and 26266.4mg/L. Variations in TDS may be due to the inflow of industrial, animal and agriculture wastes and also by evaporation and less rainfall. Verma *et al*. [22] observed that large amount of dissolved solids may result in high osmotic pressure.

3.12. Total hardness
The total hardness ranged between 3999.1 and 5122.4mg/L during post monsoon and pre monsoon in 2011. In 2012 it ranged between 4124.6 and 4703.8mg/L during summer and post monsoon. Total hardness is used to describe the effect of dissolved minerals (mostly calcium and magnesium) determining suitability of water for domestic, industrial and drinking purpose attributed to presence of bicarbonates, sulphates, chloride and nitrate of calcium and magnesium. High values of hardness are probably due to regular addition of large quantities of detergents used by the nearby residential localities which drains into estuaries [4].

3.13. Calcium
In 2011 the calcium varied between 1334.0 and 1657.0mg/L among the four seasons. In 2012 it varied between 1386.5 and 1646.8mg/L. In the present study, high values of calcium were recorded during the post monsoon and summer seasons in both the years. Low values were recorded during monsoon. Calcium is an element occurring normally among the eleven ions of seawater and is considered as 'major constituents', which are leached into the aquatic system by weathering process. In coastal waters, comprising the near shore areas, concentration of these two ions varies with the factors involving land drainage, precipitation and dissolution. High concentrations of calcium and magnesium in summer can be attributed to the release from the exchangeable sites of majority of riverine clays with other cations in the early stage of estuarine mixing thereby indicating that the higher values of these two parameters can be attributed to the industrial pollution [10].

3.14. Magnesium
Magnesium ranged between 370.75 and 526.1mg/L during post monsoon and summer during 2011. In 2012 it ranged between 379.8 and 565.9mg/L during post monsoon and monsoon. The normal amount of magnesium present in sea water is about 1300mg/L. Magnesium present in Pulicat lake water was much lower than normal [23].

3.15. Sodium
In 2011 the sodium varied between 4404.1 and 5475.0mg/L among the four seasons. In 2012 it varied between 4833.3 and 5899.9mg/L. High values of sodium were recorded during the pre-monsoon season in both the years. Minimum values were recorded during post monsoon and monsoon in these two years. The normal amount of sodium in sea water is about 10,500mg/L [23].

3.16. Potassium

The potassium ranged between 505.0 and 643.3mg/L between post monsoon and summer during 2011 and in 2012 it ranged between 429.1 and 615.8mg/L between pre monsoon and monsoon. The normal amount of potassium in sea water is 392 mg/L [23]. High values of potassium was recorded in Pulicat lake during the two years of study.

Table 1: Physicochemical parameters of Pulicat lake in 2011

Parameters	Post Monsoon	Summer	Pre Monsoon	Monsoon
Physical parameters				
Temperature (^{O}C)	28.8	31.7	30.4	27.4
pH	7.6	7.7	7.7	7.7
Turbidity (NTU)	6.1	5.0	2.7	3.8
Salinity (ppt)	31.8	31.7	31.7	31.3
Chemical parameters (mg/L)				
DO	2.3	2.4	2.4	2.4
BOD	50.6	40.5	38.6	46
COD	352.3	292.0	291.1	313.2
Alkalinity	147.9	135.6	138.0	139.3
Chloride	10991.9	12782.2	12098.7	11144.0
Fluoride	0.5	0.4	0.5	0.4
TDS	21337.2	24598.3	22982.0	26084.6
TH	3999.1	4748.3	5122.4	4912.5
Calcium	1334.0	1519.6	1547.6	1657.0
Magnesium	370.7	526.1	471.0	455.6
Sodium	4404.1	5341.6	5475.0	4845.8
Potassium	505.0	643.3	562.5	580.8

Table 2: Physicochemical parameters of Pulicat lake in 2012

Parameters	Post Monsoon	Summer	Pre Monsoon	Monsoon
Physical parameters				
Temperature (^{O}C)	29.1	30.0	29.2	28.4
pH	7.5	7.4	7.3	7.4
Turbidity (NTU)	6.1	5.6	5.4	4.6
Salinity (ppt)	31.0	31.1	31.1	30.9
Chemical parameters (mg/L)				
DO	2.3	2.2	2.4	2.4
BOD	44.7	45.0	88.9	107.6
COD	271.1	287.5	288.4	252.5
Alkalinity	176.2	159.9	169.7	161.5
Chloride	13346.5	13515.2	12434.5	13280.9
Fluoride	0.5	0.4	0.5	0.4
TDS	22428.0	26266.4	25912.4	25815.7
TH	4703.8	4124.6	4625.9	4605.3
Calcium	1386.5	1419.3	1640.0	1646.8
Magnesium	379.8	424.5	478.6	565.9
Sodium	4833.3	4983.3	5041.6	5899.9
Potassium	515.0	498.3	429.1	615.8

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