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ORIGINAL ARTICLE

COMPARATIVE PHYSICO-CHEMICAL PROFILING OF TWO COASTAL WATER BODIES FROM SOUTH EAST COAST OF INDIA WITH SPECIAL REFERENCE TO THEIR POLLUTION STATUS

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ABSTRACT

In the present study, efforts have been made to analyze selected physico-chemical characteristics of the water bodies of Uppanar estuary and Periyavaikkal region of Killai backwater area, Cuddalore District, Tamilnadu India. The comparative analytical study was conducted for one calendar year and water samplings were done on monthly basis. The parameters analyzed include rainfall, atmospheric temperature, water temperature, pH, salinity, turbidity, total dissolved solids, electrical conductivity, dissolved oxygen, biochemical oxygen demand and hardness. The results of the study clearly indicate the environmentally degraded ambience of Uppanar estuary and a comparatively less polluted water body at Killai region. The study also indicated significant seasonal variations among the parameters within each sites as well as between sites indicating the eco-toxicological susceptibility of Uppanar estuary.

Keywords: Uppanar estuary, Killai back waters, Physico chemical characters.

1.INDRODUCTION

As estuary is the area where river get emptied into the ocean it has hydrological characteristics different from sea and river. Since the hydro-geographical characters prevailing in the estuarine habitat is well suited for the breeding and feeding activities of a wide variety of fauna and flora, more than 90 percent of marine fish and other living resources are found in estuaries and in the adjacent coastal water bodies Croot and Hunter, (1998). Coastal marine environments are reported to have greater biodiversity than open ocean regions and majority of world's most productive marine ecosystems are found within coastal environments and owe their productivity, diversity and wealth of life to their terrestrial adjacency (Gray., 1997; Bierman *et al.*, 2009). Therefore marine water quality plays an important part in the conservation of marine resources, which contribute to the stability of the marine ecosystem. However, Pollution from land-based sources as well as from the sea can be detrimental to these invaluable resources. In recent years, coastal environment including estuaries are subjected to increased pollution stresses originating mainly from land-based human activities such as disposal of agricultural, industrial, municipal, domestic and other wastes/ in substantial quantities

The proximity of these ecosystems to land area often provides nutrients and favorable conditions that support primary producers, which in turn provide nourishment for higher levels of the food chain. However, the threat of rapid and often devastating changes to water quality by means of anthropogenic as well as natural processes in an ever increasing mode. As a result, the inhabitant species are threatened by conditions which are no longer suitable for their survival in many coastal ecosystems. Such unwelcome changes in water quality pose serious threats to humans also through utilization of these water bodies for recreation, fishing as well as industrial purposes.

The indiscriminate mixing of effluents, sewage and other contaminants with the water bodies not only impair their physicochemical composition but also bring in adverse impacts on the inhabitant organisms with far reaching consequences. These deleterious effects include not only the manifestation of the direct contaminant impacts but also the polluted ambient environment favours the general deterioration of health status of the inhabitant organisms leading to secondary infections, parasitic infestations, increased probabilities of predation and many other problems having detrimental effects on the survival of the organisms. The situation becomes more complicated as these water bodies are the preferred habitats of many of the aquatic organisms such as crustaceans, mollusks and fishes which are the preferred food sources for human beings. It is estimated

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that 40% of deaths around the world can now be attributed to various environmental factors, especially organic and chemical pollutants (Science Day, 2008). In the present state of affairs, good quality water has become a scarce commodity and ecotoxicological investigations on aquatic ecosystems have emerged as an important part of the societal life.

In view of the large scale consumption potential of the fishery resources from Uppanar estuary which includes fishes as well as shellfishes, it will felt highly appropriate to evaluate the physicochemical profile of these estuarine water bodies. The need of the present study is also strongly felt from the reports of industrial effluents induced water quality deterioration along the Cuddalore coast and Uppanar estuary (Sundaramanickam *et al.*, 2008; Santhi, 2012).

The impacts of pollution changes in coastal regions are seriously degrading them, decreasing their aesthetic and economic value and in many cases, endangering public health and safety, as well as threatening the living resources (Duxbury and Duxbury, 1994). Therefore, it is important to monitor the various physico-chemical parameters as a preliminary step to assess the pollutants and their impact because water quality criteria have key roles to play in the management and protection of marine community from the ill effects of pollutants. A well planned and executed water quality monitoring system is required to predict the changes in the quality of any particular water bodies so that, curative or preventive measures can be taken to restore and maintain ecological balance in that water body.

In this context the present study was carried out to monitor and compare pollution on the physicochemical parameters of the Uppanar estuary, Cuddalore, Tamilnadu, India with those of Periyavaikal region of Killai back water from the same district. The study was extended over one year.

2.MATERIALS AND METHODS

Study sites and water sampling

The sites selected for the study were the Uppanar estuary (here after referred to also as polluted site) and Periyavaikal area of Killai coast (here after referred to also as reference site) of Cuddalore district, Tamilnadu, India. Monitoring of the physico- chemical parameters of these water bodies were done for one whole year (January 2012 – December 2012) and samplings were carried out on monthly intervals. In order to have uniformity, water samples were collected from fixed locations on each of the study sites. Water samplings and preservations were carried out according to the methods prescribed by APHA *et al.* (1989) and Prakash (2004)

Parameters analysed

The physico chemical parameters analysed to assess the water quality in both the sites include, Rainfall (RF), Atmospheric temperature (AT), Water temperature (WT), P^H, Salinity (S), Turbidity (T), Total Dissolved Solids (TDS), Hardness (H), Electrical Conductivity (EC), Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD), the

parameters were analysed following the standard methods of APHA *et al.*(1989), and Murugesan and Rajakumari (2005).

3.RESULTS

Rainfall (RF)

Both the study sites received maximum rainfall during the monsoon month of November (154.95±0.04 and 153.62±0.62; (Fig 1a). Both the areas received no rainfall during the summer months of April, May and June. The significant correlations of RF with the other physicochemical factors are shown in (Tables 1, 2).

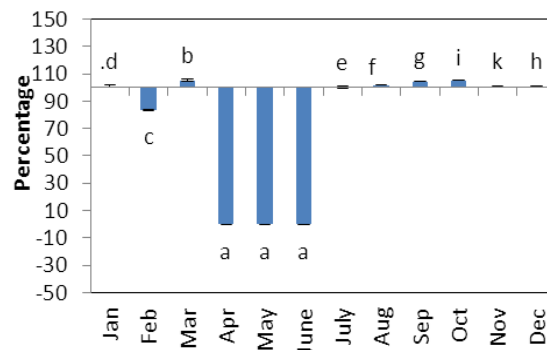


Fig 1a. Variations in the rainfall (RF) of Uppanar estuary from Periyavaikal (reference site). (Reference site values taken as 100%; based on ANOVA and DMRT; values with different superscripts are significantly different at P≤0.05)

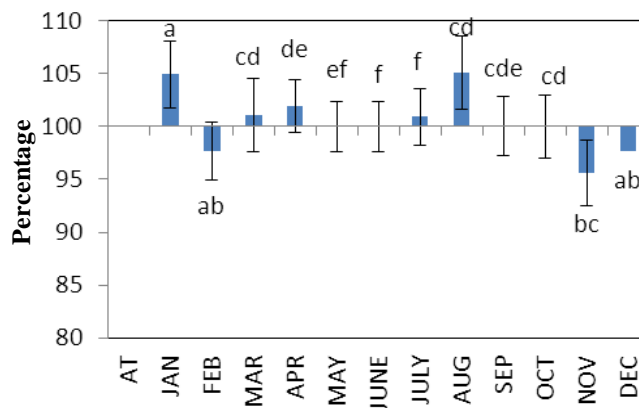


Fig 1b. Variations in the atmospheric temperature (AT) of Uppanar estuary from Periyavaikal (reference site). (Reference site values taken as 100%; based on ANOVA and DMRT; values with different superscripts are significantly different at P≤0.05)

Atmospheric temperature (AT)

Both the study areas recorded more or less similar annual variations in air temperature with no significant difference between them (Table- 3 Fig 1b). However, there were significant variations in the (AT) during various months in each of the sites (Fig 1b). In general, at both the study area, air temperature was found to be minimum during the confluence of monsoon and winter seasons and maximum during the summer season.

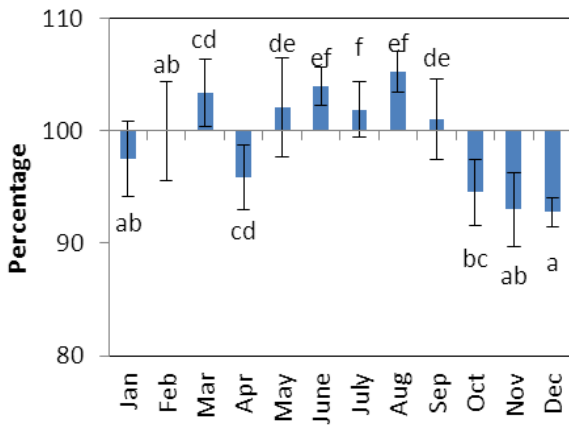


Fig 1c. Variations in the Water temperature (WT) of Uppanar estuary from Periyavaikal (reference site). (Reference site values taken as 100%; based on ANOVA and DMRT; values with different superscripts are significantly different at $P \leq 0.05$)

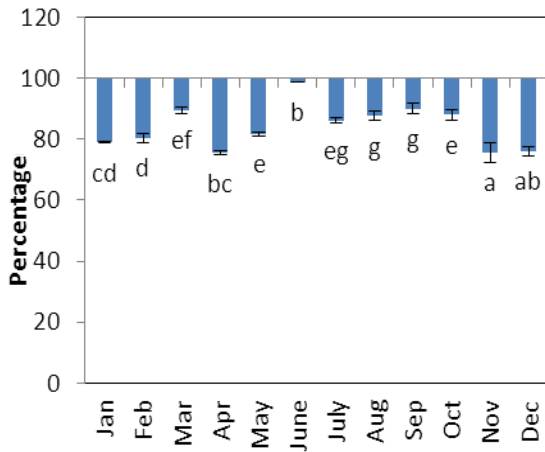


Fig 1d. Variations in the hydrogen ion concentration (pH) of Uppanar estuary from Periyavaikal (reference site). (Reference site values taken as 100%; based on ANOVA and DMRT; values with different superscripts are significantly different at $P \leq 0.05$)

Water temperature (WT)

The general pattern of WT was also more or less similar to that of AT (Fig 1c). In both the study sites, the water temperature was found to be less than the atmospheric temperature and there was no significant difference between their annual patterns (Table 3). The significant correlations of WT with other factors are shown in Tables 1, 2.

Hydrogen ion concentration (pH)

There was significant difference between the annual averages of pH of the two sites (Table 3) and the same trends of variations in pH during various seasons were also observed among the two sites (Fig 1d). Even though the variations observed in the pH of Killai were limited only to the alkaline range (7.40 ± 0.21 to 8.13 ± 0.088) (Fig 1d), that of Cuddalore ranged from acidic to alkaline ranges (5.57 ± 0.18 to 8.00 ± 0.00) (Fig 1d). It showed significant positive correlations with AT and WT. and significant negative correlations with RF, T, EC, TDS, EC and DO (Tables 1, 2).

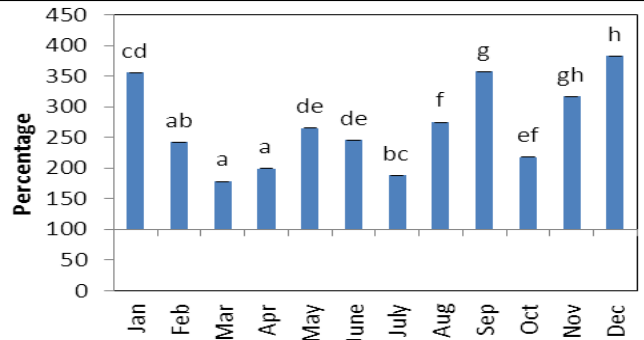


Fig 2a. Variations in the salinity (S) of Uppanar estuary from Periyavaikal (reference site). (Reference site values taken as 100%; based on ANOVA and DMRT; values with different superscripts are significantly different at $P \leq 0.05$)

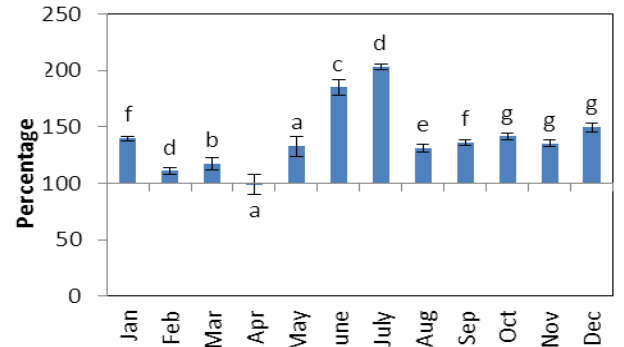


Fig 2b. Variations in the Turbidity (T) of Uppanar estuary from Periyavaikal (reference site). (Reference site values taken as 100%; based on ANOVA and DMRT; values with different superscripts are significantly different at $P \leq 0.05$)

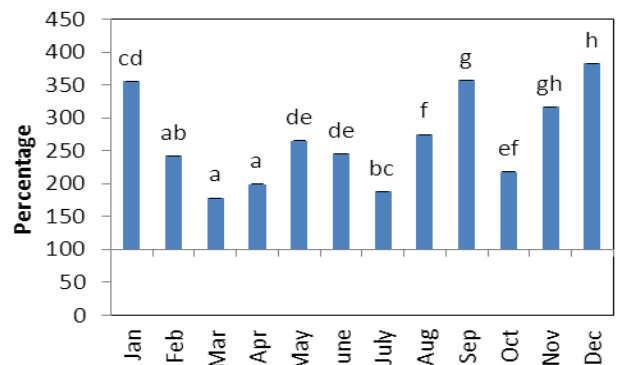


Fig 2c. Variations in the Total dissolved solids (TDS) of Uppanar estuary from Periyavaikal (reference site). (Reference site values taken as 100%; based on ANOVA and DMRT; values with different superscripts are significantly different at $P \leq 0.05$)

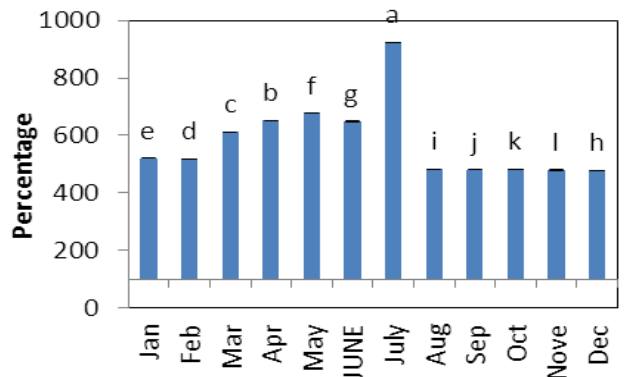


Fig 2d. Variations in the Electrical conductivity (EC) of Uppanar estuary from Periyavaikal (reference site). (Reference site values taken as 100%; based on ANOVA and DMRT; values with different superscripts are significantly different at $P \leq 0.05$)

Salinity (S)

There existed significant differences in the salinities during various seasons and between both the sites also (Fig2a). While it varied from 24.67±0.88% to 32.67±0.88% in Killai, Cuddalore showed a minimum salinity of 28.67±1.45% and maximum value of 35.00±1.53%. (Fig 2a).In both the cases maximum salinity was observed during the summer months. In both the sites salinity was negatively correlated significantly to most of the parameters (Tables 1, 2).

Turbidity (T)

Turbidity was significantly higher in the case of Uppanar estuary than Killai backwater (Fig 2b and Table 3). Turbidity of the Uppanar estuary was maximum (86.33 ± 2.60 NTU) in the monsoon month of October and minimum (29.67 ± 2.60 NTU) in the summer month of April. Similarly in the case of the Killai backwater, the minimum values of 22.33 ± 2.03 NTU was observed during May and the maximum value was recorded during November (61.33 ± 0.88 NTU). It also showed significant positive correlation with RF, EC, TDS, DO and significant negative correlation with BOD and pH (Tables 1, 2).

Total dissolved solids (TDS)

Monsoon season witnessed maximum amount of TDS in both the sites (Fig 2c) and minimum values were obtained during pre summer season. While Killai backwater showed a maximum value of 9043.00 ± 4.04 mg/l during November, Cuddalore site had the maximum TDS (30692.66 ± 2.67 mg/l) during December. TDS showed significant positive correlation with RF, T, EC, DO (Tables 1, 2).

Electrical conductivity (EC)

Electrical conductivity ranged between 18762.33 to 28922.00 µs/cm in the Uppanar estuary and 2872.00to 6031.33 µs/cm in the Killai backwaters (Fig 2d). The minimum value (2872.00 µs/cm) was recorded at Killai site and maximum value of (28.922.00 µs/cm) was recorded at Uppanar estuary. EC showed significant positive correlations with RF, TDS, A etc. and negative correlations with S and BOD (Tables 1, 2).

Dissolved oxygen (DO)

Uppanar estuary recorded significantly reduced DO content throughout the year in compassion to Killai backwater (Fig 3a Table 3). In both the study areas maximum DO was recorded during the monsoon month. While in Uppanar estuary it varied from 4.20 ± 0.35 mg/l (April) to 6.17 ± 0.12 mg/l (November), at Killai it remained significantly higher throughout the year. DO showed significant positive correlation with RF, TDS, EC and significant negative correlation with S (Tables 1, 2).

Biochemical oxygen demand (BOD)

In both the sites, minimum BOD values were recorded during the monsoon winter confluence (Fig 3b and Table 3). While Killai site showed a minimum value of 1.56 ± 0.04 mg/l

during September, Cuddalore site had a minimum BOD of 2.32 ± 0.01 mg/l during December. While the Killai sites had a peak of 2.66 ± 0.26 mg/l during March, the Cuddalore site showed the maximum value of 6.52 ± 0.03 mg/l during March. BOD had significant negative correlation with RF, TDS and EC (Table 1, 2).

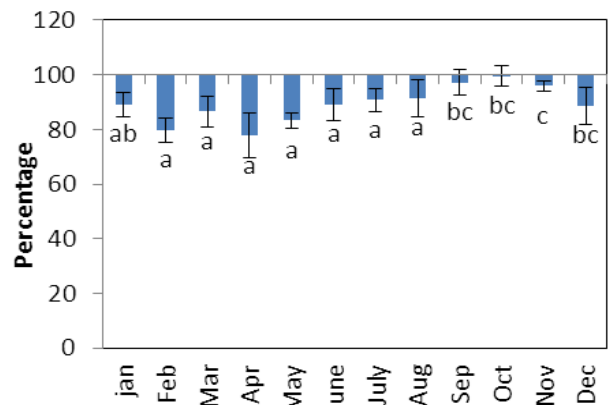


Fig 3a. Variations in the Dissolved oxygen(DO) of Uppanar estuary from Periyavaikal (reference site). (Reference site values taken as 100%; based on ANOVA and DMRT; values with different superscripts are significantly different at P≤0.05)

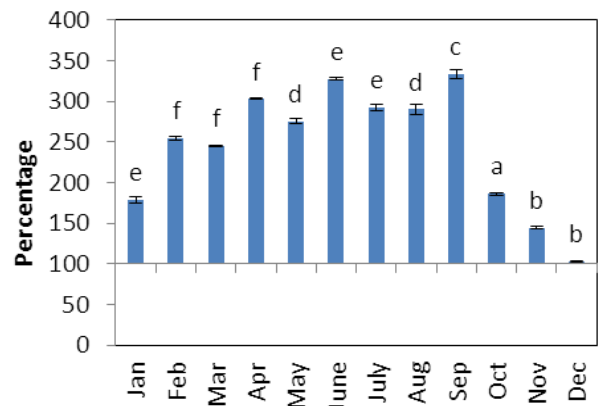


Fig 3b. Variations in the Biochemical oxygen demand(BOD) of Uppanar estuary from Periyavaikal (reference site). (Reference site values taken as 100%; based on ANOVA and DMRT; values with different superscripts are significantly different at P≤0.05)

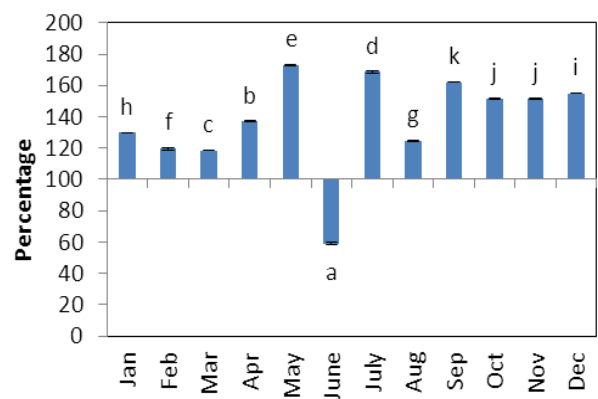


Fig 3c. Variations in the Hardness(H), of Uppanar estuary from Periyavaikal (reference site). (Reference site values taken as 100%; based on ANOVA and DMRT; values with different superscripts are significantly different at P≤0.05)

Table 1. Correlation matrix between various physico-chemical indices of Uppanar estuary, Cuddalore.

Parameters (units)	RF (mm)	AT (°C)	WT (°C)	pH	S (‰)	T (NTU)	TDS (mg/l)	EC (µs/cm)	DO (mg/l)	BOD (mg/l)	H (mg/l)
RF (mm)	1										
AT (°C)	-.287	1									
WT (°C)	-.313	.922**	1								
pH	-.303	.690**	.802**	1							
S (‰)	-.655**	.567**	.573**	.241	1						
T (NTU)	.825**	-.460**	-.408*	-.255	-.713**	1					
TDS (mg/l)	.779**	-.274	-.272	-.155	-.648**	.743**	1				
EC (µs/cm)	.763**	-.250	-.230	-.038	-.690**	.754**	.886**	1			
DO (mg/l)	.790**	-.320	-.298	-.275	-.378*	.810**	.747**	.672**	1		
BOD (mg/l)	-.814**	.486**	.569**	.465**	.732**	-.787**	-.785**	-.746**	-.678**	1	
H (mg/l)	.811**	-.524**	-.490**	-.345**	-.741**	.880**	.793**	.814**	.794**	-.761**	1

Note: **Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed); RF = Rainfall; AT = Atmospheric temperature; WT = Water temperature; pH = Hydrogen ion concentration; S = Salinity; T = Turbidity; TDS = Total Dissolved Solids; EC = Electrical Conductivity; DO = Dissolved oxygen; BOD = Biochemical oxygen demand; H = Hardness

Table 2. Correlation matrix between various physico-chemical indices of Periyavaikal area, Killai back

Parameters (units)	RF (mm)	AT (°C)	WT (°C)	pH	S (‰)	T (NTU)	TDS (mg/l)	EC (µs/cm)	DO (mg/l)	BOD (mg/l)	H (mg/l)
RF (mm)	1										
AT (°C)	-.201	1									
WT (°C)	-.161	.937**	1								
pH	-.360*	.757**	.754**	1							
S (‰)	-.660**	.307	.205	.427**	1						
T (NTU)	.743**	-.655**	-.559**	-.546**	-.705**	1					
TDS (mg/l)	.861**	.122	.126	-.070	-.539**	.487**	1				
EC (µs/cm)	.728**	-.430**	-.354**	-.344*	-.694**	.854**	.665**	1			
DO (mg/l)	.570**	-.413*	-.381*	-.531**	-.489**	.594**	.351*	.511**	1		
BOD (mg/l)	-.506**	-.510**	-.514**	-.364*	.269	-.158	-.712**	-.396**	.033	1	
H (mg/l)	.755**	-.562**	-.473**	-.451**	-.752**	.938**	.618**	.926**	.560**	-.270	1

Note: **Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed); RF = Rainfall; AT = Atmospheric temperature; WT = Water temperature; pH = Hydrogen ion concentration; S = Salinity; T = Turbidity; TDS = Total Dissolved Solids; EC = Electrical Conductivity; DO = Dissolved oxygen; BOD = Biochemical oxygen demand; H = Hardness

Table 3. Student's t- test showing significant differences between the physico chemical parameters of Periyavaikal and Uppanar estuary on annual basis

Sites	RF	AT	WT	pH	S	T	TDS	EC	DO	BOD	H
Periyavaikal (Reference)	46.19 ± 7.84	32.17 ± 0.58	30.61 ± 0.60	7.76 ± 0.06	29.64 ± 0.48	43.06 ± 2.42	6526.17 ± 275.14	4415.64 ± 236.11	5.56 ± 0.58	2.05 ± 0.06	2739.56 ± 177.27
Uppanar Estuary (polluted)	47.04 ± 8.00*	32.31 ± 0.60 ^{NS}	30.44 ± 0.47 ^{NS}	6.53 ± 0.12***	31.72 ± 0.50***	59.47 ± 3.40***	17848.47 ± 1235.18***	24083.78 ± 689.36***	4.96 ± 0.73***	4.94 ± 0.25***	3830.78 ± 305.54***

Note: $\bar{X} \pm SE$; RF = Rainfall; AT = Atmospheric temperature; WT = Water temperature; pH = Hydrogen ion concentration; S = Salinity; T = Turbidity; TDS = Total dissolved solids; EC = Electrical conductivity; DO = Dissolved oxygen; BOD = Biochemical oxygen demand; H = Hardness; comparison is made between the annual averages of parameters of reference and polluted sites. = p < 0.05, *** = p < 0.001

Hardness (H)

In both the study sites, maximum 'H' was seen during the commencement of monsoon (Fig 3c). The reference and polluted sites showed wide annual fluctuations in their 'H' (Table 3). While the minimum 'H' for the reference

site was 1024.00±2.65 mg/l (April), the maximum values for the same site was 4012.33±4.33 mg/l (September). On the other hand, in the case of the polluted site, the minimum value of 1099.00± 7.81mg/l was obtained in the month of June and the maximum value of 6506.00± 6.51 mg/l was noted in the month of September (Table 1, 2)

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4.DISCUSSION

Analysis of the results of the present study reveals that while the various parameters of Uppanar estuary (Polluted site) surpass the permissible limits at different months, those of Periyavaikal area (Reference site) are either within the permissible limits or much lesser than the respective values recorded at Uppanar estuary. This might be due to the industrial and urban effluents getting released into the Uppanar estuary. Uppanar estuary, Cuddalore is already reported as polluted mainly due to the industrial discharges in to it (Sundaramanickam *et al.*, 2008; Soundarapandian *et al.*, 2009). Killai area is also endowed with various aquatic biotopes viz., neritic, estuarine and mangrove associated faunal diversity.

The wide fluctuations in p^H , TDS, DO and BOD at Uppanar estuary are indicative of its ecological vulnerability and could be primarily attributed to its proximity to the industrial units operating in the nearby area. Choudhuri and Panigrahy, (1991) and Soundarapandian *et al.*, 2009 have also reported that emptying from the land based industrial units and other sources of drainage could impact the physico-chemical parameters and as a result coastal environments are subjected to considerable seasonal variations in their physico-chemical parameters

The physico-chemical variables of the present study areas are subjected to wide spatial and temporal variations. Rainfall is supposed to be the most important cyclic phenomenon in Tropical countries and it brings about important changes in the physical and chemical characteristics of the coastal and estuarine environments. In the present study also, both the sites received bulk quantities of RF during the monsoon months due to northeast monsoon. The present study has clearly showed that RF causes important ecological changes especially among the various physicochemical parameters of both the study sites as revealed by the correlation analysis (Tables 1, 2) The monsoon run off brings in various contaminants in bulk amounts in to the estuarine as well as the back water areas as indicated by a sudden increase in most of the physicochemical parameters analyzed in the present study (Fig 1a). However, in general, the rate of increase was much higher in the case of the polluted site than the reference site. Such a differential increase could be attributed to the increased influx of industrial and urban effluents at the Uppanar estuary.

The present study has shown a significant positive correlation between AT and WT in both the sites (Tables 1, 2). While AT in both the study areas remains higher than WT, their fluctuations are more or less similar. (Fig 1b c). The

significant differences in AT and WT between summer and monsoon months could be attributed mainly to the reduced penetration of solar radiations through the cloudy sky during monsoon and winter seasons.. Role of clouds in blocking solar radiations have been reported by Govindasamy and Azariah (1999) as well as Subramanian and Mahadevan (1999). Temperature being an important ecological factor has profound influence in all the living beings and therefore may act as an ecological limiting factor. It plays a very important role in aquatic ecosystems by affecting metabolism and other physiological activities (Rakhi, 2009). As WT affects dissolved oxygen, alkalinity, salinity etc., (Jayakumar, 2009) it is specifically important in relation to fish life also. It plays important roles in controlling the diversity, reproduction, migration and behavioural characteristics of animals and plants (Shanthi, 2012).

It is evident that temperature variations in the coastal and estuarine system is not only influencing the physico-chemical characteristics of the water body but also influence the distribution and abundance of inhabitant flora and fauna (Soundarapandian *et al.*, 2009). According to Maheshkumar and Prabhakar (2012). WT is basically important for its effects on the chemistry and biological activities of organisms in water and could influence other factors like pH, conductivity, dissolved gases and various forms of alkalinity.

Therefore the comparatively high WT in the Uppanar estuary when compared to Killai backwaters along with the other unfavourable ecological factors could adversely affect the fishery resources of that area. This is particularly because of the fact that most of the aquatic organisms are cold blooded and they cannot control their body temperature. In such situations they may avoid high temperature areas in favour of favourable ambient temperature conditions.

pH is one of the most important parameters in water chemistry and affects almost all biochemical activities. Hydrogen ion concentration affects the solubility of metals and a wide spectrum of other physicochemical factors. Aquatic organisms are also affected by pH because most of their metabolic activities are pH dependent (Morgan and McMohan, 1982; Chen and Lin, 1995; Wang *et al.*, 2002; Fakayode, 2005; Jayakumar, 2009). It is also an important factor in chemical and biological systems and is closely related to respiration and photosynthesis (Naik and Purohit, 1997). It tends to increase during day largely due to the photosynthetic activity (consumption of CO_2) and decreases during night due to respiratory activity (consumption of O_2) pH of waste water and polluted natural waters depend largely on the nature of the pollutant.

The hydrogen ion concentration gets changed with time due to the changes in temperature, salinity and biological activity (Sundaramanickam *et al.*, 2008) and is also affected by the buffering capacity of water, geological parameters of the catchment area (Prabhakar *et al.*, 2014), sea water penetration and high biological activity such as photosynthesis (Balasubramanian and Kannan, 2005; Sridhar *et al.*, 2006). In general higher values of pH are recorded at Periyavaikal region (reference site) than in Cuddalore coast indicating its less polluted status. Uppanar estuary region being a polluted site, the pH range many times entered the acidic range.

Increased pH during summer in the study areas may be attributed to the increase in salinity due to sea water penetration and higher rate of primary productivity utilizing CO₂. Increase in pH during summer season has also been reported by (Balasubramanian and Kannan, 2005); Rao, 2001; Das and Jana, 2003; Sridhar *et al.*, 2006 and Jayakumar and Paul, 2006).

The low pH observed during the rainy season may be due to the influence of fresh water influx, dilution of sea water, low temperature and organic matter decomposition as suggested by various workers (Ganesan, 1992; Ananthan, 1994; Pillai, 1994). The significant decrease in pH in Uppanar estuary during rainy season may be attributed to the additional load of organic and industrial effluents brought about by the rainy run off from the adjoining industrial area.

In the present study salinity (S) was significantly higher at Uppanar estuary when compared to periyavaikal of Killai backwaters (Table 3). This may be due to the high influx of fresh water in the reference site and increased influx of industrial effluents at the polluted site. Additionally, while Uppanar estuary is having very wide open connection with Bay of Bengal, Killai area is full of back water regions with increased incursions to the land area and mostly cut off from Bay of Bengal by thick mangrove forest and thereby limiting the mixing of highly saline sea water with the backwater. The significant variations in salinity within the two sites at various seasons may be attributed in general to rainfall, temperature, dilution, evaporation and most significantly the effluent mixing especially at Uppanar estuary.

Salinity is regarded as the second important physical characteristic of the marine environment and has high influence on the faunal distribution especially, in the estuarine environment and acts as a limiting factor. (Balasubramanian and Kannan, 2005; Sridhar *et al.*, 2006; and Rault *et al.*, 2011).

Turbidity (T) is an expression of optical property of the water wherein light is scattered by suspended particles present in water (Tyndall effect) and is measured using a Nephelometer. Suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton and other microscopic organisms cause 'T' in water. Turbidity of water is an important parameter that influences the light penetration (Shradha *et al.*, 2011). At both the study sites 'T' was high during the monsoon season (Fig 2b Table 3) primarily due to the rain run off coupled with higher concentration of dissolved organic matter and suspended sediment brought about by the fresh water influx, which resulted in increased turbulence of the water. Correlation analysis also showed such an impact on 'T'. While 'T' was negatively correlated to AT, WT, pH and S all other parameters showed significant positive correlations (Tables 1, 2). Land run-off, wave action and wind agitation mediated churning movements of bottom might have also contributed to the increasing 'T' of the study areas during rainy seasons. Similar observations have also been made by Mitra *et al.* (1990) from Poonthura estuary, Ananthan (1995) from Pondichery coast and Sampathkumar and Kannan (1998) from Tranquebar, Nagapattinam coast. The comparatively increased 'T' at the polluted site (Uppanar estuary) could be due to the increased presence of industrial

effluents from the SIPCOT industrial area Jacob (1996) and Iyyappan (2000) have observed a higher turbidity in Noyyal and Paravanar rivers, due to the influence of industrial effluents.

In both the sites, least amount of turbidity was recorded during the summer season (Fig 2b Table 3) This may be due to the settling and/ or removal of suspended materials from the water column due to hydro- geo- bio actions and cessation of fresh water in flow. Increased 'T' also, reduces the productivity of water body and decreases dissolved oxygen by increasing BOD and COD.

Total dissolved solids (TDS) accounts for the various types of solids (e.g. mineral salts) that are in the dissolved form they may be organic or inorganic. Waters with high amount of dissolved solids generally are of inferior palatability and may induce unfavourable physiological reactions in the consumer. In the present study, TDS is comparatively more during the months of monsoon in both the study sites (Fig 2c) and show significant positive correlations with many of the parameters analyzed (Table 1,2). In natural waters, TDS are composed mainly of carbonates, bicarbonates, chlorides, sulphates, phosphates and compounds of silica, calcium, magnesium, sodium and potassium (Jayakumar, 2009; Santhi, 2012). As most of these factors are derivatives of industrial and other human activities as well as natural leaching process, TDS is important in determining the water quality standards. The higher amount of TDS recorded in Uppanar estuary could be attributed to the effluent discharges from industries as reported by Ushamary *et al.* (1998) According to various workers, in many natural water bodies of India, TDS is proportional to the degree of pollution (Singh and Singh, 1990); Tripathy and Adhikari, 1990; Bharathi and Krishnamoorthy, 1990). These reports are in agreement with the results of the present study where the polluted site has a much higher presence of TDS throughout the year when compared to that of the reference site (Table 3) and such an increased level may be attributed to the industrial effluents originating from the Cuddalore industrial belt. Industrial activities related higher level of TDS has also been reported by Ramasamy and Sridharan (1998) from the tannery belt of Vaniambadi and Ambur, Tamilnadu. The results of the present study are in contrast to the observation made by Manosathiyadevan (2009), who reported a diluting effect during rainy season. This may be due to the fact that, irrespective of the diluting effect, the rain runoff (especially from the polluted industrial area) may be bringing in huge amounts of various mineral salts that would have otherwise remained in the adjoining land areas.

Electrical conductivity (EC) is the numerical expression of the ability of water to conduct electric current. It is measured in micro Siemens per cm ($\mu\text{s}/\text{cm}$) and depends on the total concentration, mobility and valence of ions in the water. 'EC' was significantly higher in the Uppanar estuary than Periyavaikal area indicating the presence of increased ionic forms at Uppanar. Similarly at both the study sites, rainy season recorded higher EC (Fig 3d) indicating the influx of inorganic ions along with the surface run off. 'EC' also showed significant positive correlations with most of the physicochemical parameters (Table 1, 2). Abdulla and Masta (1999) also reported increased 'EC' in presence of more

salts. It is also an indicator of degree of pollution (Dar et al, 2012) showing the presence of more inorganic ions in the effluent discharges received by the water body. The significant positive correlation with TDS (Tables 1, 2) is worth mentioning as the latter is also a measure of inorganic chemicals dissolved in water samples. Most dissolved inorganic substances are in the ionised form in water and contribute to conductance because electrolytes in a solution disassociate into positive (cations) and negative (anions) ions and impart conductivity. Conductance gives a rapid and practical estimate of the variation in the dissolved mineral contents of the water and in the present study; 'EC' clearly shows the inferior water quality at Uppanar estuary. Nevertheless, when the salt concentration reaches a certain level, EC no longer directly match the salts concentration. This is due to the formation of ion pairs. Ion pairs weaken each other's charge so that above this level higher 'TDS' will not result in equally higher electrical conductivity (SMART, 2014).

Dissolved oxygen (DO) is a very important parameter as it serves as an indicator of the physical, chemical and biological activities of the water body. Throughout the study, Killai backwater maintained a higher DO content over Uppanar estuary indicating the less polluted status of the former. DO is very crucial for the survival of aquatic organisms and is also used as a parameter to evaluate the degree of freshness of water (Fakayode, 2005). It is usually considered as an index of physical and biological processes going on in water (Prakash, 2004; Murugesan and Rajakumari, 2005). The two main sources of dissolved oxygen are diffusion of oxygen from the air and photosynthetic activity. Oxygen depletion is brought about by respiration and decomposition of organic matter. The amount of dissolved oxygen in water depends on several factors including temperature (the colder the water, the more the oxygen can dissolve), volume and velocity of water flow, salinity and the number and diversity of organisms using oxygen for respiration as well as primary productivity. In addition to all these, anthropogenic activities such as runoff from roads, sewage, agricultural and domestic discharge and industrial pollution. According to Santhi (2012), at lower temperature and salinity water can hold more oxygen and the present study is also in agreement with this report as indicated by significant negative correlation of DO with temperature and salinity

The decreased level of DO in the Uppanar estuary (Table 3 and Fig 3a) indicates the possibility of presence of organic and inorganic pollutants in it. In both the study areas, maximum oxygen content is seen during monsoon season and winter months. The important factors contributing to this increase in oxygen concentration are the turbulent monsoon water rushing into the sea and the decreased atmospheric and water temperature as well as salinity. It is a well known fact that less saline water at lower temperature holds more oxygen (Govindasamy et al., 2000; Saravanakumar et al., 2007; Santhi, 2012). Even though rain runoff and flooding brings in fresh quantum of pollutants, its turbulent flow causes more atmospheric oxygen dissolution also. On the other hand the lower DO content as observed during the summer season could be attributed to the lesser freshwater inputs into the

study areas, higher temperature and salinity. At higher temperature the capacity of water to hold oxygen decreases (Murugesan and Rajakumari, 2005) and this might also have contributed to the reduced oxygen content during the summer season. Additionally, in Uppanar estuary the industrial effluents from SIPCOT area might be consuming a major share of the dissolved oxygen for its natural degradation processes resulting in reduced 'DO' than the reference area. 'DO' also aids in organic pollution assessment by giving an idea about the quality of biodegradable organic substances present in the water (Singh *et al.*, 1999 a, b; Santhi, 2012). When any material containing biodegradable organic matter is released into a water body, the process of utilizing the organic matter or sewage by microorganisms causes reduction in the 'DO' content of the water. This happens because microorganisms utilize 'DO' for their respiration and the more the quantity of utilizable organic matter, the more the microbial activity of feeding upon the sewage. Consequently, the demand for 'DO' will be more severe.

The significant increase in the biochemical oxygen demand (BOD) of the polluted study site during the pre summer season may be attributed to the organic pollution load brought in by the just concluded rain runoff along with effluents received from SIPCOT area (Fig 3b Table 3). Nandan and Azis (1990) and Joe (1993) have also suggested that very high organic load would result in greater microbial decomposition and depletion of oxygen along with high BOD values and eventually form a state of anoxia. Saraswathi (1993) has also reported a similar pattern of seasonal variations in BOD of Arasalar and Kaveri estuaries. When 'BOD' exceeds the available 'DO', the 'DO' in the water is also depleted. The correlation matrices also show significant negative correlations between BOD and DO (Tables 1, 2). Total hardness (H) is contributed by alkaline earth metals such as calcium, magnesium, iron, manganese and strontium (Sing et al 1999 a, b., Murugesan and Rajakumari, 2005) and is a measure of polyvalent cations in water. It is predominantly caused by divalent cations of calcium and magnesium as they are the most common polyvalent cations. According to Mahesh kumar and Prabhahar, 2012 heat transferred from heating equipments, boilers and pipelines may also cause increased hardness.

However 'H' induced by the bicarbonates and carbonates of alkaline earth metals is called temporary hardness and it can be removed by boiling the water. However sulphates and chlorides bring about permanent hardness, which is not removed by simple boiling of water (Abbasi, 1996; Prakash, 2004; Murugesan and Rajakumari, 2005). In the present study, in general, the hardness of the polluted site was much higher than that of the reference site (Fig 3c) and both the sites show comparatively increased hardness during the monsoon seasons. The higher values of total hardness in the Uppanar estuary could be due to higher amount of Ca^{++} , Mg^{++} , SO_4^{2-} and Cl^- present in the discharges of SIPCOT industries (Rao, 2001). Aravinda *et al.* (1998) have also reported the increased hardness due to Ca^{++} , Mg^{++} , SO_4^{2-} and Cl^- in Thunga Bhadra River. High hardness in Bhadra River due to azo-dye contaminated effluents from cotton textile industries was also observed by Doctor *et al.* (1998).

Since the polluted site also shows signs of seasonal partial recovery it is probable that the degraded water body could be recovered from the threat of pollution if appropriate steps are taken for its restoration. This may be accomplished especially by blocking the entry of untreated or partially treated industrial effluents and other contaminants such as rural and urban runoff from entering the water body. It is also very important to completely process and remove the polluting substances if any from the effluents of the adjoining SIPCOT industrial area.

5. CONCLUSION

Among the entire parameters investigated, except for air temperature and water temperature, all other parameters exhibited significant variations between Uppanar estuary and Killai back waters. While the Uppanar estuary showed significant increase in turbidity, salinity, biochemical oxygen demand, total dissolved solids and hardness on seasonal as well as annual basis, Killai backwater exhibited higher pH and dissolved oxygen content. While most of the physico-chemical parameters of the Killai backwater lie within the permissible limits, those of the Uppanar estuary cross the safe limits on many occasions indicating the contaminated nature of the water body.

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