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Short communication

Assessment of Pollution in Lagoons Using Water Quality Indices: A Case Study in Sainthamaruthu Coastal Lagoon

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ABSTRACT

An understanding about pollution status is vital for remediating water resources, which is lacking in context of Sri Lanka's lagoon system. The aim of this study was to assess the pollution in a lagoon in terms of degree, dynamics and sources of pollution using water quality indices. The water samples collected from up, mid and down streams of Sainthamaruthu lagoon across different rainfall seasons were analyzed for pH, temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), ammonium nitrogen (NH_4^+), nitrate nitrogen (NO_3^-) and Total Phosphorus (TP). The measured variables were subjected to computation of Water Quality Index (WQI), Comprehensive Pollution Index (CPI) and statistical analyses. Subsequently, it was found that upstream region of the lagoon was severely polluted during North East Monsoon (NEM) whereas significantly higher concentrations of nutrient pollutants (NH_4^+= 4.5 mg/L, TP=3 mg/L) and physiochemical attributes (EC=3007μS/cm, TDS=801.7 mg/L) respectively were associated with the higher pollution in NEM. Meanwhile, the other regions were moderately polluted throughout the year. Besides, the greater WQI (greater than 100) observed at all the regions across the different rainfall seasons implied that Sainthamaruthu lagoon was not suitable for drinking and fish culture. Furthermore, the results of Principal Component Analysis (PCA) revealed that the pollution in Sainthamaruthu lagoon is caused by mixed sources of natural and anthropogenic factors including mineralization, sea water intrusion, effluent discharge and wastewater release. Ultimately, this study scientifically proved the occurrence of pollution in Sainthamaruthu lagoon and the facts identified could be used during remediation of the lagoon in near future.

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INTRODUCTION

The total land area of 55% and 45% are respectively covered by permanent and seasonal water bodies in Sri Lanka (Somasundaram et al., 2020). Lagoons, a kind of permanent surface water body, are economically, environmentally and socially important and provide numerous services inclusive of provisioning, regulatory, support and cultural. Over the years, the both natural and anthropogenic factors have exerted pressure on these water sources and eventually make them polluted. Water pollution in Sri Lanka's lagoon system has to be considered as a serious environmental issue presently as it diminishes the ecological services offered by the lagoons. To ensure their services in long term, pollution has to be managed sustainably where assessment of pollution status in each lagoon has become imperative.

In the context of lagoons in Sri Lanka, the scholars have focused investigating the dynamics of water quality vastly in a few lagoons and have made decisions about pollution status by comparing the individual water quality attributes with the standard threshold levels. For example, deterioration in individual water quality parameters such as pH, temperature, salinity, dissolved oxygen, nitrate, phosphate and total suspended solids has made the Batticaloa and Puttalam lagoons polluted (Dalpathadu et al. 2016; Sugirtharan et al., 2017). Meanwhile, lower nutrients and organic matter had resulted less pollution in Panama lagoon (Amarathunga et al., 2021). It is important to note individual parameters-based assessment does not provide an idea about the degree of pollution, which are on contrary expressed by the indices-based assessment.

The two indices widely employed to describe the status of water quality and pollution are WQI and CPI. These indices convert the complex several individual parameters into a single value which provide quick and logical expression on status of water quality and pollution. Though, they have been used in assessing the water quality in different water resources like rivers (Barbulescu et al., 2021; Makubura et al., 2022; Siriwardhana et al., 2023), lakes (Mishra et al., 2016), lagoons (Taner et al., 2010) around the globe, its application in Sri Lanka's lagoon system has found limited. Therefore, the present study was undertaken to assess the pollution in a lagoon, which is not explored so far.

The lagoon located in Sainthamaruthu village in Ampara district was selected considering its prevailing condition. The lagoon seems to be polluted, associated with the visual signs of proliferation of aquatic weeds and unpleasant odour, however, it is not scientifically proven yet. Hence, at present era, the lagoon has found losing its potential uses and serve as drainage canal nowadays during heavy rainfall. Consequently, attempts are to be taken to restore its potential in near future, which creates necessity to assess the pollution status in lagoon first. Therefore, the objectives of the study were (1) to assess the degree of water pollution in Sainthamaruthu Lagoon using water quality indices (2) to analyze the spatiotemporal variation in water pollution and its sources. Subsequently, this study helps document the status of Sainthamaruthu lagoon in scientifically acceptable format.

METHODOLOGY

Study area

The Sainthamaruthu coastal lagoon is situated in the Ampara district in the dry zone of Sri Lanka, at latitudes 7°23′52.27″N and longitudes 81°49′43.86″E. It begins at the border of Karaitivu and Ninthavur Divisional Secretariat (D.S.) divisions, where Vattaru connects with the lagoon and meets the sea at the south end of Kalmunai municipal council. The lagoon spans a distance of 4.02 km from its origin to its confluence, with an elevation ranging from 3.05 to 12.5 m and covers a catchment area of 0.33 km^2. This lagoon falls under the low country dry zone agroecological region, characterized by low rainfall and high temperatures. The primary rainfall season is the NEM, with an average annual rainfall of 1465 mm in the study area. The average maximum and minimum monthly temperatures are 32.7 °C and 24.8 °C, respectively. The primary land uses in the lagoon area are paddy fields and residential area. A specific section of the lagoon, measuring 665 m in length and covering an area of 22,630 m^2, where the infestation of an aquatic weed is prominent, was selected as the study area and divided into three regions *viz* up, mid and downstream (Figure 1).

Water sampling and analysis

A minimum number of sampling sites were selected based on the recommendations of previous study (Begum et al., 2024). Three sites representing the three regions of the study area, were considered for water sampling. At each site the composite water samples were collected at a depth of 30 cm below the water surface into 500 ml polyethylene bottles using a handmade setup, each was replicated thrice. Nine water samples per week were collected from October 2022 to September 2023 across the different rainfall seasons *viz* North East Monsoon, First Inter Monsoon (FIM), South West Monsoon (SWM) and Second Inter Monsoon (SIM). The unfiltered samples were analyzed weekly for basic physiochemical parameters such as pH, temperature, EC, TDS and DO and monthly for TP. While samples were filtered using 0.45 µm nylon membraned syringe filters (Whatman Uniflo) and analyzed monthly for nutrient pollutants namely NH_4^+ and NO_3^-. The instruments and methods used for analysis are given in the Table 1. Temperature of the samples was measured with these instruments as it is inbuilt.

To maintain quality assurance and control, all instruments were calibrated according to the instruction manual and periodically checked for a "zero" reading using deionized water as a calibration blank for internal checks. During testing, the recommended elapsed time between collection and analysis, the standard methods prescribed by the American Public Health Association (APHA-23rd Edition, 2017), were adhered in order to minimize unknown errors.

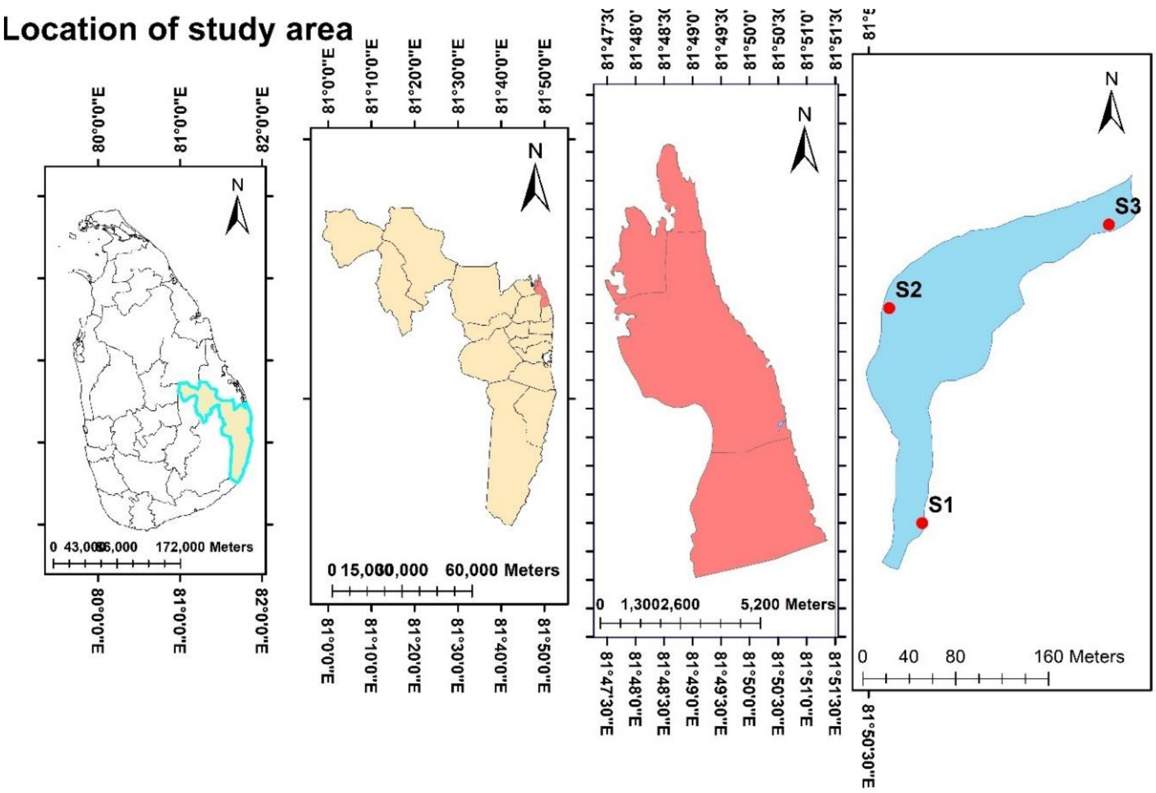

Figure 1: Location map of study area (S1, S2, S3 are monitoring sites, black arrows indicate the inlets

Table 1: Instruments and methods used for analysis

Parameters	Instrument/Method
pH	Benchtop pH meter (BP3001)
EC	Benchtop EC/TDS meter (HI2300)
TDS	Benchtop EC/TDS meter (HI2300)
DO	Portable DO meter (HD3030)
NH_4^+	Salicylic acid/ spectrophotometry/LIHERO multiparameter analyzer (LFS 2002)
NO_3^-	Spectrophotometry/LIHERO multiparameter analyzer (LFS 2002).
TP	Ascorbic acid/colorimetric/ spectrophotometry/ LIHERO multiparameter analyzer (LFS 2002) (APHA 4500-P E)

Computation of WQI and CPI

The WQI and CPI were computed as defined in the Equation 1 and 2 to evaluate the status of water quality and degree of pollution. The measured water quality parameters that are of ease, simple and cheap laboratory testing (temperature, TDS, EC, pH, DO, NH_4^+, NO_3^-, and TP) were considered of for WQI and CPI calculation. Permissible standard limits of these variables were obtained from either ambient standard established by Central Environmental Authority (CEA) (National Environmental (Ambient Water Quality) Regulations, No. 01 of 2019) or Sri Lanka Standards Institute (SLSI) drinking water quality standards (SLS 614:2013). Meanwhile, the temperature of 25°C was considered as the standard level as the suitable temperature range for aquaculture is 25-32°C (Dubey and Trivedi, 2012).

$$\mathrm{WQI} = \frac{\Sigma \mathrm{WiQi}}{\Sigma \mathrm{Wi}} \qquad \text{(Eqn. 1)}$$

where, Wi: unit weight of ith parameter, Qi: Quality rating/sub-index of ith parameter

$$\mathrm{CPI} = 1/\mathrm{n} \sum_{\mathrm{i}}^{\mathrm{n}} (\mathrm{CiSi}) \qquad \text{(Eqn. 2)}$$

where, Ci: measured concentration, Si: allowable concentration limit, n: number of parameters

The status of water quality is excellent, good, poor, very poor, or unsuitable for drinking or fish culture if the WQI is in the ranges (0–25), (26–50), (51–75), (76–100), and (> 100), respectively (Makubura et al., 2022). Similarly, the criteria of pollution level are defined as clean, sub -clean, slight pollution, moderate pollution and severe pollution when the CPI is in the ranges (0-0.2), (0.21-0.4), (0.41-1), (1.01-2) and (>2.01) respectively (Koliyabandara et al., 2020).

Statistical analysis

The normal distribution of the dataset was evaluated with the Shapiro-Wilk normality test, and the data with a significance greater than 0.05 were retained for further analysis. Meanwhile, the outlier data were replaced with the next extreme value, and the significance of the Shapiro-Wilk normality test ($p>0.05$) was reconfirmed. If the significance till remains lesser than 0.05, the skewness range of +1 to -1 was taken into consideration and assumed to be the normally distributed data.

Two-way Analysis of Variance (ANOVA) was employed to test hypotheses and assessed significant differences in water quality variables among monitoring regions and seasons at a 0.05 significant level. Subsequently, mean comparisons were conducted through Tukey's post-hoc test. Further, after the examination of the assumptions such as sampling adequacy and the linear relationship between variables, Principal Component Analysis was performed to explore the underlying factors causing variation in water quality during wet (NEM and SIM) and dry seasons (SWM and FIM). All of these statistical analyses were carried out using MS Excel 2019 and SPSS (Version 25.0).

RESULTS AND DISCUSSION

Spatiotemporal variation of water quality and pollution level

The pollution status, expressed by WQI and CPI across different regions and rainfall seasons in Sainthamaruthu lagoon is presented in the Table 2. Based on the WQI Sainthamaruthu lagoon was found unsuitable for drinking and fish culture as its WQIs were greater than 100 at all the monitoring regions across different rainfall seasons. This was in consistent with those reported by Jayathunga et al. (2018) in Lunawa lagoon. Further, the CPIs provide clear insights about the degree of pollution than WQI. The lagoon was found to be severely polluted at the upstream region during NEM, as the CPI values were greater than 2.01. Meanwhile, the mid and down streams were moderately polluted (with CPI greater than 1.01 but lesser than 2) throughout the year.

In comparison with other studies, the degree of pollution in Sainthamaruthu lagoon was similar to the pollution level in Surha lake located in India, the neighbour country to Sri Lanka during dry and wet seasons (Mishra et al., 2016). Hence, the degree of pollution with a mean CPI of 1.32 in the western part of Chaohu lake located in China, was in accordance with the observed CPI in Sainthamaruthu lagoon (Yang, X.et al., 2020). While the pollution level in this lagoon contradicts with the pollution level in Mahin lagoon located in south western Nigeria, which also was severely polluted (CPI=5.98) (Loto et al., 2023).

The variation observed in the degree of pollution is associated with the spatiotemporal variation observed in the individual water quality parameters (Table 2). In particular, the significantly ($p<0.05$) highest concentrations of EC (1684-3082 µS/cm) and TDS (565-943 mg/L) were observed in downstream during dry season (SWM and FIM). These concentrations exceeded the standard levels of 700 µS/cm (CEA, 2019) and 500 mg/L designated by Food and Agriculture Organization (FAO) (Abdollahi et al., 2017). Sub-surface saline water mixing, arrival of inorganic ions and dissolved solids *via* the effluent from fish processing center and surface runoff, less rainfall and higher temperature may elevate the EC and TDS in downstream during dry season. Similarly, higher EC and TDS were recorded in Batticaloa lagoon (Sugitharan et al., 2017; Azam and Sugirtharan, 2021), Malala, Embilikala lagoons of Bundala wetland system (Piyankarage et al., 2004), southern parts of Lunawa lagoon (Jayathunga et al., 2018) and Kpeshi lagoon (Apau et al., 2012) due to mixing of sea water with the breaching of sand bar and poor water circulation.

In contrast, the physiochemical concentrations were less (719-724 µS/cm EC, 365-390 mg/L TDS, 1-1.2 mg/L DO) at upstream during wet season (NEM and SIM) due to dilution effect of rainfall and decomposition organic matter. These concentrations were yet beyond the standards (>700 µS/cm EC and <5 mg/L DO) prescribed for ambient purposes such as agriculture, irrigation, aquatic life, bathing and recreational activities. The similar dilution effect during rainy season was observed in Batticaloa lagoon (Sugirtharan et al., 2017), Lunuwa lagoon (Jayathuna et al., 2018), Bundala lagoon (Piyankarage et al., 2004), Gregory Lake (Perera et al., 2012), Beira Lake (Weerasinghe and Handapangoda, 2019) and Badulu Oya (Rajapaksha et al., 2020), in turn decreased EC and salinity. The lesser DO concentration in the Kotte Canal was due to the release of heavily contaminated domestic wastewater (Nishanthi et al., 2021).

However, the concentrations of NO_3^- (1.4-2 mg/L), NH_4^+ (3.5-4.5 mg/L) and TP (2.9-3 mg/L) were high in this region during wet season (NEM and SIM). Though, NO_3^- concentration was within the standard limit of 10 mg/L (CEA, 2019), NH_4^+ concentration exceeded the standard level of 0.94 mg/L (CEA, 2019). Furthermore, NH_4^+ and TP concentration were beyond the thresholds of eutrophication (0.3 mg/L for NH_4^+ and 0.05 to 0.075 mg/L for TP) as specified by Savic et al. (2022) and Qi et al. (2022). As the lagoon belongs to low country dry zone agroecological, the predominant rainfall is NEM. The rainfall induced surface runoff which carries minerals, organic matters, solids, may be the main reason for the observed higher concentration of nutrient pollutants. This result was in line with Sugirtharan et al. (2017) and Thivyatharsan et al. (2015) in Batticaloa lagoon. Besides, mineralization of nitrogen and phosphorous rich organic waste, discharge of domestic wastewater containing PO_4^{3-} detergents and drainage diversion from upstream paddy fields also may elevate the nutrient concentrations in upstream of Sainthamaruthu lagoon.

Factors causing pollution

In the attempt of exploring the sources of pollution, PCA was performed, for which suitability of sample referring to adequacy and correlation was first tested. The respective KMO values of 0.528 and 0.757 for wet and dry seasons and 0.000 significance (<0.05) for Bartlett's test of sphericity for both seasons confirmed the sample suitability.

PCA explained that the two factors, which had eigen values greater than 1, cumulatively caused 81% of variance in lagoon water quality during dry season. Of the two factors, factor 1, accounting 49% of total variance, showed strong positive factor loadings for TDS and strong negative loadings for DO, TP and temperature, while EC had moderate positive loading, according to Liu et al. (2003) (Table 3, Figure 2). The dissolved ions, solid, organic matter, nutrients enter the lagoon via many routes including biological processes (e.g. mineralization, breakdown of organic matter, aquatic plant growth), natural process (e.g. subsurface seawater mixing) and anthropogenic point sources (release of domestic wastewater and effluent from fish processing centers) that take place in and around the lagoon. Subsequently, this factor can be attributed to "mixed sources". As the primary land use in the lagoon area is paddy field and residential area, agricultural drainage during yala season from upstream paddy fields, unsafe disposal of solid waste and release of untreated wastewater might influence the variation in EC, TDS and DO. Dissolved organic matter carried with runoff and dissolved ions emerging from domestic waste and agricultural activities caused a 23% variation in water quality in Aby lagoon system (Miyittah et al., 2020). Meanwhile, the factor 2, accounting 32% of total variance, showed strong positive and negative factor loadings for pH and NH_4^+ respectively. As the prevailing weather condition affects the pH and NH_4^+concentration in water, the factor 2 can be interpreted as "dry weather".

In the wet season, three factors (with the eigen values greater than 1) explained 77% of total variance, for which almost all the studied variables, except NH_4^+, had strong positive factor loading, while NH_4^+showed moderate positive loading with factor 2 (Table 3, Figure 2). The first factor accounted 36% of total variance for water quality and it had strong positive factor loadings with EC, TDS and DO. Discharge of untreated wastewater may enhance the ions, salt and organic matter content in the lagoon water; therefore, the factor 1 can be attributed to "wastewater release". The mineral nutrient pollutants which showed positive strong (NO_3^-, TP) and moderate (NH_4^+) factor loadings with the factor 2 explained 27% of total variance. Since these pollutants enter the lagoon via rainfall induced surface runoff, the factor 2 can be termed as "agricultural runoff". The 3rd factor comprising pH only contributed to total variance at a smaller extent of 14%. As the climatic parameters primarily rainfall influences the pH, the factor 3 can be interpreted to rainfall conditions. In overall, the both natural and anthropogenic processes caused pollution in Sainthamaruthu lagoon. The results of the study were in consistent with Baldiris-Navarro et al. (2018), who reported the mixed sources of natural processes (poor communication with the sea) and anthropogenic activities (discharge of untreated urban wastewater and solid waste) in Juan Polo coastal lagoon.

Table 2: Surface water quality characteristics in Sainthamaruthu lagoon

Rainfall seasons	NEM			FIM			SWM			SIM		
Monitoring regions	**Upstream**	**Midstream**	**Downstream**	**Upstream**	**Midstream**	**Downstream**	**Upstream**	**Midstream**	**Downstream**	**Upstream**	**Midstream**	**Downstream**
Temperature	26.08±0.03^{a}	26.84±0.04^{a}	26.51±0.14^{a}	29.25±0.25^{a}	29.86±0.82^{a}	30.57±0.61^{a}	28.29±0.16^{a}	28.72±0.16^{a}	28.77±0.09^{a}	28.54±0.07^{a}	26.99±0.64^{a}	27.50±0.34^{a}
pH	6.96±0.04^{a}	6.67±0.12^{a}	6.96±0.06^{a}	7.26±0.36^{a}	7.43±0.42^{a}	7.12±0.16^{a}	7.15±0.22^{a}	6.94±0.05^{a}	7.55±0.06^{a}	6.96±0.08^{a}	7.12±0.13^{a}	6.99±0.07^{a}
DO (mg/L)	1.02±0.05^{a}	1.11±0.09^{a}	1.57±0.16^{b}	3.49±0.13^{a}	3.73±0.11^{a}	3.04±0.04^{b}	4.71±0.18^{a}	4.56±0.09^{a}	4.77±0.08^{a}	1.19±0.16^{a}	0.85±0.09^{c}	1.53±0.2^{b}
EC (µS/cm)	718.75±74.72^{a}	463.89±22.49^{a}	1277.75±540.2^{b}	3007.00±70.46^{a}	749.96±35.51^{b}	3082.33±0.29^{a}	1641.03±62.04^{a}	539.33±45.11^{b}	1684.14±30.52^{a}	723.67 ± 19.67^{a}	289.88±20.72^{b}	827.04±37.78^{a}
TDS (mg/L)	389.56±35.34^{a}	253.39±6.96^{a}	653.81±251.41^{b}	801.71±33.29^{a}	569.79±70.49^{b}	943.33±137.48^{a}	496.09±15.19^{a}	397.57±39.36^{a}	565.92±22.57^{a}	365.42±89.82^{a}	159.32±8.84^{b}	452.79±54.26^{a}
NH_4^+ (mg/L)	4.45±0.15^{a}	3.42±0.19^{b}	3.67±0.43^{b}	4.4±0.6^{a}	3.13±0.22^{b}	3.26±0.06^{b}	3.09±0.26^{a}	2.29±0.2^{b}	3.6±0.33^{a}	3.45±0.08^{a}	3.59±0.27^{a}	3.43±0.18^{a}
NO_3^- (mg/L)	2.04±0.29^{a}	1.32±0.18^{b}	1.18±0.16^{b}	1.63±0.19^{a}	1.68±0.14^{a}	0.65±0.13^{b}	1.4±0.18^{a}	1.25±0.13^{a}	1.53±0.39^{a}	1.44±0.12^{a}	0.95±0.05^{b}	1.4±0.07^{a}
TP (mg/L)	2.98±0.31^{a}	2.31±0.1^{b}	2.06±0.22^{b}	0.81±0.29^{a}	0.64±0.18^{a}	0.48±0.12^{a}	1.77±0.13^{a}	1.16±0.1^{b}	1.73±0.45^{a}	2.86±0.34^{a}	1.41±0.24^{b}	1.14±0.14^{b}
WQI	596.44	462.65	431.22	256.77	196.09	174.12	369.19	251.58	378.36	549.07	328.58	281.74
CPI	2.03	1.60	1.78	1.93	1.27	1.71	1.76	1.24	1.86	1.86	1.28	1.37

Values are means of replicates ± standard deviation

Different superscript letters indicate the significant differences at $p < 0.05$

NEM-North East Monsoon, FIM-First Inter Monsoon, SWM-South West Monsoon, SIM-Second Inter Monsoon

Table 3.: Causes for variation in surface water quality in Sainthamaruthu lagoon

Season	Factors	% of total variance	% Cumulative variance	Variables	Factor loadings	Underlying causes	p value
Dry season	Factor 1	48.75	48.75	EC	0.73	Biological processes, sub surface sea water mixing, domestic wastewater release, fish processing centre effluent	0.593
				TDS	0.83		
				DO	-0.96		
				TP	-0.87		
				Temperature	0.89		
	Factor 2	32.04	80.79	pH	0.91	Dry weather	0.001
				Ammonia	-0.87		
Wet season	Factor 1	36.18	36.18	EC	0.96	Wastewater release	0.000
				TDS	0.96		
				DO	0.89		
	Factor 2	26.80	62.97	NO_3^-	0.84	Agricultural runoff	0.000
				NH_4^+	0.71		
				TP	0.87		
	Factor 3	13.70	76.67	pH	0.79	Rainfall	0.977

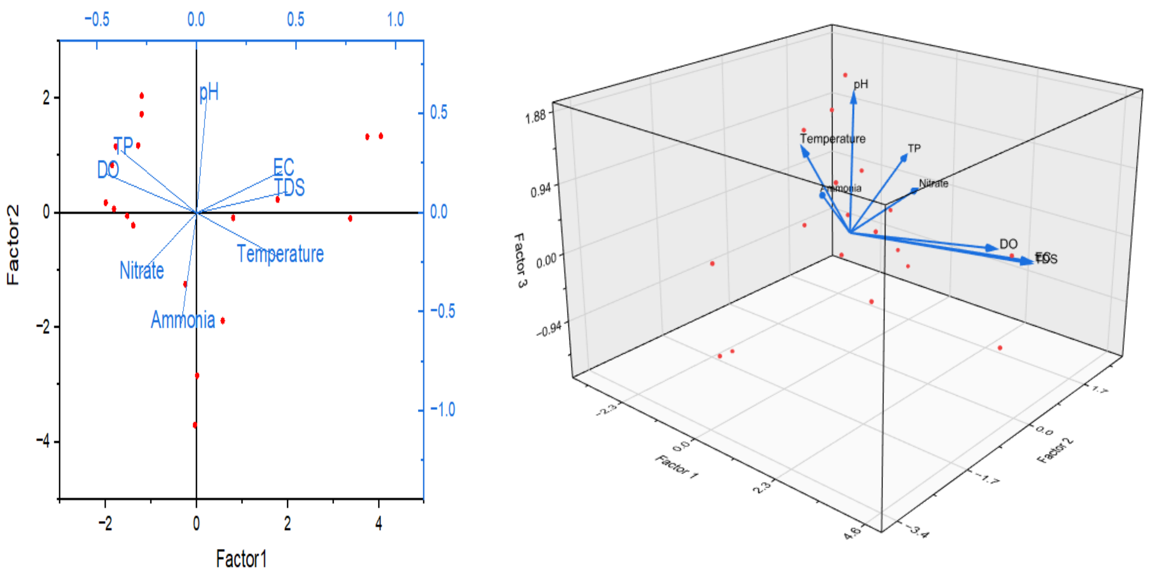

Figure 2: PCA plot diagram for (a) dry season (b) wet season (n=18).

CONCLUSION

This study scientifically documents the pollution status in Sainthamaruthu lagoon. The pollution level in the lagoon varies spatially and temporally, whereas, upstream region was found severely polluted (with CPI greater than 2.01) during NEM rainfall season. This region is characterized by significantly higher concentrations of NH_4^+ (3.5-4.5 mg/L), TP (2.9-3 mg/L) and lower concentrations of EC (719-724 µS/cm), TDS (365-390 mg/L) and DO (1-1.2 mg/L) during wet season. On the other hand, the other regions were found moderately polluted (with CPI greater than 1.01 but lesser than 2) throughout the year. Furthermore, the Sainthamaruthu lagoon was found unsuitable for drinking and fish culture, indicated by WQI of greater than 100. The pollution in Sainthamaruthu lagoon is primarily caused by a mixed sources including mineralization, sea water intrusion, effluent discharge and wastewater release during both the seasons. While, agricultural runoff and weather condition also caused pollution substantially in Sainthamaruthu lagoon. The facts identified in this study provide a baseline information to remediate the lagoon in near future.

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