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***Research Article** (Open Access)*

WATER QUALITY ASSESSMENT USING WATER QUALITY INDEX IN THE FRESHWATER TIDAL STRETCH ALONG THE KALINGAPATNAM ESTUARY, SRIKAKULAM, ANDHRA PRADESH, INDIA

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ABSTRACT
In the present investigation twenty two water quality parameters were estimated to calculate the Water Quality Index (WQI) in Kalingapatnam estuary. The results revealed that the Kalingapatnam estuary has excellent water quality during the monsoon and post-monsoon seasons (< 50), in pre-monsoon, the WQI is somewhat higher than 50 at the S2 and S3 sample stations. The seasonal variations of WQI were reported post-monsoon (50.38), monsoon (31.34), pre-monsoon (37.41), and total period (39.71). The Kalingapatnam estuary had outstanding water quality throughout the year. The Piper diagram compares the cations and anions plots of water quality in the Kalingapatnam estuary. In the pre-monsoon period, the water chemistry is calcium chloride type, where cations are Mg2+ type and anions are chloride type. The results of the Pearson correlation indicated that there is a significant large positive relationship between total period (X) with Pre-monsoon, Monsoon and Post-monsoon seasons and it was exhibited that (Y), (r(20) = .998, 0.96 and 0.99 p < .001). The p-value equals 0, $P(x \leq 69.44) = 1$). It means that the chance of type I error (rejecting a correct H0) is small: 0 (0%). The smaller the p-value the more it supports H1. The study of One Way ANOVA test, using F distribution, the difference between the sample averages of all groups is not big enough to be statistically significant at 0.05 levels. The p-value equals 0.847, the bigger the p-value the stronger it supports H0. The test statistic F equals 0.166, which is in the 95% region of acceptance to the present study. The aforesaid findings, when compared to other statistical expressions, shown good water quality in the Kalingapatnam estuary.

***Keywords:** Water Quality Index, Monsoon, Post-monsoon, Pre-monsoon, Correlation. ANOVA, p-value, H_0 hypothesis, F-Statistic*

INTRODUCTION

Estuaries apart from being the interface between rivers and oceans have been mediating man's predominantly land based activities and interacting with oceans. The study of estuarine regions plays vital role as they are highly productive and play an important role as nursery grounds for many commercially important fishes especially fish and shrimps (Vijayakumar *et al.,* 2000). The estuarine environment is characterized by constant churning of freshwater from the river with marine water, which may be challenged by modifications in water quality. Aquatic animals living in such a challenged estuarine environment should be able to match appropriate changes with their physiological requirements (Ujjania and Monika 2015). It is observed that estuarine environment is polluted by discharges of domestic sewage and industrial effluents besides other anthropogenic activities including agricultural runoff (Pai *et al.,* 1981). Though, considerable attention has been paid in the recent years to study the physicochemical parameters of the coastal waters around India in order to ascertain the water quality and productivity, very little information is available on these aspects of the Palk Bay (Sridhar *et al.*, 2006). The Water Quality

Indices (WQI) is among the most effective way to communicate the information on water quality trends for the water quality management. The environmental conditions such as topography, water movement and stratification, salinity, oxygen, temperature and various nutrients characterizing particular water mass determine the composition of its biota. Several reports are available on the physico-chemical features of Indian estuaries Rajasegar (2003), Balasubramanian and Kannan (2005), Ajithkumar *et al.*, (2006), Asha and Diwakar (2007), Ashok Prabu *et al.*, (2008), Gadhia *et al.*, (2012).

The independent rivers (directly draining into Bay of Bengal) in the basin from north to south are the Rushikulya, Bahuda, Vamsadhara, Nagavati, Sarada, Varaha, Tandava, Eluru, Gundlakamma, Tammileru, Musi, Paleru and Manneru etc. The major part of basin is covered with agricultural land accounting to 59.85% of the total area and 3.66% of the basin is covered by water bodies. The basin spreads over 19 districts (2011) comprising 11 of Andhra Pradesh and 8 of Odisha state (ISRO and CWC, 2014). Water Quality Index (WQI) is a useful technique for assessing water quality by combining numerous water quality measures into a single value. It is one of the most effective instruments for communicating water quality information to concerned individuals and policymakers (Hemant, 2020). A water quality index (WQI) is a one-of-a-kind number that exposes the state of water by integrating numerous water characteristics such as total hardness, dissolved oxygen, sulphate and nitrate (Uddin, *et al.*, 2021). Furthermore, by reducing the aggregate data of numerous water characteristics to a single number, it simplifies and conveys logical data. This index incorporates data from multiple parameters into a mathematical equation that rates the quality of water bodies.

The purpose of this study was to assess the water quality parameter and its relationship with biodiversity indices, which might allow for a wide variety of ecological issues in correlation with other anthropogenic activities. This research helps with water quality inspections as well as periodic monitoring to limit human activities in this region. The present investigation was carried out to calculate the Water Quality Index (WQI) in order to assess the quality of estuarine waters of Kalingapatnam.

MATERIALS AND METHODS

i. Study area

Samples were collected from Pallipeta (S1) 18.354302, 84.114280; Rajarampuram (S2) 18.355016, 84.127272; Kalingapatnam (S3) 18.343635N), 84.120134E

ii. Sample collection

Sampling was made at bimonthly intervals from three stations during February 2021 to January 2022. Water samples were collected during high tides from the selected stations. To minimize the change in chemical composition, all water samples were collected in a clean, sterile polypropylene wide mouth reagent container with a 1-litre capacity, delivered to the AOC laboratory, Srikakulam and maintained at 40°C. Water samples were analyzed using slandered procedures for" Temperature, pH, Transparency, DO, BOD (mg/l), COD (mg/l), Total Hardness, Alkalinity, Carbonates, Bicarbonates, Ca^{2+} (mg/l), Mg^{2+}, Ammonia (mg/l), Nitrites (mg/l) and Nitrates (mg/l) are all used to compute WQI.

iii. Water quality assessment:

Hydro-chemical analyses were carried out immediately after the water samples were collected by following the analysis procedures recommended by the "American Public Health Association (APHA, 2005)"and "Handbook of Methods in Environmental Studies Vol. 1: Water and Wastewater Analysis" (Maiti, 2004). Physicochemical parameter analysis was carried out in local laboratory. Water temperature was determined by the Thermometer, Electrical Conductivity was determined through the digital conductivity meter and pH was measured by pH meter on site during the sampling. Turbidity was measured by the digital turbidity meter. Salinity was determined by using Salinometry. TSS, TS and TDS were measured by the Gravimetric method. Alkalinity, Chloride, Total Hardness and Calcium Hardness were analyzed through the Titration method. BOD and DO were analyzed through the Winkler method. COD and Ammonium were assessed in SICART. Nitrate, by the help of Spectrophotometer (Model: 302). Sulfate was analyzed by the Turbidimetric method (Model: 302). The average mean value calculated statistically with Standard Deviation (SD ±).

iv. Water quality index calculation

The following methods are used to test the water quality Water temperature measured by precise mercury-in-glass thermometer and pH meter respectively. Salinity, dissolved oxygen and nutrients such as ammonia nitrogen, nitrite-nitrogen, nitrate-nitrogen, phosphate-phosphorus and were estimated following standard methods (Strickland and Parsons, 1972).

For the calculation of WQI, the ranking was given to the selected variables which have variance with the standard values.

$WQI = \Sigma Q_iW_i / \Sigma W_i$

(Where, Qi = Quality rating Wi = Relative weight)

Water quality grads can be classified as excellent, good, poor, very poor and unsuitable with reference to the grads provide in Table

Table: 1 Coastal water quality ranking criteria (Vishnupriya *et al.*, 2015)

CWQI- Range	Category-Rank
< 50	Excellent water
50-100	Good water
100-200	Poor water
200-300	Very poor water
>300	Unsuitable

Table: 2 CPCB Guidelines (2007)

Parameters	Quality standards	Reference	Parameters	Quality standards	Reference
Temperature (0^C)	30	Moore (1991)	BOD (mg/l)	30	Moore (1991)
Ph	8.3	Moore (1991)	COD (mg/l)	250	Moore (1991)
TDS	500	Moore (1991)	Ca^{2+} (mg/l)	75	Moore (1991)
Turbidity NTU	30	Moore (1991)	K+	12	Moore (1991)
Salinity	15-30	Moore (1991)	Phosphate (mg/l)	0.1	Moore (1991)
Chlorides (mg/l)	1000	Surana *et al.*, (2013)	$Magnesium^{2+}$ (mg/l)	1300	Moore (1991)
Alkalinity (mg/l)	400	Moore (1991)	Ammonia (mg/l)	0.6	Surana *et al.*, (2013)
Carbonates CO_3^{2-} (mg/l)	60	Moore (1991)	Nitrite-N (mg/l)	10	Moore (1991)
Bicarbonates (mg/l)	400	Moore (1991)	Nitrate-N ($N0^{2-}$)	10	Moore (1991)
Total Hardness (mg/l)	200	Moore (1991)	Sulphates ($SO2^{-4}$)	2700	Hitchcock(1975)
DO (mg/l)	4	Moore (1991)			

v. Multivariate analysis

A correlation examination is a statistical tool for representing the relationship between two variables. Correlation coefficient values near +1 or -1 indicate the likelihood of a linear link between the x and y variables (Bhandari and Nayal, 2008). The one-way ANOVA test for independent measurements compares the means of many independent samples determined by using the Tukey's HSD online calculator. Statistical Analysis: Some univariate (Linear Regression) and multivariate (Cluster Analysis) statistical analysis were carried out by using PAST 3.0 software

RESULTS AND DISCUSSION

The physiochemical water quality parameters of Kalingapatnam estuary was studied at three sampling stations from February 2021 to January 2022. Throughout the period, four physical parameters (temperature, pH, total solids, and turbidity) and 18 chemical characteristics (salinity, chlorides, alkalinity, carbonates, bicarbonates, total hardness, Do, BOD, COD, calcium, sodium, potassium, phosphate, magnesium, ammonia, and nitrites) were recorded. Salinity indicated a bimodal type of oscillation. The recorded average vales have been given into Mean ± SD and the parameters are determined in mg/l (Table 3). Li, S., Chen *et al.*, (2019) explained the standard deviation (StD) of WQI provided a further indication of water quality, which is a higher StD value meant the sampling evaluation results were more unstable, in the Eastern Pearl River Delta, China.

The recorded Temperature of water quality values varied between 21.17^{0}C and 28.97^{0}C, while the lower values were recorded in December and high value was recorded in May for both the tides. The values did not show much fluctuation seasonally except that the water temperature was moderately high during summer. The pH of water values varied between 7.44 and 7.74, while the lower values were recorded in August and high value recorded in March for both the tides. The values did not show much fluctuation seasonally except that the water was alkaline during summer, when the influx of freshwater was minimum and the waters in the estuary was dominated by seawater (Sudhir, 1990, Sahu, 1981). Total dissolved solids of water values estimates varied between 256.33 and 672, while the lower values were recorded in April and high value recorded in Auguest-21 for both tides. The values show much fluctuation seasonally during monsoon, the influx of freshwater was maximum and the waters in the estuary were dominated by freshwater. Turbidity of water values recorded between 29.00 and 41.5, while the lower values were recorded in April and high value recorded in Auguest-21 for both tides. The values show much fluctuation seasonally during monsoon, the influx of freshwater was maximum and the waters in the estuary were dominated by freshwater (Table 4). The similar study was recorded the minimum and maximum values of water temperature, pH, dissolved oxygen (DO), chlorides, calcium, total hardness (TH), magnesium, sodium and potassium of Bhatye estuary show variations during the study period.

Brackish water salinity effects by tidal influence with fresh and marine water. A well marked seasonal fluctuation with relatively low values during monsoon months 13‰ and higher values during the pre-monsoon seasons 32‰ were noticed. Brackish water chlorides are affected by tidal interaction with fresh and marine water along the shore. A significant seasonal variation was observed, with values as low as 6612.330 mg/l during monsoon months and as high as 10531.33 mg/l during pre-monsoon seasons. Alkalinity in brackish water is a well-marked seasonal fluctuation with a relatively low value of 146.0mg/l during monsoon period and higher values of 171.67mg/l during the pre-monsoon period was recorded. Brackish water Carbonates are affected by tidal interaction with fresh and marine water along the shore. A significant seasonal variation was observed, with values as low as 28.67mg/l during monsoon months and as high as 35.33 mg/l during pre-monsoon seasons. Bicarbonates are affected by tidal interaction, a significant seasonal variation was observed, with values as low as 117.33mg/l during monsoon months and high value 136.33mg/l during pre-monsoon seasons. Total Hardness affected by tidal interaction, a significant seasonal variation was observed, with values as low as 339.67mg/l during monsoon and high value 503.73mg/l during pre-monsoon seasons (Table 4).

The dissolved oxygen data revealed that, it fluctuated between the high tide and low tide periods. Higher values of dissolved oxygen (7.88 mg/l) were observed during monsoon and a low value (4.24 mg/l) during pre-monsoon seasons. Temperature and salinity have been shown to influence oxygen dissolution, and all stations are highly oxygenated at high and low tides. While the comparatively lower readings in October may be attributed to the use of oxygen for organic matter decomposition, Pillai *et al.,* (1973) discovered that tides impact dissolved oxygen concentration (Singbhal, 1973). The similar results were observed in the Dissolved oxygen levels at Malidevi estuary have been found to be high during the monsoon season. Transparency values varied between 0.58±0.21 and 0.97±0.21. The mean pH ranged from 7.2±0.20 to 9.2±0.32. Salinity ranged from 19.33±0.76 to 34.68±1.00 (‰). Dissolved oxygen levels varied from 3.3. Freshwater input and rainfall help to facilitate this process (Saravankuamr *et al.,* 2008, Pravat Ranjan Dixit et al., 2013, Budharatna *et al.*, 2013).

The Biological Oxygen Demand revealed that it fluctuated between various seasons. The higher values of BOD (2.14 mg/l) were observed during the pre-monsoon and a low value (0.69 mg/l) during the monsoon seasons. The Chemical oxygen demand revealed that it fluctuated between various months in the total period. The higher values of COD (v mg/l) were observed during the pre-monsoon and a low value (9.33mg/l) during the monsoon seasons (Table 4).

Calcium in brackish water is a well-marked seasonal fluctuation with a relatively low value of 753.0 mg/l during Post-monsoon period and higher values of 873.33mg/l during the pre-monsoon period was recorded. Sodium in brackish water is a well-marked seasonal fluctuation with a relatively low value of 1471.67mg/l during monsoon period and higher values of 2740 mg/l during the pre-monsoon period was reported. Potassium in brackish water is affected by tidal influence with fresh and marine water along the coast line. A well-marked seasonal fluctuation with a relatively low value 57.8 mg/l during monsoon months and higher values of 100.5 mg/l during the pre-monsoon seasons was recorded. Phosphates in brackish water are affected by tidal influence with fresh and marine water along the coast line. A well-marked seasonal fluctuation with a relatively low value 0.06mg/l during monsoon months and higher values of 0.073mg/l during the pre-monsoon seasons was recorded. Magnesium in brackish water is affected by tidal influence with fresh and marine water along the coast line. A well-marked seasonal fluctuation with a relatively low value of 3.33 mg/l during post-monsoon months and higher values of 3391.67 mg/l during the pre-monsoon seasons was observed (Table 4).

Ammonia affected by tidal interaction exhibit a significant seasonal variation was observed, with values as low as 0.63mg/l during monsoon months and high value 1.39mg/l during pre-monsoon seasons. Nitrites affected by tidal interaction showed a significant seasonal variation, with values as low as 0.02 mg/l during monsoon months and a high value of 5.09 mg/l during pre-monsoon seasons. Nitrate affected by tidal interaction exhibit a significant seasonal variation was observed, with values as low as 18.99 mg/l during monsoon months and high value 30.47mg/l during pre-monsoon seasons. Sulphates affected by tidal interaction showed a significant seasonal variation, with values as low as 1546.67 mg/l during monsoon months and a high value of 1786.67 mg/l during pre-monsoon seasons (Table 4). Various authors were reported to ammonia concentrations reported a peak in June and September, with lesser peaks in October and November. During the research period, the concentration ranged from 0.13 to 22.43 pg/l at high tide and 0.25 to 25.59 pg/l at low tide (Sarala Devi *et al.,* (1983) reported similar findings in the Vellar estuary. The results were shows high concentrations to comparison with our present study. The similar results were observed by Vijayakumar *et al.,* (2000) observed that pH and salinity increased at high tides, though the dissolved oxygen trend was unaffected by tidal influences. Ammonia, nitrite, nitrate, phosphate, and silicate levels increased during low tide in the Mulki Estuary on India's south-west coast. Sridhar *et al.,* (2006) found that the dissolved oxygen level ranged from 4.15 to 7.18 mL-1, whereas the particulate organic carbon (POC) content ranged from 0.49 to 2.28 mg Cl-1. Nutrient concentrations changed individually, including nitrate (2.15 to 8.28 μM), nitrite (0.12 to 0.62 μM), inorganic phosphate (1.28 to 2.15 μM), and reactive silicate (5.15 to 12.52 μM). Surana *et al.,* (2013) assessed physico-chemical features and calculated correlation coefficients between them. There were significant relationships discovered between salinity, TS, TDS, sodium, and chloride. High BOD and COD levels were detected, indicating a positive association in the Tapi estuary in Dumasjetty, Surat.

The water quality index was computed and shown in accordance with the CPCB Guidelines (2007), Vishnupriya *et al.,* (2015). In the present study Kalingapatnam estuary has excellent water quality during the monsoon and post-monsoon seasons (< 50). In the pre-monsoon, the WQI is somewhat higher than 50 at the S2 and S3 sample stations (Table 3 Fig. 2). The seasonal variations of WQI were reported post-monsoon (50.38), monsoon (31.34), pre-monsoon (37.41), and total period (39.71). The Kalingapatnam estuary had outstanding water quality throughout the year (Table 4, Fig 3). Junli Wang *et al.,* (2019) assessed water quality in all three regions of Lake Wuli. The average TLI and WQI values in the wet season were 61.69 and 60.70, respectively, while in the dry season they were reported to 57.40 and 65.74. There were significant variances between the three regions of the lake. The results were exhibiting more WQI comparatively with Kalingapatnam estuary.

This contributes to a better knowledge of the chemical processes and differences in environmental factors, nutrient concentrations in the river-estuarine system. Separate ternary plots (Fig. 4) illustrate how the Piper diagram compares cations and anions in the Kalingapatnam estuary. In the pre-monsoon period, the water chemistry is calcium chloride type, where cations are Mg^{2+} type and anions are chloride type. During the monsoon and post-monsoon periods, the water chemistry was calcium chloride type, which implies the cations were not dominant types and the anions were chloride types. The general water chemistry in the Kalingapatnam estuary shows that a mixed type of water quality was reported, which is that the cations are sodium and potassium types and the anions are chloride types.

Results of the Pearson correlation indicated that there is a significant large positive relationship between total period (X) with Pre-monsoon, Monsoon and Post-monsoon seasons and it was exhibited that (Y), ($r(20) = .998$, 0.966 and 0.999 $p < .001$). The difference between the sample correlation and the expected correlation is big enough to be statistically significant. The p-value equals 0, ($P(x \leq 69.4461) = 1$). It means that the chance of type I error (rejecting a correct H0) is small: 0 (0%). The smaller the p-value the more it supports H1. The test statistic T equals 69.4461, 52.2528 and 97.99 which is beyond 95% region of acceptance in all seasons in the Kalingapatnam estuary (Fig 5, 6 and 7). Shefali *et al.,* (2021) analyzed the Water Quality Index. Linear regression research showed the type and size of correlations between distinct independent and dependent variables. The regression equations may be used to continually estimate component concentrations in the Par River estuary.

One Way ANOVA test, using F distribution, the difference between the sample averages of all groups is not big enough to be statistically significant at 0.05 levels. The p-value equals 0.847, the p-value exceeds α, the null hypothesis (H0) is accepted. The bigger the p-value the stronger it supports H0. The test statistic F equals 0.166, which is in the 95% region of acceptance. The observed effect size f is small (0.073). That indicates that the magnitude of the difference between the averages is minimal. The η^2 equals 0.0053. It means that the group explains 0.5% of the variance from the average (similar to R^2 in the linear regression). There is no significant difference between the means of any pair (Fig 8). The Pearson correlation and One Way ANOVA clearly indicated that the water quality Index was no major fluctuations in the Kalingapatnam estuary. According to Mohd Saiful Samsudin and Azman Azid (2018), the p-value corresponds to the F-statistic in a one-way ANOVA and is less than 0.05, indicating that one or more sample stations are substantially different. In some circumstances of the Tukey HSD test, the p-value for the F-statistic of one-way ANOVA is less than 0.05, indicating that one or more sample stations are statistically different.

Table 4: Seasonal variation Water Quality Index

Parameters	Pre-monsoon	Monsoon	Post-monsoon	Total period
Temp (0^C)	28.97	25.77	21.17	25.30
Ph	7.74	7.44	7.68	7.62
Total Solids	256.33	672	343.33	423.88
Turbidity (NTU)	29.00	41.5	34.17	34.89
Salinity	32.0	13.0	21.33	22.11
Chlorides (mg/l)	10531.33	6612.330	8987.33	8710.33
Alkalinity (mg/l) CaCO3	171.67	146.0	162.67	160.11
Carbonates (mg/l) CO_3^{2-}	35.33	28.67	30	31.33
Bicarbonates (mg/l) A	136.33	117.33	132.67	128.78
Total Hardness (mg/l)	503.73	339.67	441.9	428.43
DO (mg/l)	4.24	7.88	6.3	6.14
BOD (mg/l)	2.14	0.69	1.6	1.48
COD (mg/l)	14.17	9.33	12.9	12.133
Ca^{2+} (mg/l) C	873.33	846.67	753.0	824.33
Sodium (mg/l)	2740	1471.67	2431.67	2214.46
Potassium (K+)	100.5	57.8	92.17	83.49
Phosphates (mg/l) PO_4^{3-}	0.071	0.06	0.073	0.068
Mg^{2+} (mg/l) C	3391.67	1463.33	2003.33	2286.11
Ammonia (mg/l)	1.39	0.63	0.84	0.95
Nitrites (mg/l) NO3-	5.09	0.02	0.09	1.73
Nitrate ($N0^{2-}$)	30.47	18.99	23.4	24.29
Sulphate ($SO2^{-4}$)	1786.67	1546.67	1761.67	1698.34
WQI = $\sum Wn \times Qn$	**50.38**	**31.34**	**37.41**	**39.71**

Sample size: 22

Fig: 2. WQI at three sampling stations

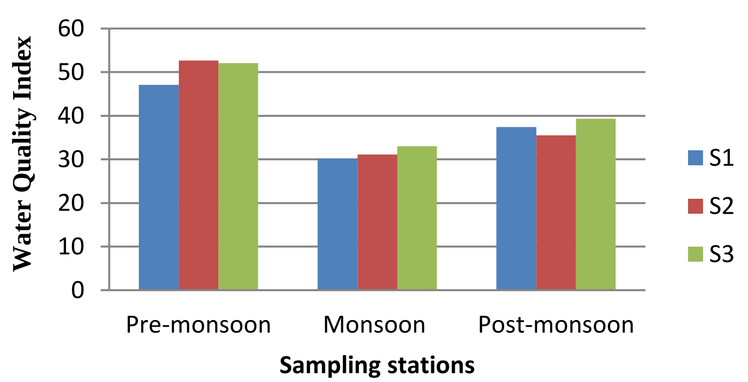
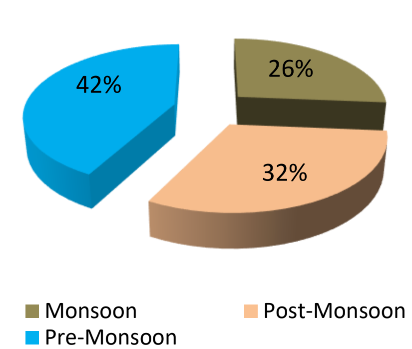


Fig: 3. Seasonal variation of WQI



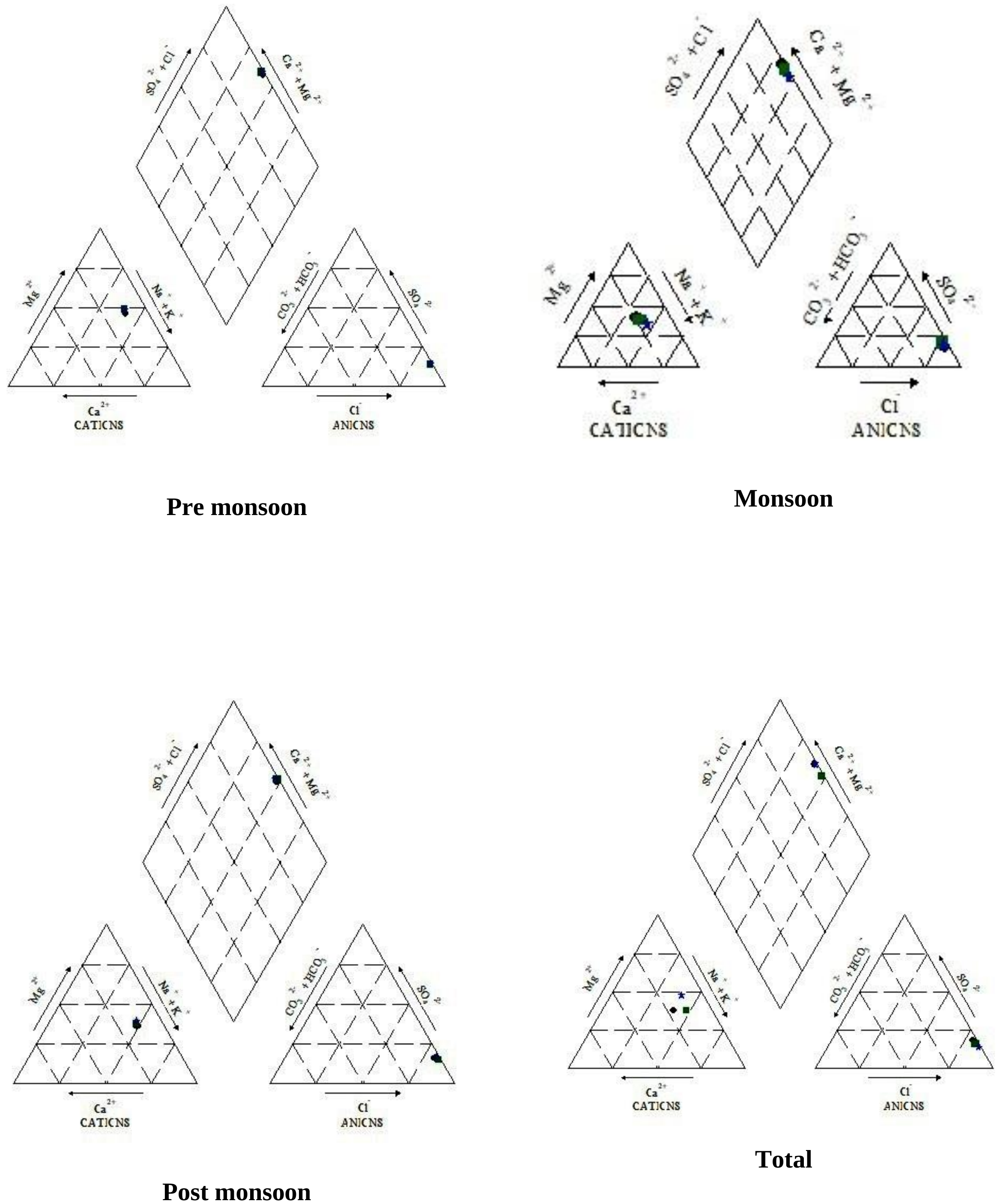


Figure 4: Cation and anion Piper diagrams ternary plots of various seasons

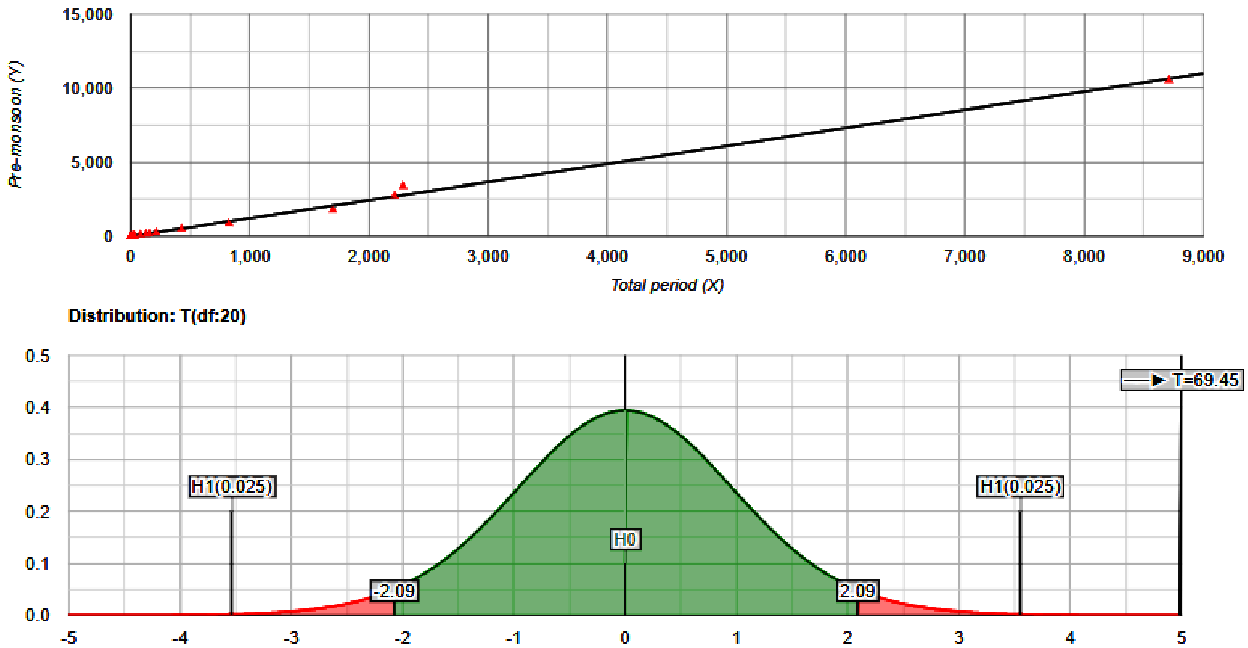


Figure 5: Pearson correlation between of total period (X) and Pre-monsoon (Y)

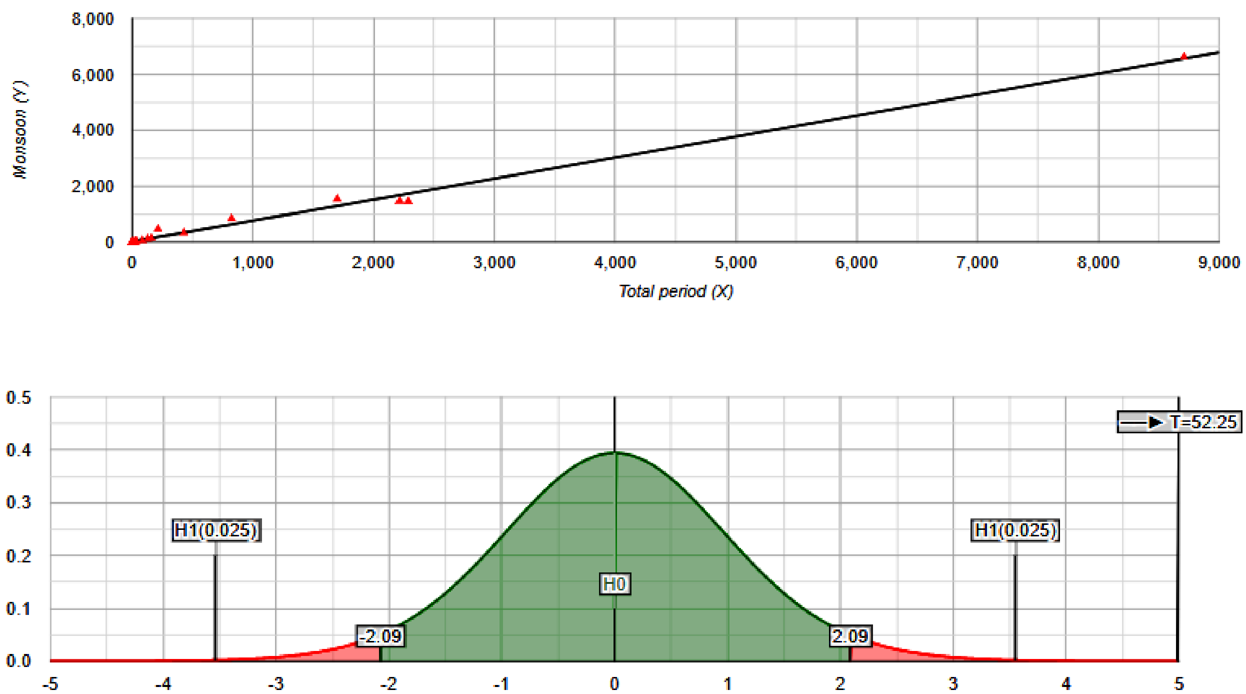


Figure 6: Pearson correlation between of total period (X) and Monsoon (Y)

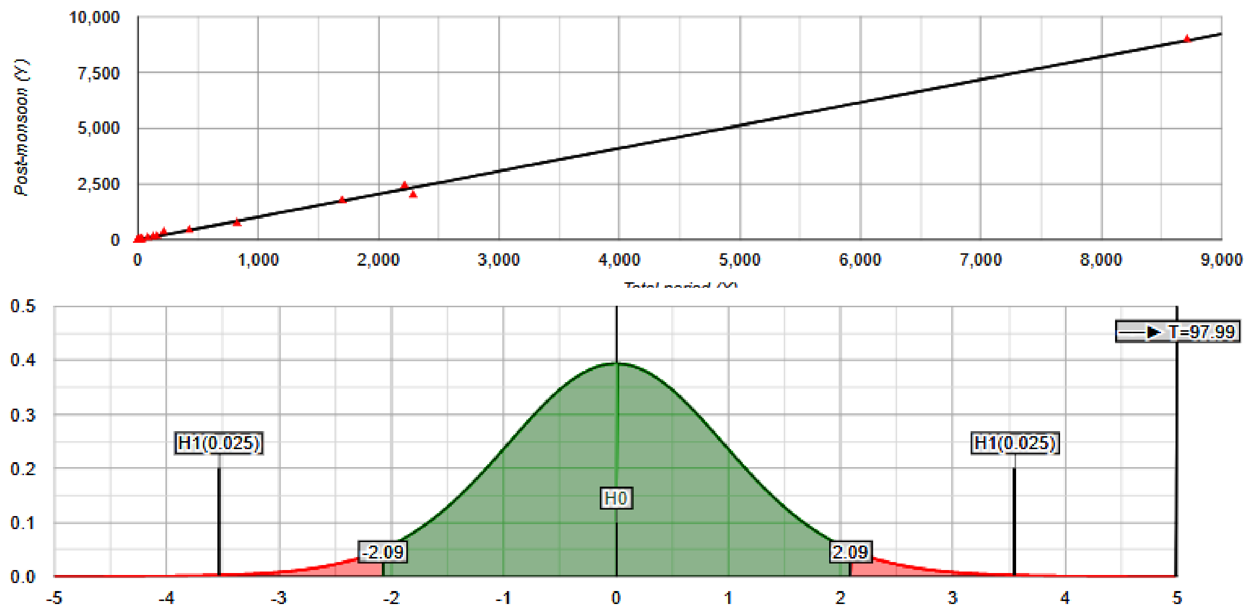


Figure 7: Pearson correlation between of total period (X) and Post-monsoon (Y)

ANOVA

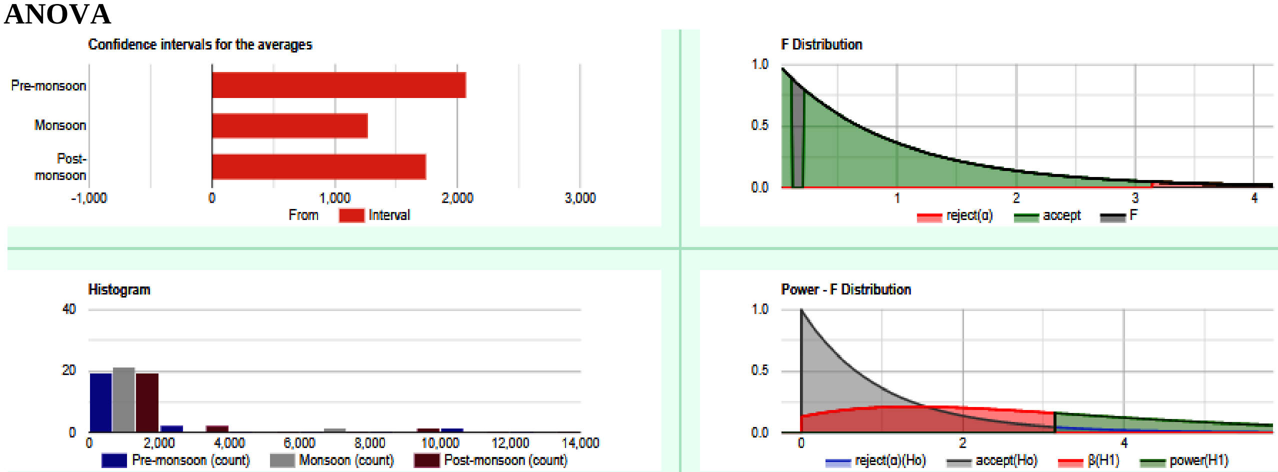


Figure 8: One Way ANOVA test, using F distribution df (2, 63) at 95% significant level

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Table 3. Average Physico-chemical Parameters for Water Quality Index at three sampling station from June 2021 to May 2022

S. no	**Parameters**	Pre-Monsoon (Feb-May)			Monsoon (Jun-Sep)			Post-Monsoon (Oct-Jan)		
I	**Physical parameters**	S1	S2	S3	S1	S2	S3	S1	S2	S3
1	Temp (0^{C})	28.5	28.8	29.6	25.3	25.6	26.4	20.5	21.4	21.62
2	Ph	7.74	7.85	7.63	6.82	7.52	8.0	7.64	7.56	7.83
3	Total Solids	264	250	255	698	650	668	345	360	325
4	Turbidity (NTU)	28.1	30.6	28.3	42.5	42.4	39.6	35.7	35.2	31.6
II	**Chemical parameters**									
1	Salinity	30	32	34±	11	12	16	18±	22	24
2	Chlorides (mg/l)	10742	10500	10352	7225	6247	6365	8562	9665	8735
3	Alkalinity (mg/l) CaCO3	175	168	172	140	146±5.32	152	168	158	162
4	Carbonates (mg/l) CO_3^{2-}	39	24	43	30	31	25	34	22	34
5	Bicarbonates (mg/l) A	136	144	129	110	115	127	134	136	128
6	Total Hardness (mg/l)	515.4	500.5	495.3	326.4	356.2	336.4	457.2	425.4	443.1
7	DO (mg/l)	4.39	4.12	4.22	7.57	7.96	8.12	6.66	6.42	5.82
8	BOD (mg/l)	2.33	2.12	1.98	0.72	0.74	0.62	1.75	1.52	1.54
9	COD (mg/l)	13.5	14.2	14.8	10	10	8	11	14.5	13.2
10	Ca^{2+} (mg/l) C	855	875	890	860	830	850	742	762	755
11	Sodium (Na+)	2650	2785	2785	1220	1345	1850	2415	2435	2445
12	Potassium (K+)	102.6	98.4	105.5	52.5	58.5	62.4	83.4	94.5	98.6
13	Phosphates (mg/l) PO_4^{3-}	0.06	0.072	0.081	0.052	0.073	0.056	0.08	0.06	0.08
14	Mg^{2+} (mg/l) C	3100	3525	3550	1460	1430	1500	1850	2020	2140
15	Ammonia (mg/l)	1.25	1.52	1.42	0.6	0.62	0.68	0.85	0.75	0.92
16	Nitrites (mg/l) NO3-	0.12	0.15	015	0.02	0.01	0.03	0.08	0.12	0.08
17	Nitrate ($N0^{2-}$)	31.2	30.4	29.8	18.43	18.21	20.33	24.5	22.2	23.5
18	Sulphate $SO2^{-4}$	1760	1790	1810	1550	1560	1530	1740	1765	1780
	WQI = ∑Wn × Qn	**47.07**	**52.68**	**52.09**	**30.14**	**31.14**	**33.02**	**37.38**	**35.51**	**39.34**

Values have been given into Mean and the parameters are determined in mg/l
S1= Pallipeta S1; S2 = Rajarampuram; S3= Kalingapatnam

Table: 5. The physicochemical parameter's correlation coefficient (r) of variation at 0.05 significance level in the Kalingapatnam estuary

	Temp.	Ph	TS	Sali	Cl-	Alk	Carb	Bico	TH	DO	BOD	COD	Ca^{2+}	Na	K+	Pho	Mg	Am	Nit	Ni	Su
Temp.	1																				
Ph	0.09	1																			
Total Solids	-0.38	0.88	1																		
Turbidity	-0.31	-0.97	-0.75	1																	
Salinity	0.47	0.92	0.63	-0.98	1																
Cl-	0.29	0.98	0.77	-0.99	0.98																
Alkalinity	0.25	0.99	0.80	-0.99	0.97	1															
Carbonates	0.68	0.79	0.41	-0.91	0.96	0.87	1														
Bicarbonates	0.08	0.99	0.89	-0.97	0.92	0.98	0.78	1													
Total Hardne	0.28	0.98	0.78	-0.99	0.97	0.99	0.88	0.98	1												
DO (mg/l)	-0.48	-0.92	-0.63	0.98	-0.99	-0.96	-0.9	-0.91	-0.97	1											
BOD (mg/l)	0.27	0.98	0.78	-0.99	0.97	0.99	0.88	0.98	0.99	-0.97	1										
COD (mg/l)	0.15	0.99	0.85	-0.98	0.94	0.99	0.82	0.99	0.99	0.99	0.99	1									
Ca^{2+} (mg/l)	0.98	-0.12	-0.56	-0.11	0.28	0.04	0.52	-0.12	0.07	0.99	0.06	-0.05	1								
Sodium	0.14	0.9	0.86	-0.98	0.93	0.99	0.8	0.99	0.98	0.07	0.98	0.99	-0.07	1							
K+	0.08	0.99	0.88	-0.97	0.92	0.98	0.78	0.99	0.98	0.98	0.98	0.99	-0.12	0.99	1						
Phosphates	-0.24	0.94	0.98	-0.84	0.74	0.87	0.54	0.94	0.86	0.98	0.86	0.92	-0.43	0.92	0.94	1					
$Magnesium^{2+}$	0.62	0.83	0.48	-0.94	0.98	0.91	0.99	0.83	0.92	0.86	0.92	0.86	0.44	0.85	0.86	0.60	1				
Ammonia	0.62	0.83	0.48	-0.93	0.98	0.91	0.99	0.82	0.92	0.92	0.92	0.86	0.44	0.85	0.83	0.60	0.99	1			
Nitrites	0.80	0.66	0.24	-0.82	0.91	0.77	0.98	0.65	0.79	0.92	0.79	0.71	0.66	0.69	0.65	0.38	0.96	0.96	1		
Nitrate	0.53	0.89	0.58	-0.97	0.99	0.95	0.97	0.88	0.96	0.79	0.96	0.92	0.33	0.91	0.89	0.69	0.99	0.99	0.92	1	
Sulphates	-0.01	0.99	0.92	-0.95	0.88	0.96	0.72	0.99	0.95	0.96	0.96	0.98	-0.21	0.99	0.99	0.97	0.77	0.77	0.58	0.84	1

CONCLUSION

From the present study, it is concluded that the water quality of the Kalingapatnam estuary is in normal condition and there is no indication of any coastal pollution even after the development of aquaculture industry in this region at present.

Conflict of interest

The authors have no competing interests to declare that are relevant to the content of this article. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

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