Coastal Water Pollution Index (CWPI) –a tool for assessing coastal water quality along the North East Coast of India.

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Abstract: - In order to assess the coastal water quality coastal water Quality Index (CWPI) particularly applicable for estuaries where seawater undergoes considerable dilution with freshwater was compared based on the data of their spatial and temporal variation of several physiochemical parameters of the coastal water. Principal Component Analysis (PCA) of 12 variables of 19 stations in four different regions along the study area indicated good to excellent water quality in middle and lower reaches at Bahuda and Rushikulya estuaries as well as Gopalpur creek particularly during post and pre-monsoon seasons. On the other hand, the water quality was worst at Chilika Lake which was attributed to the combined effect of discharge of untreated domestic sewage, aquaculture and industrial wastes. Further the water quality was rated as bad in the upper reaches of the estuaries and sewage discharge points particularly during monsoon season.

Introduction

Water Quality index (WQI) is useful parameters to study the impact of different activities causing the deterioration of water quality along the coast. The important application of WQI could be (i) identification and ranking of different activities for environmental degradation of coastal sites (ii) prioritization of pollution prevention resources (iii) determination of seasonal changes environment indices have been so reported for classification of coastal or estuarine water quality where considerable dilution of sea water takes place during monsoon in addition to the impact of anthropogenic inputs. The purpose of this study is to compute Water Quality Index (WQI) of water based on the data of several physico-chemical parameters and to correlate the index with different anthropogenic activities along the Orissa coast, on the north-eastern part of Bay of Bengal.

Materials and Methods

Water samples were collected in pre-monsoon, monsoon and post-monsoon periods during 2009-2010 from four regions having 19 stations representing Bahuda estuary (Lat. 19° 03′N, 84°02′E), Gopalpur creek (19°15′N, 84°54′E), Rushikulya estuary (19°22′N) and Chilika (19°41′N, 85° 13′E) along northeast coast of India (Fig. 1).

During the study period the average depth of water column was 1.5m in pre-monsoon, 2.0m monsoon and 3.5m in monsoon period.

Water samples were collected from the surface and near bottom of the water column at different stations during both low and high tide using Nansen's water samples and the integrated water samples were used for analyses of physico-chemical parameter. The temperature was measured in the field by thermometer in degree centigrade. The pH of water samples were measured by digital pH meter (Systronic-363), Salinity was determined by Knudsen's titrimetric method [10]. Dissolved oxygen was fixed immediately at field after collection and then estimated by Winkler's method [11].

Out of 19 stations different pre- selected active complex stations are given below:

Station code	Nature of effect
B2,G2,R1,C1 & C3	Urban and municipal sewage
G5& R2	IRE & Chloro alkali industry
C2	Intensive hatcheries & extensive aquaculture farm
B5 & R5	Saltpan
G1 & R3	Agriculture
B1	Upper reach (Freshwater domi nate)
B3, G3	Middle reaches (Combined effect of freshwater and marine water)
B4,G4,G6 & R4	Lower reaches (marine dominate)

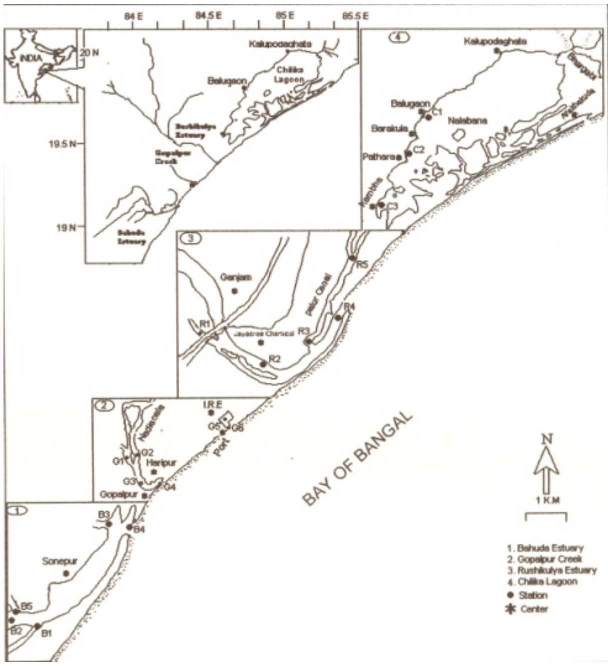


Fig. 1: Map of the study area of North East Coast, Bay of Bengal with sampling stations.

Biochemical Oxygen Demand was estimated after 5 days of incubation at 20'C. Chemical Oxygen Demand was determined by titrating against a strong oxidizing agent, $K_2Cr_2O_7$ [12]. Water samples were filtered through Millipore filter paper (0.45µm) and were analysed for nutrients by Spectrophotometery method [13]. Using double beam UV-VIS Spectrophotometer 2201 (Systronic).

For data treatment average raw data was interpreted using computer software package STATSTICA R as suggested by StatSoft [14]. Analysis of WQI was performed in the following steps (i) arrangement of experimental data. (ii) data exploration and extraction of factor loading without rotation by PCA analysis. (iii) selection of the most important affected variable from PCA for derivation of CWPI only when component loading was greater than 0.7 [15] (iv) examination of weight for selected variables and (v) water quality rating based on the percentile in the data set.

CWPI was calculated basing on the modified arithmetic weighted formula derived by Scottish Development, (SDD, 1976) as follows:

$$CWPI= (q_i w_i)^2 / 100$$

Where q_i = water quality rating of ith variable

w_i = weight of ith variable

The weight, w_i attributed to each variable in CWPI was computed on the basis of the proportion of Eigen values classified from the result of PCA. Based on the rating of water quality conditions was classified into five bands: excellent (0-20), good (21-49), average (50-60), bad (61-80) and worst (81-100).

Result and Discussion:

Data on physico-chemical parameters at four studied regions have been given in Table-I. Ratios of all physico-chemical parameters with salinity were used for PCA loading was not performed.

Table-1: Statistical analysis of physico-chemical and bacteriological

parameters of the studied regions.

Parameters	Pre-monsoon mean±SD	Post-monsoon mean±SD	Monsoon Mean
Temperature (◦C)	28.01±.36	22.36±.77	27.16±0.41
Salinity(ppm)	23.16±8.11	19.13±7.4	6.72±4.98
pH	8.33±0.38	7.81±0.36	7.71±0.36
Turbitidity (NTU)	17.18±5.96	29.49±8.9	42.93±14.2
Dissolved oxygen(mg/l)	3.54±0.39	4.64±0.46	6.06±0.68
BOD(mg/l)	1.87±0.39	2.91±0.60	4.78±1.09
COD(mg/l)	5.63±1.14	9.65±1.87	15.32±3.11
Nitrate (µmol/l)	3.66±0.52	6.54±0.81	9.31±1.31
Nitrite (µmol /l)	1.56±0.42	2.31±0.61	3.60±0.96
Ammonia (µmol /l)	3.67±0.51	6.30±1.02	10.76±1.59
Silicate (µmol/l)	146.43±275.3	220.47±64.72	351.58±104.4
Phosphate (µmol /l)	3.02±0.34	5.05±0.50	7.23±0.83
TP (µmol /l)	5.53±0.64	9.42±1.6	15.78±2.06

TP= Total phosphorus.

Result of PCA showed that all twelve components were found to explain 97.7% of the total variation in water quality data set. The principal components and associated loading are presented in Table-2 and all the variables were selected for the derivation of the coastal water pollution index, since the absolute value of the component loading was greater than 0.7.

Table- 2: Factor loading before varimax rotation for coastal water data set of Orissa coast.

	PC1
Eigen value	11.7
% of variance	97.7
Loadings of variables	
Temperature	.992
pH	.988
Turbidity	.974
Dissolved oxygen	.972
BOD	.989
COD	.99
Nitrate	.997
Nitrite	.972
Ammonia	.996
Silicate	.994
Phosphate	.996
Total Phosphorus	.997

The weight (w_i) attributed to each of these variables in the CWPI calculation according to proportion of Eigen values of all was provided in Table 3.

Table-3: Weights for each of 12 variables selected from Prinicipal Component Analysis (PCA) for calculation of coastal pollution index of Orissa coast.z

PC	Eigen Value	Relative eigen value	Variable	Loading Value	Relative loading value on same PC	Weight (Relative eigen value X relative loading value)
1	11.7287	1.00	Temperature	0.992	0.0836	0.0836
			pH	0.988	0.0833	0.0833
			Turbidity	0.974	0.0821	0.0821
			Dissolved oxygen	0.972	0.0820	0.0820
			BOD	0.989	0.0834	0.0834
			COD	0.99	0.0835	0.0835
			Nitrate	0.997	0.0841	0.0841
			Nitrite	0.972	0.0819	0.0819
			Ammonia	0.996	0.0840	0.0840
			Silicate	0.994	0.0838	0.0838
			Phosphate	0.996	0.0840	0.0840
			Total Phosphorus	0.997	0.0840	0.0840
Total	11.73	1.00				1.000

Table-4 summarizes the CWPI for 19 stations in four regions over the monitoring period of 2011-2012. Water quality was classified as bad at sewage, average at industry, good at aquaculture and salt pan while excellent at agriculture and estuarine vicinity zone.

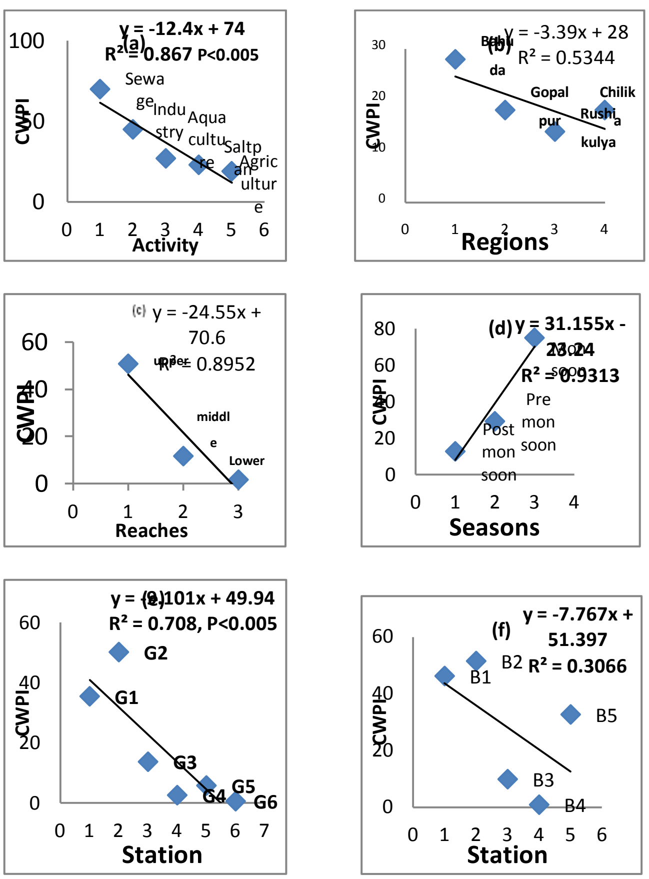
Table-4: Summary of coastal water quality index computed for the studied region.

Sl. no	Polluted zone	No. Of monitoring stations	WQI	No. Of observation	Classification of water quality based on mean WQI
1	Sewage	5	70	30	Bad
2	Industry	2	45	12	Good
3	Aquaculture	1	27	18	Good
4	Saltpan	2	24	12	Good
5	Agriculture	2	19	18	Excellent
6	Upper reaches	1	51	72	Average
7	Middle reaches	2	12	18	Excellent
8	Lower reaches	4	2	24	Excellent
9	Post-monsoon (all stations)	19	13	114	Excellent
10	Pre-monsoon (all stations)	19	30	114	Good
11	Monsoon (all stations)	19	75	114	Bad

Out of four regions, three areas namely Bahuda, Gopalpur and Rushikulya the water were classified as '*good*' while in the other area i.e. Chilika the water categorized as *'worst'*. Spatially, the middle and lower reaches of each estuary were identified as excellent whereas the upper reaches were classified as average. Seasonally, the water quality in monsoon was bad whereas in post and pre- monsoon periods it was good and excellent respectively. Fig-2 depicts the spatial variation of CWPI in all the regions of the study area. A significantly increase (analysis of variance [ANOVA], $p< 0.05$) in mean CWPI from two polluted regions was noted (Figs. 2a and 2e). The approach adopted in developing the CWPI index in this study was based on PCA of the water chemistry data. As of multivariate statistical technique, PCA has largely been used in identification of patterns of environment contamination [16, 17, 18, 19, 20, 21] and the relationship between abiotic and biotic factors [22, 23, 24, 25]. The use of PCA for proper understanding of a CWPI has, however, not been demonstrated. [26] made use of PCA to interpret sediment chemical composition and calculated "pollution scores" on the basis of regression model derived from PCA results.

Due to large number of variables and study location, it was necessary to use PCA to reduce dimensionality of the complex data set, so as to make sense of the variation observed [27]. The present result shows that all the 12 variables are found to be important in contributing to the variation of monitoring data. Of these 12 variables identified from PCA all the physico-chemical from parameters are indicators of water pollution from anthropogenic activities [28].

It is interesting to note that the rating of CWPI was maximum from areas polluted with sewage. It may be due to the indiscriminate discharge of untreated domestic sewage, intensive hatcheries and semi intensive aquaculture waste to the coastal sea. However, lower contribution is exhibited at agricultural and estuarine zones resulting from limited dispersion of pollutant due to poor flushing of average chemical component over monitoring period and diluted by incursion of non-polluted naritic water. It shows that the variation of CWPI value could usually be explained by influx of anthropogenic material derived from surrounding urban, domestic and aquaculture sources.



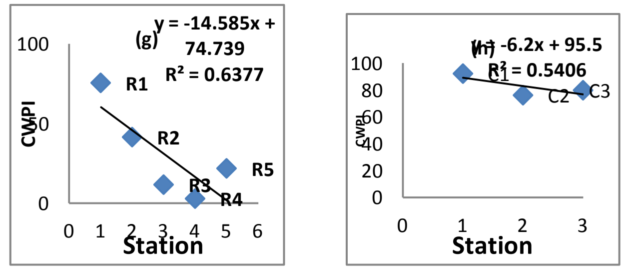


Fig. 2 : Spatial and seasonal change of water quality index in different polluted regions of Orissa coast.

CWPI rating in the present study showed average quality at upper reaches (51.0) whereas excellent quality was found at middle (12.0) and lower (2.0) reaches of all the estuarine. Almost all the major pollutant sources viz. Sewage, aquaculture, industrial and terrestrial organic load fall near upper reaches resulting in contamination whose intensity gradually decreases towards the mouth region due to dilution and dispersion into coastal water. This is also reflected in high nutrient concentration at upper reaches as compared to lower ones. Seasonal variation of nutrient in the upper reaches were found 361.7±13.1, 229.7±23.9, 135.7±13.1 μg l^{-1} for nitrogen and 236.6±8.05, 164.7±11.1, 98.7±8.05 μg l^{-1} for phosphorous during monsoon, post monsoon and pre monsoon respectively. The overall N: P: Si ratio for the study area were found 3.3:1:48.6, 3:1:43.6 and 2.9:1:48.4 during monsoon, post-monsoon and pre monsoon respectively indicating the deviation from Redfield ratio and nitrogen limiting condition [29]. Dissolved oxygen showed 79.6, 59.4 and 51.6 percentage of saturation during monsoon, post monsoon and pre monsoon respectively. Considerable decreases of saturation of DO could be due to the impact of BOD load of 4.78 ± 1.09 mg l^{-1} during monsoon compared to non- monsoon season (Table-1). There is a significant negative relationship between nutrients and salinity ($p<0.01$), which signify that the main sources of nutrient are from anthropogenic activity and land run-off. [30] observed the higher concentration of nitrogen (292-439 μ gl^{-1}) and phosphorus (40-71 μ gl^{-1}) of Hoogly river compared to that of worldwide average river water concentration (N: 226 μ $gl^{-1}$and P: 20 μ gl^{-1}) due to the release of about 379,000 kg d^{-1} discharge from domestic and industrial sources, 8,200 t nitrogen yr^{-1} and 900 t phosphorus yr^{-1} from agricultural waste. [31] pointed out that the nutrient concentration especially silicate and nitrate were high at lower salinity (lower reaches) and lower at higher salinity (upper reaches) in the Rushikulya estuary. According to [32], values of dissolved silicon were highest in the up-stream region of Vellar estuary because dissolved content of silicon was very high in river water. He also suggested in upper reaches, the removal was about 12% but in lower reaches it was greater because of mixing of river water with seawater. In present study the decrease of nutrient ratio with salinity was observed 11.0% for N, 9.0% for P and 8.6% for silicon during the period monsoon, pre-monsoon and post monsoon indicating their removal in coastal water.

Conclusion:

Seasonal variation of CWPI in coastal marine ecosystem depends on the freshwater influx, tidal and physical, chemical and biological changes. In present investigation, CWPI (75) reveals the degradation of water quality during monsoon as compared to post monsoon (12) and pre monsoon (29) seasons. This may be attributed to the effect of precipitation and river runoff containing high organic load from terrestrial origin into the adjoining estuarine and coastal environment, reflects the pollution status of the study area, where as pollutant load was low in non-monsoon period due to utilization by phytoplankton in estuarine and coastal area [33]. In Mandovi estuary, [34], suggested minimum concentration of nutrient found in pre-monsoon after phytoplankton blooming, subsequently nutrient maximum was observed during monsoon Period. Views too that nutrients were more pronounced during monsoon as compared to non-monsoon period [35]. In the present study the average water quality was noticed to be good (CWPI= 28) in Bahuda, Excellent (18) in Gopalpur, good in Rushikulya and worst in Chilika. High CWPI at Chilika compared to other region is to the combined effect of domestic sewage (C1=93, C3=80, &R1=76), aquaculture (C2=77) and industrial (R2=42) wastes discharges.

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