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Water Quality Monitoring using Water Quality Index from Estuarine Water body of Par River, South Gujarat, India

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Abstract

The basic foundation of water resources management is monitoring of water quality. For this case study, seasonal assessment of water quality has been carried out and a water quality index (WQI) is established. Monitoring of water quality from Par River estuary was carried out form the period of January to December 2019. Results showed that water quality index of the water body which lies between 105.66 - 180.40 indicate poor water quality. The water quality index was quite higher during summer season and site wise at downstream site. The water quality during monsoon period was less poor in comparison to summer and winter seasons. Over the period of a year, WQI was 164.28 and 131.20 for downstream station and upstream station respectively. Results further revealed that water quality in the coastal region showed more seasonal fluctuations due to more rapid changes in hydrologicalas well as climatic properties. Cluster analysis was attempted to explain the assemblages of objects. The generated dendrogram grouped the sampling sites and seasons and revealed that water quality over the year has affinity of winter's water quality > summer's water quality > monsoon's water quality. Linear Regression Analysis revealed nature and magnitude of relationships among various independent variables and dependent variables. The regression relations may be used to continuously estimate constituent concentrations in Par river estuary and these estimates may be used to continuously estimate concentration loads.

Keywords: Water quality monitoring, Estuary of Par River, Water quality index, Cluster analysis, Linear Regression

INTRODUCTION

The abundance and biodiversity of marine organisms as well as recreational utility of the coast are directly or indirectly affected by the water quality of respective water bodies. Hence, evaluation agenda of aquatic ecosystems have a significant property in water quality management. Due to mixing of both freshwater and marine environment, Estuaries are characterized by pronounced gradients of physical and chemical components (McLusky, 1993). Major estuaries are usually classified into three types based on their longitudinal salinity distribution and flow characteristics: i) highly stratified or salt wedge, ii) partially mixed, and iii) well mixed (Pritchard, 1989). However, for many systems wherein physical forces are highly variable, such as the shallow macrotidal estuaries (Trigueros and Orive, 2000), assigning to one estuary type considering temporal (seasonality, tidal cycle variation) and spatial (lower, intermediate, upper estuary) variations is difficult. The structure and functions of estuaries are controlled by internal processes as well as by adjacent land and sea. Coastal zones and estuaries are important ecological systems and resources for variety of uses. The total life on the earth depends on the water for different purposes. 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 (Ranjana et. al., 2013). Estuaries are socio - economically important in terms of coastal activity of societies as they are used for recreational fishing, boating, and tourism. Unfortunately, the increased human interferences have been degrading the quality of these vital ecosystems (Costanza et. al., 1997). Water quality of estuaries and their contiguous river-stretches are often badly affected by a variety of human activities. Therefore, it is essential to monitor their water quality on seasonal bases (Gupta et. al., 2018).

The rapid industrialization, urbanization, agricultural activities and other anthropogenic activities along the estuarine system and the coastal areas have brought considerable decline in the water quality of the estuaries. These activities lead to alternation of physical, chemical and biological quality of water. Organic pollution of water bodies is one of the most significant issues in present days (Bordoloi and Baruah, 2014). Agricultural wastes, industrial effluents and urban activities are considered to be the primary source for increasing nutrient load in coastal environment (Kucuksezgin et. al., 2006). Excessive component loading from the surrounding has been deteriorating water quality of water bodies (Carpenter et al., 1998; Smitha et al., 1999). Physico-chemical parameters of any water body though, provide a good indication about the water chemistry and quality, that alone does not reflect the clear picture of the ecological condition of the water body due to lack of proper integration with ecological factors (Karr et al., 2000). Uncontrolled discharges of domestic wastes and industrial effluents have affected the Par river estuary. The study showed that the water quality of Par river estuary at Atul and Umarsadiwas affected by the industrial and anthropogenic activities respectively. Patel and Vaghani (2015) highlighted that the water of the Par River showed serious threat to the ecosystem due to anthropogenic pollution.

Water quality is difficult to be evaluated from a large number of samples, each containing varying concentrations of various water quality variables. Most of the studies related to the assessment of the water resources quality use several water quality indices, among them the most important are the water quality index (WQI) and the water pollutionindex(WPI) (Dunca, 2018). The Water Quality Indices (WQI) is among the most effective way to communicate the information on water quality trends for the water quality management. A Water Quality Index (WQI) is a means by which water quality data is summarized for reporting to the public in a consistent manner. It is similar to the UV index or an air quality index. Water quality index was for the first time used to highlight the physico-chemical changes that may occur during the year on the flowing water quality (House and Ellis, 1987).Most often, the water quality index is used in the evaluation of surface water quality. This index incorporates data from multiple parameters into a mathematical equation that rates the quality of water bodies. The present investigation was carried out to calculate the Water Quality Index (WQI) in order to assess the quality of estuarine waters of Par River, Valsad.

The objective of the study was to describe and discuss inter-annual and seasonal changes of water quality based on indicators monitored in Par River estuary, as well as identifying the main drivers of such changes. We considered two estuarine areas or habitats (upper estuary and lower estuary), and three seasons (winter, summer and monsoon) for anchoring sample design.

2.MATERIALS AND METHODS

2.1 STUDY AREA:

Table 2.1: Sampling stations and their geographical locations

Stations	Downstream	Upstream
Latitude (N)	**20.5321**°	**20.5291**°
Longitude (E)	**72.8897**°	**72.9441**°

Valsad district is situated in the southern division of Western Indian state of Gujarat. Among the 1600 km coastline of Gujarat; Valsad district has 73 km of coastline. There are four economically and ecologically valuable rivers: Damanganga, Kolak, Par and Auranga. Par is a river in south Gujarat with its springs from near Paykhad village in Maharashtra, has a maximum length of 51 km. The total catchment area of the basin is 907 square kilometres (350 sq mi) (Figure 2.1.2). It flows through Valsad district and discharges into the Arabian Sea near Umarsadi, Pardi. The estuarine region of the river is situated across Umarsadi and Atul village in Pardi (Figure 2.1.1). Par River is very important for the socioeconomic life in the southern Gujarat.

The water intakes from Par hydrographical system are providing the drinkable as well as agricultural water supply or the use of water for industrial purposes as well as domestic purposes, which can influence the river hydro-morphological level, changing the features of the natural water discharge regime on their courses.

Figure 2.1.1: Map showing the filed station in the present stuady area of South Gujarat

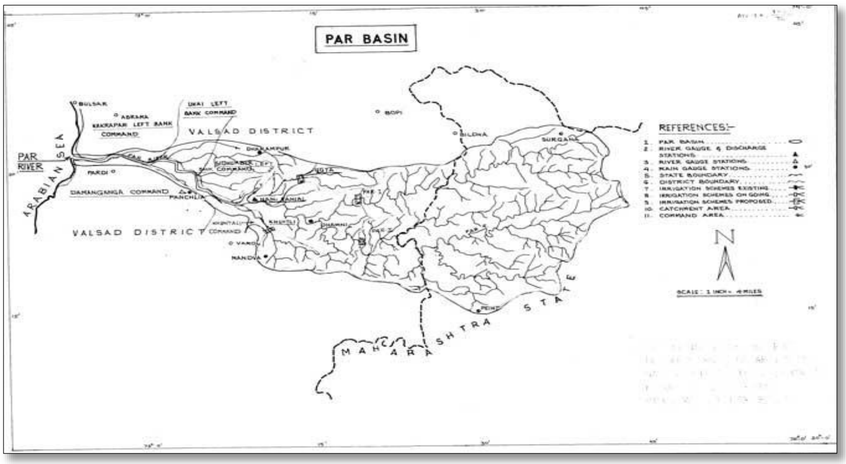


Figure 2.1.2: Map of the Par River Basin

2.2 SAMPLE COLLECTION:

Table 2.2: Water sampling frequency from downstream and upstream during different seasons

Water Sampling Frequency		Sampling Stations	
		Downstream (Site 1)	**Upstream (Site 2)**
	Winter	**12**	**12**
	Summer	**12**	**12**
	Monsoon	**12**	**12**

The water samples were collected in pre-cleaned plastic polyethylene bottles for physico-chemical parameters analysis (George et. al., 2015) throughout the year which include all three seasons; winter, summer and monsoon from January to December, 2019 based on bimonthly intervals. The sampling activity was conducted from four sites (two sites belong to downstream station and the other two sites belong to upstream station) of the Par river estuary. The three samples were collected from each site and then made into composite samples, so total 24 samples were analyzed that includes physicochemical parameters including heavy metals. The sampling sites were selected based on resources available for sampling, experimental sampling and to check water quality parameters. The water samples were collected by using 1 liter clean polythene bottle and stored in ice box at 4˚ C temperature and then it was transported to the laboratory as soon as possible for physicochemical parameter analysis. The estuarine water samples were fixed in 300 ml BOD bottles for the immediate estimation of dissolved oxygen and measurement of biochemical oxygen demand after 5 days of incubation at 20˚ C in incubator. The variables like

Temperature, pH, Electrical conductivity and Dissolved oxygen were assessed at the time of sampling on the site(George et. al., 2015).

2.3 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 NVPAS laboratory. Water temperature was determined by the Thermometer (Bel-Art; Model: B60800-3100), Electrical Conductivity was determined through the digital conductivity meter (DiST: Hanna instruments) and pH was measured by pH meter (pHep®: Hanna instruments) on site during the sampling. Turbidity was measured by the digital turbidity meter (Model: 331). Colour was analyzed in SICART (Model: HACH-DR 2010). Salinity was determined by using Salinometry (Model: SSM 21). TSS, TS and TDS were measured by the Gravimetric method. Alkalinity, Free CO_2, 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 (Model: HACH-DR 2010). Nitrate, Inorganic Phosphate and Silicate were determined by the help of Spectrophotometer (Model: 302). Sodium and Potassium were analyzed by the Flame photometric method (ESiCO - Digital flame photometer model: 381; ESiCO - Compressur unit model: 380). Sulfate was analyzed by the Turbidimetric method (Model: 302). Heavy metals (Boron, Zinc and Iron) were analyzed through the Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES) (Model: Perkin Elmer, USA) in SICART.

2.4 WATER QUALITY INDEX:

Most often, the water quality index is used in the evaluation of water quality. This index incorporates data from multiple parameters in to a mathematical equation that rates the quality of water bodies with numbers which can be separated in five classes, each class with a different quality state and with a different usage domain (Tyagi et. al., 2013).

The two steps water quality index calculation method was adopted. Firstly the more reflected parameters are chosen from the 27 parameters from the study area. Secondly, using the quality curves, and for the weights of selected parameters, an integrated WQI score is constructed.

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

$$\mathbf{WQI = \Sigma\ QiWi / \Sigma\ Wi}$$

(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 2.4.

Table 2.4: Coastal water quality ranking criteria (Vishnupriya, 2015)

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

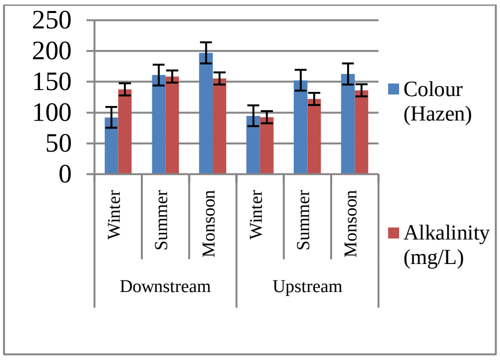
2.5 Statistical Analysis: Some univariate(Linear Regression) and multivariate (Cluster Analysis) statistical analysis were carried out by using PAST 3.0 software.

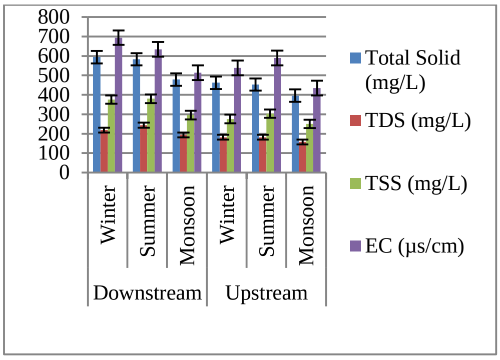
3. RESULT AND DISCUSSION:

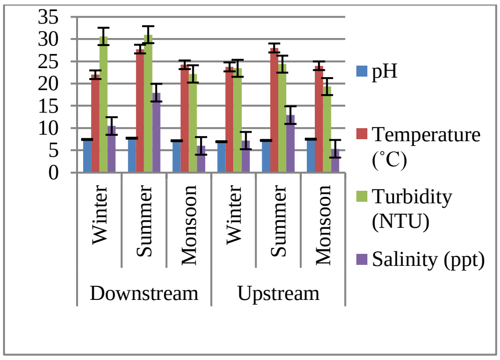
For given estuarine water body the water quality is the result of several interrelated parameters with a local and temporal variation which are influenced by the water flow rate during the year (Mandal et. al., 2010).

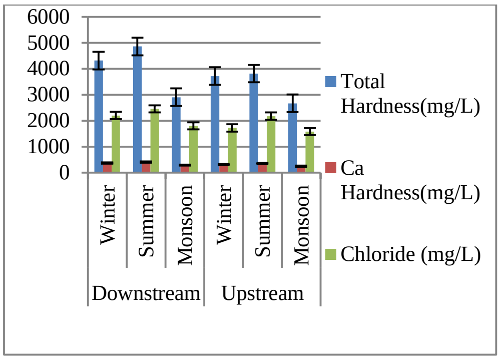
3.1 Water quality assessment: In the case study area, initial total 27 parameters were assessed. The downstream site is at Umarsadi fishing point where hydrological systems are highly affected by the tidal condition and the upstream site is near urban and industrial area, Atul, Pardi town. Hence the study field suffers from serious domestic as well as commercial pollution. Tables 3.1.1 and 3.1.2 are showing the statistical description of all checked physico-chemical variables. All the average distribution was consistent with seasonal fluctuations for this estuarine region (Figure 3.1).

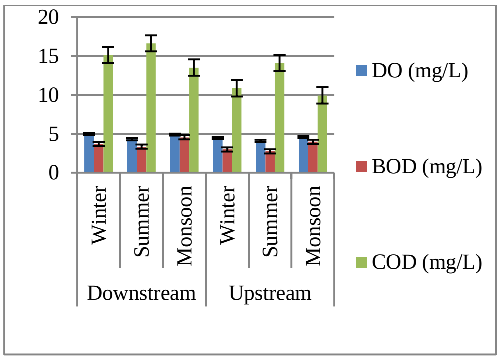
In this study, the minimum and maximum value of colour was observed during winter (36.19 ± 7.22) and monsoon (189.92 ± 22.98) respectively. This seasonal colour changes of water mostly showed at downstream station may be due to the more tidal affect and more turbid addition of organic compounds with sedimental material. The water was very turbid during winter (36.41 ± 3.33) might be due to the water containing more sedimental materials and less turbid during monsoon (9.34 ± 1.02) because of the freshwater addition due to the rainy season (Ranjana et. al., 2013).

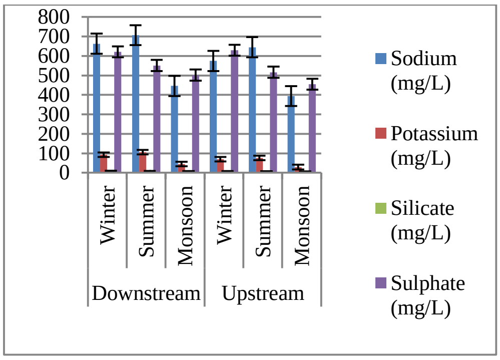

250
200
150
100
50
0
Winter
Summer
Monsoon
Winter
Summer
Monsoon
Downstream
Upstream
Colour (Hazen)
Alkalinity (mg/L)

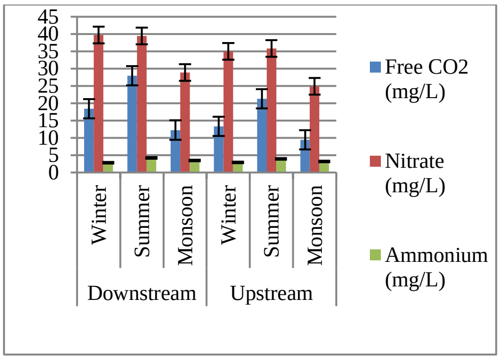

800
700
600
500
400
300
200
100
0
Winter
Summer
Monsoon
Winter
Summer
Monsoon
Downstream
Upstream
Total Solid (mg/L)
TDS (mg/L)
TSS (mg/L)
EC (µs/cm)

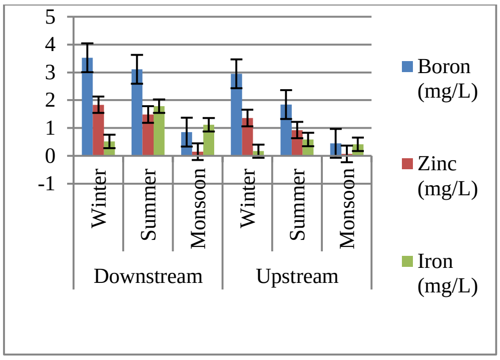

35
30
25
20
15
10
5
0
Winter
Summer
Monsoon
Winter
Summer
Monsoon
Downstream
Upstream
pH
Temperature (˚C)
Turbidity (NTU)
Salinity (ppt)

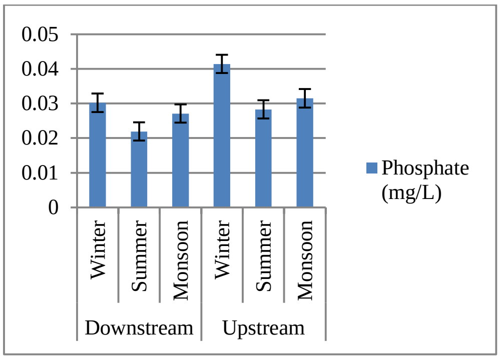

6000
5000
4000
3000
2000
1000
0
Winter
Summer
Monsoon
Winter
Summer
Monsoon
Downstream
Upstream
Total Hardness(mg/L)
Ca Hardness(mg/L)
Chloride (mg/L)


20
15
10
5
0
Winter
Summer
Monsoon
Winter
Summer
Monsoon
Downstream
Upstream
DO (mg/L)
BOD (mg/L)
COD (mg/L)


800
700
600
500
400
300
200
100
0
Winter
Summer
Monsoon
Winter
Summer
Monsoon
Downstream
Upstream
Sodium (mg/L)
Potassium (mg/L)
Silicate (mg/L)
Sulphate (mg/L)


45
40
35
30
25
20
15
10
5
0
Winter
Summer
Monsoon
Winter
Summer
Monsoon
Downstream
Upstream
Free CO2 (mg/L)
Nitrate (mg/L)
Ammonium (mg/L)


5
4
3
2
1
0
-1
Winter
Summer
Monsoon
Winter
Summer
Monsoon
Downstream
Upstream
Boron (mg/L)
Zinc (mg/L)
Iron (mg/L)



More turbid water was found at downstream in comparison to upstream, reason can be the wide estuarine down reaches area has more sedimental containing water as well as more coastal water. Temperature was higher during summer at the downstream with 27.75 ± 1.70 and at the upstream with 28.00 ± 1.00 and lower during winter (22.00 ± 2.16) at the downstream. Similar observation was found from Tapi river estuary (Dubey and Ujjania, 2015). Total solids, Total dissolve solids (TDS) and Total suspension solids were more during winter (594.48 ± 93.94; 218.85 ±23.66; 375.70 ±65.49) and less during monsoon (478.70 ± 76.61; 193.83 ± 28.43; 295.90 ± 51.08). The similar report is available from Tapi estuary, Surat (Ranjana et. al., 2013). Electrical conductivity (EC) of the water depends on the salts contaminations under water. So, EC of this water body was higher in winter (690.41 ±110.14) with higher Total solids and lower in monsoon (423.40 ± 84.28). The maximum pH was recorded from downstream during summer (7.72 ± 0.42) and minimum from upstream during winter (6.95 ± 0.23). Total and Calcium hardness accounted more in the estuarine water body due to the coastal hydrological effects. In this study, total and calcium hardness were higher in summer (4860.25 ± 395.79; 400.07 ± 49.21) followed by winter (4116.00 ± 100.10; 369.54 ±146.65) and monsoon (2903.29 ± 284.55; 286.72 ± 45.25). This record was supported by Gaspar and Lakshman from Thamirabarani estuary (2014). Alkalinity also more concentrated at the downstream than upstream because of the more amount of sea water. It showed minimum and maximum concentration during winter (92.59 ±7.91) and summer (258.72 ± 26.65) season respectively. This study had similar result of the study from Marine National Park and Sanctuary, Sikka, Okha and Khijadiya (Salvi et. al., 2014). The organic materials, nitrogenous wastes, industrial wastes and animal excretions caused pollution that indicated the presence of chloride in the water body (Dubey and Ujjania, 2015). As like hardness, chloride was also more during summer (2455.85 ± 209.50) might be due to the high salinity, tidal flow and less freshwater content due to the decreased current of water and lower during monsoon (1577.16 ± 164.58) because of the increased current of freshwater due to heavy rain. Similar result was reported from Tapi estuary, Hazira (Gadhia et. al., 2012). The distribution of biotic components is governed by the limiting factor called salinity in the coastal ecosystem, it's changes occurred due to the evaporation as well as influx of freshwater from land run off caused by monsoon or by tidal variations lead to dilution of water (Pandit and Fulekar, 2017). Maximum salinity was reported during summer at the downstream (20.94 ± 2.63) and minimum during rainy season at the upstream (3.53 ± 2.24). The finding about salinity from Mahanadi estuary (Upadhyay, 1988) and from Sundarban mangroves estuarine system was maximum salinity was showed during dry winter and minimum during monsoon season (Rahaman et. al., 2013). The atmospheric evasion and carbon cycling majorly exist on estuaries (Jeffrey et. al., 2018). The photosynthetic metabolism, temperature intervention and anthropogenic inputs are key drivers of CO_2. Free CO_2 was maximum during summer (27.94 ± 11.03) and minimum during monsoon (09.43 ± 1.75). Temperature and salinity affected on dissolve oxygen (DO) of water; optimum content of DO is crucial for maintaining aesthetic qualities of water as well as for supporting life (Gadhia et. al., 2012). Dissolve Oxygen (DO) content varied from 4.11 ± 0.42 to 4.99 ± 0.70 between these two sites. Higher content of DO was found during winter and lower during summer. This data supported from the Sundarban mangrove estuary from Bangladesh (Rahaman et. al., 2013). BOD values were range from 2.37 ± 0.53 to 4.70 ± 0.88 during these seasons between these sites. BOD had more concentration during monsoon (4.55 ± 0.71) and less during summer (2.76 ± 0.84). More concentration of BOD might be due to the degradation of organic compounds as well as vegetation in the water body (Gadhia et. al., 2012). The presence of Chemical oxygen demand (COD) is one of the indicator of organic contamination, which is caused by the household inflow, livestock materials and industrial waste input that raised the levels of organic pollutants (Gadhia et. al., 2012). COD was high during summer at the downstream (16.65 ± 3.90) and low during monsoon at the upstream (9.95 ± 0.99). Similar outcome on seasonal variation of COD was reported from Atoyac River basin, Central Mexico (Martinez et. al., 2017). The nutrient components moderate the high COD value. The high COD content might be due to the runoff from surroundings like agricultural, industrial and domestic fields.

The growth, metabolism and reproduction of biotic organisms mainly depend on the presence of nutrients. Spatial and temporal conditions, fresh water inputs and tidal conditions have impact on the nutrient distribution (Pandit and Fulekar, 2017). The maximum phosphate was recorded from upstream site during winter (0.0414 ±0.0028) and minimum from downstream during summer (0.0219 ± 0.0023). According to Pandit and Fulekar (2017) migration and diffusion of phosphorus from the sedimental pore water to laminating water lead to the high concentration of phosphate. Similar findings were reported from Mandovi estuary (Fernandes et. al., 2018); Bay of Bengal, Vishakhapattanam, India (Vishnupriya, 2015); Pashurtala, Sundarban mangrove ecosystem, Bangaldesh (Rahaman et. al., 2013); Merbok estuary, Malaysia (Fatema et. al., 2014). The minimum value of nitrate was due to the low flow rate while maximum due to agricultural runoff and decaying the vegetation (Dubey and Ujjania, 2015). Another possible way of nitrates existence is the oxidation of ammonia form of nitrogen to nitrite formation mechanism (Gadhia et. al., 2012). In this study, nitrate concentration was similar during winter (39.70 ±6.22) and summer (39.44 ± 2.39) at the downstream station that is maximum and during monsoon it was minimum (24.94 ± 3.07) at the upstream. The concentration of nitrate also recorded from Tapi estuary, Hazira (Gadhia et. al., 2012). The high contamination of ammonia mainly due to the surface runoff refuse, more algal growth and excretion of ammonia by living organisms (Pandit, P. R., and Fulekar, M. H. (2017). Ammonium was higher (4.19 ± 0.52) during summer and lower (2.83 ± 0.28) during winter period. Similar report from Merbok estuary, Malaysia is available (Fatema et. al., 2014). The geological and biological conditions of an area lead to the conservative or non-conservative behavior of silicate as well as temporal fluctuations in $Si(OH)_4$ concentrations (Fernandes et. al., 2018). In the present study, silicate was higher during winter (10.25 ±1.65) and lower during monsoon (5.83 ± 0.75). The sources of silicate contamination seems to be preliminary the natural environmental conditions of the rocks and erosion of water body. Sodium and Potassium were found more during summer at the downstream (707.09 ± 51.83; 105.31 ± 21.48) and less during monsoon at the upstream (393.76 ± 78.05; 29.20 ± 12.08). The reason of this seasonal fluctuation might be the high salinity during summer and heavy rainfall during monsoon. Similar record was observed from Tapi estuary, Hazira (Gadhia et. al., 2012). Sulphate concentration was higher during winter (621.84 ±64.48; 629.21 ±128.99) followed by summer (551.18 ± 77.27; 516.59 ± 65.88) and monsoon (501.88 ± 30.54; 454.57 ± 37.02) at the both sites of the estuary. The sources of sulphate in this field might be the degradation of organic compounds release sulphate with hydrogen and photochemical degradation process also liberated sulphate. The similar seasonal variation of sulphate was recorded from Sundarban mangrove estuary, Bangladesh (Rahaman et. al., 2013).

The main source of boron in the ecosystem is the atmospheric condition of rocks, volatilization of boric acid from seawater, and volcanism. Boron is also liberated from anthropogenic sources to a lesser extent which includes agricultural waste and combustion of fuel wood, coal and oil, fabrication of glass products, domestic as well as industrial uses of borates/perborates, ejection of sewage/sludge and leaching of treated wood/paper (Emiroglu et. al., 2010). The maximum concentration of boron was showed during winter at the downstream (3.5216 ±0.68) and minimum during monsoon at the upstream (0.4491 ± 0.27). The supported result was found from the Kirka, Turkey (Emiroğlu et. al., 2010). Zinc was more accumulated at the downstream than upstream of the estuary. It was more during winter (1.8354 ±0.32) and less during rainy season (0.0657 ± 0.01). Similar record was found from some estuaries of U.K. (Stockdale et. al., 2015); Er-Ren estuary, Taiwan (Chen et. al., 2014) and from shallow estuary (Priya et. al., 2014). Estuaries are suitable places for iron trapping. In this case, Iron had higher concentration during summer at the downstream (2.2866 ± 0.22) and lower during winter at the upstream (0.1284 ±0.08). Similar range of iron concentration was found from Ravenglass estuary (Daneshvar, 2015) and some estuaries of U.K. (Stockdale et. al., 2015). The loadings of heavy metals in the water body might be due to the industrialization and urbanization and anthropogenic activities.

Table 3.1.1: Statistical description of checked water quality parameters at downstream station

Variables	Min.	Max.	Mean ± SD	Skewness	Kurtosis	Coeff. Var.
Colour (Hazen)	61.55	189.44	124.56 ± 52.30	-0.077	-1.959	28.126
Alkalinity(mg/L)	119.85	213.71	150.20 ± 20.69	0.2319	-0.8876	13.778
Total Solid (mg/L)	385.63	698.17	540.39 ± 106.20	0.0046	-1.0934	19.665
TDS (mg/L)	104.41	364.44	218.43 ± 41.637	0.9237	1.0976	15.062
TSS (mg/L)	237.66	442.58	350.75 ± 66.084	-0.1391	-0.3733	18.268
pH	6.7	8.3	6.39 ± 0.470	0.2089	-0.4267	6.3620
Temperature (˚C)	19	30	24.55 ± 3.323	-0.022	-0.114	13.533
Free CO_2 (mg/L)	9.87	27.83	19.434 ± 9.057	1.137	0.769	42.607
Salinity (ppt)	4.96	20.44	11.605 ± 5.528	0.377	-1.314	47.63
TH(mg/L)	2622.51	5230.00	3970.428 ± 983.99	-0.114	-1.864	24.78
Ca Hardness(mg/L)	232.24	515.92	354.186 ± 94.152	0.402	-0.541	26.582
Turbidity (NTU)	10.22	36.41	21.693 ± 5.609	-0.177	-0.331	20.255
EC (µs/cm)	48.70	1420.00	680.40 ± 145.	0.249	-0.972	15.229
Chloride (mg/L)	1520.55	2655.30	2110.60 ± 380.385	-0.0023	-1.378	18.035
DO (mg/L)	3.76	5.80	4.707 ± 0.614	0.250	0.059	13.053
BOD (mg/L)	0.00	4.70	3.825 ± 0.625	-0.044	-1.078	16.359
COD (mg/L)	10.54	24.58	15.025 ± 3.477	0.285	-0.955	23.144
Phosphate(mg/L)	0.0198	0.0329	0.0264 ± 0.004	0.165	-1.151	17.126
Nitrate (mg/L)	15.67	34.12	25.386 ± 6.588	-0.0377	-0.822	18.383
Ammonium (mg/L)	1.28	4.63	3.425 ± 1.159	-0.479	0.190	33.84
Sulphate (mg/L)	163.58	481.50	253.925 ± 442.162	0.520	-0.537	13.027
Sodium (mg/L)	246.81	765.23	498.90 ± 143.127	-0.589	-0.760	23.915
Potassium (mg/L)	24.53	184.77	93.737 ± 57.374	0.591	-0.884	61.207
Silicate (mg/L)	6.26	18.38	11.945 ± 1.924	0.485	-0.275	21.510
Boron (mg/L)	0.3356	4.2031	2.4242 ± 1.4202	-0.187	-1.475	58.590
Zinc (mg/L)	0.0476	2.6522	1.242 ± 0.902	0.088	-1.068	72.668
Iron (mg/L)	0.3895	2.2648	1.1383 ± 0.6956	0.4066	-1.4164	61.112

Table 3.1.2: Statistical description of checked water quality parameters at upstream station

Variables	Min.	Max.	Mean ± SD	Skewness	Kurtosis	Coeff. Var.
Colour (Hazen)	36.14	147.83	93.45 ± 11.513	-0.064	-1.657	30.97
Alkalinity(mg/L)	85.25	177.62	118.92 ± 26.795	0.638	-0.385	22.532
Total Solid (mg/L)	284.17	514.82	339.748 ± 61.472	0.088	-0.735	13.979
TDS (mg/L)	95.53	256.55	126.49 ± 40.855	0.854	0.512	23.148
TSS (mg/L)	209.45	412.28	289.575 ± 64.264	0.530	-1.000	22.192
pH	6.8	8.5	7.92 ± 0.370	0.352	-1.173	5.085
Temperature (˚C)	20	29	25.19 ± 2.788	-0.528	0.037	11.069
Free CO_2 (mg/L)	6.31	24.81	12.83 ± 6.607	1.148	0.589	44.557
Salinity (ppt)	3.76	13.55	8.55 ± 4.096	1.011	0.582	47.905
TH(mg/L)	1384.30	3664.50	2410.88 ± 760.808	0.261	-1.010	22.305
CaHardness(mg/L)	184.65	375.44	281.485 ± 68.124	0.0032	-1.326	22.596
Turbidity (NTU)	2.04	15.48	8.136 ± 4.145	0.0051	-0.340	18.539
EC (µs/cm)	40.85	784.00	473.97 ± 51.57	-0.1312	-1.529	14.210
Chloride (mg/L)	765.73	2437.14	1440.38 ± 264.977	0.282	-1.088	19.832
DO (mg/L)	3.46	4.92	4.30 ± 0.505	-0.659	-0.489	11.759
BOD (mg/L)	0.37	2.23	1.294 ± 0.464	-0.109	-1.541	20.758
COD (mg/L)	7.29	17.86	11.522 ± 3.109	0.938	1.2604	26.9897
Phosphate(mg/L)	0.0216	0.0449	0.0340 ± 0.0073	-0.252	-0.612	21.685
Nitrate (mg/L)	08.68	19.08	11.055 ± 3.067	-0.2168	-1.4070	19.118
Ammonium (mg/L)	0.87	3.11	1.891 ± 0.985	-0.6709	1.6134	29.289
Sulphate (mg/L)	94.39	322.51	127.91 ± 45.924	0.9111	0.1912	19.0848
Sodium (mg/L)	122.89	588.34	337.615 ± 90.256	-0.4104	-1.1284	24.2214
Potassium (mg/L)	16.59	140.37	68.808 ± 42.111	0.5980	-0.6544	61.1999
Silicate (mg/L)	5.28	9.51	6.997 ± 1.276	0.8090	0.7834	18.2438
Boron (mg/L)	0.1337	3.7256	1.7237 ± 1.1679	0.3143	-0.5122	67.7573
Zinc (mg/L)	0.0412	1.8464	0.7849 ± 0.6414	0.2317	-1.0430	81.7182
Iron (mg/L)	0.1284	0.6628	0.4004 ± 0.1950	-0.2327	-1.5607	48.6965

Table 3.1.3: Water Quality Index of over the year and relative weight and quality ranking of selected parameters

	Index/ Rank (wi)	Quality Rate (qi)	
		Downstream (Site 1)	Upstream (Site 2)
Chloride	1	882.89	727.47
Boron	2	341.50	247.74
Zinc	2	281.36	160.78
Iron	2	386.73	139.10
Phosphate	2	264.00	339.00
Sulphate	2	225.94	219.38
Silicate	2	312.50	226.78
DO	3	130.75	118.00
Ammonium	3	165.00	147.27
pH	4	87.76	84.11
Temperature	4	82.76	87.76
Turbidity	4	98.63	77.20
Ca Hardness	4	68.46	60.24
Nitrate	4	73.92	68.18
TDS	5	21.95	16.26
WQI		164.28	131.20

Table 3.1.4: Water Quality Index based on seasonal monitoring

Season	Water Quality Index (WQI)	
	Downstream (Site 1)	Upstream (Site 2)
Winter	166.39	143.56
Summer	180.40	140.34
Monsoon	126.97	105.66

Water Quality Indices are established from important physico-chemical parameters for all three seasons and for the period of one year to understand the coastal water quality better for the general public. A lower value of WQI would indicate a better quality of water whereas high values indicate poor quality of water. The traditional WQI take into consideration DO, BOD, pH, faecal coliforms, nitrate, phosphate, turbidity, temperature and total solids (Li et. al., 2019). Total 15 water quality parameters were selected from 27 parameters for computation of WQI in this case study. Selection of important parameters can eliminate the influence of unimportant parameters that can give more accurate evaluation result. The computed values of water quality index for Par river estuary from all the three seasons were lays between 105.66 to 180.40 means between 100 to 200 which indicated the poor water quality of this water body (Table 2.4). The water quality index over the year was 164.28 at the downstream and 131.20 at the upstream which indicate poor water quality at the both sites (Table 3.1.3). The water of this estuary was less poor in monsoon season with the WQI of 126.97 and 105.66 at downstream and upstream respectively, moderately poor at downstream during winter (166.39)and highly poor quality (180.40) during summer season at downstream site (Table 3.1.4). The reason behind might be the dilution of water through the heavy rain water during monsoon, while during winter and summer the flowing rate of water decreased hence the organic and inorganic component contamination was increased. The WQI during winter (143.56) and summer (140.34) were identical at the upstream site (Table 3.1.4). The water quality of downstream site was poorer during all three seasons than upstream site. These Water quality index ranks revealed that the estuarine water of the Par River was affected by increasing anthropogenic activities as well as agricultural and industrial runoff occurred in surrounding area. Hence, this area can degrade the water quality and making it unfit for public use.

3.2 Cluster Analysis: Cluster analysis (CA) is a multivariate statistical technique, which allows the grouping of objects on the basis of their similarity (Bhat et. al., 2014) and therefore it is a very useful tool for the assessment of water quality data to get the relationship among stations and seasons. CA explores assemblages and sets of variables with similar properties, thus potentially allowing us to simplify our description of observations by allowing us to find the structure or patterns in the presence of confusing data. Bray-Curtis cluster analysis is the most common approach of CA, which provides intuitive similarity relationships between any one sample and the entire dataset and is typically illustrated by a dendrogram (treediagram). The dendrogram provides a visual summary of the clustering processes, presenting a picture of the groups and their proximity with a dramatic reduction in dimensionality of the original data (Shrestha and Kazama, 2007). In this study, CA showed strong spatial and temporal association on the basis of variations of principal factors which affected the water body and indicated that the effects of human activities on water quality vary spatially as well as temporally. The dendrogram indicates pollution status as well as the effect of contamination at the sampling sites. It provides a visual summary of the clustering processes, presenting a picture of the groups and their proximity. Cluster analysis (CA) was used to detect similarity between the two sampling sites and three seasons with over the period of a year study. CA generated a dendrogram, grouping all three seasons with sampling sites on the basis of percentage of similarity and dissimilarity of water quality parameters. The dendrogram of percentage similarity of all three seasons as well as throughout the year with sampling sites on the basis of physico-chemical factors is presented in Figure 4. The analysis of similarity at downstream site from 87% to 100% was carried out to indicate relationship intensity between seasons with site as cluster. The Bray-Curtis similarity analysis confirmed that there is a similarity of 98% between YD (over the year) and WD (winter). Contrary to these sites; MD (monsoon) showed maximum dissimilarity with other sites during the entire study period as it is heavy rainy season diluted the water of the body. Hence, the component loadings during monsoon period were less in comparison to other two seasons.

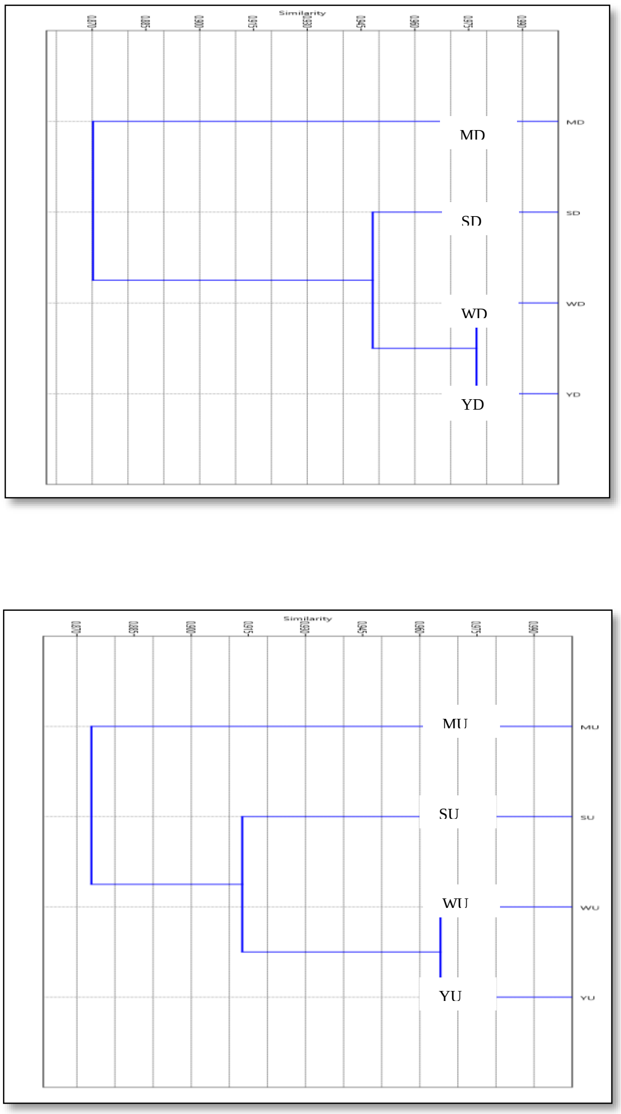


Figure 3.2: Bray-Curtis cluster analysis

The dendrogram of percentage seasonal and station similarity at upstream site shows that there is a maximum similarity of 97% between YU (over the year) and WU (winter) and 82% between winter and summer clusters. Summer and winter clusters showed only 88% similarity with MU (monsoon) and SU (summer) clusters. The generated dendrogram grouped the sampling sites and seasons and revealed that water quality over the year affinity to winter's water quality > summer's water quality > monsoon's water quality.

3.3 Regression Analysis: To explain the nature and magnitude of relationships among various physicochemical parameters, we plotted concentrations of all dependent variables against independent variables. Concentrations of most variables increased with increasing independent variable (Table 3.3). Correlation coefficient -1 to +1 indicate strong negative correlation to strong positive correlation between the variables. This correlation behavior of the variables revealed the qualitative feature of the water body and changes in it. The use of regression analysis is to estimate constituent concentrations provide timely water-quality information to resource managers that are otherwise not available. The regression relations may be used to continuously estimate constituent concentrations in Par river estuary and these estimates may be used to continuously estimate concentration loads.

Table 3.3: The results of linear regression analysis of different variables with results from Kruskal-Wallis test

	Variable	No. of *X* values	α	β	r	R^2	P value (Kruskal-Wallis)
Electrical Conductivity	TDS	08	37	2.72	0.77	0.5929	< 0.0001
	Chloride	08	228.26	30.45	0.85	0.7225	
	Ca Hardness	08	26.58	5.15	0.87	0.7569	
	Sodium	08	-71.02	11.19	0.88	0.7744	
	Sulphate	08	289.79	4.46	0.65	0.4225	
Temperature	DO	08	7.59	-0.11	-0.65	0.4225	< 0.0001
	Free CO_2	08	-25.21	1.68	0.59	0.3481	
	Ammonium	08	-0.26	0.14	0.63	0.3969	
	Phosphate	08	0.059	-0.0011	-0.42	0.1764	
	Nitrate	08	22.47	0.47	0.19	0.0361	
DO	Phosphate	08	0.033	-0.00081	-0.05	0.0025	< 0.0001
	Free CO_2	08	7.81	2.58	0.09	0.0081	
	Alkalinity	08	265.32	-32.41	-0.24	0.0576	
	Nitrate	08	65.93	-7.33	-0.38	0.1444	
	Ammonium	08	-187.67	44.56	0.34	0.1156	
	Iron	08	0.067	0.173	0.12	0.0144	
	Zinc	08	1.55	-0.197	-0.11	0.0121	

Phosphate	Nitrate	08	40.00	-187.71	-0.21	0.0441	< 0.0001
	Chloride	08	3089.1	-36.39	0.69	0.4761	
	pH	08	8.27	-31.69	-0.72	0.5184	
	Ca Hardness	08	464.54	-4622.3	-0.52	0.2704	
	Zinc	08	1.08	-2.86	-0.02	0.0004	
	Iron	08	3.20	-80.83	0.87	0.7569	
TDS	Temperature	08	24.17	0.0048	0.07	0.0049	< 0.0003
	Sulphate	08	390.15	0.81	0.41	0.1681	
	Sodium	08	81.65	2.54	0.70	0.4900	
	Potassium	08	27.48	2.33	0.70	0.4900	
	Silicate	08	-0.22	0.040	0.85	0.7225	
	Boron	08	-2.70	0.024	0.68	0.4624	
Colour	Total Solids	08	563.42	-0.472	0.21	0.0441	< 0.0001
	pH	08	7.09	0.0015	0.21	0.0441	
	Temperature	08	21.33	0.025	0.44	0.1936	
	Turbidity	08	30.65	-0.035	0.29	0.0841	
	Boron	08	5.30	-0.021	-0.71	0.5041	
pH	Alkalinity	08	-328.44	62.77	0.70	0.4900	< 0.0009
	TDS	08	-298.02	67.37	0.56	0.3136	
	Temperature	08	15.27	1.34	0.16	0.0256	
	Free CO_2	08	-72.37	12.24	0.52	0.2704	
	DO	08	4.22	0.060	0.04	0.0016	
	Sodium	08	-274.92	116.54	0.27	0.0729	
Nitrate	Alkalinity	08	133.59	-0.077	-0.01	0.0001	< 0.0006
	pH	08	6.98	0.0097	0.19	0.0361	
	Temperature	08	22.40	0.0789	0.19	0.0361	
	Ca Hardness	08	10.41	9.169	0.92	0.8464	
	Ammonium	08	2.726	0.0202	0.21	0.0441	
	Sodium	08	-138.63	20.85	0.97	0.9409	
	Zinc	08	-3.063	0.118	0.94	0.8836	
COD	pH	08	6.57	0.055	0.51	0.2601	< 0.0001
	Temperature	08	21.66	0.257	0.28	0.0784	
	DO	08	4.418	0.0184	0.11	0.0121	
	Sulphate	08	458.39	6.721	0.26	0.0676	
	Boron	08	-1.416	0.262	0.56	0.3136	
	Zinc	08	-1.175	0.162	0.59	0.3481	
	Iron	08	-1.605	0.177	0.77	0.5929	

Free CO_2	Nitrate	08	22.23	0.705	0.81	0.6561	< 0.0002
	COD	08	7.505	0.343	0.86	0.7396	
	Alkalinity	08	107.99	1.334	0.34	0.1156	
	Salinity	08	-2.377	0.709	0.99	0.9801	
	Ca Hardness	08	184.83	8.179	0.95	0.9025	
	Sodium	08	294.68	16.47	0.89	0.7921	
Turbidity	EC	08	10.419	1.868	0.94	0.8836	< 0.0001
	Total Solids	08	63.07	16.953	0.95	0.9025	
	pH	08	6.55	0.0301	0.51	0.2601	
	Temperature	08	24.365	0.0294	0.06	0.0036	
	Chloride	08	373.58	63.649	0.90	0.8100	
	Sodium	08	23.753	21.766	0.87	0.7569	
Boron	Alkalinity	08	136.07	-2.440	-0.11	0.0121	< 0.0001
	Salinity	08	4.876	2.348	0.60	0.3600	
	Ca Hardness	08	248.53	36.523	0.78	0.6084	
	Potassium	08	322.63	76.051	0.83	0.6889	
	Silicate	08	5.467	1.053	0.79	0.6241	
	Free CO_2	08	9.919	3.453	0.63	0.3969	
Salinity	Alkalinity	08	110.98	2.03	0.37	0.1369	< 0.0007
	Total solids	08	374.77	12.206	0.66	0.4356	
	Temperature	08	22.219	0.294	0.59	0.3481	
	Ca Hardness	08	216.31	11.112	0.92	0.8464	
	EC	08	44.40	1.382	0.68	0.4624	
	Chloride	08	1327.60	67.835	0.94	0.8836	
	DO	08	4.971	-0.0310	-0.35	0.1225	
	Free CO_2	08	3.625	1.381	0.99	0.9801	
	Sulphate	08	518.77	3.033	0.21	0.0441	
	Sodium	08	361.60	21.988	0.84	0.7056	
	Potassium	08	287.77	19.857	0.84	0.7056	
	Silicate	08	5.931	0.178	0.52	0.2704	

CONCLUSION:

The outcomes of this investigation revealed the quality assessment of the estuarine water body of Par River from two different stations denoted as downstream and upstream sites. This study highlighted poor water quality conditions of estuary in association with various hydro-chemical parameters. The WQI for downstream station ranging from 126.97 to 180.40 and for upstream station ranging from 105.66 to 143.56 that indicates degraded water quality at both sites but downstream station has poorer water quality than upstream station. Over the period of a year, WQI for downstream and upstream stations were 164.28 and 131.20 respectively. The water quality variables showed fluctuations. There were higher contaminations of components found during summer season followed by winter and then monsoon season. This monitoring case study provides an informative preliminary data about water quality variables and helps to understand the quality status of water bodies. The Water quality index revealed that the estuarine water of the Par River was affected by increasing anthropogenic activities as well as agricultural and industrial runoff occurred in surrounding area. Hence, this area can degrade the water quality and making it unfit for public use. The generated dendrogram through cluster analysis grouped the sampling sites and seasons and revealed that water quality over the period of one year affinity to winter's water quality > summer's water quality > monsoon's water quality. On the basis of physico-chemical characteristics, the Par river estuary can be classified into well mixed coastal plain estuary. The study has provided detailed information about water quality condition of the area that can help to surrounding population about utilization, management and conservation of the water body. This study also will help to develop water quality standard for Indian estuaries.

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