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Assessment of Surface Water Quality Using Multivariate Statistical Techniques in a Part of River Cauvery, Tamil Nadu, India

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The study explains water quality of the Cauvery River in the southern region of Peninsular India. Thirteen parameters including trace elements (Cd, As, Cu, Cr, Zn and Pb) have been monitored on 50 sampling points from a hydro-geochemical survey, conducted in the river stretch under study. Several water quality parameters showed considerable changes due to increased runoff from the catchments and other seasonal factors. Multivariate discriminant analysis delin-eated a few parameters responsible for temporal variation in water quality. Factor analysis (FA) identified three factors responsible for data struc-ture explaining 91% of total variance in surface water. It allowed grouping selected parameters according to common features. The results indicated that point source pollutants primarily affected the water quality of this region. This study indicates the necessity and usefulness of multivariate statistical techniques for evaluation and interpretation of the data. It facilitates better information about the water quality and designs some remedial techniques to prevent future contamination.

Key words : *River water quality, water pollution, multivariate analysis, factor analysis*

Introduction

Rivers serve as the most important freshwater resource for human being storing about 2,000 km^3 water globally[1, 2]. They present a continuously renewable physical re-source used for domestic, industrial, and agri-cultural purposes, as means for waste disposal, transportation, getting food resources, and recre-ational activities [3]. Besides these human influences, river water quality is also affected by a wide range of natural influences viz. geological, hydrological, and climatic factors [4].

Water quality is highly variable, which occurs not only with regard to its spatial distribution but also over time. Temporal variations in pre-cipitation, surface runoff, interflow, groundwater flow, and pumped in and outflows have a strong effect on river discharge and subsequently on the concentration of pollutants in river water[5]. Assessment of seasonal changes in surface water quality is an important aspect for evaluating temporal variations of river pollution due to natural or anthropogenic inputs of point and nonpoint sources[6]. In view of spatial and temporal variations in hydro-chemistry of rivers, regular monitoring programs are required for reliable estimate of water quality. The particular problem in the case of water quality monitor-ing is the complexity associated with analyzing the large number of measured variables, which are often difficult to interpret draw-ing meaningful conclusions [7]. The multivariate statistical techniques in data analysis help in better understanding of the underlying natural and anthropogenic processes characterizing the seasonal changes in the river water quality [8].

Cauvery is an easterly flowing river of the Peninsular India that runs across three of the southern Indian states i.e. Karnataka, Tamil Nadu, Kerala and a Union Territory of Puducherry. The fourth largest river of southern region, begins its 800 km long journey from the Western Ghats; traverses through Mysore plateau and finally forms a delta on the eastern coastline of the subcontinent before falling into the Bay of Bengal. The point of origin of Cauvery, Talakaveri is in the Brahmagiri ranges of the Western Ghats at an elevation of 1341m. The rocks in the entire basin are predominantly metamorphic and igneous; however sedimentary rocks are exposed along the eastern margin. The eastern deltaic area is the most fertile areas in the basin and the soil type is alluvial in this region. The principal soil types found in the basin are red soils, black soils, laterite, alluvial soils, forest soils and mixed soils. Red soils occupy large areas in the basin. The basin is characterized with a unique forest with some of very distinct fauna and flora and is home to many sanctuaries and National Parks. Average density in the population is around 192 persons per sq km. which is far less than the national average, but demographic changes expected in near future and also in recent years may lead to higher population density in the catchment, especially in some of the urban centers. An average

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annual surface water potential of 21.4 km^3 has been assessed in this basin. Out of this, 19.0 km^3 is utilizable water. Cultivable area in the basin is about 5.8 Million ha, which is 3.0% of the total cultivable area of the country. Present use of surface water in the basin is 18.0 km^3. The hydropower potential of the basin has been assessed as 1359 MW at 60% load factor. Domestic use, both urban and rural makes around 6% of the total water use in the basin. Water used for agriculture, domestic, or industrial processes is returned to the river as wastewater. Because of the large scale abstraction of water, negligible flows during some months, the river gets polluted by both point and non point sources. Intense human and cattle population, pollution from agriculture and especially from industries and untreated or partially treated sewage is altering the water quality of the river severely. Although industrial consumption is fairly less compared to agricultural consumption, Erode has the highest demand for water in the industrial sector[9]. The location of the stretch of the river Cauvery under study is shown in **Fig.1**.

Materials and methods

Surface water samples were collected from 50 locations during February 2009 along the course of the Cauvery River and its major tributaries namely Bhavani River, Noyyal River, Amaravathi River and Thirumanimuthar. The samples were collected in 1-litre double cap polythene bottles. The samples were filtered through pre-cleaned 0.45 µm acetate filters and were acidified with HNO_3 (1%) for the chemical analysis. The samples were analyzed for its pH, dissolved oxygen, alkalinity, hardness, turbidity, total dissolved solids, chloride, potassium, magnesium and trace elements like copper, arsenic, lead etc., with a view of finding out some hints on river water management [10]. Electrical Conductivity (EC) and pH were measured electromagnetically in the field using digital meters immediately after sampling. The samples were analyzed for determining the concentrations of various chemical constituents such as, sodium, potassium, calcium, magnesium, chloride, bicarbonate, carbonate, sulphate, nitrate, fluoride and total dissolved solids (TDS) in the laboratory using the standard methods as suggested by the American Public Health Association (APHA 1989 and1995)[11]. Ca^{2+}, Mg^{2+}, HCO_3^-, CO_3^{2-}, Cl^- and TDS were analysed by volumetric titrations. Concentrations of Ca^{2+} and Mg^{2+} were estimated titrimetrically using 0.05-N EDTA. Concentrations of HCO_3 and CO_3^{2-} were determined using 0.01-N H_2SO_4. Cl^- was estimated using 0.05-N $AgNO_3$. Na^+ and K^+ ions were measured using flame photometer. SO_4^{2-}, NO_3^- and F^- were determined by spectrophotometric techniques. The accuracy of the chemical analysis was verified by calculating ion-balance errors and the errors were generally found to be around 10%.

The study area forms part of the catchments of Cauvery River, which is one of the main sources of drinking water to Erode city. The industrial effluents contain appreciable amounts of inorganic and organic chemicals besides their by-products. Most of the industries are small to medium-scale sectors and do not have any sewer lines. Many of them do not have proper wastewater treatment plants and they discharge industrial effluents in unlined chan-nels/streams, thereby causing contamination of air, water and soil [12]. As a result, the highly coloured and toxic chemical efflu-ents join river Cauvery, polluting the surface water and the groundwater. The area consists of variety of industries like tanneries, textile factories, dyeing industries, printing industries, bleaching units, etc.,

The Cauvery stretch in Erode region receives untreated sewage from the areas located in left and right banks. In the stretch of Cauvery taken for study, river Bhavani is one of the main tributary and joins Cauvery before it reaches Erode city as stated earlier. River Bhavani is also receiving the sewage and industrial effluents generated by the areas located around it. The next tributary through which the Cauvery River receives water is river Noyyal, which has International attention for its polluted state because of the discharge of wastewater from the textile city of Tirupur. River Amaravathy, which runs through the Karur town, is the next major tributary for river Cauvery in which around five samples were collected for analysis along its flow. On the left bank of the Cauvery, another tributary Thirumanimuthar joins and flows into it. This river stream is found to be dry most of the days in a year and receives flow only when there is rainfall in the nearly Sherveroys hill region. During the time of study, there was no flow in this tributary of river Cauvery.

Results and discussion

Surface water samples were collected from 50 locations along the Cauvery river stretch within the study area including its four tributaries namely Bhavani River, Noyyal River, Amaravathi River and Thirumanimuthar. All the samples were found to have the parameters within the permissible limits in the river Cauvery except for Na^+ which exceeded the permissible limits at two locations in the Cauvery. Similarly, Na^+ concentrations were also found to exceed the permissible limits at two locations in Amaravathy River. In Noyyal, all the samples were found to exceed the permissible concentrations for Na^+, and this may be due to the huge volume of industrial effluents being discharged into the Noyyal River from the Tirupur region.

Generally all the samples were moderately alkaline with pH ranging from 7.1 to 8.7. Ca, Mg, Cl and SO_4 were present in very low concentrations (less than 100 and 150 mg/L respectively), except in Noyyal river where the Chloride concentration was found to vary between 1333 mg/L to 156(

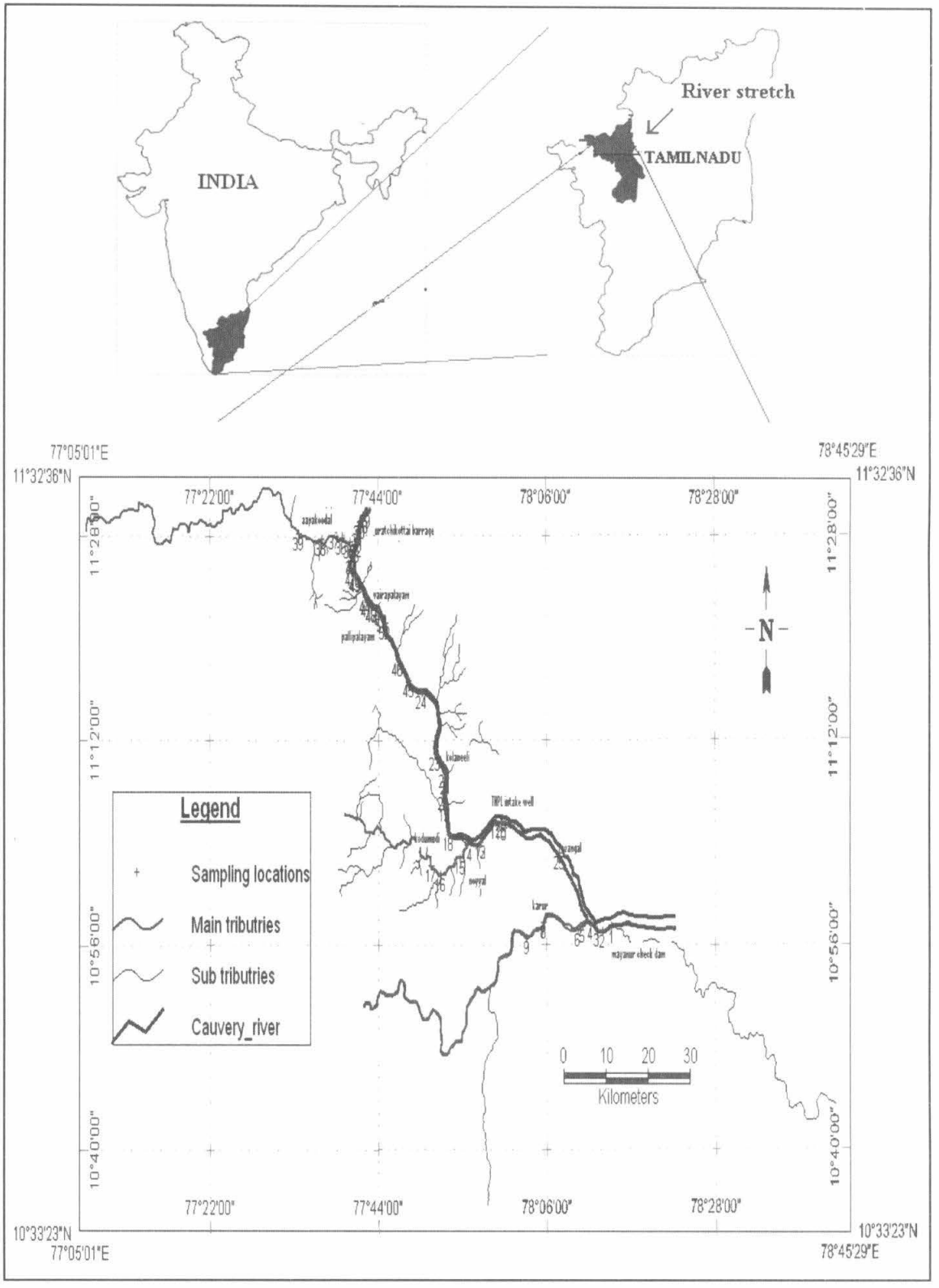

Fig. 1 : Location map of the study region

mg/L in all the four locations. Noyyal River showed high TDS levels varying from 3210 to 3615 mg /L. The samples exceeded the permissible limits prescribed by World Health Organisation (WHO) - **Table 2**.

Surface water chemistry

The pH in the Cauvery river stretch was alkaline and found to vary between 7.1 and 8.5 (**Fig. 2**). The EC values were found to vary from 310 µmhos/cm to 1940 µmhos/cm in the Cauvery. The TDS values in Cauvery River varied from 208 mg/L to 1324 mg/L with an average of 388 mg/L. The TDS concentration was found to increase at Sites 21, 26 and 29 with an average of 506 mg/L which proves the influence of industrial discharges in to the river. There was an increase in TDS level around 886 mg/L in Site 33 which is the confluence point of river Cauvery and its tributary Amaravathi. Site 14 also showed high level of TDS with an average of 1324 mg/L near the municipal solid waste dumping yard. Hardness was reported with an average value of 181 mg/L, the maximum and minimum value being 320 mg/L and 125 mg/L respectively. The hardness showed a slight decrease along the course of river before the confluence point of Amaravathy and Cauvery with exceptions near Site 11 (170 mg/L) and, Site 5 (170 mg/L) immediately after the Barrage across the river. The samples showed high levels of hardness in Site 33 (265 mg/L) and Site 14 (320 mg/L), which may be due to the anthropogenic sources[13] and its value was found to decrease along the course of the river Cauvery. Nitrate content in the river stretch was found to vary from 1 mg/L to 45 mg/L, with an average of 7.3 mg/L which falls within the permissible limits of WHO. The maximum value was reported in Site 11 (45 mg/L) which is near the solid waste dumping yard. The Na^+ ions varied between 28 mg/L to 357 mg/L exceeding the permissible limits at some places, which have an average value of 76.9 mg/L. The major ions were in the order $Na^+ > Ca^{2+} > Mg^{2+} > K^+ = HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > CO_3^{2-}$ in Cauvery river. The variation of the pH, EC, TDS, Total Hardness, Alkalinity and fluoride along the river Cauvery is shown in **Fig. 2** and **Fig. 3** respectively.

Factor analysis

By factor analysis complex linear correlation between surface water quality data was determined, which enabled interpretation of correlation of elements in the study area. Elements belonging to a given factor were defined by factor matrix after varimax rotation [14], with those having strong correlations grouped into factors. Considering the influence they exerted from surface water into the groundwater table by determining the distri-bution of elements in the study area, the said multielement factors were divided into two groups: (i) fac-tors with strong scattered anthropogenic influence and (ii) factors caused

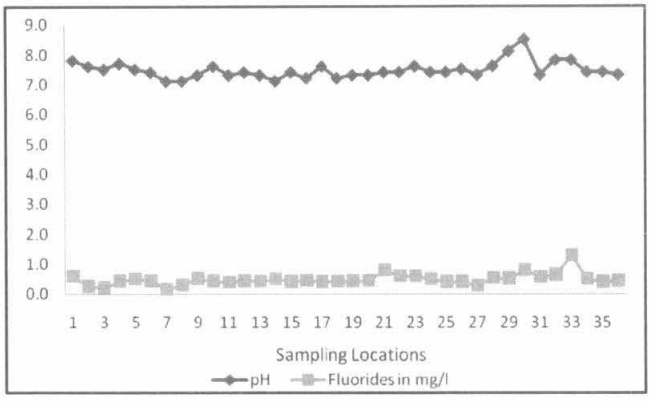

Fig. 2 : Variations of fluoride and pH in Cauvery River

by predominantly natural processes or other anthropogenic influences. The identification of factors is based on dominant influence. The distribution manner of individual association of element determined by princi-pal component method (results are shown in **Table 1**). Based on eigen values and varimax rotation three factors explained most of the variability (total variance explained was about 90.76% for the surface water data).

Factor 1

Factor 1 exhibited 72.66% of the total variance of 90.76% with posi-tive loading on EC, TDS, Hardness, Ca, Mg, Na, Cl, Bicarbonates and F. This factor indicated strong association (r = 0.91-0.99) of EC, TDS, Hardness, Mg, Na, Cl, and Bicarbonates in surface water.

The TDS values in Cauvery River varied from 208 mg/L to 1324 mg/L with an average of 388 mg/L. The TDS concentration was found to increase near the sites at Tamil Nadu News Prints and Paper Limited (TNPL) intake well, Kodumudi and Kolanelli with an average of 506 mg/L which proves the influence of Paper mill and such industrial

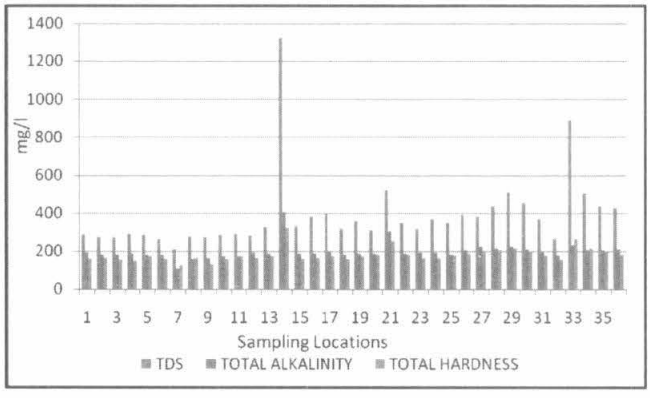

Fig. 3 : Variations of alkalinity, TDS and TH in Cauvery River

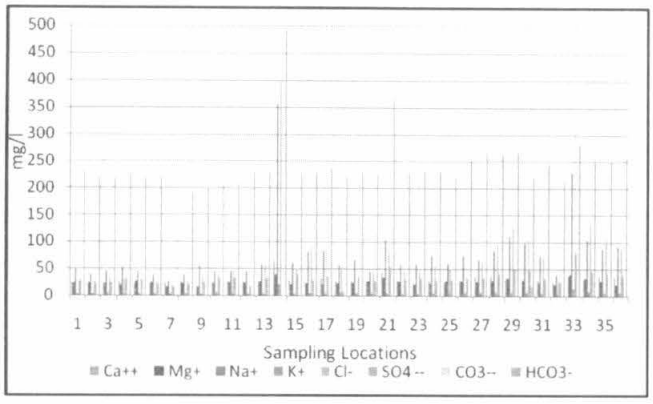

Fig. 4 : Variations of major ions in river stretch

discharges in to the river. The TDS concentration was high in Pasupathipalayam with a value of 943 mg/L and was found to decrease along the Amaravathi river course up to 586 mg/L; similarly, there was an increase in TDS level around 886 mg/L in Kattalai Koodurai which is the confluence point of its tributary river Amaravathi with river Cauvery. Vairapalayam also showed high level of TDS with an average of 1324 mg/L near the municipal solid waste dumping yard. High values of TDS up to 3675 mg/L were reported in all the samples in river Noyyal, which may be due to the discharge of industrial effluents from textile units on the banks of the river Noyyal.

Hardness was reported with an average value of 181 mg/L, the maximum and minimum values being 320 mg/L and 125 mg/L respectively. The Hardness of surface water showed a slight decrease along the course of river Cauvery before the confluence point of Amaravathy and Cauvery with exceptions near Manjula Textiles (170 mg/L) and Kuranaickan palayam, (170 mg/L) immediately after the Barrage across the river. The samples showed high levels of hardness in Kattalai Koodurai (265 mg/L) and Vairapalayam (320 mg/L), which may be due to the anthropogenic sources and its value was found to decrease along the course of the river Cauvery. All the samples reported high levels of Hardness in river Noyyal with a maximum of 2450 mg/L and a minimum of 930 mg/L having an average of 1510 mg/L.

Chloride concentration varied from 397 mg/L to 25 mg/L with an average of 75 mg/L. Samples 4, 5, 6, 7 and 48 showed a comparatively high concentration. The chloride levels were very high in River Noyyal with an average of 1464 mg/L which may be due to the mixing of untreated industrial discharges in to the river.Magnesium was reported with a maximum of 41 mg/L and a minimum of 16 mg/L, the average value being 25 mg/L. Sodium concentration was found to vary from 357 mg/L to 28 mg/L exceeding the permissible standards in samples 4, 6, 7, 14, 15, 16, 17 and 48 respectively.

Factor 2

Factor 2 exhibited 10.27 % of the total variance with positive load-ing on Carbonate. Carbonate was reported only in Nanchaipugalur (18 mg/L) which is located in the downstream of TNPL intake and in Karur (12 mg/L) located near the paper mill. Carbonate was found to vary from 36 mg/L to 54 mg/L with an average of 37.5 mg/L in river Noyyal, which may be assumed to be derived from the effluent discharges from the textile mills in that region. Hence this factor can be attributed to anthropogenic sources.

Factor 3

Factor 3 exhibited 7.83% of the total variance with positive loading on Nitrates. This factor can be attributed to the influence of agricultural activity and municipal solid waste disposal in the study area. Nitrates varied from 45 mg/L to 1 mg/L with an average of 5 mg/L. The maximum value was reported in Vairapalayam (45 mg/L) which is near the solid waste dumping yard and mild concentrations were observed in Kodumudi (10 mg/L) nearby the agricultural lands.

Table 1. Varimax rotation factor loadings on various variables

	Component		
	PC1	PC2	PC3
pH	0.676	0.178	-0.176
EC, umho/cm	**0.994**	-0.018	0.081
TDS, mg/L	**0.981**	-0.024	0.187
NO_3^-, as mg/L	0.566	-0.259	**0.769**
Phenolic Alkalinity, mg/L	0.586	**0.795**	-0.072
Total Alkalinity, mg/L	**0.974**	0.038	0.196
Total Hardness, mg /L	**0.918**	-0.234	-0.286
Calcium Hardness, mg/L	**0.848**	-0.343	-0.283
Ca++, mg/L	**0.848**	-0.343	-0.283
Mg++, mg/L	**0.948**	-0.117	-0.276
Na+, mg/L	**0.944**	0.058	0.314
K+, mg/L	**0.934**	0.09	-0.238
Cl-, mg/L	**0.991**	-0.01	0.125
SO_4^{2-}, mg/L	0.665	-0.22	-0.266
CO^{3-}, mg/L	0.586	**0.795**	-0.072
HCO^{3-}, mg/L	**0.966**	-0.074	0.222
F-, mg/L	**0.829**	0.116	0.101
Percent of Variance %	72.658	10.273	7.833
Cumulative percentage %	72.658	82.931	90.764

Conclusion

The rise of the inflow of waste is clearly due to the rapid growth of residential and commercial activities in the study area. The present study is an attempt to detect changes in the water quality characteristics within the river system with respect to major pollutants. The study reveals that there are additions of large quantities of effluents due to movement of industrial effluents, agricultural and anthropogenic wastes particularly in the down streams of the river. Regular monitoring of the quality of water should be undertaken temporally and spatially to identify the source of toxic pollutants and other inhibitory chemicals which affects the quality of water in and around Erode. Protecting the water resources in the study area will be a for-midable challenge in future. To create more sustainable means of production, there must be a shift in attitudes towards proactive waste management practices that represent a move away from control measures towards preventative measures in cities and in all industrial sectors.

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