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Evaluation and Quantification of Pollution Caused by Open Drains in Ganges River Basin Using Multivariate Cluster Analysis

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Abstract. The colossal expansion and pace of global development have completely deteriorated the water quality of major river basins of the world such as Amazon, Ganges, Nile etc. Rivers have become receivers of wastewater discharged from industrial, agricultural and domestic sectors. Ganges river basin of India is considered as one of the heavily polluted river basin with 144 open drains entering into the river body without proper treatment. Therefore, monitoring and analysing the water quality of these drains and their sources is essential not only to suggest proper treatment procedures but also to ensure sustainability of the river ecosystem. The present study conducts an exhaustive quality analysis of 85 drains carrying both industrial and domestic sewage, either directly into river Ganges or indirectly through tributaries (Kali-East, Ram Ganga and Pandu) in 'Haridwar to Kanpur' stretch. Multivariate technique namely Principal Component Analysis (PCA) and Cluster Analysis (CA) have been employed using 'Analyse it' software to evaluate the intensity and sources of pollution. The methodology generates monoplots and two dimensional biplots to identify the relationships among pollutants and their sources. Finally, quality assessment of drains has been performed by calculating the water quality index of each drain, and sensitivity analysis is carried out to evaluate the effect of critical water quality parameters. Results direct the policy makers to identify the industries responsible for polluting the drains above critical levels and further measures are suggested to improve the deteriorating quality of drains.

Key words: Multivariate analysis, open drains, river basin, water quality.

Introduction

Rivers have been sustaining the mankind since age-old by providing freshwater for numerous purposes such as agricultural, domestic, and industrial demands. In addition, rivers also support the rich biodiversity along their banks, which contribute towards a healthy ecosystem (Srinivas et al., 2017). River Ganges of India is the second largest river in the world by water discharge. The Ganges basin is heavily populated with a density of about 390 inhabitants per square kilometres (Das and Tamminga, 2012). Ganges not only provides life sustenance to environment and ecology, but is also regarded as sacred and worshiped by Indians. River water plays a significant role in the growth of Indian civilization and economy. However, in recent times, the massive and unending demands of urbanization and industrialization have led to overuse of river water, which has not only reduced the discharge of Ganges, but also severely deteriorated its water quality.

An enormous amount of hazardous industrial waste, domestic sewage and agrarian runoff consisting of

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pesticides and fertilizers are discharged into river premises. The Haridwar to Kanpur stretch is one of the heavily polluted stretch with more than 85 open drains discharging about 823.1 million litres per day (MLD) of sewage and 212.42 MLD of industrial waste. This stretch spans a distance of 543 km, and is severely affected by 1,072 grossly polluting industries, which release heavy metals and pesticides (CPCB, 2016). It is astounding to note that despite advancement in science and technology, most of the industries and residential towns doesn't have proper treatment plants to treat the waste. Moreover, the existing treatment plants are of substandard quality and are not equipped with latest technology (CPCB, 2013).

This results in heavy quantities of untreated/partially treated waste entering into the river body through various open drains. Such practices not only degrade water quality, but also destroys river ecosystem which is essential for its self-purifying capacity. Therefore, it is necessary that the researchers, decision makers and controlling agencies must identify the critical pollutants in these open drains, analyse their water quality and identify the sources of pollution, so that appropriate remedial action plans can be suggested by the governmental agencies.

Since, the analyses pertaining to various drains are characterized by huge data sets of numerous pollutants corresponding to all drains, it needs an all-inclusive approach, which not only assesses the water quality of drains in a mathematical way, but also reduces the dimensionality of the data set into few components or clusters. This makes task of policy makers simpler as they have to study few components/clusters to have a broad understanding of all the pollutants, so as to formulate policies and suggest treatment measures. Multivariate statistical analysis is considered as one of the best approaches to deal with big data sets (Simeonova and Simeonov, 2007; Astel et al., 2008). Srinivas et al. (2017) used fuzzy based multivariate analysis technique to identify critical trace metals and their sources in the Kanpur-Varanasi stretch of river Ganges. Rawat et al. (2009) quantified the heavy metals discharged from small scale industries in the Kanpur city of India using statistical analysis. Jan et al. (2010) used multivariate and univariate statistical techniques to analyse the heavy metal pollution in the industrial area of Peshawar, Pakistan. Pandey and Singh (2015) studied heavy metal concentration in the sediments of river Ganga using Mann–Kendall trend analysis and Principal Component Analysis (PCA).

In addition to PCA, usage of Water Quality Index (WQI) to assess the water quality of various pollutant sources is emphatic. WQI gives both qualitative and quantitative assessment of the water quality (Bora and Goswami, 2007). WQI also identifies critical parameters and allows the decision makers to perform sensitivity analysis. However, it doesn't reveal the correlation among the pollutants. Coupling of PCA with WQI is considered as an effective approach to analyze the water quality data.

Although numerous studies for quality analysis have been conducted using multivariate technique, there is scope to develop an approach which can incorporate the impacts of both metals and organic pollutants on the water body while identifying their corresponding sources. Accordingly, the present study assesses the quality of 85 open drains joining the river Ganges and its tributaries (Kali-East/Ramganga) between Haridwar and Kanpur using multivariate clustering of 'Analyse it' software. The study has been conducted in three phases. The first phase includes clustering of drains and identification of critical parameters using Principal Component Analysis. This is followed by quantification of the quality of drains by finding their Water Quality Index (WQI). In the third phase, sensitivity analysis of the critical parameters with respect to the Water Quality Index has been carried out, which enables the policy makers to develop future scenarios of load reduction.

Methodology

Study Area and Data

The study area includes all the 85 drains joining river Ganges and its tributaries (Kali-East, Ram Ganga and Pandu) from Haridwar to Kanpur (Figure 1). The districts covered under the study area are Muzaffarnagar, Bijnaur, Ghaziabad, Bulandshahar, Kanpur, Unnao, Moradabad, Bareily, Meerut and Aligarh. There are 35, 24, 22 and 5 drains joining river Ganges, Ram Ganga and East Kali and Pandu respectively.

The data for the year 2016 have been obtained from Central Pollution Control Board (2016). A total of twelve essential water quality parameters have been considered for the analysis in 'Analyse it' software. These parameters are pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) Total Dissolved Solids (TDS), Total Coliform (TC), Ammoniacal Nitrogen (NH_3-N), Chloride (Cl^-), Total Chromium (TCr), Ferrous (Fe), Zinc (Zn), and Manganese (Mn).

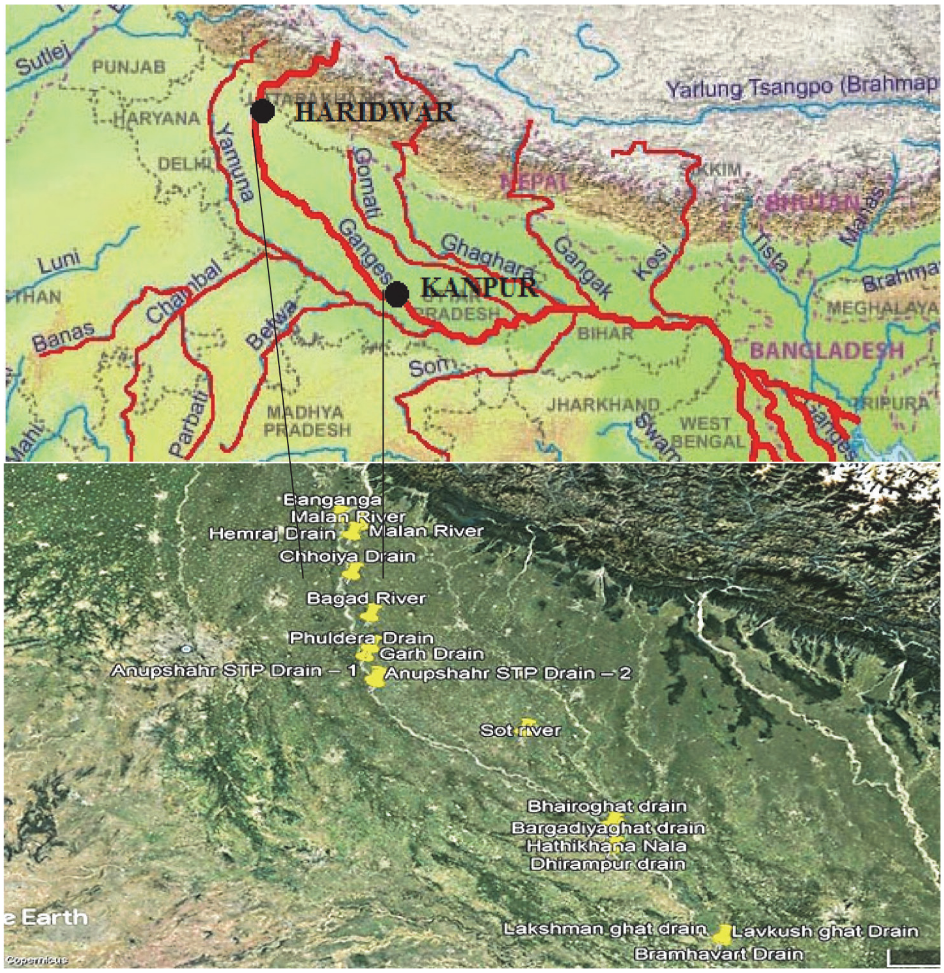

Figure 1: Study area depicting some of the drains.

As discussed earlier, the study has been conducted in three phases, where in the first phase, clustering of drains and identification of critical parameters is performed using Analyse it software; in the second phase, WQI of each drain is evaluated to identify critical parameters, and finally, the third phase performs sensitivity analysis to give guidelines to the controlling authorities.

Clustering of Drains and Identification of Critical Parameters Using Principal Component Analysis

In this phase Principal Component Analysis of all the 85 drains is performed using 'Analyse it' software. A total of twelve parameters were included in the analysis as there is a constraint of number of variables that can be used in the software. The software initially develops correlation among the various parameters. Then, PCA is carried out and a monoplot and biplot are generated. Monoplot is a circular diagram with various vectors diverging away from the centre of the circle. These vectors represent the variables (i.e. 12 water quality parameters) and the length of each vector reveals how well the variance of that variable has been represented by the principal component. The angle between the vectors explains the inter-relationships among the parameters. An angle close to 0° meant that the parameters are positively correlated, angle close to 90° meant no correlation and close to 180° meant negatively correlated.

On the other hand, biplot represents a two-dimensional approximation to the original multidimensional space. 70% of the original variation in the data set is represented by biplot. Each axis of the biplot represents the various water quality parameters and each point represents the various drains considered for the analysis. The distance between the various points represents the similarities between the drains. The approximate observed concentration of a particular pollutant in a particular drain can be obtained by orthogonally projecting the point on to the axis. Biplot also forms clusters of drains possessing similar characteristics. These clusters not only help in identifying critical drains and pollutants, but also indicate that there is a single (or few) pollutant sources, which are contributing towards forming of this cluster. The critical parameters in the clusters can be found and thus the source of pollutants can be identified.

Obtaining Water Quality Index of Drains

The quality of drains is a combination of various parameters. WQI is used for the purpose of representing (quantifying) the water quality pertaining to any drain into a single number. As a result, huge information on water quality of drains becomes comprehendible and usable for further mathematical operations as well.

Initially the data value of any pollutant for a particular drain is normalized, so that to have a uniformity as different water quality parameter have different dimensions. Equation (1) represents the formula for calculating WQI.

$$WQI = \sum Q_n W_n / \sum W_n \quad (1)$$

where Q_n = Quality rating of nth water quality parameter and is given as

$$Q_n = 100 \frac{[(F_n - F_i)]}{[(F_s - F_i)]} \quad (2)$$

where F_n = actual amount of nth parameter present, F_i = ideal value of the parameter,and F_S = standard permissible value for the nth water quality parameter.

W_n is the unit weight of nth water quality parameter and is calculated using the formula $W_n = k/F_S$ where k is the constant of proportionality and it is calculated using the equation (3) as given below:

$$k = \frac{1}{\sum 1/F_s} \quad (3)$$

Once the standardization is done, the parameters are given further priority by multiplying their weights with priority factors (W_n*). These priority factors have been obtained from the experts belonging to CPCB, research and scientific organizations. Therefore, the final formula for evaluating WQI thus obtained is given using equation (4) as given below:

$$W_{QI} = \sum Q_n (W_n \times W_n^*) / \sum (W_n \times W_n^*) \quad (4)$$

After the WQI of the drains is calculated, the drains are classified according to classification given by National Sanitation Foundation (NSF) in Table 1 (Bhutiani et al., 2016).

Table 1: Classification of Water Quality Index

Classification according to NSF	*Range of WQI*
Very good	0-20
Good	20-50
Moderate	50-100
Bad	100-200
Very bad	>200

Sensitivity Analysis

Once the critical drains and parameters are identified using WQI, the individual effect of various critical parameters on the WQI is studied by performing sensitivity analysis. The values of WQI of each drain are observed to obtain good rating, by trying to reduce the concentration of critical parameters to the prescribed standard limits.

Results and Discussion

Outcomes of Principal Component Analysis

Table 2 represents the correlation obtained among 12 variables considered for all the 85 drains. Figures 2 and 3 represent the monoplot and two-dimensional biplot obtained using PCA.

It is evident from Table 2 and Figure 2 that there are two groups of positively correlated variables. One group comprises BOD, COD, TSS, TDS, NH_3-N, pH and Total Cr. The other group consists of pollutants such as Fe, Mn, Zn, Cl^- and TC. However, there is no correlation among the pollutants of the two groups.

In the first group, BOD, COD, TDS and TSS are highly correlated while the correlation with Total Chromium and pH is not very high. For illustration, the correlation coefficient values of BOD with COD, TDS and TSS are [0.957, 0.766, 0.73]. It can be inferred that drains are mostly domestic or mixed type, and the correlation with Total Chromium can be explained by the presence of a lot of tanneries in the Kanpur region, which contribute Total Chromium as a major pollutant along with BOD and TSS.

In the second group, correlation among heavy metals such as Fe, Mn and Zn is high, while their correlation with Cl^- and TC is quite low. This explains presence of drains carrying effluents from industries, which include dyeing and textile industries as they discharge lot of heavy metals as pollutants. The correlation with Total Coliform is not significant as it is mostly contributed by non-point sources of pollution in the form of open

Table 2: Correlation observed among various parameters using PCA

Pearson's R	*pH*	*BOD*	*COD*	*TSS*	*TDS*	*Cl*	*NH_3-N*	*TC*	*Total Cr*	*Fe*	*Mn*	*Zn*
pH	-	0.054	0.132	-0.004	0.284	0.144	0.266	-0.02	0.195	-0.03	0.053	0.022
BOD	0.054	-	0.957	0.766	0.73	-0.06	0.484	0.019	0.632	0.057	0.093	0.055
COD	0.132	0.957	-	0.664	0.799	-0.03	0.572	-0.004	0.755	0.089	0.1	0.064
TSS	-0.004	0.766	0.664	-	0.457	-0.05	0.148	0.001	0.315	0.146	0.123	0.146
TDS	0.284	0.73	0.799	0.457	-	0.269	0.668	-0.05	0.681	-0.01	0.123	0.11
Cl	0.144	-0.06	-0.03	-0.05	0.269	-	0.344	0	-0.03	-0.02	0.448	0.512
NH_3-N	0.266	0.484	0.572	0.148	0.668	0.344	-	0.024	0.498	0.009	0.225	0.254
TC	-0.023	0.019	-0.004	0.001	-0.05	0	0.024	-	-0.04	0.337	0.298	0.208
Total Cr	0.195	0.632	0.755	0.315	0.681	-0.03	0.498	-0.04	-	-0.02	0.002	-0.04
Fe	-0.03	0.057	0.089	0.146	-0.01	-0.02	0.009	0.337	-0.02	-	0.573	0.648
Mn	0.053	0.093	0.1	0.123	0.123	0.448	0.225	0.298	0.002	0.573	-	0.645
Zn	0.022	0.055	0.064	0.146	0.11	0.512	0.254	0.208	-0.04	0.648	0.645	-

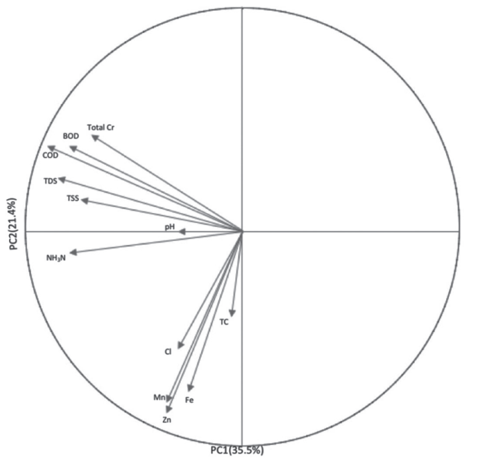

Figure 2: Monoplot of variables depicting correlation in 2-D.

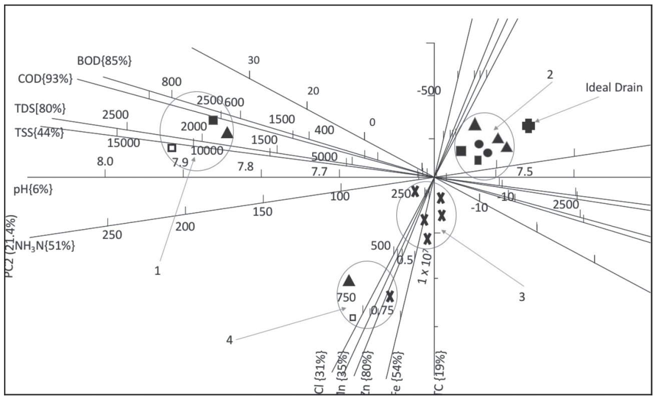

Figure 3: Biplot depicting clusters obtained from PCA.

defecation. No correlation among the two groups of pollutants explains the fact that the source of pollutants in the two groups are completely different.

From Figure 3, it can be observed that there are four clusters of drains. One important finding obtained from Figure 3 is that more the distance of the drains from the ideal drain, worse is the quality of water in the drain. The cluster 2 consists of drains close to the ideal drain. These drains have almost all the pollutants within the permissible limit and are labelled as good quality drains. The cluster 1 consists of drains with higher values of group 1 pollutants, the source of effluents in these drains is mostly sewage or effluents from slaughter houses, tanneries, sugar mills, food and dairy industries and pulp and paper industries. The cluster 3 consists of drains from Moradabad catchment area, which have higher content of heavy metals due to presence of lot of dyeing, textile and chemical industries in the region. The cluster 4 consists of only three drains. These drains have a very high value of Total Coliform and are thus very far from the ideal drain.

Water Quality Index of Drains

The WQI of each drain has been calculated using the procedure described in the previous section. The ideal value of all the pollutants is taken as zero, except for pH which is taken as seven. For brevity reasons, the WQI of first 20 drains are given in Table 3.

The drains with WQI values less than 50, possess good quality. Some of the drains had WQI values even greater than thousand, which is due to extremely high values of Total Coliform in these drains. Drains with WQI greater than 100 were observed to have more than two parameters above the permissible limit. These drains possess bad quality water according to the classification (Table 1) and drains with WQI greater than 200 have an extremely bad quality water.

Table 3: Water Quality Index of first 20 drains

Drain name	*WQI*	*Drain name*	*WQI*
Bagad Drain	90.62	Shetlabazar Drain	547.34
Phuldera Drain	8253.95	Budhiya ghat Drain	517.13
Sot River	84.91	Wazidpur Nala	2808.5
Bramhavart Drain	4762.09	Manohar Nagar -II Drain	137.19
Luvkush ghat Drain	199.97	Railway Bridge Drain	152.84
Ranighat Nalla	865.71	Indranagar Drain	323.51
Muir Mill Nalla	851.52	City Jail drain	107.63
Gola Ghat Nalla	509.49	Loni Drain	178.68
Bhagwat Das ghat Drain	497.1	Nohra Drain	10.98
Sattichaura Ghat Drain	131.6	Rampur Drain	27.7

Outcomes of Sensitivity Analysis

Once the WQI is calculated and sources of pollutants in the drains are identified, sensitivity analysis has been done for critical parameters of those drains, whose WQI is high. For illustration, Figures 4-8 represent the results of sensitivity analysis of some of the critical drains.

For Kadarabad drain, Total Coliform and BOD have been varied (Figure 4). It is observed that the WQI improves more by decreasing Total Coliform as compared to reduction in the concentration of BOD. WQI value of less than 40 has been achieved by reducing the Total Coliform below 40,00,000 MPN/100 ml and BOD to 55 mg/l, since BOD and TC are the critical parameters. Some of the industries, which were identified to contribute towards this drain are Sugar Mills, Pulp and Paper, Slaughter Houses and Tanneries. The list of these industries is given below:

- Brijnathpur Sugar Mills, Vill. Brijnathpur, Hapur, Ghaziabad.
- Modi Sugar Mills, Modi Nagar, Ghaziabad.
- Ved Cellulose Ltd., 16 Km. Stone, Hapur Road, Vill. Lakhan, P.O. Galand, District Ghaziabad.
- Modi Nagar Paper Mills, Modi Nagar, Ghaziabad
- Paswara Papers(P) Ltd, Mohiuddinpur, Delhi Road, Meerut
- Kripa Ram Dairy Pvt. Ltd., Village Bhojpur, Tahsil Modinagar, Ghaziabad
- Alps Industries Ltd., Vill. Aminagar, Bhoorbaral, Partapur, Meerut. 45. M/s. Ghaziabad Organics Ltd (Distillery Division), Vill. Bhojpur, Modi Nagar, Ghaziabad
- Modi Distillery, Modi Nagar, Ghaziabad
- Simbhaoli Sugar Mills Ltd (Distillery Unit), Simbhaoli, Ghaziabad
- Simbhaoli Sugar Mills Ltd. (Brijnathpur Distillery Unit), Vill. Brijnathpur, Ghaziabad.
- Merino Industries Ltd., Village Achheja, P.O. Hapur, Ghaziabad

In case of Sot drain, Fe and BOD have been varied (Figure 5) and it is observed that decreasing the Fe level had more effect on WQI as compared to decreasing BOD. WQI < 50 has been achieved by bringing the Fe level to 12 mg/l and BOD to 35 mg/l. Some industries releasing effluents in Sot drain are listed as given below:

- Chandpur Enterprises Limited (Paper Division), Noorpur Road, Chandpur (Bijnor), U.P.

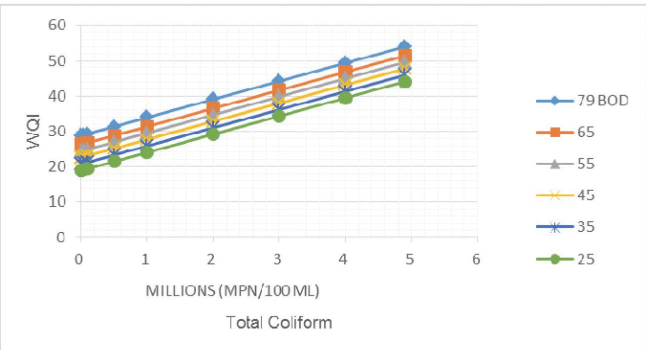

Figure 4: Variation of WQI of Kadarabad drain with BOD and TC.

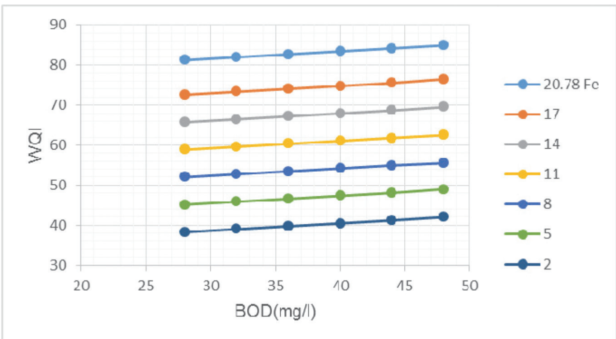

Figure 5: Variation of WQI of Sot drain with BOD and Fe.

- Wave Industries Pvt. Ltd, Vill. Malaysia, P.O. Mandi Dhanaura, Distt. J.P. Nagar
- Wave Industries Pvt. Ltd. Unit Amroha, J.P. Nagar
- International Electron Device, Site 5, Panki, Kanpur

In similar manner, TC has been modified for Bagad drain to obtain improved values of WQI. Industries releasing effluents in Bagad Drain are mainly food and dairy industries:

- Coral News Prints Ltd. Gajraula, J.P. Nagar
- Umang Dairies Ltd. 3 Km. Hasanpur Road, Gajraula, J.P. Nagar

For the City Jail Drain, Total Chromium and BOD have been varied (Figure 7), and it was found that for total Chromium content of 2.05 mg/l and BOD of 50 mg/l, WQI obtains a value of 90. City Jail drain primarily carries effluents from tanneries and slaughter houses. The list of critical industries identified are given below:

- Arifi Tanners, 6, Akarampur, Unnao
- Mirza International Ltd. Magarwara
- Mustang Leather Pvt. Ltd. Magarwara
- Rahaman Industries Ltd. Site-III, Akarampur-Chakarampur, Unnao
- Sadaf Enterprises Exports (P) Ltd. Industrial Area, Akarampur, Unnao

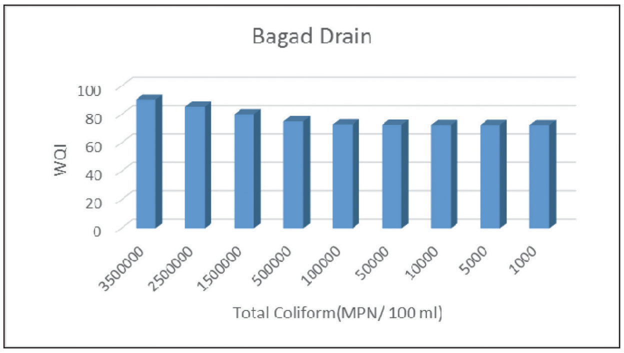

Figure 6: Variation of WQI of Bagad drain with TC.

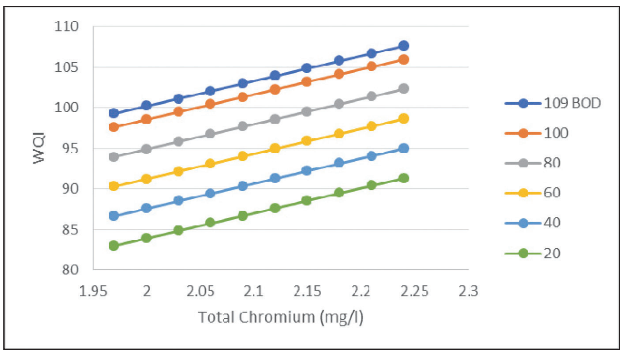

Figure 7: Variation of WQI of City jail drain with Total Chromium and BOD.

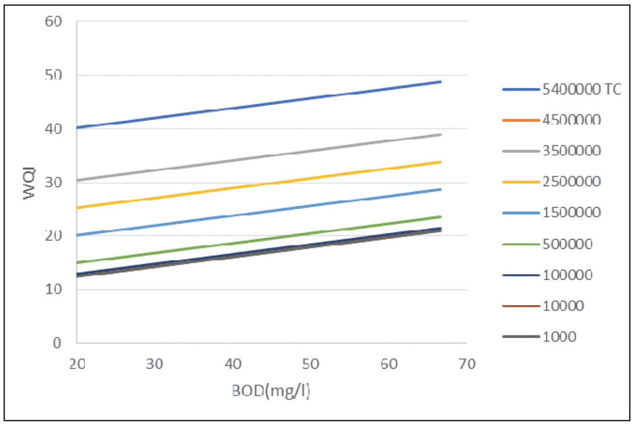

Figure 8: Variation of WQI of Ganda Nala drain with BOD and TC.

- Unnao Distillery and Breverege Ltd. Sekhpur, Unnao
- ZAM-ZAM Tanners, Kundan Road, Unnao

For the Ganda Nala, Total Coliform and BOD have been varied (Figure 8) and initially WQI decreased more on decreasing TC, but after reaching a TC level of 50000 MPN (per 100 ml), it did not affect WQI much. WQI obtains a value of less than 20, when TC is reduced to 50000 MPN and BOD to 50 mg/l. Some industries releasing effluents in Phuldera drain and Ganda Nala are listed as given below:

- Simbhaoli Sugar Mills Ltd. (Sugar Division), Simbhaoli, Ghaziabad
- Field Gun, Kalpi Raod, Kanpur
- Small Arms, Kalpi Raod, Kanpur

Conclusion

The present study develops an approach to analyze the quality of open drains in Haridwar to Kanpur stretch of Ganges river basin by using multivariate clustering and WQI methodology. Principal component analysis identifies the clusters of various pollutants, their inter-relationships and thus recognizes their possible sources. In order to understand to what degree the pollutants corresponding to each of these drains are impacting their wastewater, WQIs have been calculated and concentrations of critical parameters have been varied to perform sensitivity analysis. The WQI calculated for all the drains, reveal that the quality of most drains joining Ganges is poor and the effluents released into these drains exceed the standard prescribed limits. PCA proves to be an excellent tool to comprehend with huge data sets by forming useful clusters of critical parameters. These results can be used by the researchers, experts and controlling agencies to formulate drain and industry specific policies as it is clear from the sensitivity analysis which parameters are critical or are major pollutants for a particular drain. Also, there is an acute need to revise the prescribed discharge standards for both industrial and domestic sources of pollution. This is mainly due to reduced self-purifying capacity of the river. One important finding from this study was that the concentration of Total coliform (TC) has been found to be humongous in almost all the drains. There is a need to provide proper sanitation facilities in the cities located along the banks of Ganges. In addition, proper treatment procedures must be adopted by reinforcing the current sewage treatment systems. The present study can be further modified by incorporating the impact of new sewage and effluent treatment technologies on the drain characteristics and water quality of river Ganges.

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