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Index Analysis, Graphical and Multivariate Statistical Approaches for Hydrochemical Characterisation of Damodar River and its Canal System, Durgapur, West Bengal, India

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Abstract

Damodar river, one of the most important tributaries of river Ganges, flows through two Indian states Jharkhand and West Bengal. The river basin is characterised by the presence of large scale mining and industrial activities owing to the rich occurrence of mineral resources. The river in West Bengal flows through the steel city Durgapur where a massive 692 metres barrage is located across the river. Two main canals originate from the Durgapur barrage supplying water to an extensive network of canal systems. The major objectives of the present study were, i. to investigate the hydrochemical profile of the Damodar river and its canal waters, ii. to develop an objective water quality index (WQI) indicating their overall ecological status, iii. to apply intelligent data analyses techniques like graphical methods and multivariate statistical approaches on water quality data for better interpretation of water chemistry, iv. to test the suitability of waters for irrigation using sodium adsorption ratio (SAR), percentage sodium (%Na) and permeability index (PI). Water samples were analysed for sixteen parameters to develop a suitable hydrochemical profile. Piper diagram was used for plotting major cations and anions suggesting the water types. Principal component analysis (PCA)/Factor analysis (FA) and cluster analysis (CA) along with correlation analysis was performed on the data matrix for apportionment of sources of chemicals found in the river and canal waters. Important findings of the study are i.WQI (53.63 – 65.00) classified river and canal waters into medium category indicating anthropogenic influence on the surface water characteristics, ii. Piper diagram suggested water types ranging from Mixed-Ca^{2+}-Mg^{2+}-Cl^- to Na^+-Cl^- type, *iii. PCA/FA and CA interpreted both geogenic and anthropogenic factors responsible for influencing the water chemistry, iv. SAR (1.43 – 2.27), %Na (39.96 – 55.93) and PI (56.49 – 101.19) values along with the United States Salinity Laboratory diagram and the Wilcox diagram reflected suitability of the river and canal waters for irrigation. The organic pollution load emerged to be a serious concern and proper attention is required for controlling this problem.*

Keywords: Box and whisker plot, cluster analysis, Damodar river, principal component analysis, water quality index.

Introduction

Damodar river flows across two Indian states namely Jharkhand and West Bengal. The river basin is rich in mineral resources and home to large scale mining and industrial activities. In West Bengal it flows mainly through two districts Bardhaman and Hoogly. Massive coal deposition is found in the central basin in Jharkhand state and Raniganj in West Bengal. Apart from many other factories three integrated steel plants of Steel Authority of India Limited (SAIL) are located at Bokaro, Burnpur and Durgapur in the valley[1]. Durgapur (Durgapur subdivision, Bardhaman district, West Bengal) is regarded as the most industrialised steel city of the eastern India. It is home to many industrial units like Durgapur steel plant, Integrated steel plant of SAIL, Alloys steel plant, Durgapur thermal power station etc. The coal rich Raniganj lies upstream of Durgapur. A small rivulet Tamla flows through the area and joins the Damodar river. The total area of Durgapur is about 154 km^2 and ranks 77th most populated city of India. Since 2002 onwards Durgapur is undergoing rapid growth especially in infrastructure and industrial sectors. It is also becoming important real estate and educational hub of eastern India[2]. Durgapur barrage, a part of the Damodar Valley Corporation (DVC) multipurpose project, across river Damodar was constructed in the year 1955 with head regulators for canals on either side for feeding a vast network of canals and distributaries[1]. Much before the construction of Durgapur barrage, in 1932 the Anderson weir was constructed at the Rondiha which is about 19 km downstream of Durgapur barrage. Though there are some reports available about the water quality of the river Damodar[3, 4], studies on the canal network have remained neglected. Two main canals originate from Durgapur barrage, left bank main canal (LBMC) and right bank main canal (RBMC). The length of LBMC and RBMC is 136.8 and 88.5 km respectively. These canals form an extensive network of main and branch canals with total length of about 2494 km covering a large command area[5]. The canal waters are extensively used for domestic purpose by the local settlements. The canal has also become dumping place of garbage and other domestic wastes at some of the sites.

Monitoring and assessment of water quality is a continuous process which is must for the proper conservation and management of water resources. The major objectives of the present study were i. to investigate the hydrochemical profile of Damodar river and its canal waters flowing through Durgapur subdivision, ii. to develop an objective water quality index (WQI) indicating their overall ecological status, iii. to apply intelligent data analyses techniques like graphical methods and multivariate statistical approaches on water quality data for better interpretation of water chemistry, iv. to test the suitability of waters for irrigation using sodium adsorption ratio (SAR), percentage sodium (%Na) and permeability index (PI).

Material and methods

Sampling and analyses: Water samples were collected in three sets from five sites along the route of the Damodar river and five sites along its left bank main canal (figure-1). Sampling was done during second and third week of September, 2012, month. Collected samples were immediately stored in acid cleaned and properly rinsed (three times) high density polythene bottles (1000 ml) to minimise container pollution and better sample preservation[6]. Samples were stored at 4°C prior to analyses and all analyses were finished within seventy two hours of their collection, except BOD. Water quality of the collected samples was assessed for sixteen parameters viz. bicarbonate (HCO_3^-), biological oxygen demand (BOD), calcium (Ca^{2+}), chloride (Cl^-), dissolved oxygen (DO), electrical conductivity (EC), hardness (HARD), magnesium (Mg^{2+}), nitrate (NO_3^-), pH, phosphate (PO_4^{3-}), potassium (K^+), sodium (Na^+), sulphate (SO_4^{2-}), total dissolved solids (TDS) and temperature (TEMP) following standard procedures[7]. TEMP, pH and DO were measured at the sites. All the chemicals were of analytical grade purchased from Merck, India. Millipore water was used for preparation of all reagents and standards.

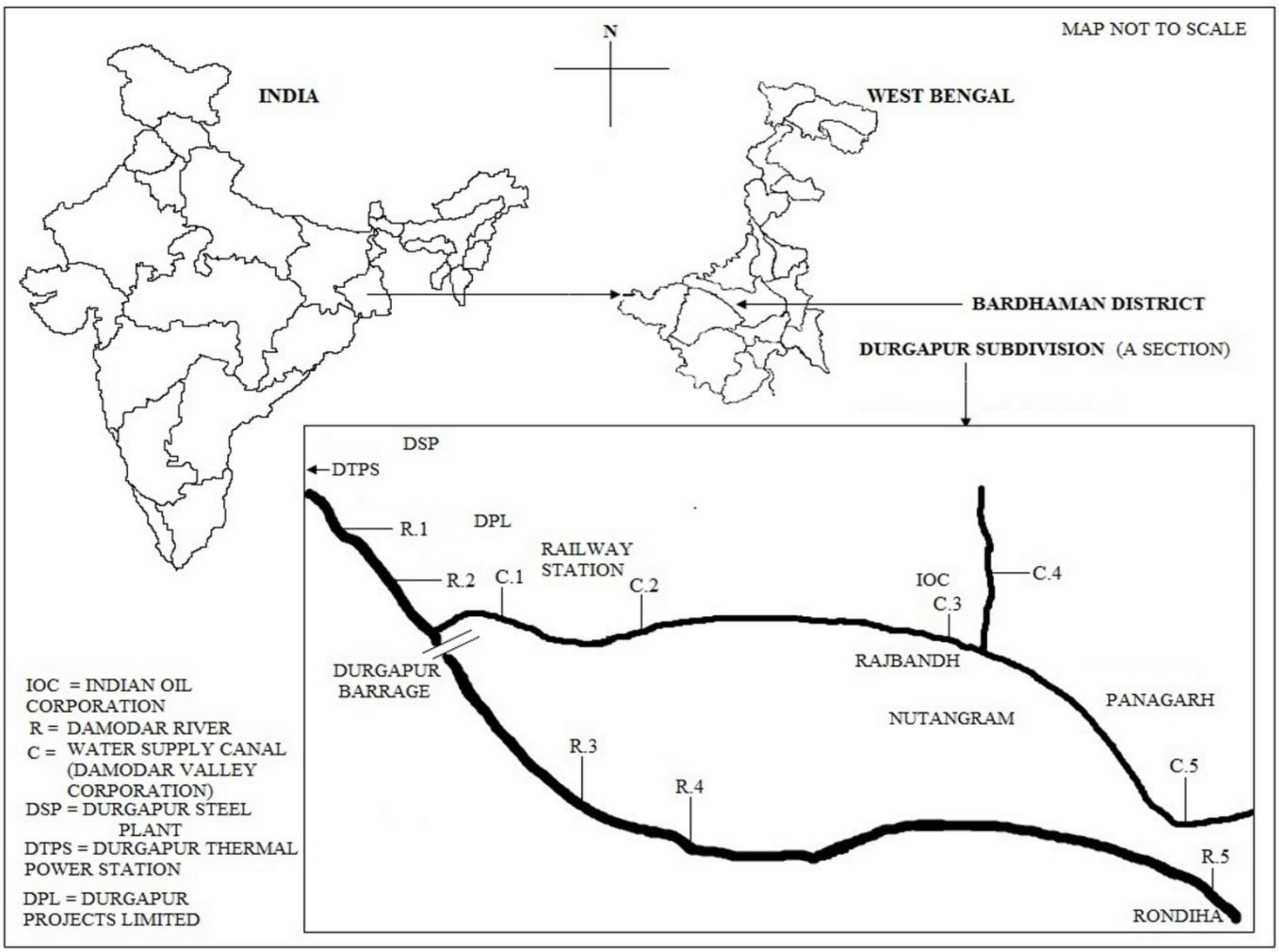

Figure-1
Study area and the sampling locations

Determination of Water Quality Index: Objective water quality index (WQI) was determined to know the ecological status of the surface waters[8].

$$WQI = k \frac{\sum_i C_i P_i}{\sum_i P_i}$$

Where, k is a subjective constant representing the visual impression of the surface water; k = 0.25 for highly contaminated water, 0.5 for moderately contaminated water, 0.75 for light contaminated water and 1.00 for apparently good quality water. *Ci* and *Pi* are normalised and relative weight values assigned to each parameter respectively. Constant k was not considered in the present study to avoid any subjective evaluation. *Ci* and *Pi* values were taken from the same the literature mentioned above in superscript letter. The reader is also referred to the work of the same authors. WQI values range from 0 – 100. WQI between 0 – 25 is classified as "very bad"; WQI between 26 – 50 is classified as "bad"; WQI between 51 – 70 is classified as "medium"; WQI between 71 – 90 is classified as "good" and WQI between 91–100 is classified as "excellent"[9,10].

Statistical analyses: Box and whisker plots were developed to know the variations of water quality parameters. Pearson correlation analysis was performed to determine the degree of association between studied parameters.

Piper diagram: Water samples can be classified by plotting distribution of major cations like Na^+, K^+, Ca^{2+} and Mg^{2+} and some major anions like Cl^-, SO_4^{2-} and HCO_3^- on graphs. Piper and Stiff diagrams are two important graphical methods employed for water type classification. In this research work graphical study was done constructing trilinear Piper diagram.

Multivariate hydrostatistical analyses: Multivariate hydrostatistical analyses were performed on water quality data using agglomerative hierarchical cluster analysis (AHCA) and principal component analysis (PCA)/Factor analysis (FA). Basic aim of the cluster analysis is identification of relatively homogeneous groups of the variables based on their similarities. AHCA is presented in the form of a dendrogram where cohesiveness and correlations between the variables can be observed[11]. PCA basically is a dimension reduction intelligent data analysis technique. It reduces a large number of variables to a small number of variables which are the principal components[12].

The principal component generated through PCA can be expressed as:

$$y_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + a_{i4}x_{4j} + \cdots + a_{im}x_{mj}$$

Where y = component score, a = component loading, x = measured value of the variable, i = component number, j = sample number, and m = total number of variables

Assessment of waters for irrigation purpose: Sodium adsorption ratio (SAR), percentage sodium (%Na) and permeability indices were used to investigate the suitability of river and canal waters for irrigation.

Sodium adsorption ratio: Sodium hazard is typically expressed as SAR. SAR quantifies the proportion of Na^+ to the sum of Ca^{2+} and Mg^{2+} ions[12] and is determined as given below[13]:

$$SAR = \frac{[Na^+]}{\sqrt{\frac{[Ca^{2+} + Mg^{2+}]}{2}}}$$

Percentage sodium: %Na is also used to assess sodium hazard as Na^+ can react with soil rendering clogging of soil particles. This can impair the physical properties of the soil and reduce soil permeability. %Na is computed from the equation displayed below[14]:

$$\%Na = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100$$

Permeability index: Long time use of irrigation water containing ions like Na^+, Ca^{2+}, Mg^{2+} and HCO_3^- can affect the physical properties of soil and impair soil permeability. Permeability index (PI) is used to evaluate the likely influence of irrigation water on the soils' physical properties. This index was evolved in 1964 to assess the suitability of water for irrigation which is calculated as presented below[15]:

$$PI = \frac{(Na^+ + \sqrt{HCO_3^-})}{Ca^{2+} + Mg^{2+} + Na^+} \times 100$$

Results and discussion

Water chemistry: The values obtained for the sixteen studied water quality parameters are presented in Table 1and Table 2. The variability in assessment of water quality parameters obtained is displayed as Box and whisker plots in Figure 2. BOD ranged from 12.30 to 47.30, Ca^{2+} ranged from 15.23 to 82.56; Cl^- ranged from 6.00 to 74.00; DO ranged from 1.30 to 3.80; EC ranged from 343.00 to 1520.00; HARD ranged between 52.00 to 296.00; HCO_3^- ranged between 56.00 to 196.00; K^+ ranged from 3.50 to 13.60; Mg^{2+} ranged from 0.45 to 21.87; Na^+ ranged between 24.90 to 83.00; NO_3^- ranged between 0.85 to 6.31; pH ranged from 6.46 to 7.80; PO_4^{3-} ranged from 0.12 to 0.31; SO_4^{2-} ranged between 50.02 to 120.37; TDS ranged from 193.00 to 823.00 and TEMP ranged from 29.30 to 31.70. Most of the parameters displayed high variance and range values suggesting anthropogenic influence on the surface water quality. An increasing trend in ionic concentrations is noticed from R2 to R3 and from C1 to C2. Higher values of BOD and lower values of DO than the regulatory standard indicate strong organic pollution of the Damodar river and canal waters. Our measured values of DO vary significantly from earlier reported values[3]. The regulatory value of BOD in surface water prescribed by the Central Pollution Control Board, India, ranges from ≤ 2 to ≤ 3 mg/l whereas, the recommended value of DO ranges from ≥ 4 to ≥ 6 mg/l. R3 lies just downstream to the *Tamla nala* discharge point and C2 lies downstream to the Durgapur station and adjoining areas. Canal waters from

Durgapur barrage to just upstream of C2 is used for cooking, bathing, washing and dumping of wastes etc.

Correlation analysis: Correlation analysis is used to measure the degree of association between chemical constituents. Good correlations between water quality parameters indicate interactions and interrelationships among them[16]. Correlation matrix of studied water quality parameters is displayed in Table 3. Most of the parameters display strong association among themselves indicating possible interactions between them. Significantly very high positive correlation is shown by TDS and all major ions like Ca^{2+}, Cl^-, HCO_3^-, K^+, Na^+, NO_3^-, Mg^{2+} and SO_4^{2-} (r > 0.800). Total hardness displays significant and positive correlation with all major cations and anions (r > 0.800) and DO. BOD and DO shows significant negative correlation (r = -0.660).

Table-1
Damodar River water quality

Parameters	Sampling sites				
	R1	**R2**	**R3**	**R4**	**R5**
BOD (mg/l)	18.60 ± 0.62	28.30 ± 1.35	17.60 ± 0.66	12.30 ± 0.40	21.40 ± 0.79
Ca^{2+} (mg/l)	17.43 ± 0.67	15.23 ± 0.87	82.56 ± 2.61	38.47 ± 1.67	19.24 ± 0.66
Cl^- (mg/l)	26.00 ± 1.73	22.00 ± 1.00	74.00 ± 3.61	46.00 ± 2.65	8.00 ± 1.00
DO (mg/l)	1.70 ± 0.10	1.30 ± 0.26	3.80 ± 0.53	3.50 ± 0.17	2.70 ± 0.10
EC (µS/cm)	437.00 ± 11.79	430.00 ± 15.13	1520.00 ± 50.21	1260.00 ± 37.98	381.00 ± 14.73
HARD (mg/l)	63.00 ± 2.31	60.00 ± 2.65	296.00 ± 7.00	128.00 ± 3.61	56.00 ± 3.00
HCO_3^- (mg/l)	89.00 ± 3.61	94.00 ± 1.00	196.00 ± 5.19	152.00 ± 7.21	72.00 ± 2.64
K^+ (mg/l)	4.60 ± 0.17	3.50 ± 0.17	13.60 ± 0.62	11.30 ± 0.70	3.80 ± 0.10
Mg^{2+} (mg/l)	6.20 ± 0.19	5.35 ± 0.23	21.87 ±0.66	7.78 ± 0.21	1.94 ± 0.08
Na^+ (mg/l)	27.40 ± 1.01	29.80 ± 0.79	83.00 ± 3.29	64.20 ± 1.82	26.40 ± 0.85
NO_3^- (mg/l)	1.74 ± 0.06	1.33 ± 0.05	6.31 ± 0.27	4.39 ± 0.15	1.83 ± 0.07
pH (pH units)	7.31 ± 0.23	7.38 ± 0.15	6.46 ± 0.16	7.80 ± 0.20	7.71 ± 0.26
PO_4^{3-} (mg/l)	0.17 ± 0.01	0.13 ± 0.01	0.29 ± 0.06	0.13 ± 0.02	0.30 ± 0.01
SO_4^{2-} (mg/l)	56.34 ± 1.61	52.82 ± 1.54	120.37 ± 4.78	71.95 ± 2.82	66.16 ± 1.48
TDS (mg/l)	237.00 ± 5.12	231.00 ± 4.36	823.00 ± 26.28	683.00 ± 29.51	203.00 ± 6.93
TEMP (°C)	29.70 ± 0.26	29.50 ± 0.31	31.70 ± 0.27	30.60 ± 0.72	29.40 ± 0.20

Table-2
Water quality of the left bank main canal

Parameters	Sampling sites				
	C1	C2	C3	C4	C5
BOD (mg/l)	37.50 ± 1.51	47.30 ± 1.32	31.20 ± 1.14	24.70 ± 0.69	16.90 ± 0.87
Ca^{2+} (mg/l)	20.04 ± 1.54	23.67 ± 0.98	17.64 ± 0.87	17.64 ± 0.75	24.85 ± 1.01
Cl^- (mg/l)	16.00 ± 1.73	28.00 ± 1.00	6.00 ± 1.73	10.00 ± 1.00	16.00 ± 3.61
DO (mg/l)	1.80 ± 0.17	1.40 ± 0.17	1.90 ± 0.32	2.10 ± 0.17	2.10 ± 0.17
EC (µS/cm)	418.00 ± 13.00	432.00 ± 13.52	414.00 ± 15.13	343.00 ± 12.12	569.00 ± 17.57
HARD (mg/l)	52.00 ± 1.73	64.00 ± 2.65	52.00 ± 3.46	52.00 ± 2.51	76.00 ± 3.00
HCO_3^- (mg/l)	56.00 ± 1.73	76.00 ± 3.61	64.00 ± 2.00	68.00 ± 3.46	84.00 ± 3.61
K^+ (mg/l)	3.50 ± 0.17	5.70 ± 0.26	3.60 ± 0.44	3.50 ± 0.17	3.70 ± 0.20
Mg^{2+} (mg/l)	0.45 ± 0.03	2.37 ± 0.08	1.94 ± 0.06	1.94 ± 0.07	3.40 ± 0.14
Na^+ (mg/l)	28.20 ± 1.14	31.50 ± 1.20	24.90 ± 0.92	25.60 ± 0.96	36.80 ± 1.61
NO_3^- (mg/l)	1.51 ± 0.05	2.98 ± 0.08	1.54 ± 0.06	0.85 ± 0.03	2.36 ± 0.08
pH (pH units)	7.47 ± 0.29	7.23 ± 0.24	7.40 ± 0.31	7.48 ± 0.22	7.42 ± 0.32
PO_4^{3-} (mg/l)	0.28 ± 0.01	0.31 ± 0.03	0.24 ± 0.01	0.23 ± 0.02	0.12 ± 0.02
SO_4^{2-} (mg/l)	63.18 ± 1.98	68.54 ± 2.73	64.40 ± 2.05	60.02 ± 2.50	50.02 ± 1.47
TDS (mg/l)	227.00 ± 9.17	246.00 ± 9.54	216.00 ± 6.24	193.00 ± 7.00	312.00 ± 9.85
TEMP (°C)	29.80 ± 0.15	30.20 ± 0.61	29.30 ± 0.46	29.70 ± 0.52	29.30 ± 0.30

Table-3
Correlation analysis of the water quality data

	BOD	Ca^{2+}	Cl^-	DO	EC	HARD	HCO_3^-	K^+	Mg^{2+}	Na^+	NO_3^-	pH	PO_4^{3-}	SO_4^{2-}	TDS	TEMP
BOD	1	-0.360	-0.334	-0.660*	-0.522	-0.406	-0.551	-0.413	-0.461	-0.483	-0.338	-0.047	0.551	-0.170	-0.515	-0.193
Ca^{2+}		1	0.919**	0.801**	0.919**	0.994**	0.911**	0.911**	0.939**	0.946**	0.940**	-0.745*	0.214	0.945**	0.920**	0.924**
Cl^-			1	0.685*	0.925**	0.929**	0.953**	0.949**	0.930**	0.944**	0.939**	-0.670*	0.035	0.836**	0.929**	0.956**
DO				1	0.868**	0.786**	0.804**	0.836**	0.701*	0.848**	0.792**	-0.239	0.083	0.745*	0.864**	0.711*
EC					1	0.919**	0.968**	0.975**	0.875**	0.993**	0.948**	-0.481	-0.064	0.809**	1.000**	0.887**
HARD						1	0.933**	0.906**	0.970**	0.945**	0.925**	-0.759*	0.153	0.931**	0.919**	0.913**
HCO_3^-							1	0.956**	0.941**	0.971**	0.924**	-0.558	-0.110**	0.801**	0.968**	0.883**
K^+								1	0.867**	0.971**	0.963**	-0.502	0.061	0.849**	0.977**	0.942**
Mg^{2+}									1	0.898**	0.867**	-0.779**	0.036	0.867**	0.874**	0.867**
Na^+										1	0.962**	-0.546	-0.023	0.835**	0.995**	0.910**
NO_3^-											1	-0.592	0.129	0.863**	0.951**	0.918**
pH												1	-0.335	-0.751*	-0.484	-0.665*
PO_4^{3-}													1	0.479	-0.062	0.265
SO_4^{2-}														1	0.808**	0.910**
TDS															1	0.893**
TEMP																1

*.Correlation is significant at the 0.05 level **. Correlation is significant at the 0.01 level

Table-4
Classification of Water and salinity indices

Sampling sites	WQI classification	Piper classification (water type)	SAR	%Na	PI
R1	Medium	Mixed-Ca^{2+}-Mg^{2+}-Cl^-	1.43	48.52	93.02
R2	Medium	Na^+-Cl^-	1.67	53.46	101.19
R3	Medium	Mixed-Ca^{2+}-Mg^{2+}-Cl^-	2.09	39.96	56.49
R4	Medium	Na^+-Cl^-	2.27	54.51	81.53
R5	Medium	Na^+-Cl^-	1.54	52.74	98.68
C1	Medium	Na^+-Cl^-	1.71	55.93	96.48
C2	Medium	Na^+-Cl^-	1.65	52.41	90.55
C3	Medium	Na^+-Cl^-	1.50	52.94	99.06
C4	Medium	Na^+-Cl^-	1.54	53.57	100.47
C5	Medium	Na^+-Cl^-	1.84	52.65	88.78

Table-5
Principal component analysis of the water quality data

Parameters	Principal Components		Communalities
	1	2	
BOD	-0.428	0.795	0.815
Ca^{2+}	0.981	0.117	0.976
Cl^-	0.961	0.017	0.924
DO	0.830	-0.268	0.761
EC	0.967	-0.201	0.975
HARD	0.983	0.074	0.971
HCO_3^-	0.966	-0.201	0.974
K^+	0.968	-0.078	0.944
Mg^{2+}	0.948	0.008	0.898
Na^+	0.981	-0.138	0.981
NO_3^-	0.965	0.021	0.931
pH	-0.660	-0.510	0.695
PO_4^{3-}	0.110	0.871	0.770
SO_4^{2-}	0.913	0.350	0.956
TDS	0.968	-0.195	0.975
TEMP	0.946	0.196	0.934
Eigenvalues	12.43	2.05	
% variance explained by component	77.72	12.79	
Cumulative % variance	77.72	90.51	

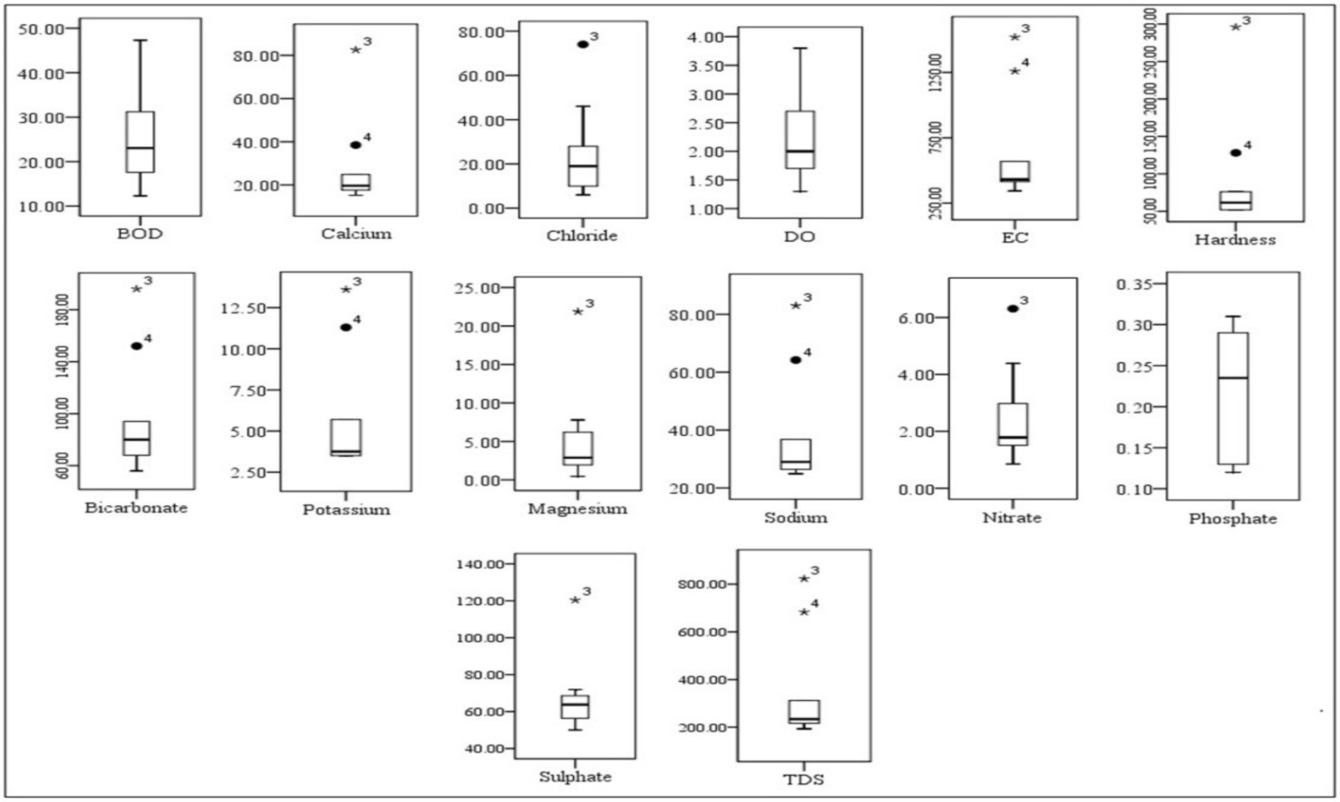

Figure-2
Box and whisker plot of the water quality data (3 = R3; 4 = R4)

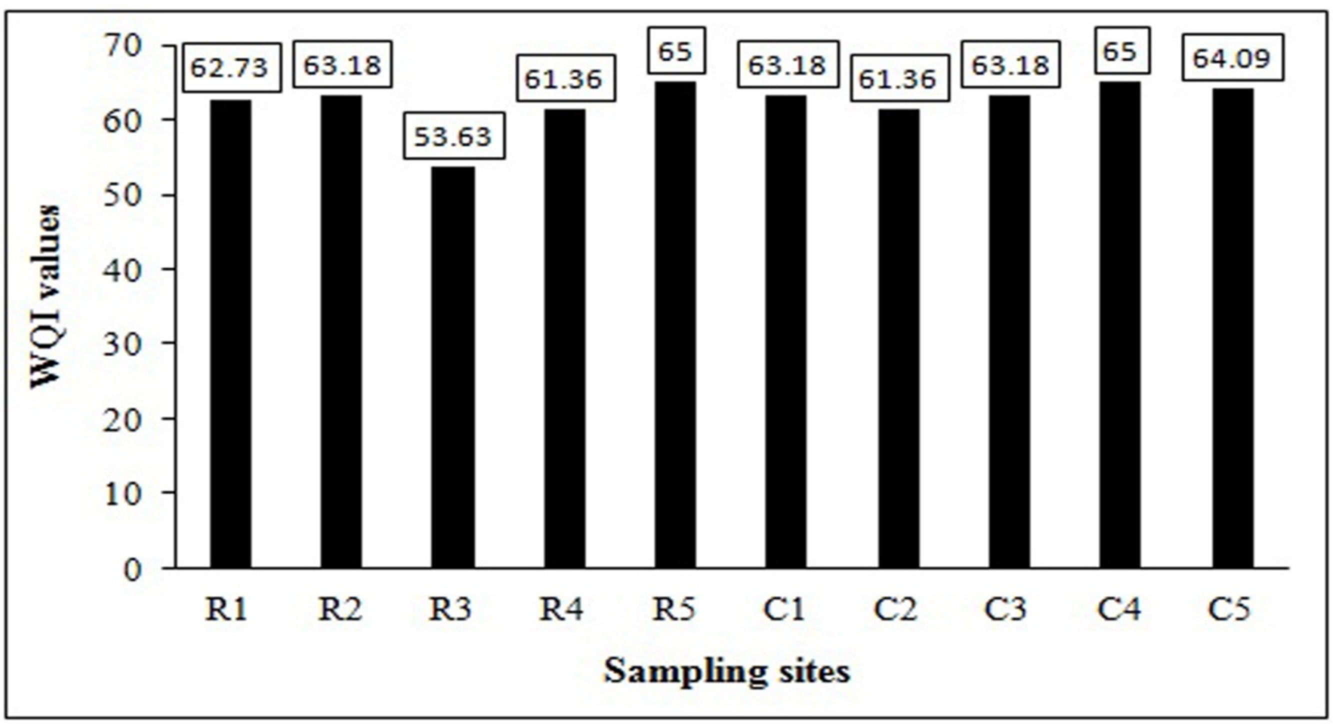

Figure-3
Water quality index values

Water quality index: Water quality assessment is must for proper conservation and management of water resources. Data interpretation simply on the basis of chemical analyses is a complex task which is not very helpful for the general public and decision makers to understand. Water quality index is a single unitless number ranging from 0 – 100 which can be suitably used as indicator of overall surface water quality. Moreover, this is easy to understand and effectively conveys information to the general public and policy makers. In the present study WQI for the river Damodar and its LBMC ranged from 53.63 to 65.00 (Figure 3). Though the surface water quality at all sampling sites can be classified as medium (Table 4), a sudden decrease in WQI value (53.63) was noted at site R3 which lies just downstream of *Tamla nala* discharge point. WQI values from 25 – 50 are classified as bad and R3 is very close to this range. The discharged waste water after mixing with the Damodar river water gets diluted and with increasing distance from the discharge point the WQI gets better. This trend can be noted at R3, R4 and R5. A close look at the hydrochemical data and the WQI values reveal similar pattern.

Piper diagram: Piper diagram[17] is a trilinear plot consisting of two lower triangles and middle quadrilateral. The left and the right triangles represent the distribution of cations and anions respectively. Major cations and anions such as Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^- and CO_3^- are plotted on it for hydrochemical evaluation and classification of surface waters. The diamond summarises the dominant cations and anions to indicate the final water type. The water types are designated according to the area in which they occur on the diagram segments[18]. To determine and compare the water types of the Damodar river and its canal waters classification system described in known literature was consulted[19]. Piper diagram constructed is displayed in Figure 4. The right hand side of the Figure 4, modified from earlier study, describes the segments for overall designation of the final water type. Two distinct water types are observed on the Piper plot belonging to K and I category. Accordingly samples R1 and R3 can be designated Mixed-Ca^{2+}-Mg^{2+}-Cl^- water type and samples R2, R4, R5 and all canal water samples belonging to Na^+-Cl^- water type (Table-4).

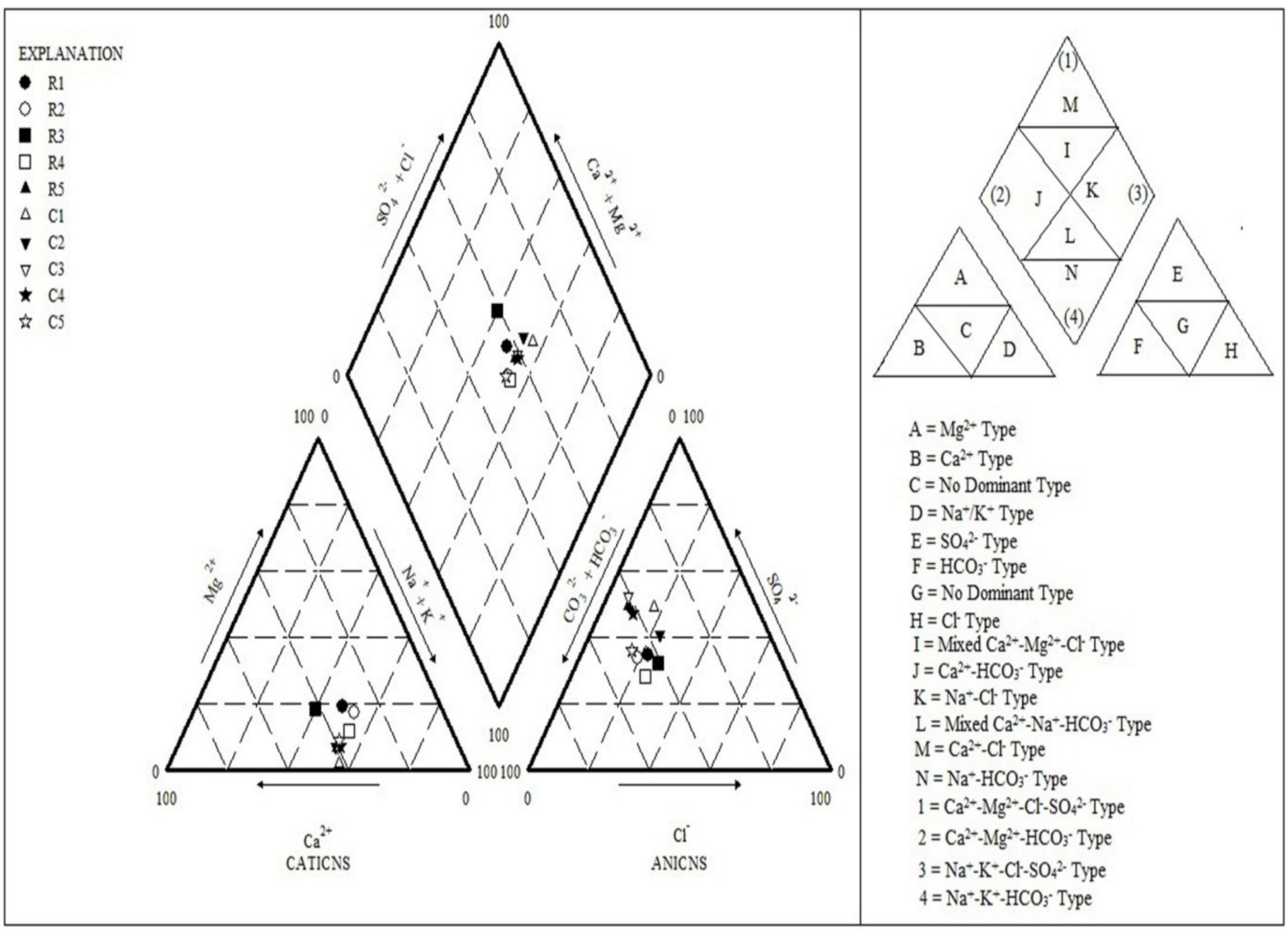

Figure-4
Piper trilinear diagram of the water quality data (Right side reference diagram modified from earlier study[19])

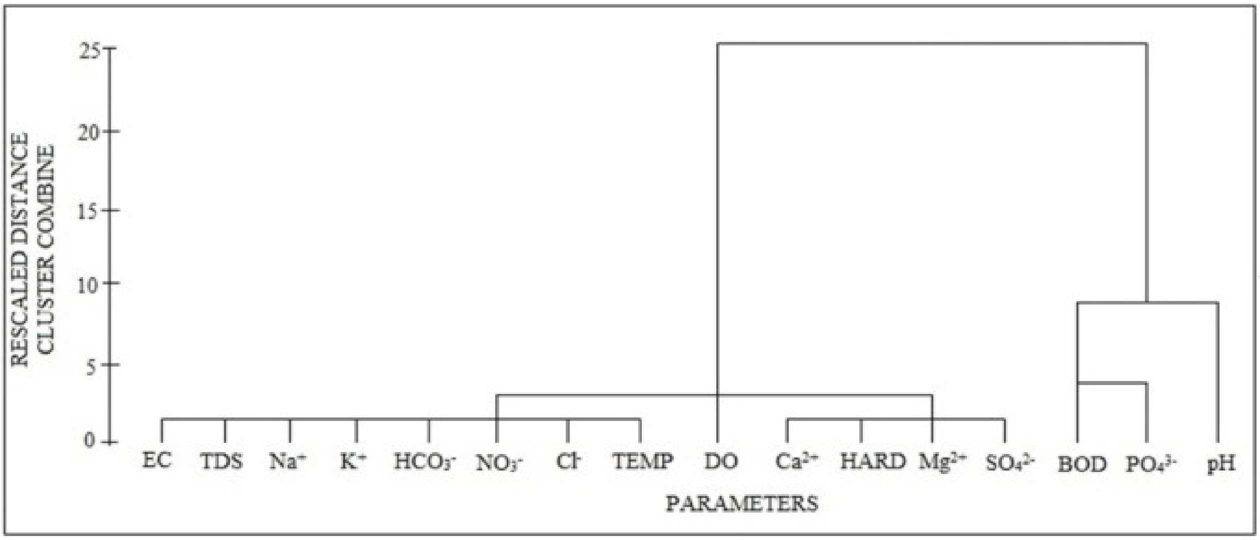

Figure-5
Agglomerative hierarchical cluster analysis

Agglomerative hierarchical cluster analysis: AHCA was performed using Ward's method and Squared Euclidean Distance to form a combination of clusters. Three main clusters are observed from the dendrogram presented in Figure 5. The AHCA displays strong association between most of the variables.

Principal component analysis/Factor analysis: Principal component analysis of the water quality data is presented in Table 5. PCA can be applied to more accurately evaluate the clustering behaviour. Principal components (PC) with Eigenvalues greater than one were only selected for the analysis of water chemistry. PCs having Eigenvalues more than unit value are shown in Figure 6. The values of PCs are represented as factor loadings. Factor loading > 0.75, 0.75 – 0.5 and < 0.5 can be classified as strong, moderate and weak respectively[20]. PCA generated two PCs explaining 90.51% of the total variance. PC1 accounts for 77.72% of the total variance whereas, PC2 accounts for 12.79% variability. PC1 displays high positive factor loadings for Ca^{2+}, Cl^-, DO, EC, HARD, HCO_3^-, K^+, Mg^{2+}, Na^+, NO_3^-, SO_4^{2-}, TDS and TEMP (Factor loading > 0.75) and moderate negative factor loading for pH (factor loading 0.5 – 7.5). Significantly high and positive factor loadings are obtained for BOD and PO_4^{3-} (> 0.75) in PC2. pH again reveals itself in PC2 with moderate negative factor loading. The same pattern can be observed in the AHCA hydrostatistical modeling. The presence of major cations and anions in PC1 suggests rock-water-soil interaction. However, river Damodar flows through important mining and industrial belts in the West Bengal and its LBMC is directly exploited by the local human settlements. At some of the studied sites a sudden increase in the concentrations of all ions was noted. Moreover, PCA did not result in any significant reduction of variables suggesting all variables play a role in influencing the chemical properties of the river and canal waters. These arguments clearly indicate about the anthropogenic influence on the alterations of the surface water chemistry. In PC2 BOD and PO_4^{3-} are present together with high factor loadings pointing to the organic pollution load of the surface waters.

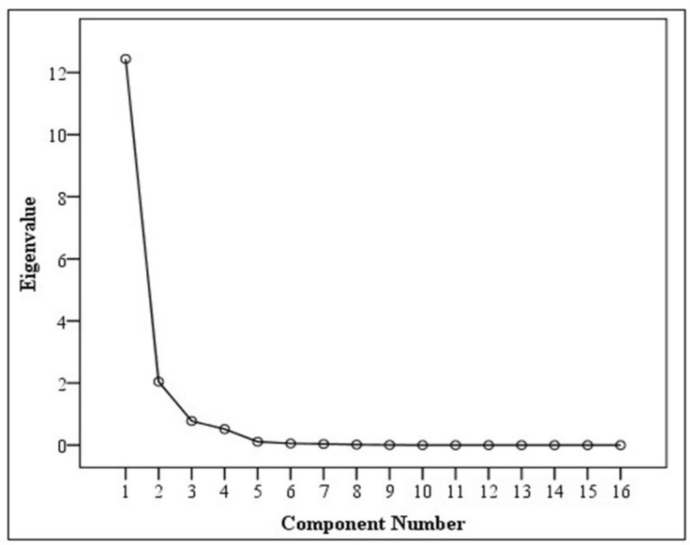

Figure-6
Scree plot of PCA displaying all components and PC 1 and 2

Sodium adsorption ratio and salinity hazard: SAR is simply the ratio of Na^+ to the average and square root of Ca^{2+} and Mg^{2+}. Ca^{2+} and Mg^{2+} ions tend to counter the effects of Na^+ on the soil. Irrigation water with high SAR value can damage the physical structure of the soil as Na^+ can enter into cation exchange reaction with the soil replacing already adsorbed Ca^{2+} and Mg^{2+} ions. The sodium enriched soil becomes hard and compact when dry and increasingly impervious to water penetration[21]. Waters with SAR values < 10 are excellent for irrigation[22]. SAR in the Damodar river and its canal waters varied from 1.43 – 2.27 (Table 4) indicating their suitability for irrigation related works. Salinity hazard for crop productivity is also measured in terms of EC and TDS. Waters with conductivity in the range of 250 – 750 µS/cm are classified as good for irrigation whereas, waters with conductivity between 750 – 2250 µS/cm are considered permissible. All sampling sites except R3 and R4 showed EC between 250 – 750 µS/cm. EC at R3 and R4 was recorded in the range 750 – 2250 µS/cm. Water with TDS < 1000 mg/l is classified as best for irrigation purposes. All sampling sites along the Damodar river and its LBMC displayed TDS < 1000 mg/l. Plotting SAR values against EC on the United States Salinity Laboratory diagram[13] puts all water samples except R3 and R4 into C2S1 category (Figure 7). R3 and R4 fall into C3S1 category. These observations further suggest suitability of the river and canal waters for irrigation.

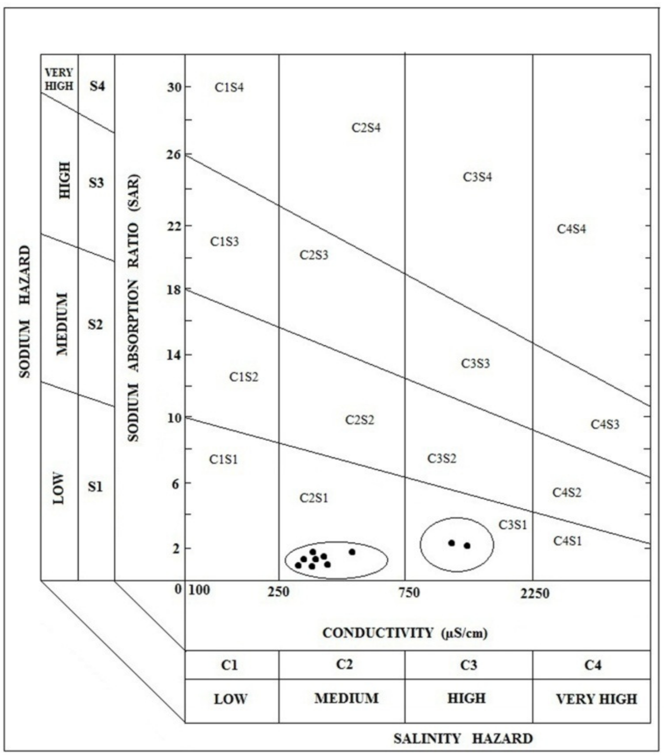

Figure-7
Salinity diagram displaying SAR versus conductivity

Percentage of Sodium: Another index used to assess sodium hazard is %Na. Irrigation waters high in Na^+ content can cause decrease of Ca^{2+} and Mg^{2+} in the soil resulting in reduction of soil permeability and development of a hard salt pan. Na^+-HCO_3^-, Na^+-SO_4^{2-} and Na^+-Cl^- types soil support little or no plant growth[23]. The values of %Na are given in Table 4. Wilcox diagram, which plots %Na against conductivity, classifies irrigation waters varying from excellent to unsuitable[14]. Two discrete categories ranging from excellent to good and good to permissible are observed from the Wilcox diagram (Figure 8) for the Damodar river and its canal waters.

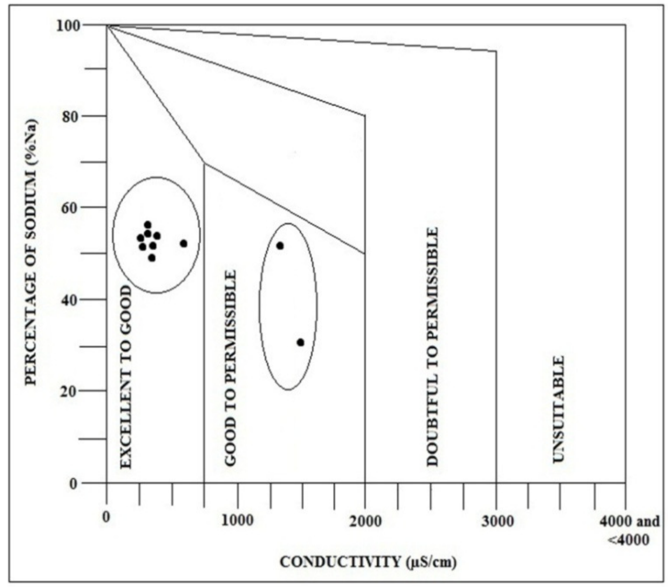

Figure-8
Wilcox diagram displaying %Na versus conductivity

Permeability index: Based on PI irrigation waters can be categorised in class I, class II and class III having PI values > 75, 25 – 75 and < 25 respectively. PI values of R1, R2, R4, C1, C2, C3, C4 and C5 come under class I category whereas, PI of R3 falls under class II category (Table 4). This classification further reflects suitability of the Damodar river and LBMC waters for irrigation and agricultural purposes. The suitability of Damodar river waters for irrigation purpose has also been reported earlier[4]. This study further documents the suitability of the canal waters for the irrigation work.

Conclusion

Monitoring and assessment of water quality is a continuous process which is must for the proper conservation and management of the water resources. This study was conducted to assess the environmental quality of the river Damodar and its LBMC flowing through the Durgapur subdivision. WQI (53.63 – 65.00) classified the river and canal waters into medium category indicating anthropogenic influence on the surface water characteristics. Piper diagram suggested water types ranging from Mixed-Ca^{2+}-Mg^{2+}-Cl^- to Na^+-Cl^- water types. AHCA and PCA interpreted both geogenic and anthropogenic factors responsible for controlling the water chemistry. SAR (1.43 – 2.27), %Na (39.96 – 55.93) and PI (56.49 – 101.19) values along with the United States Salinity Laboratory diagram and Wilcox diagram reflected suitability of the river and canal waters for irrigation. Though the concentrations of major ions were within the prescribed standards severe organic pollution load was noted at all the sampling sites much beyond the regulatory standards.

Under the National River Conservation Plan many steps have been undertaken for the abatement of pollution of the river Damodar like treatment of industrial and domestic wastewaters before discharging into the river. But this study demonstrates more is needed for proper conservation and management of this precious water body including strict enforcement of the environmental laws. Moreover, the local people must be educated not to dump wastes into the canal waters and Non Government Organisations can play helpful roles in this direction.

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