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Evaluation of Water Quality of Ganges River Using Water Quality Index Tool

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Abstract

Water quality of Ganges river was evaluated using the Water Quality Index (WQI) tool. Water sampled at five designated locations from Rishikesh to Allahabad (about 720 km long stretch). Collected samples were measured by ion chromatography, titrimetry and aquameter kit methods. The parameters like pH, electrical conductivity (EC), dissolved oxygen (DO), total dissolved solids (TDS), turbidity, salinity, major cations e.g. Na^+, K^+, Mg^{2+}, Ca^{2+}, major anions e.g. F^-, Cl^-, SO_4^{2-}, NO_3^{2-} and alkalinity of samples were measured at designated locations. Subsequently, WQI has been calculated from all the measured parameters. The result showed WQI of Ganges river water from Rishikesh to Allahabad ranged from 28.93 to 73.24 which denotes degradation of water quality along the downstream. In addition, values of most of the evaluated parameters increased significantly along the downstream of river suggesting that local environmental pollutants contributed incrementally in deterioration of the quality of river water. Pearson correlation matrix analysis showed a strong correlation between some of the measured parameters suggesting their origin from common source. WQI values showed easy understanding and trend of water quality of Ganges river. These results point towards requirement of urgent plans for prevention of river water pollution.

Keywords: water quality index; water chemistry; water quality; Ganges river

1. Background

River Ganges is the largest river in India spread over almost 2,525 km long from Gangotri to Bay of Bengal and its basin covers about 8,61,404 km^2, providing water for life to more than twenty five cities and thousands of villages (Meher *et al*., 2014). Ganges river represents vast diversity of billions of microbial and aquatic habitats living in it and therefore, monitoring of the water quality of the river is of central importance especially because of known worldwide concern for declining the water quality (Carpenter *et al*., 1998; Junshum *et al*., 2007). Due to increasing industrial, agricultural and domestic factors river Ganges is considered a largely polluted river in the world (Mukherjee 1993; Sharma *et al*., 2012). The quality of water depends on the physicochemical parameters like pH, total dissolved solid (TDS), electrical conductivity (EC), dissolved oxygen (DO), alkalinity, salinity, major cations (Na^+, K^+, Mg^{2+}, Ca^{2+}, etc.,) and major anions (F^-, Cl^-, SO_4^{2-}, NO_3^{2-}, PO_4^{2-}, etc.,). These factors widely vary from location to location due to discharges from the human activities. The major sources of ions in rivers are from terrestrial and anthropogenic weathering processes (Sarin *et al*., 1992; Jangwan *et al*., 2010; Chakrapani *et al*., 2009) and the water quality of rivers are greatly affected by changes in melting glaciers and increasing constructions on banks of the river. The increasing pollution in river water poses greater threat to health and life of the people as they drink and use this water for utility purposes. The qualitative studies on major ions make a significant approach in determining quality, biochemical properties, hydrogeology, and chemistry of the water (Li *et al*., 2008; Pehlivan, 2010). Based on various physicochemical parameters, Water Quality Indices (WQI) is a mathematical tool that evaluates the water quality as a whole. It facilitates better understanding of water quality in aquatic resources. Studies on WQI of many rivers have been reported e.g. Cauvery river (Kalavathy *et al*., 2011); Atharabanki river (Samantray *et al*., 2009); Ramganga river (Alam *et al*., 2010) and Subernarekha (Parmar *et al*., 2010). Moreover, several studies have been reported in the literature elucidating the water quality of Ganges river (Rai *et al*., 2010; Misra 2011; Thomas *et al*., 2011). However, variation in water quality along long stretch of Ganges river have not been elaborated elsewhere. This study was aimed to evaluate water quality and spatial variation using WQI tool in the

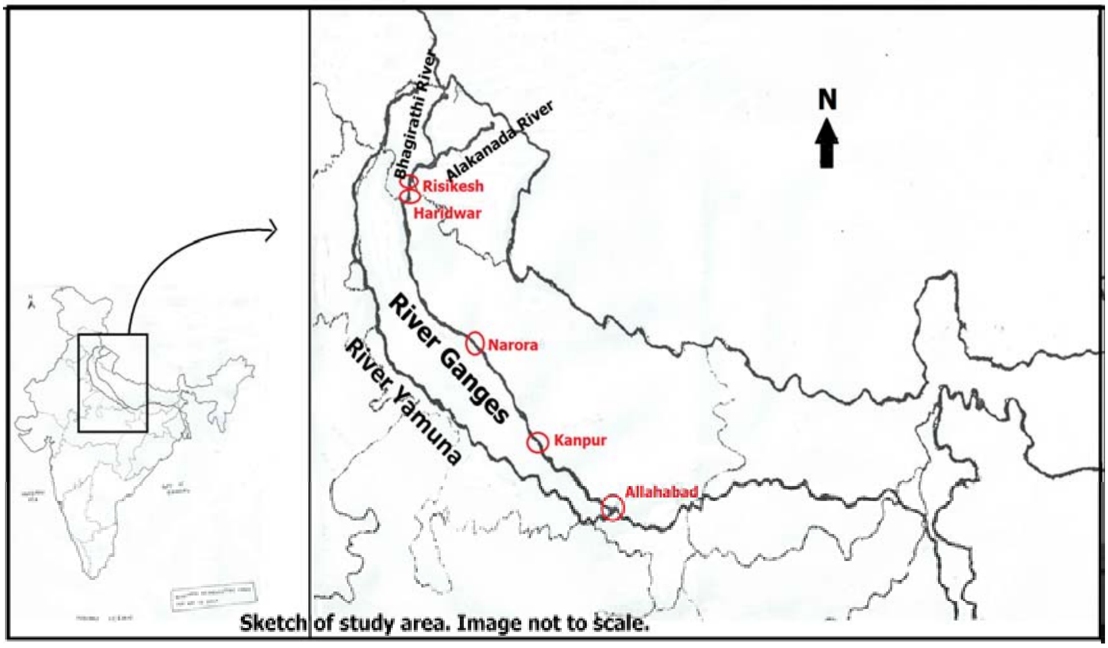

Figure 1. Geological map of the study area

river Ganges from Rishikesh to Allahabad that covers about 720 km stretch of the river. The research results are likely to help plan controlling the pollution in river water and for reducing risk to human health.

2. Materials and Methods

2.1. Locations

The locations for the sampling and analysis were selected along the river Ganges, namely: Allahabad, Kanpur, Narora, Haridwar and Rishikesh (Fig. 1). The details of the sampling sites are given in the Table 1. Water samples were collected in the month of November 2011 for the analysis which represents post rainy season sampling.

2.2. Sampling procedure and method of analysis

The physicochemical properties were measured in situ in the flowing water using the water analysis kit (GPS Aqua Meter- AP-1000, Aqua Read Ltd, U.K), and was calibrated each time before use. Water samples were collected in plastic bottle washed with double distilled water which was previously rinsed with 15% (v/v) HNO_3 for 24 hour. Before analysis, the samples were filtered with Whatman-542 filter paper (G.E. Healthcare U.K. Limited). Alkalinity of water was measured by Titration method, major cation (Na^+, K^+, Mg^{2+}, Ca^{2+}) and anions(F^-, Cl^-, SO_4^{2-}, NO_3^{2-}) were measured using the ion exchange chromatography system (Dionex Corporation, Sunnyvale, CA, USA). All the statistical analysis was performed using SPSS statistics 17.0 software.

Table 1. Details of the sampling stations and site

Stations	Site Code	Latitude	Longitude	Altitude	Description
Allahabad	A	25^0 25.55' N	81^0 52.97' E	64	River Ganges prior to Sangam
Kanpur	B1	26^0 26.09' N	80^0 24.53' E	100	Jajmau Bridge, (River Ganges after industrial discharges)
	B2	26^0 36.83' N	80^0 16.49' E	81	Bithoor, (Entry of Ganges to Kanpur)
Narora	C1	28^0 08.77' N	78^0 25.77 E	168	Lower canal (Ganges canal after Narora Atomic Power Station)
	C2	28^0 11.37' N	78^0 23.79 E	162	Narora Barrage at river Ganges
	C3	28^0 12.61' N	78^0 23.08' E	166	NPCIL Ghat (Entry of Ganges at Norora)
Haridwar	D	29^0 55.86' N	78^0 08.34 E	277	Krishna Ghat, (River Ganges after Har ki Pauri)
Rishikesh	E	29^0 57.19' N	78^0 10.17 E	305	River Ganges at Laxman Jhula

2.3. Determination of WQI

WQI was calculated by the measured values of physiochemical parameters as described elsewhere (Hameed *et al*., 2010). In brief, according to its relative importance to overall water quality each measured parameter was assigned a definite weight (W_a) (Table 5). Parameters having significant influence were assigned higher weight (5) and lower weight (1) to that of the least influencing. Subsequently, relative weights (W_r) were calculated by using the formula

$$W_r = W_{ai} \div \sum_{i=1}^{n} W_{ai} \quad \text{(Eq. 1)}$$

(W_r = Relative weight, W_a = assigned weight of each parameter, n = Number of parameters considered for the WQI). Further, quality rating scale (Q) has been calculated for the each parameter by dividing its respective standard values as suggested in the BIS guidelines.

$$Q_i = [C_i \div S_i] \times 100 \quad \text{(Eq. 2)}$$

However, to calculate Q for the DO and pH, different methods were employed. The ideal values (V_i) of pH (7.0) and DO (14.6) were deducted from the measured values in the samples (Hameed *et al*., 2010).

$$Q_{i\,pH,DO} = [(C_i - V_i) \div (S_i - V_i)] \times 100 \quad \text{(Eq. 3)}$$

(Q_i = Quality rating scale, C_i = measured concentration of each parameter, S_i = Drinking water standard values for the each parameter according to BIS). Next, sub indices (SI) have been calculated to compute the WQI.

$$SI_i = W_r \times Q_i \quad \text{(Eq. 4)}$$

$$WQI = \sum SI_i \quad \text{(Eq. 5)}$$

Finally, the obtained WQI values were categorized as proposed. (Table 6, Yadav *et al*., 2010).

3. Results and Discussions

3.1. Determination of physicochemical parameters in water samples

3.1.1. Variation in pH

Present investigations have shown that in water of Ganges the pH ranged between 7.53 and 8.69. Towards the downstream of river an increasing trend of alkalinity were found. However, it fall within the recommended value of BIS and WHO. It may be noted that our studies showed some exceptions at stations A, B1, and B2 (Table 2). The observed minor increases in alkalinity at these stations may partly be due to contributions of calcium and magnesium carbonate by anthropogenic and weathering from the soil and rocks (Samuel *et al*., 2007; Taner *et al*., 2010). Earlier it was reported that between Kannauj and Allahabad river Ganges is mostly polluted (Trivedi, 2010). Our study reports higher pH value in this stretch of river indicating no improvement in water quality during these years.

3.1.2. Measurement of DO

Dissolved Oxygen (DO) was found to be > 10 mg/L at all of the locations which is relatively high probably indicating high rate of photosynthesis (Tripathi *et al*., 1991) by the phytoplanktons present in the river Ganges. Other studies have also reported high DO in the Ganges water (NRCD, 2009) which was assumed to be due to comparatively lower oxygen consumption by the microbial respiration than the oxygen production by the photosynthetic activities in the Ganges river environment (Tare *et al*., 2003). However, it also to be noted that DO in water depends on many factors like temperature, microbial loads, atmospheric pressure and time of sample collection. High DO favours the self-purification capacity of water which may be attributed to largely believe high quality, self-purification (Nautiyal, 2008) and bactericidal properties of water from river Ganges.

3.1.3. Electrical conductivity, turbidity and alkalinity

In water of Ganges the pattern of Electrical Conductivity (EC) and turbidity are in conformity while EC increased along the downstream. The EC values in the Ganges river ranged from 119.86 - 494.94 µS/cm which is lower as compared to 111.4 - 604.4 in Uppar Han river (Li and Zhang, 2008) and high comparing with Huai river China (Zhang *et al*., 2010). However, it remained within the guideline limits of BIS & WHO (Table 3). Turbidity was found to vary with the location of sampling suggesting greater addition of particulate matters along the cities on the bank of river. The trend of alkalinity concentration increased from the station E to A, but did not exceed the prescribed limit of 200 mg/L (BIS, 2009) suggesting contributions of alkaline salts as the river flows down along the route.

3.1.4. Total dissolved solids and salinity

Total Dissolved Solids (TDS) and salinity of river Ganges were measured at selected locations and results are given in Table 2. The value of TDS ranged from 77.4±3.9 - 328.54±5.2 ppm and the average TDS value on this stretch of Ganges river was found 173 ppm, which is more than two fold higher than the global median value of TDS (65 ppm) in river water (Meybeck, 2003). Higher TDS value and its increasing pattern towards the downstream of river can be attributable to the increasing anthropogenic activities and long term

Table 2. Water chemical data at different station (all units in mg/L except Temp. in ^{o}C, EC in μs/cm, Turb in NTU; values with±standard deviation EC= Electrical Conductivity; TDS= Total Dissolved Solid; Turb= Turbidity; ND= Not Detected)

Code	pH	DO (mg/L)	TDS (ppm)	EC (µS/cm)	Salinity (ppt)	Alkalinity (mg/L)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	F^{-}	SO_4^{2-}	NO_3^{2-}
A	8.65±0.05	12.53±0.02	328.54±5.2	494.93±43.28	0.24±0.025	198.8±16.2	62.33±5.167	18.92±1.85	68.31±4.85	6.14±0.48	68.55±3.15	0.499±0.17	14.22±0.725	3.33±0.230
B1	8.69±0.01	12.48±0.01	234.6±3.1	358.4±8.79	0.17±0.001	187.56±13.3	19.02±2.265	ND	18.92±0.54	2.52±0.216	14.28±1.24	0.086±0.01	10.37±0.736	3.35±0.131
B2	8.54±0.04	11.26±0.02	245.5±2.7	378±9.67	0.18±0.001	158.72±9.71	35.2±2.277	17.05±1.58	55.82±4.77	6.48±0.60	11.3±1.58	0.388±0.02	9.72±1.273	3.28±0.232
C1	8.38±0.01	10.17±0.01	133.31±2.9	185±25.9	0.08±0.037	97.36±3.51	42.27±3.939	9.24±0.58	22.42±0.96	4.92±0.33	3.37±0.28	0.584±0.04	0.66±0.013	2.96±0.150
C2	8.32±0.01	10.14±0.01	133.24±3.8	205.86±8.7	0.1±0.001	98.4±4.78	35.32±2.511	7.82±0.45	16.16±0.92	3.14±0.16	3.48±0.33	0.063±0.01	6.77±0.385	3.18±0.225
C3	8.34±0.01	10.05±0.01	132.65±4.1	202.05±18.78	0.096±0.009	25.40±1.28	41.3±2.79	9.33±0.55	19.75±1.34	3.69±0.25	2.86±0.24	0.46±0.03	4.63±0.199	3.19±0.417
D	7.53±0.001	10.9±0.02	100.71±3.7	135.57±12.3	0.07±.004	60.16±3.72	33.2±1.52	7.63±0.20	12.11±0.72	2.57±0.13	1.97±0.11	0.39±0.02	1.26±0.071	2.89±0.234
E	7.85±0.07	10.94±0.02	77.43±3.9	119.86±9.82	0.054±0.005	46.6±2.33	27.57±0.79	5.93±0.19	15.07±0.73	4.25±0.31	2.3±0.13	0.073±0.01	0.84±0.027	2.91±0.122

Table 3. Values of physicochemical variables in Drinking water; Bureau of Indian Standards (BIS 2009) and WHO (2011) (units: mg/L, except, EC in µs/cm, salinity in ppt, turbidity in NTU and pH)

Parameter	Bureau of Indian Standards (BIS 2009) acceptable limit	WHO standard 2011 desirable limit
pH	6.5 - 8.5	7.0 - 8.5
TDS	500	600
Alkalinity	200	300
DO	5	NA
EC	750	750
Salinity	100 PPT	100 PPT
Turbidity	1 NTU	1 NTU
Na^+	200	50
Mg^{2+}	30	30
Ca^{2+}	75	100
F^-	1	1.5
Cl^-	250	250
NO_3^{2-}	50	50
SO_4^{2-}	200	250

NA - Not Available

farming practices that results higher TDS by increase in weathering and erosion of soil (Zhang *et al.*, 1995). Salinity ranged from 0.054±0.005 - 0.24±0.025 ppt along the stretch of Ganges river (Table 2). It can be seen that an increasing pattern of salinity values dominated towards the downstream of river Ganges. However, both the values were found within the prescribed limit of WHO & BIS (Table 3).

3.2. Determination of major ions

The major elemental cations Na^+, Ca^{2+}, K^+, and Mg^{2+} were measured in the water of Ganges and the values obtained are given in Table 2. It was observed that the contributions of Ca^{2+} and Na^{2+} ions concentration remained dominant in water of Ganges during the post monsoon period. The concentration of K^+ and Mg^{2+} showed increasing trend towards the downstream implying the significant contributions from precipitation, agriculture, biogenic activities, silicates and carbonates weathering from soil into the river water.

The elemental anions Cl^-, F^-, SO_4^{2-}, and NO_3^{2-} were measured in the water from the selected sampling locations. The obtained values are given in Table 2. Measurement of Cl^- ion concentration showed an increasing pattern along the downstream of river Ganges. As chloride is mostly found in nature in the form of various salts which indicates more anthropogenic activities towards downstream due to leaching process in the river water. Concentration of NO_3^{2-} was observed nearly similar in samples from all the stations and values obtained were ~3 mg/L which is markedly low compared with BIS and WHO (50 mg/L). The major source of nitrate into the river water presumably entails from the fertilisers applied in the agricultural land and from the precipitation process. Concentration of SO_4^{2-} was found to be modestly increased along the downstream of the river. It need to be noted that the concentration of F^- was found to be markedly low (0.063-0.584 mg/L) which was significantly lower than standards given by BIS (1 mg/L) and WHO (1.5 mg/L) suggesting a controlled fluoride generating factors in the surroundings. Spatial variations study of major ions is essential as it reflects the influence of different lithologies and anthropogenic activities in the river system (Chen *et al.*, 2002). The variable concentration pattern of major ions in this study can be attributed to several sources of weathering of rocks, soils and input from many anthropogenic activities.

3.3. WQI of Ganges water

Calculated Water Quality Indices is given in Table 7. It can be seen from the table that WQI in Ganges river ranges from 28.93 - 73.24 that reflects good to poor water quality (Table 6) (Yadav *et al.*, 2010). Water sample from Haridwar showed the lowest (28.93) and water from Allahabad (73.24) has highest WQI values. The WQI values gradually increased from the upstream to downstream indicating significantly decreasing the water quality of Ganges river. WQI values at Rishikesh, Haridwar, Narora Ghat and Narora Barrage showed good water quality (Fig. 2). However, the values of Narora Ghat (49.67) and Narora Barrage (48.44) are close to poor quality (WQI=50). The WQI of samples from rest of the downstream locations were showed poor water quality. Increase concentration of physicochemical parameters in river may be the reason for higher WQI values and poor quality of water towards downstream of Ganges river.

3.4. Correlations of measured parameters

The Pearson correlation matrix obtained from our studies for each parameter is given in the Table 4. It can be seen that TDS is positively correlated with the EC ($r = 0.99, p < 0.01$), pH ($r = 0.77, p < 0.05$) and DO ($r = 0.77, p < 0.05$) which indicated that at all the stations TDS increased concomitantly with EC, DO, and pH. But, results showed absence of significant

Table 4. Pearson correlation matrix for major ions, pH, EC, salinity, alkalinity and turbidity (n=8)

	pH	DO	TDS	Salinity	Alkalinity	EC	Turbidity	Mg^{2+}	Ca^{2+}	Na^{+}	K^{+}	Cl^{-}	F^{-}	SO_4^{2-}	NO_3^{2-}
pH	1														
DO	.415	1													
TDS	.773*	.772*	1												
Salinity	.299	-.168	.074	1											
Alkalinity	.852**	.728*	.959**	.088	1										
EC	.765*	.783*	.998**	.020	.963**	1									
Turbidity	.510	.701	.853**	-.008	.681	.843**	1								
Mg^{2+}	.093	-.294	-.305	.435	-.258	-.328	-.281	1							
Ca^{2+}	-.039	-.228	-.337	-.145	-.281	-.327	-.292	.818	1						
Na^{+}	-.371	-.368	-.558	.381	-.586	-.584	-.382	.866**	.678	1					
K^{+}	-.038	-.369	-.287	.534	-.344	-.323	-.077	.867**	.623	.860**	1				
Cl^{-}	-.580	-.128	-.555	-.187	-.615	-.552	-.311	.602	.722*	.815*	.525	1			
F^{-}	.125	-.179	-.212	.085	-.057	-.204	-.338	.617	.700	.439	.513	.294	1		
SO_4^{2-}	-.756*	-.437	-.733*	.100	-.772*	-.745*	-.593	.427	.343	.756*	.379	.769*	-.020	1	
NO_3^{2-}	-.757*	-.560	-.701	.125	-.721*	-.711*	-.640	.264	.185	.595	.263	.553	-.061	.934**	1

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

Table 5. Weight and relative weight of physicochemical parameters.

Parameters	Weight (W_a)	Relative Weight (W_r)
pH	4	0.105263
Dissolved Oxygen	5	0.131579
Total Dissolved Solids	4	0.105263
Alkalinity	2	0.052632
Electrical Conductivity	5	0.131579
Na^{+}	1	0.026316
Ca^{2+}	2	0.052632
Mg^{2+}	2	0.052632
F^{-}	2	0.052632
Cl^{-}	3	0.078947
NO^{2-}	4	0.105263
SO_4^{2-}	4	0.105263

Table 6. Water quality scale

Water Quality Index (Yadav *et al*., 2010)	Water Quality
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
Above 100	Unsuitable

positive correlations between EC and major ions. This may partly be ascribed to the spatial variations. It is further seen that EC has significant positive correlation with pH ($r = 0.76$, $p < 0.05$) and DO ($r = 0.78$, $p < 0.05$). Among the major ions significant positive

Table 7. Water quality indices and water quality at different location

Location	WQI	Water Quality (Yadav *et al*., 2010)
Rishikesh	32.16	Good
Haridwar	28.93	Good
Narora Ghat	49.67	Good
Narora Barrage	48.44	Good
Narora Lower Canal	52.46	Poor
Kanpur Bithoor	52.25	Poor
Kanpur Jajmau	58.39	Poor
Allahabad	73.24	Poor

correlation was observed among Na^{+} and Cl^{-} ($r = 0.81$, $p < 0.05$), Na^{+} and SO_4^{2-} ($r = 0.75$, $p < 0.05$). These results probably indicate that contributions of major ions are nearly similar from different sources at each of the sampling location. Analysis showed negative correlations between F^{-} and SO_4^{2-} ($r = -0.020$) and F^{-} and NO_3^{2-} indicating variable contributions of ions from the potential sources at each sampling locations.

4. Summary and Conclusion

The evaluation of water quality of Ganges river using WQI and physicochemical properties showed an increasing pattern of most of the measured physicochemical parameters and WQI along the downstream from Rishikesh to Allahabad indicated a gradually declining water quality along the downstream. Our studies revealed that major ion concentration in Ganges water sampled post-monsoon followed the order $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ for cations and SO_4^{2-} >

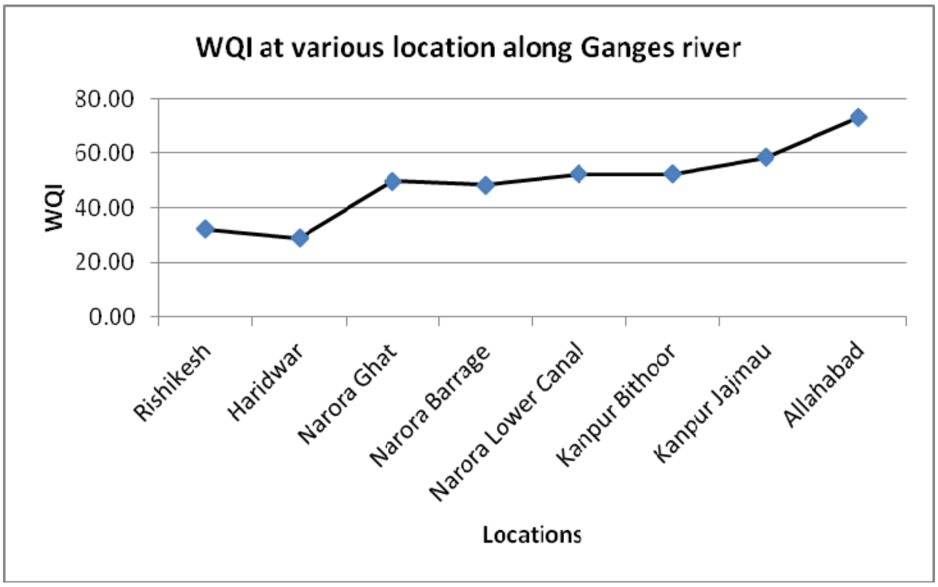

Figure 2. WQI of designated locations along Ganges river

$NO_3^{2-} > Cl^- > F^-$ for anions. These results point to the significant consequences of mindless anthropogenic activities and poorly regulated industrial discharges along the river. It is noteworthy that our studies have revealed significantly high DO values (in situ condition) at collection points moving downwards the path of river which may be, among others, a reflection of microbial organism load in Ganges water. In particular, using WQI calculations present study reports a significant trend of degrading water quality along the downward path of river which may serve a guide to planning of strategies to control pollution. Results are highly instructive to further detailed studies on health impacts on populations residing at the bank of Ganges river.

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