Evaluation of Groundwater Quality using Water Quality Index (WQI) in Bahraich District, Uttar Pradesh (India)

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Abstract: Groundwater is vital and foremost source of drinking water all around the world. Water quality is an important parameter to determine its usage for different purposes like drinking, irrigation, industry etc. The present paper presents evaluation of geochemical characteristics of groundwater based on water quality indices and the fate of arsenic (As) contamination in groundwater. Bahraich district (Uttar Pradesh, India) is selected as the study area for the present work. Groundwater samples were collected from forty-five locations of the district during January 2019. The samples were analyzed for total As, trace and toxic elements (Fe, Mn, Al, Co, Pb, Cd, Cr, Zn, Ni, and Cu), cations and anions (Na, Ca, K, Mg, NH_4, Cl, SO_4, NO_2, NO_3). EC, pH, DO and ORP were measured in-situ. Results show that trace metals in some water samples are beyond permissible limits. Water quality index is found in the range of 45 to 1219 with an average of 273, indicating poor to unfit water category for the drinking purpose. Arsenic concentration at few locations is found at higher side which needs to be addressed.

Keywords: Water quality Index, Bahraich district, correlation matrix, groundwater.

1. Introduction

Groundwater monitoring is an essential element in any environmental information system. Based on validated groundwater monitoring data, geochemical information is derived for making decisions. Bahraich is a district in the Devipatan (Gonda) division of Uttar Pradesh, India, occupying the shape like Chili. Bahraich district has almost a flat topography with gentle slope towards the south. It is drained by the Ghaghara and Sarju rivers. The river Ghagra forms the western boundary of the district and enters the district across Indo-Nepal international boundary. The district is bounded by Nepal in the north; in the east, it faces Shravasti district; in the west, Lakhimpur Khiri, and Sitapur districts lie; while south of the district is bounded by Gonda and Barabanki district. Administratively, the district is divided into four tehsils and fourteen developmental blocks. The district covers a total area of 3,168 km^2 with a total population of 2.75 million, and lying between 25°33′ to 26°11′ N latitudes and 83°38′ to 84°39′ E longitudes. Earlier studies carried out in the Bahraich district have focused on arsenic contamination **(Mehrotra et al., 2016).** Whereas, other water quality parameters and their interactions with arsenic are considerably important which needs to be analyzed and addressed. The present paper thus presents recent water quality status using WQI by monitoring various physic-chemical parameters including arsenic and trace metals.

This WQI provides a simpler means for the water quality assessment and is very useful for decision-makers, planners and field engineers for maintaining good health of groundwater and surface water resources (**Tiwari et al., 2014; Singh et al., 2013).** In general, the major objective of water quality assessment is to determine the fulfillment of defined objectives; to describe water quality at regional, national or international scales, and also to investigate trends in time so that it can be classified within the respective regulatory standards for various intended purposes such as potable water, agricultural, recreational and industrial water uses (**Singh et al., 2015; Krishan et al., 2016).** For categorizing the concentration ranges and the quality standards as per Indian conditions, **BIS (2012)** and Central Pollution Control Board (CPCB) standards have been taken into account with due regards to the international standards set by the World Health Organization (WHO) and the European Commission (EC).
Thus this paper highlights an overall water quality in the Bahraich district studied along with arsenic contamination and its interaction with other trace metals and salts in the groundwater.

2. Material and methods

2.1 Chemicals and reagents

Milli-Q water was used throughout the experiment and other dilution purposes. Analytical grade reagents were used in the digestion and extraction processes. All stock solutions were kept in a state of darkness in a cold room at 4 °C. Standards were prepared freshly from their respective stock solution on the same day of the analysis.

2.2 Sample collection and preservation

Sampling is the first step leading to the generation of water-quality data. Sampling locations were finalized such that the total area is mapped properly including block unit. The samples were collected from Bahraich during 16-22 January, 2019. A total of forty-five numbers of groundwater and surface water samples and three soil samples were collected from various locations of the district (Figure 1). The samples were collected in LDPE (Low-Density Polyethylene) tarson bottles. The samples for metal analysis are preserved by addition of nitric acid by adding 1.5-5 ml conc. HNO_3 for 1 litre of sample to acidify the sample to pH <2 in the field itself. Samples for analysis of major anions (bicarbonate, sulphate, fluoride, chloride, phosphorus and nitrate) and cations (sodium, potassium, calcium and magnesium) were collected as unpreserved.

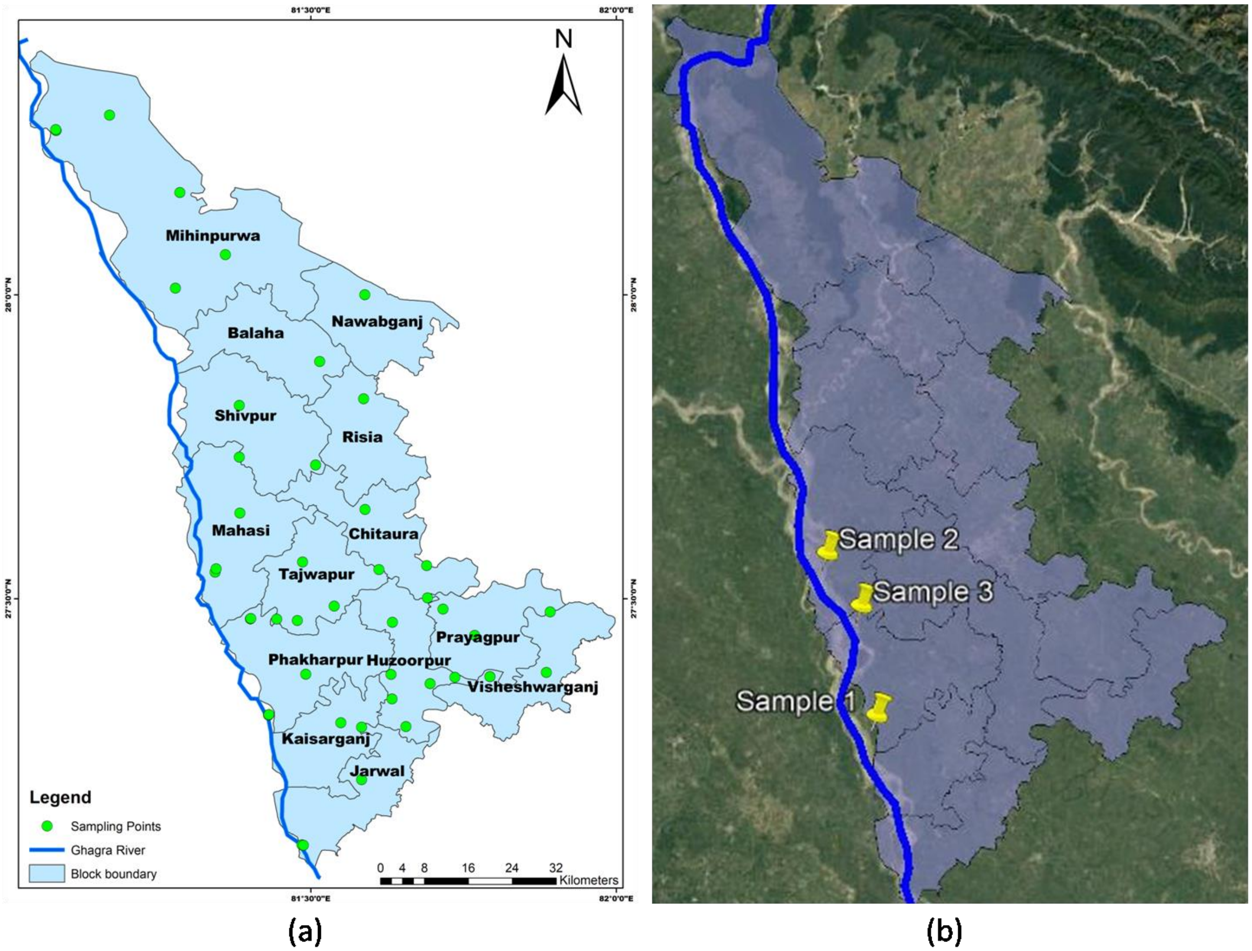

Figure 1. Map of Bahraich district showing sampling locations of (a) groundwater, and (b) soil sediments.

2.3 Analytical procedures

2.1.1 In-situ measurements

Physico-chemical parameters such as pH, EC, DO, ORP, and temperature measurements were made in the field by Hach multi-probe meter (model no. HQ 40 d). Electrodes of multi-parameter analyzer were calibrated prior to use.

2.1.2 Laboratory analysis

The unpreserved 0.45µm filtered water samples were used for the analysis of major cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) and anions (F^-, Cl^-, SO_4^{2-}, NO_3^- etc.) were analyzed by using ion chromatography technique. For trace metals analysis, inductively coupled plasma-optical emission spectrometer (ICP-OES) was used.

2.4. Water quality index method

Based on the data of different parameters, the water quality index was computed by using the equations given below. First, the Relative weight (W_i) was calculated from the following equation:

$$W_i = wi / \sum_{i=1}^{n} w_i \quad \ldots \quad (1)$$

Where, the W_i is the relative weight, w_i is the weight of each parameter and n is the number of parameters. First relative weights (W_i) were computed for each parameter. In the second step, a quality rating scale (q_i) for each parameter was assigned by dividing its concentration by its respective standard according to the guidelines laid down in the BIS 10500 (2012) and the result was multiplied by 100.

$$q_i = (C_i/S_i)x100 \quad \ldots \quad (2)$$

Where, the q_i is the quality rating, C_i is the concentration of each chemical parameter in each water sample in mg/L and S_i is the BIS standard for each chemical parameter in mg/L.

For computing the WQI, the *SI* was first determined for each chemical parameter, which is then used to determine the WQI as per the following equation:

$$SI_i = W_i \text{ x } q_i \quad \ldots \quad (3)$$

$$WQI = \sum SI_i \quad \ldots \quad (4)$$

Where, the SI_i is the sub-index of $_ith$ parameter, q_i is the rating based on concentration of $_ith$ parameter, and n is the number of parameters.

3. Results and discussion

Forty-five samples from groundwater and surface water were collected from different locations of Bahraich district in Uttar Pradesh during January, 2019. The water samples were collected according to the standard guidelines **of.** The map of sampling locations in Bahraich district, UP is shown in Figure 1. Thirty samples were found arsenic unaffected and the concentration was above 10 ppb. Out of 15 arsenic affected samples, 11 samples were in the range of 10-50 ppb. In other 4 samples, arsenic concentration was above 50 ppb which fall in the Mihinpurwa, Mahasi, Huzoorpur and Shivpur blocks of the district.
Three soil samples were also collected from the Bahraich district along the Ganga and Ghaghara river to check the soil-water interaction. These samples were collected from the depth of 25-100 cm-bgl. Location details and concentrations of metal ions in the soil samples are shown in Table

1. The highest concentration of 55.5 μg/kg for arsenic was found at Mahasi block followed by Kaisarganj (41 μg/kg) and Pakharpur (31.4 μg/kg) blocks. All samples showed the arsenic concentrations above the acceptable limit of arsenic in water according to BIS standards.

Table 1. Location details and concentration of metal ions in soil samples.

Location	Lat	Long	Conc. in μg/kg											
Bahraich			As	B	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Pd	Zn
Kaisarganj (sample 1)	27.3088	81.4305	41	417.5	13.3	12.8	10.3	59.4	4820	246.5	11.7	102.4	13.8	52.8
Mahasi (sample 2)	27.544	81.3432	55.5	220.5	18.4	10.5	8	11.2	13950	510.5	63.4	597	65.2	196.5
Pakharpur (sample 3)	27.4669	81.4008	31.4	380.5	11.35	9.39	8.6	137	5690	245	14	272	27.8	57.6

Correlations were also studied among various different water quality parameters, trace metals and ions (cation and anion) and are presented in Table 2. The correlation matrix showed that there is a good positive correlation between As and Fe (0.71), Ca and Mg (0.72) and HCO_3 and Mg (0.86). Whereas, other trace metals and salts did not show any correlation. Cd and Fe also showed a positive correlation. ORP and As showed a negative correlation. A less positive correlation between As and pH, As and HCO_3, whereas inverse correlation was observed between As and other elements. It was also noticed the less positive correlation exists between As and Mn, which supports the strong reducing character of this environment. Good correlations between EC and Ca^{2+}, Mg^{2+} and between EC and Cl^-, HCO_3^- which indicates that carbonate weathering with anthropogenic sources, like fertilizers, controls the geochemistry of the groundwater and existence of carbonate weathering in the area. Further, good correlation between Ca^{2+} and Cl^- and between Ca^{2+} and HCO_3^- are readily apparent, which indicates that both gypsum (absorbed in clay) and limestone are acting as a source of calcium.

Table 2. Correlation matrix of various chemical constituents.

	pH	EC	DO	ORP	As	Al	Ca	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Zn	Cl	HCO_3^-
pH	**1.00**																	
EC	-0.43	**1.00**																
DO	0.53	-0.42	**1.00**															
ORP	-0.17	0.17	0.14	**1.00**														
As	-0.02	0.08	-0.23	-0.39	**1.00**													
Al	0.17	-0.35	**0.65**	0.25	-0.12	**1.00**												
Ca	-0.39	**0.72**	-0.37	0.14	0.19	-0.24	**1.00**											
Cd	0.00	0.01	-0.13	-0.30	0.36	-0.05	0.03	**1.00**										
Cr	-0.16	-0.04	-0.07	-0.11	-0.03	-0.05	-0.04	0.43	**1.00**									
Cu	0.21	-0.14	0.12	-0.01	0.22	0.06	-0.22	0.27	0.24	**1.00**								
Fe	-0.05	0.03	-0.26	-0.52	**0.71**	-0.06	0.11	**0.76**	0.45	0.17	**1.00**							
Mg	-0.45	**0.77**	-0.39	0.31	0.09	-0.19	**0.72**	0.03	0.02	-0.11	0.05	**1.00**						
Mn	-0.36	0.35	-0.33	-0.18	0.22	-0.23	0.49	-0.08	-0.06	-0.20	0.11	0.41	**1.00**					
Ni	0.27	-0.21	0.41	-0.11	0.03	0.39	-0.19	-0.12	-0.04	0.07	-0.08	-0.21	-0.06	**1.00**				
Pb	0.06	-0.15	-0.12	0.00	-0.03	0.01	0.00	0.35	0.20	0.01	0.28	-0.02	-0.09	-0.19	**1.00**			
Zn	0.40	-0.34	0.05	-0.10	-0.02	-0.06	-0.02	0.07	0.04	0.20	0.05	-0.21	-0.13	0.14	0.56	**1.00**		
Cl	-0.27	0.80	-0.16	0.34	-0.11	-0.16	**0.60**	-0.08	0.04	-0.05	-0.14	0.57	0.12	-0.12	-0.13	-0.17	**1.00**	
HCO_3^-	-0.40	0.70	-0.45	0.12	0.30	-0.23	**0.64**	0.18	-0.06	-0.02	0.24	**0.86**	0.43	-0.36	0.09	-0.21	0.41	**1.00**

In computing water quality index (WQI), each of the 18 parameters (pH, TDS, F, Cl, NO_3, SO_4, Ca, Mg, total As, total Fe, total Cr, Cu, Mn, Pb, Zn, Ni, and Al) was assigned a weight factor (w_i) according to its relative importance in the overall quality of water for drinking purposes (**Singh et al., 2019**) (Table 3) and further calculated the relative weights of each parameter. Based on the status of water quality, the index value range between 0 to 300 and is classified into five categories: unfit for drinking purpose (>300), very poor (200-300), poor (100-200), good water (50-100), and excellent water (<50). If the index goes up, then it indicates that some of the water quality parameters are being affected due to any particular reason and suitable measures need to be taken to further improve the quality of water.

The highest WQI was obtained for the samples collected from the Jarwal, Kaisarganj, Huzoorpur, Mihinpurwa, Shivpur, Mahasi, Chitaura, and Phakharpur blocks, which are highly polluted and unfit for the drinking purpose. The reason for high WQI in the study area may be due to the natural and anthropogenic sources (mining activity, agriculture wastes, domestic sewage disposals, etc.) which need investigation. Among all the groundwater samples, the percentage of WQI categories are as follows: Excellent (4%), Good (15%), Poor (36%), and Very poor (9%), unfit category for the drinking purpose (36%). More than 80% the locations falls in poor to unfit category for the drinking purpose (Table 4).

Table 3. Relative weight of chemical parameters.

S. No.	Parameter	Weight Factor (w_i)	Relative Weight (W_i)
1	pH	0.018	0.02
2	TDS	0.021	0.03
3	Fluoride	0.027	0.04

4	Chloride	0.009	0.01
5	Nitrate	0.014	0.02
6	Sulfate	0.011	0.02
7	Total Arsenic	0.093	0.13
8	Total Iron	0.031	0.04
9	Cadmium	0.062	0.08
10	Total chromium	0.102	0.14
11	Copper	0.013	0.02
12	Manganese	0.035	0.05
13	Lead	0.072	0.1
14	Zinc	0.016	0.02
15	Nickel	0.085	0.12
16	Aluminium	0.024	0.03
17	Magnesium	0.01	0.01
18	Calcium	0.009	0.01
		∑wi=0.73	∑Wi=1.00

Table 4: Water Quality Index for groundwater of Bahraich district.

S. No.	Sample Description	WQI	Description
1	Jarwal	171	Poor water
2	Jarwal	519	Unfit for drinking purpose
3	Phakharpur	126	Poor water
4	Phakharpur	183	Poor water
5	Kaisarganj	315	Unfit for drinking purpose
6	Huzoorpur	507	Unfit for drinking purpose
7	Visheshwarganj	187	Poor water
8	Prayagpur	186	Poor water
9	Mihinpurwa	266	Very poor water
10	Mihinpurwa	86	**Good water**
11	Mihinpurwa	214	Very poor water
12	Mihinpurwa	328	Unfit for drinking purpose
13	Mihinpurwa	295	Very poor water
14	Mihinpurwa	1219	Unfit for drinking purpose
15	Nawabganj	139	Poor water
16	Balaha	88	**Good water**
17	Risia	75	**Good water**

18	Shivpur	759	Unfit for drinking purpose
19	Shivpur	527	Unfit for drinking purpose
20	Mahasi	574	Unfit for drinking purpose
21	Shivpur	125	Poor water
22	Chitaura	335	Unfit for drinking purpose
23	Mahasi	323	Unfit for drinking purpose
24	Mahasi	276	Very poor water
25	Tejwapur	137	Poor water
26	Jarwal	149	Poor water
27	Phakharpur	106	Poor water
28	Tejwapur	48	**Excellent water**
29	Phakharpur	130	Poor water
30	Phakharpur	372	Unfit for drinking purpose
31	Huzoorpur	447	Unfit for drinking purpose
32	Visheshwarganj	156	Poor water
33	Visheshwarganj	817	Unfit for drinking purpose
34	Visheshwarganj	129	Poor water
35	Prayagpur	53	**Good water**
36	Huzoorpur	107	Poor water
37	Huzoorpur	316	Unfit for drinking purpose
38	Tejwapur	95	**Good water**
39	Chitaura	45	**Excellent water**
40	Chitaura	456	Unfit for drinking purpose
41	Huzoorpur	422	Unfit for drinking purpose
42	Huzoorpur	189	Poor water
43	Kaisarganj	71	**Good water**
44	Tejwapur	118	Poor water
45	Tejwapur	99	**Good water**

4. Conclusions

In the present paper, groundwater quality of Bahraich district is assessed using the water quality index (WQI). A total of forty-five samples from groundwater and surface water samples were collected from different locations of the Bahraich district. Eighteen different quality parameters were considered for the computation of WQI. The WQI of groundwater samples in the Bahraich district range from 45 to 1219, which shows that the groundwater for these locations falls under poor to unfit category for the drinking purpose. Arsenic was also studied as a quality parameter, which indicates that thirty samples are found unaffected by arsenic where the concentration is found below 10 ppb. Out of fifteen affected samples, eleven samples are found in the range of 10 to 50 ppb of arsenic. In other four samples, arsenic concentration is found more than 50 ppb.

Mihinpurwa, Mahasi, Huzoorpur and Shivpur are found the most arsenic affected blocks. Poor to unfit category samples show that the water is not suitable for direct consumption and requires treatment before its consumption and utilization for different usages.

Acknowledgements

Authors are grateful to the Director, National Institute of Hydrology and DST for all administrative and financial support and encouragement to carry out this work.

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