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An assessment of trace element contamination in groundwater aquifers of Saharanpur, Western Uttar Pradesh, India

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ABSTRACT

Groundwater is a vital natural resource needed for the growth and development of life on the Earth. The aim of the present study was to estimate trace elements concentration in groundwater and their effect on human health in Saharanpur district, Uttar Pradesh, India. Groundwater samples were collected from the government hand pumps and analyzed for eight trace elements using ICP-MS. In all the samples, concentrations of two trace elements namely Hg and Fe were above the drinking water limits (mean values of 2.04 ± 1.94 and 1531 ± 1372 μg/L, respectively) as specified by Bureau of Indian Standards (2012) and World Health Organization (2011). For Cr and Pb, 10% and 15% of the groundwater samples respectively, were above the specified limits. The concentration of As, Cd, and Zn was within limits as specified for drinking water. Hazard Quotient (HQ) for the assessment of human health showed no potential adverse health risk except Fe. This study showed that the value of the Hazard Index (HI) for all the samples was also within limits except for one of the sampling sites (#S9). HQ and HI values were almost equivalent to permissible limits at the majority of sites. However, on the basis of cumulative results obtained during the study, it was concluded that urgent management actions are required to protect future groundwater quality of this region.

1. Introduction

Water is essential for survival for all living beings, hence adequate safe and accessible water must be available to all (Bekuretsion et al., 2018). Groundwater is the most crucial source of potable water throughout the world. It is widely consumed for the purpose of drinking, bathing, cooking food, etc. Groundwater contamination due to geogenic or anthropogenic activities is a global problem for the scientific community and the policymakers. Among the anthropogenic activities, industrialization, urbanization, solid waste dumping, modern agricultural, etc., play a significant role in contamination of freshwater aquifers (Bhattacharjee et al., 2019; Pugazhendhi et al., 2018; Shanmugaprakash et al., 2018; Gupta et al., 2016; Kumar et al., 2016; Arivalagan et al., 2014). Moreover, India has more than 179 million hectares (MT) area under agricultural practices which is second largest in the world after the United States of America (FAO, 2016). Indian agricultural system depends on groundwater and surface water for the irrigation. Presently, in the maximum region of India, withdrawal rate from the aquifers is higher than the recharge rate. This may alter the geogenic processes of the aquifers and results in rapid mixing of the contaminants into the aquifer. Additionally, application of excessive fertilizers, pesticides, and unmanaged dumping of hazards waste also pollute the soil (Bhattacharjee et al., 2019; Mathimani et al., 2018; Malyan et al., 2016). Pollutants from the soil, stadily percolate into freshwater aquifers and thus may result in contamination of groundwater. Groundwater is reported to be contaminated with several trace metals such as cadmium (Cd), lead (Pb), mercury (Hg), zinc (Zn), copper (Cu), cobalt (Co), selenium (Se), Iron (Fe), etc. (Kumar et al., 2017; Prasad et al., 2019). Cr is one of the most commonly used and toxic trace metals and has main sources identified as chrome-plating, leather tannery, dyes, textiles, etc. (Karthik et al., 2017). In addition to trace metals, a few frequently used pesticides are also persistent in the environment and reside for longer duration. Non-biodegradability and toxicity of these substances in groundwater poses potential risk to human health (Pugazhendhi et al., 2018; Dhanarani et al., 2016). Consumption of these compounds via ingestion poses threat to human

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health even when consumed in a very low concentration.

Distribution of trace metals in groundwater and their negative impact on human health in India has previously been studied and reported in a number of studies (Sahu, 2019; Singh et al., 2018; Srivastava and Ramanathan, 2018; Chabukdharaet al. 2017; Suthar et al., 2009). Some of the studies have reported that the groundwater of Uttar Pradesh is contaminated with trace metals (Khan and Umar, 2019; Raju et al., 2009; Ahamed et al., 2006). However, most of the studies related to groundwater quality studies have been carried out in the eastern or central region of the Uttar Pradesh and there is an urgent need to conduct such a study in the western region. Saharanpur district falls under the Hindon River catchment. The sampling sites were chosen after an extensive survey conducted in the rural areas of Saharanpur district. People had complained regarding the status of drinking water in this area and previously they had raised their voice to local administration and the public representatives but did not get any positive result so far. The aim of this study can be summarized as follows: 1) to conduct qualitative analysis of groundwater of Saharanpur district; 2) to perform comparative study of drinking water quality with Bureau of Indian Standards (BIS), and World Health Organization (WHO) guidelines followed by human health risk assessment due to ingestion of contaminated groundwater. Besides, it was also kept in mind that the results reported in this study can be used as a reference by the local administrative bodies and relevant people. Therefore, appropriate action can be taken by the government to resolve various related issue.

2. Material and methods

2.1. Study area description

The present study was carried out in the Saharanpur district of western Uttar Pradesh, India (Fig. 1). The Saharanpur district is close to Shivalik hills range and lies under upper Ganga-Yamuna Doab region of northern India (Malyan et al., 2014). The mean sea level of Saharanpur district is ~269 m and the annual average rainfall is around 1150 mm (IMD, 2017). The soil of Saharanpur is fertile due to alluvium deposited across the district by the tributaries of two river systems. The climate and soil, both are favorable for the growth of vegetation and it is one of the most agriculturally productive regions of Uttar Pradesh. The total population of Saharanpur district is 3,464,228 and around 69% of the population lives in rural areas (Census of India, 2011). The primary occupation of the rural population is agriculture and the district has seven sugarcane processing plants and many small agro-based industries. Tobacco, paper mill, cotton industry, and woodwork are among the other important industries in Saharanpur. Majority of the households depends on hand-pumps to meet their daily water requirements. The groundwater samples of 20 sites were collected according to the standard guidelines and location map and corresponding details were represented in Fig. 1 and Table 1 respectively.

2.2. Sample collection, preservation, and transportation

All the samples were collected from densely populated rural areas and all the hand pumps were being used by local population for direct (drinking) and indirect (cooking food) consumption. Prior to sampling, the hand pumps were pumped for 10 min to remove the casing volume (standing water) of the hand pump to get a representative groundwater sample. Physical parameters like electrical conductivity (EC) and pH were analyzed on-site using portable HACH multiparameter. Sterile polypropylene bottles were used to collect samples. Each sample was acidified by adding 2–3 drops of 6 M nitric acid. The collected groundwater samples were placed in a thermo-coal box with ice packs and transported to the laboratory of Indian Institute of Technology Roorkee, Saharanpur Campus, Saharanpur, Uttar Pradesh, India for further analysis. The collected samples were stored at 4 °C to check further chemical alteration (APHA, 2012). The samples were analyzed

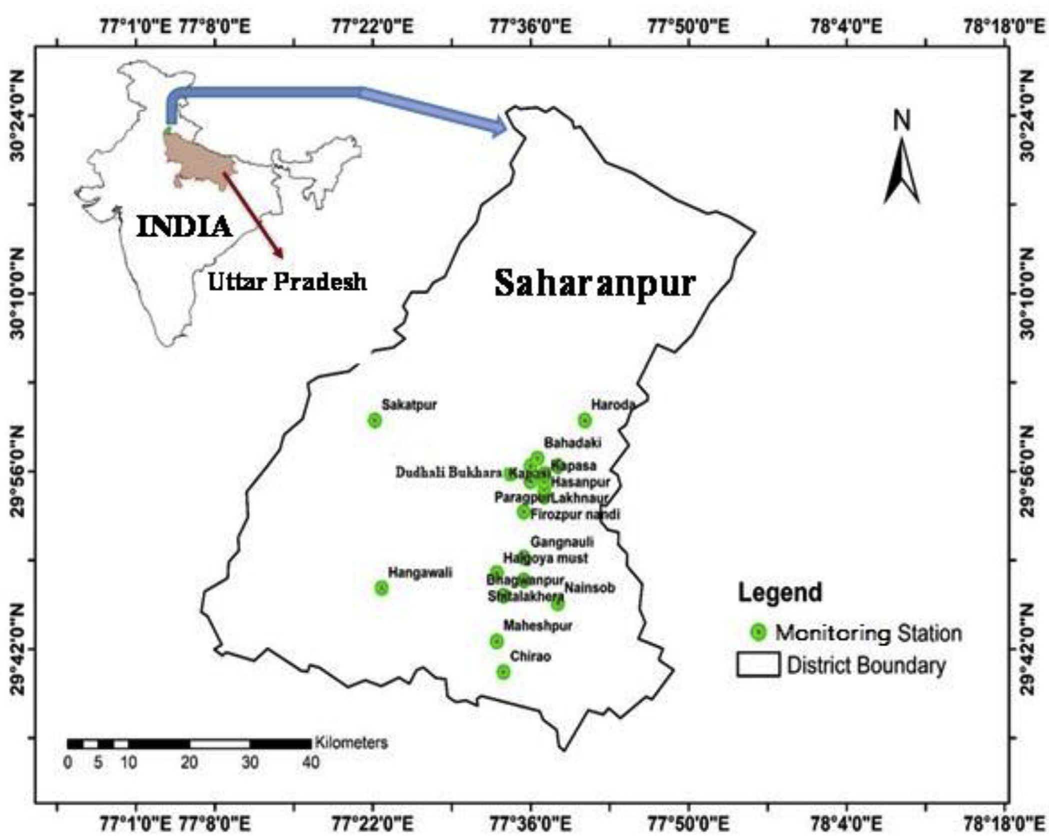

Fig. 1. Location map showing the sampling sites of Saharanpur, Western Uttar Pradesh, India.

Table 1
Sampling sites with corresponding details of the study area, Saharanpur, district, Uttar Pradesh, India.

Sr. No	Sampling location code	Sampling location	Latitude (N)	Longitude (E)
01	S1	Shitalakhera	29° 48' 11.16" N	77° 30' 20.52" E
02	S2	Santagarh	29° 55' 12" N	77° 35' 60" E
03	S3	Sakatpur	30° 2' 2.4" N	77° 22' 12" E
04	S4	Kapasa	29° 55' 1.2" N	77° 37' 1.2" E
05	S5	Nainsob	29° 45' 32.4" N	77° 38' 31.2" E
06	S6	Maheshpur	29° 42' 28.8" N	77° 33' 14.4" E
07	S7	Lakhnaur	29° 54' 14.4" N	77° 36' 57.6" E
08	S8	Kapasi	29° 54' 46.8" N	77° 37' 12" E
09	S9	Paragpur	29° 55' 26.4" N	77° 35' 60" E
10	S10	Hasanpur	29° 55' 40.8" N	77° 37' 19.2" E
11	S11	Haroda	29° 59' 42" N	77° 40' 44.4" E
12	S12	Hangawali	29° 46' 30" N	77° 22' 37.2" E
13	S13	Halgoya must	29° 48' 0" N	77° 32' 49.2" E
14	S14	Gangnauli	29° 48' 54" N	77° 35' 38.4" E
15	S15	Firozpur nandi	29° 52' 44.4" N	77° 35' 9.6" E
16	S16	Dudhalii Bhukhara	29° 56' 16.8" N	77° 35' 60" E
17	S17	Chirao	29° 40' 15.6" N	77° 33' 50.4" E
18	S18	Bhagwanpur	29° 46' 8.4" N	77° 33' 28.8" E
19	S19	Jamapur Beri	29° 56' 24" N	77° 38' 13.2" E
20	S20	Bahadaki	29° 56' 49.2" N	77° 36' 43.2" E

in triplicate to ensure the maximum accuracy and lack of error.

2.3. Health risk assessment (HRA)

Health risk assessment was estimated in terms of Hazard Quotient (HQ) and Hazard Index (HI). Contaminants in drinking water, especially trace elements, are a major stress causing agent and are hazardous to the consumers (Singh et al., 2018). Assessment of health hazards from trace element exposure can be definitely accomplished by health effect studies. However, it is impractical to carry out the epidemiological study for various contaminants on human health at a large number of locations and on a large population. Therefore, health risk assessment methods have been developed to estimate the health hazards associated with contaminant exposure. One of the basic strategies used to perform this type of assessment is to compare the concentration of the trace elements with the regulatory standards and guidelines, resulting from the toxicological criteria and is known as the quotient approach to hazard assessment (Nimick et al., 2004). The HQ due to trace metals in the drinking water was computed by total daily intake (TDI) and chronic daily intake (CDI) according to Kumar et al. (2017). The TDI was determined by using the following equation:

$$TDI = CR_D \times CE_D \tag{1}$$

where, CR_D = Water consumed per day, CE_D = Trace metal concentration in drinking water.

$$CDI = \frac{TDI}{Body\ weight} \tag{2}$$

and the HQ for the toxic metals in drinking water was calculated by the following equation:

$$HQ = \frac{CDI}{\text{References oral dose}} \tag{3}$$

The HQ less than 0.1 indicates no adverse effects on health, 0.1 to 1.0 value indicates low hazard and potential for adverse effects, 1.0 to 10.0 value indicates a moderate hazard, and values above 10.0 indicate high health hazard (Nimick et al., 2004).

HI = Sum of HQ of all trace elements.

2.4. Software and instruments used

Arc GIS Map 10.1 version was used for location map preparation, heavy metal trends map and distribution maps of heavy metals respectively, for this study. For the analysis of heavy metals, ICP – MS (PerkinElmer, model – Elan DRC-e) was used.

3. Results and discussion

3.1. Distribution of trace metals in the groundwater of Saharanpur and comparison with previous studies of the region

Table 2 shows the results of different trace metals observed in the groundwater samples of the study area. The mean, median, and range concentration of the trace metals (As, Cr, Fe, Pb, Hg, Cd, Ni, and Zn) are represented in Table 2. The findings of this study were compared with relevant literature in the nearby region or elsewhere in India (Table 2).

Table 2
Distribution of trace metals in groundwater samples of Saharanpur district, Western region of Uttar Pradesh, India.

Elements	Detection limits of ICP-MS	Drinking water (n = 20); Unit (μ/L).						
		Mean ± SD	Median	Range	BIS limits (2012)	Samples exceeding BIS values (%)	WHO guideline values	Samples exceeding WHO values (%)
As	0.01	3.18 ± 1.57	2.92	1.00–6.50	50	NA	10	NA
Cr	0.03	19.62 ± 46.0	4.19	1.89–166.4	50	2 (10%)	50	2(10%)
Fe	10.0	1531 ± 1372	1253.9	470–6849	300	20(100%)	[a]	NA
Pb	0.01	5.47 ± 5.04	3.74	0.68–19.56	10	3(15%)	10	3(15%)
Hg	0.001	2.04 ± 1.94	1.35	1.00–9.34	1	20 (100%)	[a]	NA
Cd	0.03	0.25 ± 0.35	0.12	0.02–1.28	3	NA	3	NA
Ni	0.1	9.18 ± 15.76	2.83	0.98–55.64	20	2(10%)	70	NA
Zn	0.01	529.5 ± 785	256.5	52.18–3453	15000	NA	[a]	NA

[a] Guideline not established; NA-not available.

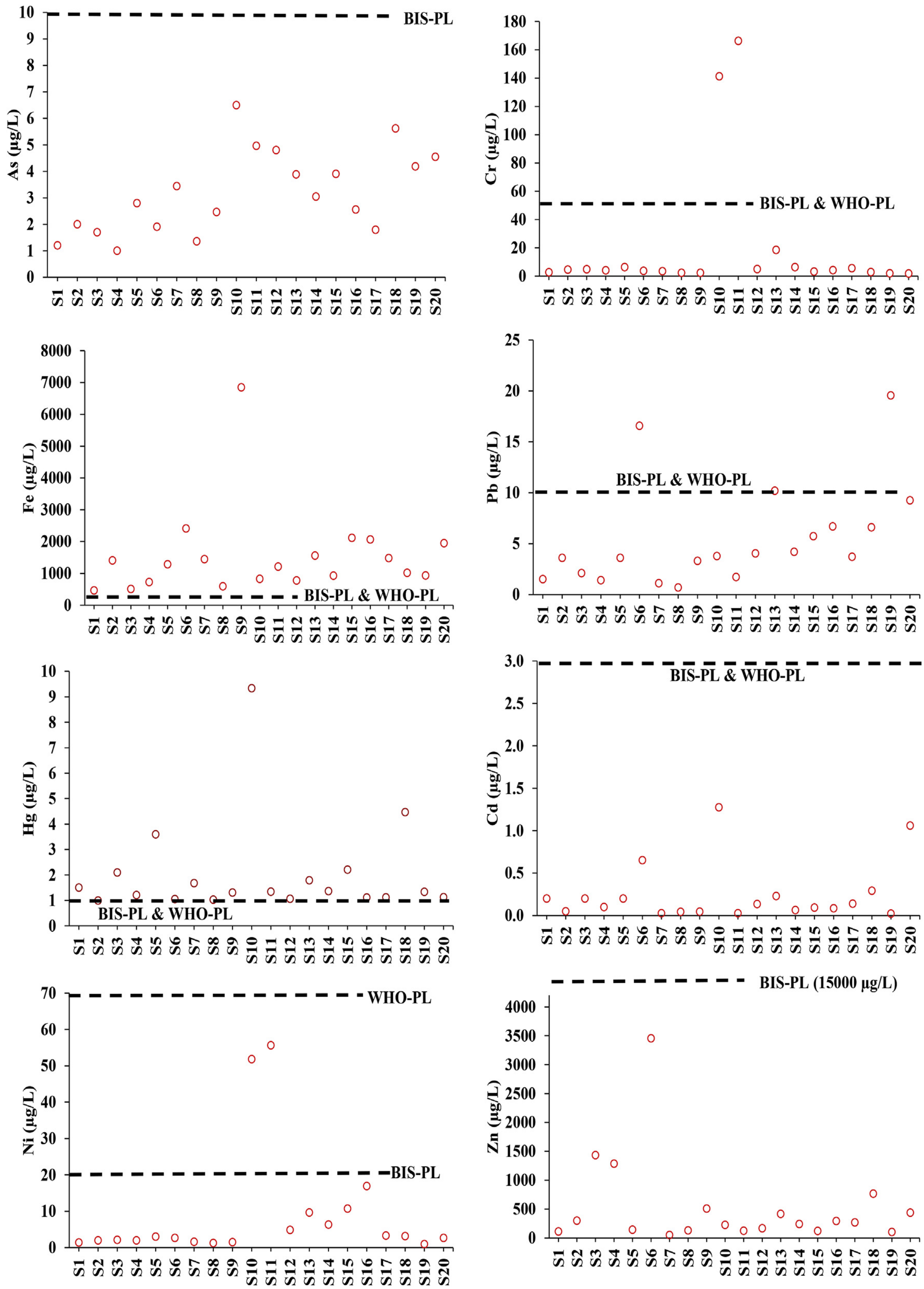

Fig. 2. The concentration of As, Cr, Fe, Pb, Hg, Cd, Ni, and Zn in groundwater samples of Saharanpur district, the western region of Uttar Pradesh comparison with BIS (2012) and WHO (2011). (BIS-PL-Bureau of Indian Standards-permissible limit, WHO-PL= World Health Organization-permissible limit).

The statistical values show that the concentrations of trace metals are variable and no two or more metals have the same values. Out of all the trace metals, Iron (Fe) and Zn were present in the maximum concentration. Fe concentration in the analyzed sample ranges from 470-6849 μg/L (Fig. 2). Results of the groundwater samples in comparison to the international standard (WHO, guideline) and Bureau of Indian standard (BIS, 2012) have been illustrated in Fig. 2. Two of the trace metals namely Fe and Hg were detected above the permissible limits as specified by BIS, 2012 in all analyzed groundwater samples (Fig. 2). All the samples tested positive for As in the concentration range between

Table 3
Comparison of heavy metals (μg/L) contamination present in groundwater of Saharanpur with other recent relevant studies.

References	Location		As	Cr	Fe	Pb	Hg	Cd	Ni	Zn
This study	Saharanpur, Uttar Pradesh	Range	1–6.5	1.89–166.4	470–6849	0.68–19.56	1.00–9.34	0.02–1.28	0.98–55.64	52.18–3453
		Mean	3.18 ± 1.57	19.62 ± 46.0	1531 ± 1372	5.47 ± 5.04	2.04 ± 1.94	0.25 ± 0.35	9.18 ± 15.76	529.5 ± 785
Prasad et al. (2019)	Garhwal, Uttarakhand	Range	ONT	0.26–4.5	ONT	0.003–11.3	ONT	0.001–0.9	0.41–5.5	5.18–4164
		Mean	ONT	1.6 ± 0.8	ONT	0.9 ± 2.0	ONT	0.1 ± 0.2	1.6 ± 0.9	338 ± 593
Singh et al. (2018)	Bathinda, Punjab	Range	0.81–2.91	66.3–359	ONT	ONT	4.6–21.3	0.12–3.00	25.5–40	2.40–224
		Mean	1.54	89.96	ONT	ONT	11.9	0.6	32.25	32.29
Chaurasia et al. (2018)	Varanasi, Uttar Pradesh	Range	ONT	ONT	2.8–15.7	4.0–13.8	ONT	0.5–34.6	1.40–20.1	0.0–310
		Mean	ONT	ONT	5.79 ± 4.05	8.26 ± 3.43	ONT	9.16 ± 8.68	3.1 ± 4.6	167.5 ± 106.2
Kumar et al. (2017)	Gautam Buddha Nagar, Uttar Pradesh	Range	0.07–237	0.8–3730	40.0–12700	Bdl-200	ONT	0.02–7.5	0.3–1.7	4.8–1500
		Mean	9.1 ± 44	211.9 ± 854	1353 ± 2879	10.4 ± 36	ONT	0.9 ± 2.5	0.6 ± 0.4	307 ± 380
Chabukdhara et al., (2017) [a]	Ghaziabad, Uttar Pradesh	Range	ONT	ND-387	97–20400	47–254	ONT	ND-12	ND-148	94–933
		Mean	ONT	23.8 ± 72.2	2653 ± 4020	130.2 ± 54	ONT	1.1 ± 2.7	22 ± 38.4	422.4 ± 244
Kumar et al. (2016)	Samastipur, Bihar	Range	6.25–135	0.09–1.34	ONT	0.59–8.4	ONT	0.03–0.12	0.50–3.53	2.8–108.20
		Mean	32.14 ± 32.85	0.47 ± 0.33	ONT	3.19 ± 2.26	ONT	0.08 ± 0.04	1.36 ± 0.70	30.82 ± 27.60
Kumar et al., (2016) [a]	Lucknow, Uttar Pradesh	Range	ONT	2.6–8.5	52.4–1385	2.7–10.0	ONT	1.9–3.0	10.2–36.3	1.7–25.4
		Mean	ONT	5.0	828.3	6.4	ONT	2.4	25.8	6.7
Singh et al. (2011)	Noida, Uttar Pradesh	Range	3–119	7.3–19.7	329–944	39–531	ONT	BDL-24.2	BDL-85.7	91–2683
		Mean	28.2	10.37	504.33	2.3	ONT	3.26	14.96	393.73

[a] Post-monsoon result; BDL-below detection limit; ND-Not deducted; ONT-observation not taken.

1.00-6.50 which was below the standard value for the safe drinking water as specified by WHO (2011) and BIS (2012) (Table 2). The mean value (μg/L) of Cr in groundwater samples was 19.62 ± 46.0 and it is observed to range from 1.89-166.4 (Table 3). In this study, in 90% of the samples, Cr concentration was found to be within the standards values specified by BIS and WHO (i.e. 50 μg/L) except sample #S10 (141.36 μg/L) and, sample #S11 (166.7 μg/L) (Fig. 2). Pb and Hg both are highly toxic trace elements and both of them were found in the groundwater sample of Saharanpur with the median value of 3.74 μg/L and 1.35 μg/L, respectively (Table 2). In this study, the detected concentration of Pb in 15% of the samples was above the safe drinking water BIS standard and WHO guideline value of 10 μg/L (Fig. 2). Further it can be seen that, the concentration of Hg exceeded the permissible limit of BIS standard (2012) (1 μg/L) in all the samples. The median concentration of Ni is found to be ranging from 0.98-55.64 μg/L, while the mean value was 9.18 ± 15.76 μg/L. The concentration of Ni in two samples is above the BIS (2012) standards values (20 μg/L). However, none of the samples exceeded the WHO (2011) guideline values of 70 μg/L for nickel (Fig. 2). Moreover, the concentration of Cd, and Zn in all the samples is within the specified limits (Table 2).

In a recent study conducted by Singh et al. (2018) in Bathinda district area, Punjab, India it is reported that Cr concentration in drinking water samples ranges between 66.3-359 μg/L (Table 3). Kumar et al. (2017) and Chabukdhara et al. (2017) have also reported higher values of Cr in Gautam Buddha Nagar and Noida city, Uttar Pradesh (mean 211.9 ± 8 μg/L and 23.8 ± 72.2, respectively) (Table 3). On the other hand, in Lucknow district, a comparatively lower mean (0.47 ± 0.33 μg/L), and range (0.09–1.34 μg/L) is observed (Kumar et al., 2016). The concentration of Cr with a lower mean (1.6 ± 0.8 μg/L) and range (0.26–4.5 μg/L) is also reported in Garhwal district, of Uttarakhand, India (Prasad et al., 2019). Iron is the second most abundant element present in Earth's crust and plays a significant role in the growth and development of many living microorganisms (Jaishankar et al., 2014). In this study, the concentration of Fe in all the samples lies above the permissible limit of BIS. Similar to the results obtained in the present study, maximum level of Fe in groundwater sample in Moradabad district (Uttar Pradesh), was 3820 μg/L. The very high concentration of Fe can cause severe health problems such as liver cancer, diabetes, and cirrhosis of the liver, etc. (Kumar et al., 2017). Bhutainai et al. (2016), reported high concentration of Fe in 99% of the total samples in Haridwar district. Several studies have reported that mining activity is the main anthropogenic source to Fe in drinking and surface water (Kamboj et al., 2017; Bayram et al., 2015; Jaishankar et al., 2014). Saharanpur district lies between the river Ganga, Yamuna and their tributary (Malyan et al., 2014). Sand mining from both the river beds is ongoing from many decades which can be a possible source of high Fe concentration reported in our study. Bayram et al. (2015) also observed that sand mining from river catchment resulted in a 111% increase in Fe concentration of water. Although all measures were taken to drain out standing water, as all the samples were taken from hand pumps, rusting of pipes can be another possible source for high Fe concentration. Mercury (Hg) in groundwater, has several potential anthropogenic sources such as combustion of coal, incineration of hospital and municipal waste (González-Fernández et al., 2014). Similar to our findings, a mean concentration of Hg i.e. 11.9 μg/L is also reported in groundwater of Bathinda, Punjab, India (Singh et al., 2018). Saharanpur district has many small and large industries which use coal for combustion. Furthermore, the western boundary of Saharanpur district has a coal-based power plant in Yamuna Nagar, Haryana which can possibly be a source of higher Hg pollution in this study. Results further reveal that Cd and Zn are below the permissible limit set by BIS and WHO. Similar findings in different parts of India are reported by Prasad et al. (2019); Singh et al. (2018); Chaurasia et al. (2018); Kumar et al. (2017); and Singh et al. (2011) (Table 2). In this study, the concentration of Ni is above the permissible limit of the BIS standard values for sample #S11 (51.84 μg/L) and #S12 (55.64 μg/L) (Fig. 2). Similarly, high concentration of Ni is reported in Ghaziabad, and Lucknow, Uttar Pradesh, India (Chabukdhara et al., 2017; Kumar et al., 2016).

3.2. Spatial distribution pattern of trace and toxic elements in groundwater of the study area

The graphical representation of spatial distribution pattern of trace metals chosen for the study i.e. As, Cr, Fe, Pb, Hg, Cd, Ni, and Zn in the specified area are represented in Fig. 3. In Fig. 3, maps range from low concentration (green color) to higher concentration (pinkish color). The hotspot of As is found in the northern zone of the study area (Fig. 3). The concentration of Cr, Pb, Fe, Cd, and Ni is higher in the northern part of the study zone, while the hotspot of Hg is in the south of the study area (Fig. 3). The distribution pattern of trace elements (Fig. 3) shows that northern parts of the study area has poor groundwater quality as compared to the southern zone of the study area (Fig. 3). Trace elements in high concentration in this northern zone of the study area may be likely due to industrial processes like brick production, and

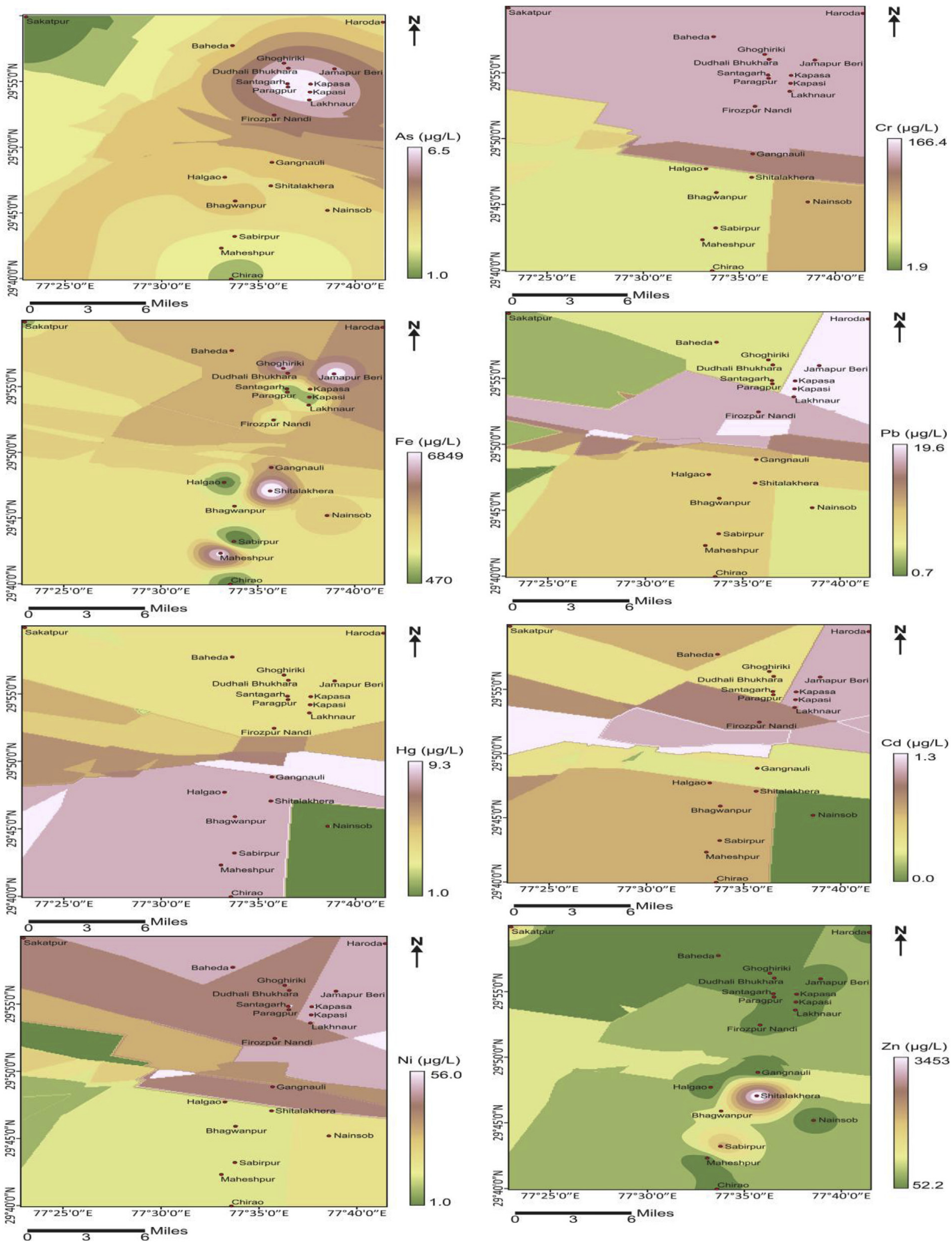

Fig. 3. Spatial distributions of trace elements (As, Cr, Fe, Pb, Hg, Cd, Ni, and Zn) in groundwater of the Saharanpur, Uttar Pradesh, India.

effluents discharge of sugar industry, paper industry, and wine distillery. Wastewater generated from these industries is discharged in different rivers directly or indirectly through unmanaged processes. Polluted effluents may percolate through sediments and hence contaminate the upper freshwater aquifers of the study area. Further complementary analysis is required for the more in-depth understating of the contamination sources.

3.3. Human health risk assessment

The average consumption of groundwater through drinking was 3 L per day and it was a little higher than the WHO (2011) guideline (2 L

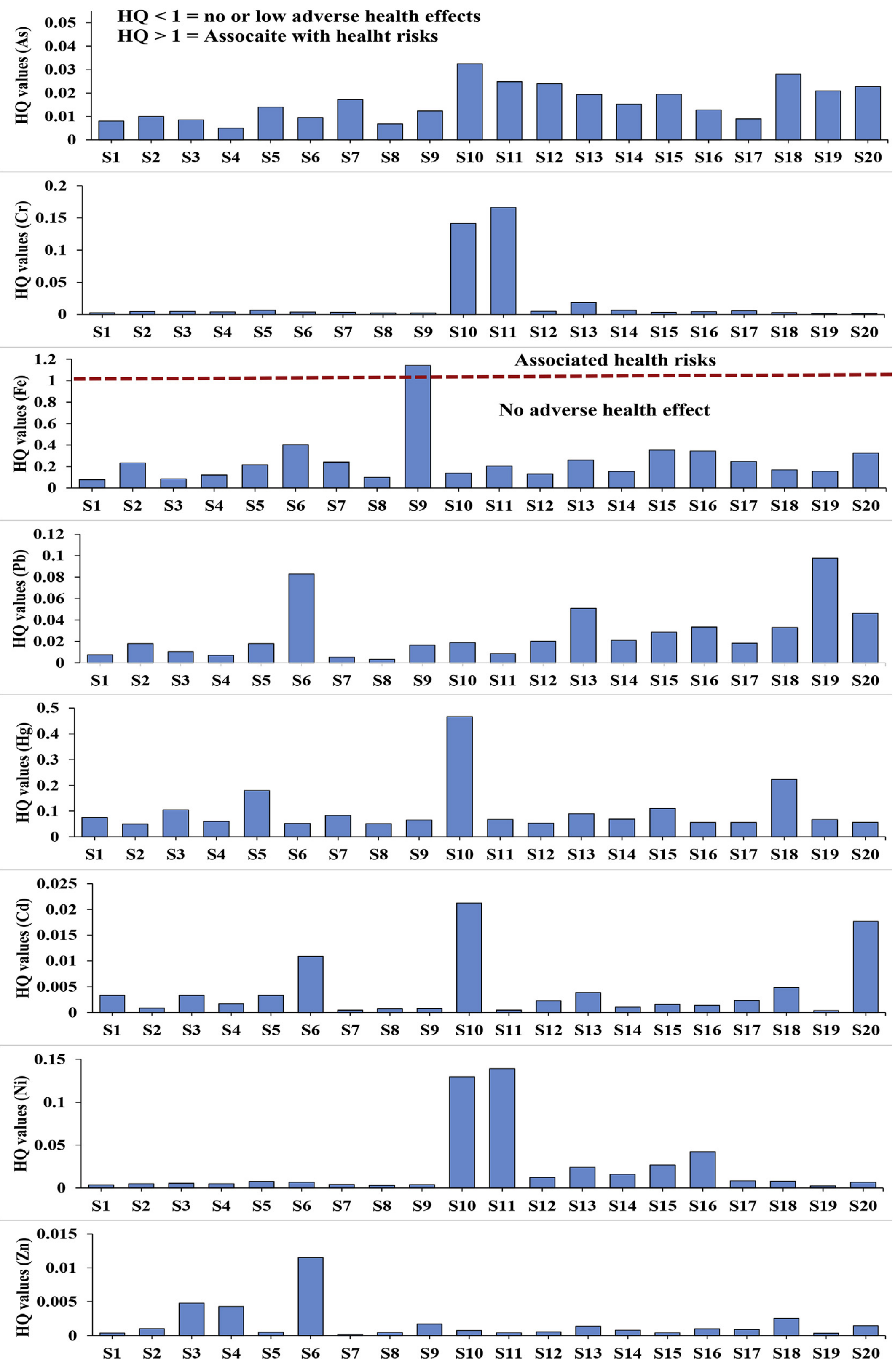

Fig. 4. Hazard Quotients of each sampling site of Saharanpur, Uttar Pradesh.

per day per adult). The amount of water intake in different regions of the world is different and it completely depends on environmental conditions, and lifestyle of people. In the area covered under this study, majority of the population lives in rural areas and is involved in agricultural activities or physical work, this can be one reason for higher water consumption in this area as compared to mean global water intake. The estimated Hazard Quotient (HQ) and Hazard Index (HI) for each trace element and the sum of all the trace elements is

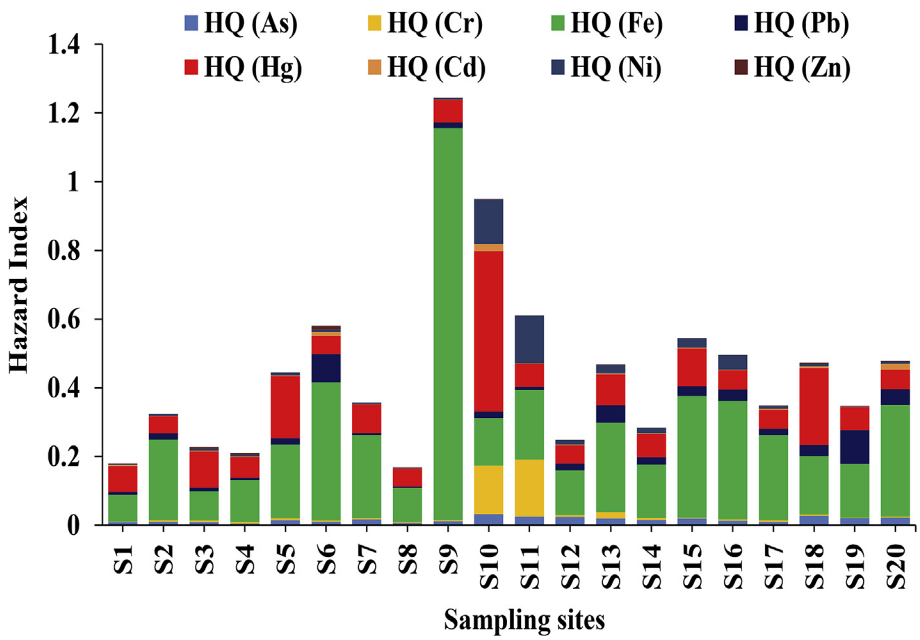

Fig. 5. Hazard Index of As, Cr, Fe, Pb, Hg, Cd, Ni, and Zn of each sampling sites in the study area (Saharanpur, Uttar Pradesh).

represented in Fig. 4 and Fig. 5, respectively. The HQ values for Fe is above 1 (Fig. 4) in sample #S9 and may impose an adverse health effect on the human population. In an earlier study, the HQ values above the safe limit is also reported in Ghaziabad (Chabukdhara et al., 2017), Gautam Buddha Nagar (Kumar et al., 2017) and, Noida (Singh et al., 2011) regions of Uttar Pradesh. Except for Fe, HQ of the other trace elements was below the limit (Fig. 4). A similar trend has also been observed by Prasad et al. (2019) in Garhwal district, Uttarakhand, India.

The assessment of cumulative risk due to ingestion of toxic elements from drinking was calculated by HI (Fig. 5). The assessment of human health risk on the basis of HI only is not accurate as human health is also affected by physiological and biological processes of the human body. However, it may give an idea of the risk associated with a particular pollutant. As specified by EPA (1986), HI values exceeding unity (1) pose an adverse effect on human health. On the other hand, HI values below unity have a negligible health effect. In this study, the HI values of almost all the samples were below unity except one location only (Fig. 5). HI values are near unity at many locations which clearly shows that the contamination level is rising in the region. Fig. 5 shows that a very high concentration of Fe in the groundwater resources may pose risk to the inhabitants of this particular area. Hence, on the basis of results obtained in this study it is suggested that a monitoring of all the groundwater resources should be carried out on regular basis and suitable measures should be taken to keep a check on increasing contamination of both surface and groundwater resources. Industrial effluents should only be discharged after suitable treatment and the different parameters of the discharged effluent should be within specified limits.

4. Conclusions

In this study, at all the sampling locations, the concentration of Fe and Hg were found above the permissible limits specified by World Health Organization (WHO, 2011) and Bureau of Indian Standard (BIS, 2012) standard for drinking water. Both anthropogenic and geological activities may contribute to such high contamination of Fe and Hg in this study area. Moreover, at a few locations, the concentration of Cr, Pb, and Ni was marginally above the WHO 2011 and BIS 2012 standard permissible values. Although Hazard Index in the majority of the area lied within safe limits, Fe seems to pose a major threat to human health. The Hazard Quotient value for Fe was above unity, which indicated potential health risk owing to consumption of groundwater in this region. Moreover, groundwater of site #S9 also seems to be unfit for consumption due to high metal contamination as compared to other evaluated sites. The results of the study provide useful information about the status of pollution and contamination level of groundwater and hence provides a reference to plan and execute suitable practices to combat groundwater pollution in the specified area and hence reduce the health and environmental risks.

Disclosure statement

The author has no potential conflict of interest.

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References

Ahamed, S., Sengupta, M.K., Mukherjee, A., Hossain, M.A., Das, B., Nayak, B., Pal, A., Mukherjee, S.C., Pati, S., Dutta, R.N., Chatterjee, G., 2006. Arsenic groundwater contamination and its health effects in the state of Uttar Pradesh (UP) in upper and middle Ganga plain, India: a severe danger. Sci. Total Environ. 370 (2–3), 310–322.

APHA, 2012. Standard Methods for the Examination of Water and Wastewater, twenty-second ed. American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC, USA.

Arivalagan, P., Singaraj, D., Haridass, V., Kaliannan, T., 2014. Removal of cadmium from aqueous solution by batch studies using Bacillus cereus. Ecol. Eng. 71, 728–735.

Bayram, A., Önsoy, H., 2015. Sand and gravel mining impact on the surface water quality: a case study from the city of Tirebolu (Giresun Province, NE Turkey). Environ. Earth Sci. 73 (5), 1997–2011.

Bekuretsion, H., Hailekiros, H., Niguse, S., Asmelash, T., Abdulkader, M., Saravanan, M., Brindhadevi, K., 2018. Bacteriological assessment of drinking water from hand-pump-fitted borehole sources in Kola Tembien, Central Tigray, northern Ethiopia. J. Water Supply Res. Technol. - Aqua 67 (8), 790–799.

Bhattacharjee, S., Saha, B., Saha, B., Uddin, M.S., Panna, C.H., Bhattacharya, P., Saha, R., 2019. Groundwater governance in Bangladesh: established practices and recent trends Ground. Sustain. Dev. round. Sustain. Dev. 8, 69–81.

Bhutiani, R., Kulkarni, D.B., Khanna, D.R., Gautam, A., 2016. Water quality, pollution

source apportionment and health risk assessment of heavy metals in groundwater of an industrial area in North India. Exposure and Health 8 (1), 3–18.
BIS (Bureau of Indian Standards), 2012. Drinking Water—Specification (Second Revision), ICS 13.060.20.
Census of India, 2011. Office of the Registrar General of India. Government of India, New Delhi.
Chabukdhara, M., Gupta, S.K., Kotecha, Y., Nema, A.K., 2017. Groundwater quality in Ghaziabad district, Uttar Pradesh, India: multivariate and health risk assessment. Chemosphere 179, 167–178.
Chaurasia, A.K., Pandey, H.K., Tiwari, S.K., Prakash, R., Pandey, P., Ram, A., 2018. Groundwater quality assessment using water quality index (WQI) in parts of varanasi district, Uttar Pradesh, India. J. Geol. Soc. India 92 (1), 76–82.
Dhanarani, S., Viswanathan, E., Piruthiviraj, P., Arivalagan, P., Kaliannan, T., 2016. Comparative study on the biosorption of aluminum by free and immobilized cells of Bacillus safensis KTSMBNL 26 isolated from explosive contaminated soil. J. Taiwan Inst. Chem. Eng. 69, 61–67.
EPA, 1986. United States Environmental Protection Agency, Guidelines for the Health Risk Assessment of Chemical Mixtures. Federal Register 51 (185), 34014–34025 Washington, DC.
FAO, 2016. online link: http://www.fao.org/statistics/en/.
González-Fernández, B., Menéndez-Casares, E., Meléndez-Asensio, M., Fernández-Menéndez, S., Ramos-Muñiz, F., Cruz-Hernández, P., González-Quirós, A., 2014. Sources of mercury in groundwater and soils of west Gijón (Asturias, NW Spain). Sci. Total Environ. 481, 217–231.
Gupta, D.K., Bhatia, A., Kumar, A., Das, T.K., Jain, N., Tomer, R., Malyan, S.K., Fagodiya, R.K., Dubey, R., Pathak, H., 2016. Mitigation of greenhouse gas emission from the rice-wheat system of the Indo-Gangetic Plains: through tillage, irrigation and fertilizer management. Agric. Ecosyst. Environ. 230, 1–9.
IMD (Indian Meteorological Department), 2017. Ministry of Earth Sciences. Government of India (Online Link. http://www.imd.gov.in/Welcome%20To%20IMD/Welcome.php.
Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B.B., Beeregowda, K.N., 2014. Toxicity, mechanism and health effects of some heavy metals. Interdiscip. Toxicol. 7 (2), 60–72.
Kamboj, V., Kamboj, N., Sharma, S., 2017. Environmental impact of river bed mining-A review. Int. J. Sci Res. Rev. 7 (1), 504–520.
Karthik, C., Ramkumar, V.S., Pugazhendhi, A., Gopalakrishnan, K., Arulselvi, P.I., 2017. Biosorption and biotransformation of Cr (VI) by novel Cellulosimicrobium funkei strain AR6. J. Taiwan Inst. Chem. Eng 70, 282–290.
Khan, I., Umar, R., 2019. Environmental risk assessment of coal fly ash on soil and groundwater quality, Aligarh, India. Ground Sustain Dev 8, 346–357.
Kumar, A., Kumar, V., Dhiman, N., Ojha, A., Bisen, P., Singh, A., 2016. Consequences of environmental characteristic from livestock and domestic wastes in wetland disposal on groundwater quality in Lucknow (India). Int. J. Environ. Res. Public Health 3, 112–119.
Kumar, M., Ramanathan, A.L., Tripathi, R., Farswan, S., Kumar, D., Bhattacharya, P., 2017. A study of trace element contamination using multivariate statistical techniques and health risk assessment in groundwater of Chhaprola Industrial Area, Gautam Buddha Nagar, Uttar Pradesh, India. Chemosphere 166, 135–145.
Kumar, S.S., Malyan, S.K., Kumar, A., Bishnoi, N.R., 2016. Optimization of fenton's oxidation by box-behnken design of response surface methodology for landfill leachate. J. Mater. Environ. Sci. 7 (12), 4456–4466.
Kumar, V., Bharti, P.K., Talwar, M., Tyagi, A.K., Kumar, P., 2017. Studies on high iron content in water resources of Moradabad district (UP), India. Water Sci 31 (1), 44–51.
Malyan, S.K., Bhatia, A., Kumar, A., Gupta, D.K., Singh, R., Kumar, S.S., Tomer, R., Kumar, O., Jain, N., 2016. Methane production, oxidation, and mitigation: a mechanistic understanding and comprehensive evaluation of influencing factors. Sci. Total Environ. 572, 874–896.
Malyan, S.K., Kumar, J., Kumar, S.S., 2014. Assessment of groundwater pollution of Saharanpur district, western Uttar Pradesh, India. Int. J. Recent Scient. Res. 5, 1112–1115.
Mathimani, T., Pugazhendhi, A., 2018. Utilization of algae for biofuel, bio-products and bio-remediation. Biocatal. Agric. Biotechnol. https://doi.org/10.1016/j.bcab.2018.12.007.
Nimick, D.A., Church, S.E., Finger, S.E., 2004. Integrated Investigations of Environmental Effects of Historical Mining in the Basin and Boulder Mining Districts, Boulder River Watershed, Jefferson County, Montana. U.S. Geological Survey., Reston, Virginia.
Prasad, M., Kumar, G.A., Sahoo, S.K., Ramola, R.C., 2019. Health risks associated with the exposure to uranium and heavy metals through potable groundwater in the Uttarakhand state of India. J. Radioanal. Nucl. Chem. 319 (1), 13–21.
Pugazhendhi, A., Boovaragamoorthy, G.M., Ranganathan, K., Naushad, M., Kaliannan, T., 2018a. New insight into effective biosorption of lead from aqueous solution using Ralstonia solanacearum: characterization and mechanism studies. J. Clean. Prod. 174, 1234–1239.
Pugazhendhi, A., Ranganathan, K., Kaliannan, T., 2018b. Biosorptive removal of copper (II) by Bacillus cereus isolated from contaminated soil of electroplating industry in India. Water Air Soil Pollut. 229 (3), 76.
Raju, N.J., Ram, P., Dey, S., 2009. Groundwater quality in the lower Varuna river basin, Varanasi district, Uttar Pradesh. J. Geol. Soc. India 73 (2), 178.
Sahu, P., 2019. Fluoride pollution in groundwater. Ground. Dev. Manage. 329–350.
Shanmugaprakash, M., Venkatachalam, S., Rajendran, K., Pugazhendhi, A., 2018. Biosorptive removal of Zn (II) ions by Pongamia oil cake (Pongamia pinnata) in batch and fixed-bed column studies using response surface methodology and artificial neural network. J. Environ. Manag. 227, 216–228.
Singh, A.K., Tewary, B.K., Sinha, A., 2011. Hydrochemistry and quality assessment of groundwater in part of NOIDA metropolitan city, Uttar Pradesh. J. Geol. Soc. India 78 (6), 523–540.
Singh, K., Singh, R., Malyan, S.K., Rawat, M., Kumar, P., Kumar, S., Sharma, M.K., Pandey, G., 2018. Health Risk Assessment of Drinking Water in Bathinda District, Punjab, India. J Indian Water Res. Society 38, 28–34.
Singh, U.K., Ramanathan, A.L., Subramanian, V., 2018. Groundwater chemistry and human health risk assessment in the mining region of East Singhbhum, Jharkhand, India. Chemosphere 204, 501–513.
Srivastava, S.K., Ramanathan, A.L., 2018. Geochemical assessment of fluoride enrichment and nitrate contamination in groundwater in the hard-rock aquifer by using graphical and statistical methods. J Earth System Sci 127 (7), 104.
Suthar, S., Nema, A.K., Chabukdhara, M., Gupta, S.K., 2009. Assessment of metals in water and sediments of Hindon River, India: impact of industrial and urban discharges. J. Hazard Mater. 171 (1–3), 1088–1095.
WHO, 2011. Guideline for Drinking-Water Quality, fourth ed. World Health Organization, Geneva.