



Assessment of ground water pollution through metal index analysis and its source identification along the Delhi-Haryana border, India

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Abstract

An integrated study of health risk assessment, pollution indices, and factor analysis was carried out to assess the pollution and heavy metal sources in groundwater of the Delhi-Haryana border, India. A total of 25 groundwater samples were analyzed for major ions, and 13 samples were analyzed for 6 elements (Mn, Cu, Cd, Zn, Fe, and Pb). Most of the samples show a high concentration of nitrate, fluoride, and EC and indicate the influence of anthropogenic activities. Out of the elements analyzed, the elements like Cd, Pb, and Fe exceed the prescribed limits of WHO standard for drinking water. Health risk index (HRI) values reveal risk of toxicity through oral pathways is less, as all trace elements are < 1. Six locations (Sl. No. 2, 7, 8, 10, 11, and 13) are considered as the most polluted based upon their heavy metal pollution index (HPI). The distribution pattern of these locations indicates that the pollution is due to anthropogenic activities. Sources of the pollution were determined by statistical analysis. There are three major factors like mining and agriculture, geogenic source, and crusher zone activities and domestic activities that are mainly responsible for the heavy metal pollution in the study area.

Keywords Metals · Health risk index · Pollution index · Factor analysis · Mining

Introduction

Water is an imperative need of a life. It is important not only for the survival of the human beings but also for other living organisms. Deterioration of fresh water is increasing nowadays. Maintaining the quality and availability of groundwater is one of the toughest environmental sustainability issues of the present era. Groundwater is an important source of drinking water, and it is contaminated by wastewater discharge or

by direct contact with metal-contaminated soil, mining waste, and debris. In present days, the number of ways degrades quality of groundwater and mining activities is one of them. Heavy metals have their unique properties, and it contributes to groundwater pollution. It has a tendency to assemble in body organs such as the liver, kidneys, and bones through drinking water and cause harmful health impact (Ravindra and Mor 2019). Increase of heavy metal contamination in the groundwater and its impact on human health is one of the serious issues in the present era (Ukah et al. 2019). Some of the heavy metal considered micronutrients and harmful to human health when their concentration exceed the permissible level. (Prasanna et al. 2012; Panda et al. 2020).

The common source of heavy metals in groundwater is geological weathering, industrial processing of mines and minerals, industrial effluents, fertilizers, its animal and human excreta, sludge, solid waste, and agricultural activities (Karim 2011; Biney and Christopher 1991). Thus, heavy metals are present in the soil toxic level due to mix up of wastewater from agriculture and industries. Heavy metals are transferred from the soil to the groundwater, which affect the human health through the water supply and food (Rattan et al. 2005).

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Heavy metal pollution studies in relation to groundwater were initiated by several authors and also the use of the index method to evaluate the water quality (Edet and Offiong 2002; Puthiyasekar et al. 2010; Selvam et al. 2015). The risk of contaminated water in regard to trace elements and its influence to human health can be more in places with arid and semi-arid climates like study area, as the main source of livelihood relies on agriculture and mining activities, and hence, application of fertilizers and pesticides in agricultural land and processing of minerals and ore smelting in mining areas makes the groundwater resources more vulnerable towards pollution (Ukah et al. 2019).

Thus, the main objective of the study is to identify potentially toxic metals and major ions present in groundwater of the study area and its impact on human health. Further, the study evaluates the pollution status and determines the probable sources of metal pollution in the study area's groundwater.

Study area

The study area covers the northern part of the Faridabad district, which is in Haryana State and the southern part of Delhi state. It lies between North latitudes 28°29'50" and 28°20'23" and longitude East longitude 77° 07'36", 77°16'56" (Fig. 1).

Upper Proterozoic rocks and quaternary sediments are represented in the area. The former (Upper Proterozoic) is represented by rocks Ajabgarh group by Delhi Super group, while the latter (Quaternary sediments) includes sediments of older alluvium (CGWB 2008).

Flat-topped ridge valleys and alluvial plains are represented in the study area. Both lithological govern physiography of the area and structural features are marked by the presence of low-lying ridges comprising of quartzite boulders and gently sloping valleys, which provide local drainage pattern of the area (CGWB 2008). The area is mainly drained by small streams such as Buria Nala, Jauhar Nala, and Paliwala Nala.

The climate of the region is characterized by the extreme dryness of the air except during the monsoon months, intensely hot summers, and cold winters. During 3 months of south-west monsoon from last week of June to September, the moist air of oceanic origin penetrates into the area and causes high humidity, cloudiness, and monsoon rainfall (CGWB 2008).

There are six major classes of land use pattern and have been identified in the study area like settlement, aravalli, thick vegetation land, mining pits, mining pits filled with water, agriculture, and crusher zone. The southern part of the study area is mainly covered with agriculture and vegetation; however, the northern part is

represented by settlement. Along the southwestern part, both the mining area and crusher zone areas are represented.

Materials and methods

A total of 25 groundwater samples are collected in a 500-ml plastic bottles during both pre- and post-monsoon of 2016, and 13 water samples are collected using 200-ml polythene bottles during post-monsoon of 2016 (Fig. 1). Two hundred milliliter polythene bottles were used to collect the water sample. At first, the sample container was flushed with the same water and then collected in the same container. The samples were filtered in the field, and physical parameters like pH, EC, and TDS were measured by using electrodes (Thermo). Using normal protocols, the collected samples were analyzed for various physico-chemical parameters (APHA 1998). Major cations such as Ca and Mg were analyzed through titrimetric method, flame photometer for Na and K (Elico CL378), titrimetric for anions like Cl and HCO₃, and spectrophotometer for SO₄ and H₄SiO₄ (SL 171 minispec). The collected samples were acidified for metal analysis with concentrated acid HNO₃ and brought to the laboratory and stored at a temperature of 4°C until the analysis. Six trace elements, Fe, Mn, Cu, Cd, Zn, and Pb, were analyzed using inductively coupled plasma-optical emission spectrometer (ICP-OES) Optima 5000 DV Series (Perkin Elmer).

The equation to compute chronic daily intake (CDI) (modified after US EPA 1999) is

$$CDI = C * DI / BW$$

where *C*, *DI*, and *BW* stand for the amount of heavy metal (µg/l), daily intake rate on an average (2 l/day) for adult (72 kg), and 1 l/day for child (32.7 kg) (Nawab et al. 2016). To assess the health risks, the accompanying equation can be utilized to figure the HRI:

$$HRI = CDI / RFD$$

where the *RFD* is the reference dosage of the trace elements for intake. The HRI is safe if (HRI < 1) (Muhammad et al. 2016).

A weightage (in between 0 and 1) for every selected element was assigned by HPI, which is indirectly proportional to the standard acceptable value (*S_i*). This can be obtained by

$$HPI = \frac{\sum_{i=1}^n W_i Q_i}{\sum_{i=1}^n W_i} \text{ (Mohan et al. 1996).}$$

[*Q_i*, sub-index of the *i*th parameter; *W_i*, *i*th parameter's weight; *n*, number of considered elements]

The *Q_i* is obtained by using the equation:

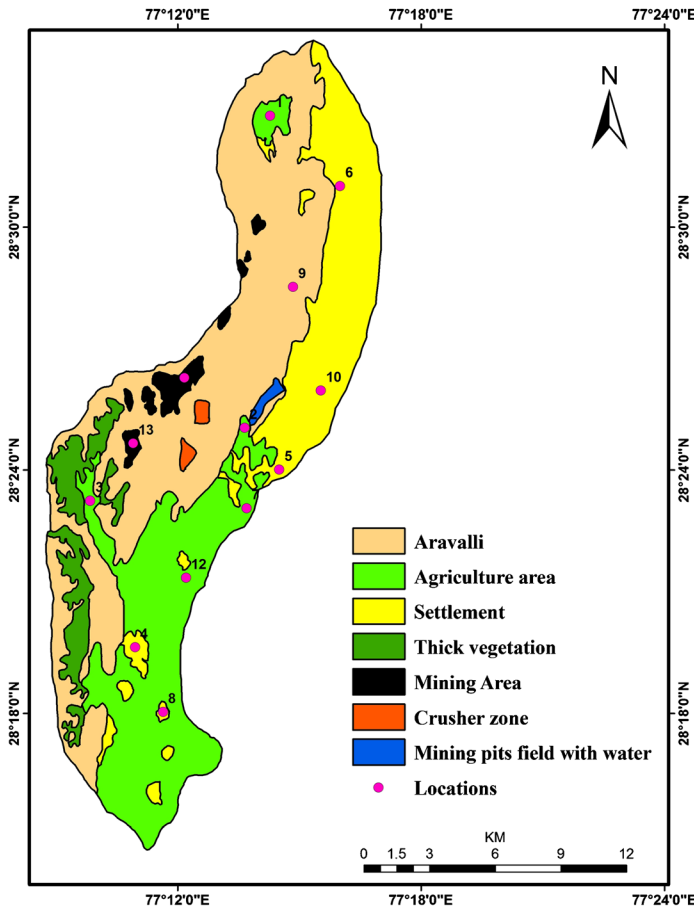


Fig 1 Location map of the study area

$$Q_i = \sum_{i=1}^n \frac{\{Mi(-)Ii\}}{Si-Ii} \times 100 [Mi, \text{monitored metal}; Ii, \text{ideal and } Si, \text{standard of the } i\text{th parameter. } (-), \text{difference between two values (neglecting the numerical sign)}].$$

The S_i and I_i of each element are assigned according to BIS (2012) standard.

Different principles for HPI of the samples have been established, which showed by their particular average values. The multiples of the average values are taken into considerations to demarcate the significant levels of contamination (Edet and Offiong 2002). Geostatistical analysis of the heavy metals has been carried out in the SPSS (Version 17) software.

Results and discussion

Physical parameters

pH In year 2016, pH value during pre-monsoon varies from 6.60 to 8.36 with mean value 7.62, and during post-monsoon,

it varies from 6.07 to 8.22 with mean value 7.44. The distribution of pH is shown in SI Fig. 1 and SI Tables 1 to 2. In general, the pH in the study area is in normal range with slightly alkaline nature.

Temperature The temperature of groundwater samples were measured in the field by using thermometer. Temperature recorded 20 to 31 °C in pre-monsoon and 17 to 25 °C in post-monsoon (SI Tables 1 and 2).

Electrical conductivity (EC) EC value during pre-monsoon ranges between 389 and 6020 $\mu\text{s/cm}$ with a mean value of 1811 $\mu\text{s/cm}$. During post-monsoon, the value varies from 376 to 6020 $\mu\text{s/cm}$ with a mean value of 1802 $\mu\text{s/cm}$. The distribution of EC of both the season is shown in SI Fig. 2 and SI Tables 1 and 2.

Table 1 Maximum, minimum, and mean concentration of heavy metals along with WHO standard

PARAMETER	MAXIMUM	AVERAGE	MINIMUM	WHO (2011)	% of samples exceeding the WHO std (2011)
Cd	31	8.07	3	3*	84.61
Cu	30	6.98	2	2000	Nil
Mn	75	46.76	9	500	Nil
Pb	248	107.46	19	10	100
Zn	303	66.84	14	3000*	Nil
Fe	757	296.61	41	50*	92.3

*Who (2006)

EC in most of the samples is observed to be high. This might be due to more interaction of deeper depth rock-water. In case of hard rocks where abstraction is high, the water levels will go deep. Since the movement of water is very low and water rock interaction is more, hence, high EC values have been observed. Salts leaching from agricultural fields can also be responsible for high values of EC.

Total dissolved solid (TDS) TDS in drinking water comes from natural sources, sewage, urban runoff, industrial wastewater, chemical used in the water treatment process, nature of the piping, and hardware used to convey the water. Generally, the total dissolved concentration is the sum of the cation and anion ions in water. Therefore, the total dissolved solid provides a qualitative measurement of the amount of dissolved ions but does not show the nature or ion relationships. The principle elements includes are calcium, magnesium, sodium, and potassium cations and carbonate, hydrogencarbonate, chloride, sulfate, and nitrate.

The TDS value ranges between 430 and 1965 mg/l during post-monsoon period; however, during pre-monsoon it varies

from 253 to 3913 mg/l with a mean value of 1177 mg/l. The distribution of TDS values is shown in SI Fig. 3 and SI Tables 1 and 2. Most of the groundwater samples have high value of TDS which may be due to the dissolution of salts and minerals with pace of time.

Chemical parameters

Calcium (Ca²⁺) Calcium is a unique and essential element among all the elements for the human body as its requirement is 0.7 to 2.0 gm/day. Inadequate intake of calcium is associated with increased risks of osteoporosis, nephrolithiasis, hypertension, stroke, and obesity. Enormous amount of calcium may produce some health problems such as kidney or bladder stones and irritation in urinary passage (McNeely et al, 1979). Excessive amount of calcium in drinking water can cause goutrheumatism. BIS (2012) and WHO (2004) have recommended the desirable limit of 75 mg/l and maximum permissible limit of 200 mg/l of calcium in drinking water.

Ca²⁺ value during pre-monsoon varies from 57.90 to 197.8 mg/l with a mean value 99 mg/l, and in post-monsoon, it varies from 53.02 to 195.12 mg/l with a mean value 97 mg/l. The distribution of Ca²⁺ ion is shown in SI Fig. 4 and SI Tables 1 and 2.

Ca²⁺ in most of the samples is observed within the permissible limits (BIS 2012), but a few samples exceed the desirable limit.

Magnesium (Mg²⁺) Magnesium is the eleventh most abundant element by weight in the human body. It is commonly existed in the mineral dolomite, brucite, carnality olivine, and dolomite. It is used in pyrotechnics, flash photography, drying agents, refractories, fertilizers, pharmaceuticals, and foods (APHA, 1998).

Magnesium is the fourth most abundant cation in the body and second most abundant cation in intracellular fluid and its behavior changing with the geo-chemical behavior. The WHO (2004) suggested 120 mg/l the maximum limit for magnesium, and BIS (2012) suggested maximum permissible

Table 2 The value of HPI, its mean and standard deviation

S.id	HPI	Mean deviation	Std deviation
1	123.57	- 27.21	- 18.05
2	161.93	11.15	7.39
3	27.57	- 123.21	- 81.71
4	64.34	- 86.44	- 57.32
5	96.70	- 54.08	- 35.87
6	68.44	- 82.34	- 54.61
7	260.99	110.21	73.09
8	216.92	66.14	43.86
9	121.18	- 29.60	- 19.63
10	218.65	67.87	45.01
11	279.52	128.74	85.38
12	82.88	- 67.90	- 45.03
13	237.46	86.68	57.48

limit 100 mg/l in drinking water. Distribution of Mg in groundwater samples is shown in SI Fig. 5.

Mg²⁺ value during pre-monsoon varies from 5.23 to 149 mg/l with a mean value 50 mg/l and in post-monsoon varies from 4.01 to 103.57 mg/l with a mean value 45.80 mg/l. The distribution of pH is shown in SI Fig. 5 and SI Tables 1 and 2. Mg²⁺ in most of the samples is observed within the permissible limits (BIS 2012). Mg²⁺ concentration in groundwater is generally in increasing trend which gives hardness to the groundwater. This might be due to the dissolution of magnesium-bearing rocks with time or due to application of magnesium containing fertilizer to the soil in agricultural fields.

Sodium (Na⁺) Limestone and dolomite contain the highest sodium concentration, and the major sources of sodium are detrital sedimentary rock type and clay minerals. The concentration of sodium in groundwater is influenced by human activities in various ways, such as disposal of waste in landfill sites, the pumping of fresh water from coastal aquifers, which leads to the intrusion of saline water.

The minimum sodium chloride requirement is about 120 mg/day (approximately 50 mg of sodium in this form) (WHO 2004). Overdose of sodium may lead to death (WHO 2004). Drinking water with high sodium concentration is unpalatable or salty in taste. Plants use sodium in limited amounts for their growth. A high amount of sodium is injurious to fruit crops ((WHO 2004), (BIS 2012), and (WHO 2006)) and does not recommend any limit for drinking water.

Na⁺ value pre-monsoon varies from 38.12 to 1020.02 mg/l with a mean value of 274 mg/l, and in post-monsoon, it varies from 27.28 to 1018.21 mg/l with a mean value 270.85 mg/l. The distribution of Na⁺ is shown in SI Fig. 6 and SI Tables 1 and 2.

Potassium (K⁺) The concentration of potassium in natural water is less than that of sodium because of greater resistance offered by potassium-bearing minerals to weather out when it enters into clay minerals during the process of weathering. Potassium is more abundant in sedimentary rocks, including mica, feldspar, and other clay minerals. The main sources of potassium in groundwater or rainwater, weathering of potash silicate minerals, the use of potassium-based fertilizers and some geological source etc.s. The amount of potassium in the soil depends upon clays, organic matter, and moisture content (Buckmann and Brady, 1960). The highest concentration of potassium is an indication of the groundwater pollution.

Potassium is a very essential nutrient, and its salts have beneficial value in the treatment of many diseases, but its excessive amount is harmful to human nervous and digestive systems (WHO, 1996). K⁺ value in pre-monsoon varies from 1.03 to 59.09 mg/l at Badkal and Mohbtabad villages with a

mean value 11 mg/l, and in post-monsoon, it varies from 1.01 to 59 mg/l with a mean value of 11 mg/l (Table 6.9). The distribution of K⁺ is shown in SI Fig. 7 and SI Tables 1 and 2.

K⁺ concentration in groundwater is generally in an increasing trend which might be due to the dissolution potassium containing rocks with time or due to fertilizer used in agricultural fields.

Bicarbonate (HCO₃⁻) Dissolution of carbonate minerals is present in the water, and CO₂ is present in the atmosphere. The presence of carbonate in soil above the water table plays an important role in increasing alkalinity in surface and groundwater. Exalted of carbon dioxide in the soil is formed by the decaying of organic matter and the root respiration. Black (1997) stated that growth and photosynthesis activities in the plant are influenced by low CO₂.

The elevated partial carbon dioxide is mainly responsible for weathering of a number of minerals in abandoned region. The existence of sufficient amount of bicarbonates in irrigated water driven up bicarbonate to precipitate as Ca²⁺ and Mg²⁺ from the soil in the form of calcium and magnesium carbonate, which leads to alter the ratio of Na⁺ and total amount of cations with increase of sodium element. HCO₃⁻ value in pre-monsoon varies from 187 to 742 mg/l with mean value of 481 mg/l, and in post-monsoon, it varies from 145 to 738 mg/l with a mean value of 477 mg/l. The distribution of HCO₃⁻ shown in SI Fig. 8 and SI Tables 1 and 2.

Chloride (Cl⁻) Most of the chloride are formed by the use of disinfectants and bleach for both domestic and industrial purposes (White, 1978). Biological processes, absorption techniques, and ion exchange do not affect the chlorine in any situation when it enters into groundwater (Chadha 1999). Due to this property, it is very difficult to remove chloride if it enters into groundwater regime by natural percolation. BIS (2012) has assigned the highest desirable limit of chloride 250 mg/l and permissible limit 1000 mg/l in drinking water.

During pre-monsoon, the value varies from 33.38 to 1198.4 mg/l, with a mean value of 285 mg/l; however, in post-monsoon, it varies from 21.89 to 1194.58 mg/l with a mean value 283 mg/l. The distribution of Cl⁻ is shown in SI Fig. 9 and SI Tables 1 and 2. Cl⁻ in most of the samples is observed within the permissible limits (BIS 2012). High concentration of chloride is mostly observed in samples, which is having high sodium content indicating high saline nature of the groundwater.

Sulfate (SO₄²⁻) High concentrations of sulfate occur in shallow, unconfined aquifers from atmospheric deposition, fertilizers use, and animal wastes. Aquifers underlying soils rich in gypsum have high concentration of sulfate often in excess of the maximum contaminated level. The WHO (2004 and 1971) has suggested the highest desirable limit of 200 mg/l and

maximum permissible limit of 400 mg/l for sulfate in drinking water. BIS (2012) recommend the highest desirable limit of 150 mg/l and maximum permissible limit 400 mg/l for sulfate and suggested that magnesium content does not exceed 30 mg/l in drinking water.

SO_4^{2-} value in pre-monsoon varies from 12.65 to 847 mg/l with a mean value 163 mg/l, and in post-monsoon, it varies from 10.45 to 846.12 mg/l with a mean value of 163 mg/l. The distribution of SO_4^{2-} is shown in SI Fig. 10 and SI Tables 1 and 2.

SO_4^{2-} values in all the samples are found to be within the permissible limits (BIS 2012). SO_4^{2-} concentrations are slightly increasing from year 2002 to 2016. Sulfate is a part of naturally occurring minerals in soil and rock formations that contain groundwater and release from them with pace of time.

Nitrate (NO_3^-) Nitrate is a naturally occurring compound, which is formed in the soil when nitrogen and oxygen combine with each other. The principle source of nitrate is atmospheric nitrogen gas. It is altered into organic nitrogen by some plants by a process called nitrogen fixation. Broken down nitrogen is the most widely recognized contaminants of groundwater. Nitrate in groundwater is generally formed by fertilizer use and land application of manure and organic wastes, septic, and sewage discharges. It is very hard to distinguish the natural and man-made sources of nitrogen contamination of groundwater. Some chemical and microbiological processes such as nitrification and denitrification also influenced the nitrate concentration in groundwater. Although there are number of researcher worked on the harmful effect of nitrate on human body, then concluded that only methemoglobinemia, (also infant cyanosis or blue-baby syndrome) diseases is caused due to the high nitrate in water above 10 mg/l. (WHO, 1996) has set 10 mg/l as the desirable limit and (BIS 2012) set permissible limit for nitrate in drinking water is 45 mg/l.

NO_3^- concentration in pre-monsoon varies from 0.09 to 472.03 mg/l with a mean value 81 mg/l, and in post-monsoon, its concentration varies from 0.09 to 471 mg/l with a mean value 77 mg/l. The distribution of NO_3^- is shown in SI Fig 11.

NO_3^- in most of the samples is observed beyond the permissible limits (BIS 2012) (SI Fig. 11). The common source of nitrate concentration is attributed to animal and human waste disposal practice and the use of agriculture fertilizer in the agricultural lands of the study area (Ediagbonya et al. 2015).

Fluoride (F⁻) There are two different sources of fluoride through which fluoride enters into groundwater: one is natural and the other is anthropogenic source. Natural source is related with geological strata, whereas fluoride concentration is higher in hard rock. The major minerals of fluoride in hard rock are fluorite, apatite, and cryolite. Water-rock interaction

plays an important role in the percolation of fluoride and deep water level highly influenced the fluoride concentration in water. Generally, dug wells have less fluoride content than bore wells, and fluoride-rich groundwater has more Mg^{2+} than Ca^{2+} . Salinity due to extensive irrigation also contributes to fluoride in groundwater. The occurrence of high fluoride is also due to prevailing hydrogeological condition. There are various anthropogenic sources, which contribute to increase of fluoride ions such as mining activities phosphate fertilizer effluent, industrialization, and urbanization.

Fluoride (F^-) is essential in trace amounts for all human beings and is one of the normal constituents of all diets. The desirable limit of fluoride in drinking water is 1 mg/l (BIS 2012). Mckee and Wolf (1963) summarize the effect of fluoride on human health (SI Table 3). F^- value in pre-monsoon varies from 0.43 to 2.80 mg/l with a mean value of 1.07 mg/l and in post-monsoon varies from 0.22 to 2.16 mg/l with a mean value 0.81 mg/l. The distribution of F^- is illustrated in SI Fig. 12 and SI Tables 1 and 2.

F^- concentration in most of the samples is observed beyond the permissible limits (BIS 2012). Fluoride in groundwater is based on geomorphology of aquifer. Most of the areas in Faridabad district have rock bed of quartzites, mica, and clay, which is the preliminary case of fluoride existence in groundwater and weathering of rocks, in humid and semi-arid climatic condition.

Heavy metals

Potentially toxic heavy metals and its health effects

The analytical details (maximum, mean, and average concentration) have noted in Table 1 along with the permissible limit of respective elements in drinking water. Basing upon the mean concentration of each elements in groundwater samples, the order of dominance is given as follows:

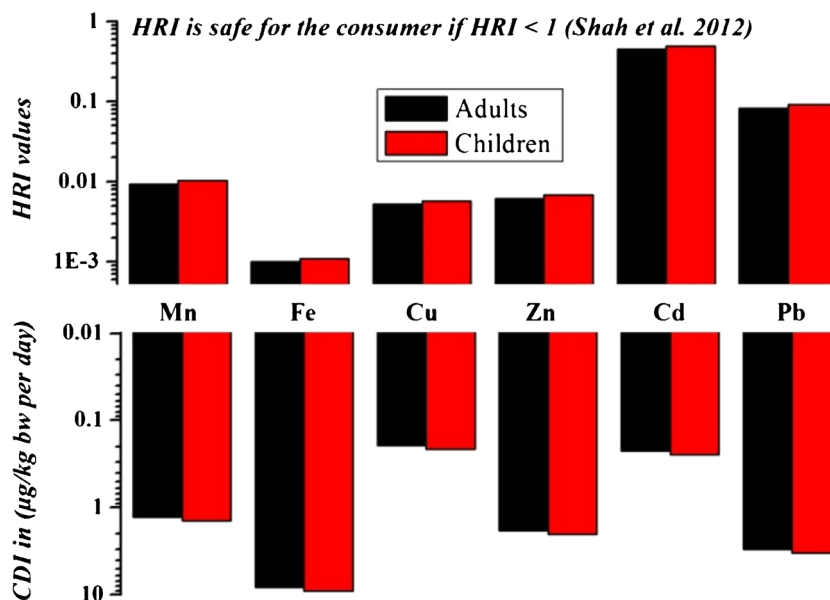
$$\text{Fe} > \text{Pb} > \text{Zn} > \text{Mn} > \text{Cd} > \text{Cu}$$

The elements like Cd, Pb, and Fe exceed the permissible limit. However, Zn, Mn, and Cu fall below the permissible limit set by WHO (2011).

Six percent of total water samples exceed the permissible limit for Cd (WHO 2006). The Cd is cancer-causing to individual and classified as group 1 by the International Agency for Research on Cancer (IARC). Cd causes lung cancer, and the investigation has indicated positive connection for kidney and prostate cancer also (IARC 2012). High ingestion of Cd can cause kidney, pneumonic, and skeletal harms (Godt et al. 2006).

One hundred percent of total groundwater samples for Pb exceed the permissible limit set by the WHO (2011); 15% of total water samples exceed the permissible limit for Pb (WHO

Fig 2 The mean CDI ($\mu\text{g}/\text{kg}\cdot\text{bw}$ per day) values and HRI of heavy metals via drinking water in the study area



2006). Exposure to Pb can cause an extensive variety of medical issues like renal disappointment, coma, digestion problem, the intelligence convulsions, and even death (Papanikolaou et al. 2005). As indicated by IARC (2012), consuming inorganic Pb compounds perhaps cancer-causing to people and categorized in group 2A.

92.3% of total groundwater samples exceed the permissible limit (WHO 2006) for Fe. The abundance of Fe in Earth’s crust makes it an indispensable and non-conservative heavy metal in drinking water. The nutritional requirement of iron per day is estimated to be 10 mg. The disease “anemia” is caused due to deficiency of iron. However, continuous intake of iron through drinking water may cause a liver disease called “hemosiderosis” (Rajgopal 1984).

Human health risk assessment

Chronic daily intake (CDI) and health risk index (HRI) of metals

The CDI and HRI values are plotted in the Fig. 2. The line drawn is the limit set for evaluating the health risk based upon CDI and HRI values. If the HRI value crosses the line (i.e., the value > 1) it suggests health risk upon consumption of groundwater. The mean of

CDI is highest for Fe and lowest for Cu in both adults and children.

The CDI values of all the elements are lesser except Fe and Pb. Figure 2 shows that the HRI values in this study are within safe limits ($HRI < 1$), suggesting no health risk (Muhammad et al. 2016). However, the HRI of Cd and Pb is higher compared to other elements.

Pollution index

Heavy metal pollution index (HPI)

Pollution indices are used to obtain the influence of all metals to the overall pollution of a region. The heavy metal pollution indices are used to obtain the influence of all analyzed metals on the overall pollution of a region. The HPI represents the total quality of water relating to metals. HPI of all the individual samples was calculated based on BIS (2012) standard. It ranges from 27.57 to 237.46 with a mean value of 150.78. The mean and standard deviation value have been calculated and provided in the Table 2. Seven sampling points (Sl. No 1, 3, 4, 5, 6, 9, and 12) have an HPI value less than the average value, and the negative deviation value depicts pollution-free status of water with respect to metals (Prasad and Bose 2001). The rest of the samples (Sl. No. 2, 7, 8, 10, 11, and 13) have HPI greater than average and, thus, are considered as polluted.

Table 3 Classification of groundwater quality of the region on categories of HPI

Index	Category	Degree of pollution	No of samples	Percentage	Samples
HPI	< 150	Low	7	53%	1, 3, 4, 5, 6, 9, and 12
	150–300	medium	6	47%	2, 7, 8, 10, 11, and 13
	> 300	high	0	0	Nil

Table 4 Rotated component matrix of heavy metals

	Component		
	1	2	3
Cd	.951	-.080	.013
Cu	.946	.216	.117
Mn	-.130	.333	.836
Pb	-.012	.905	.180
Zn	-.276	.221	.778
Fe	-.109	.810	.088
TDV %	37%	24%	20%

TDV total data variance; *Bold* strong positive and negative loading

The different contamination level of HPI have been derived from acquiring the mean approach as suggested by Edet and Offiong (2002) such as low (HPI < 150), medium (HPI = 150–

300), and high (HPI > 300) (Table 3). Seven samples (53%) are falling in the low category, and six samples (47%) are falling in medium pollution index, respectively.

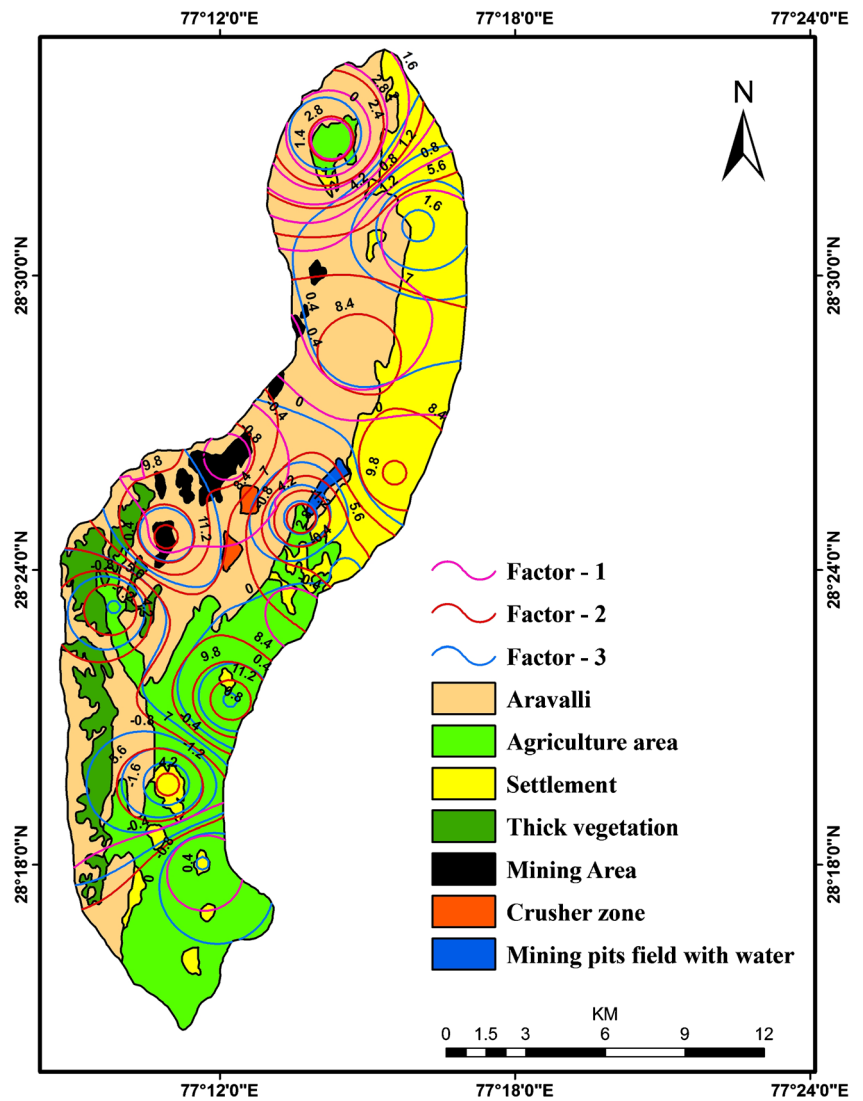
Pollution source identification

The following factors are identified:

- Factor 1: Cd and Cu
- Factor 2: Pb and Fe
- Factor 3: Mn and Zn

Factor 1 with a strong positive loading of Cd and Cu and 37% of total data variance (TDV) (Table 4). The factor could be related to mining and agricultural activities. The continuous use of chemicals in the agricultural field could be a source of Cu because Cu is considered as a common constituent of fertilizers and insecticides as well as pesticides (Huang and

Fig 3 All the three factor overlaid on land use pattern of the study area



Jin 2008). Mining water, industrial wastewater, and water from hazardous waste sites contribute Cd to the groundwater (ATSDR 1999). Figure 3 also confirms the fact that the positive scores of factor 1 mainly represented along the mining sites as well as near to agricultural lands. Thus, it is inferred that the wastewater coming from the mining as well as agricultural lands contributes higher amount of Cd and Cu to the groundwater of the study area.

Factor 2 with 24% of TDV has a strong positive loading of Pb and Fe (Table 4). Crusher zone activities as well as lithogenic source may be related to the factor 2. Common sources of lead in the study area are leaded gasoline and ore smelting contaminates local surface water by surface runoff (Magesh et al. 2017; Khalid et al. 2017). Sedimentary rocks can be a source of the accumulation of Fe to the groundwater during weathering (Drury et al. 1991). By considering the trend of factor score 2 (Fig. 3), it is depicted that natural weathering of underlying sedimentary rocks of the region may contribute higher Fe to the groundwater. Again the contaminants coming from the crusher zone during processing of ores and minerals contribute Pb to the groundwater.

Factor 3 with 20% of TDV has a strong positive loading of Mn and Zn. This factor could be linked to sewage dump and sludges. Mn comes from the wastes of the settlement area (Demirel et al. 2008). Zinc is one of the main elements present in insecticides or fungicides, and it also exists in industrial wastes and sewage sludges (Ravindra and Mor 2019). Due to its limited mobility, health impact of Zn is also negligible (WHO 2006). Figure 3 confirms that the positive scores of factor 3 represented along the settlement area. Thus, it is inferred that the main source of Mn and Zn in groundwater of the study area is influenced by domestic activities.

Conclusion

The study illustrates that the groundwater of the study area is polluted with nitrate, flouride, and other ions. The average concentration of heavy metal is in the following order of dominance Fe > Pb > Zn > Mn > Cd > Cu. The elements like Cd, Pb, and Fe exceed the WHO standard for drinking water purpose.

The average CDI value is highest for Fe and lowest for Cu. The HRI values indicate that the heavy metals of the study area are in safe zone, i.e., < 1 suggesting no human health risk upon consumption. Six samples (S. id. 2, 7, 8, 10, 11, and 13) have HPI > 100, i.e., above the critical index value. These samples fall in the southern part near to settlements and agricultural regions substantiating an extremely polluted status. The distribution pattern of the groundwater sampling points suggests that the water is mainly influenced by human activities and agricultural activities. The factor analysis of the sampling stations reveals three factors which are responsible for

the heavy metal pollution in the study area. Factor 1, factor 2, and factor 3 are suspected to associate with mining and agricultural activities, crusher zone, and natural weathering of source rocks (sedimentary) and sewage dump, respectively.

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Declarations

Conflict of interest The author(s) declare that they have no competing interests.

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