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Research article

Pollution indices and correlation of heavy metals contamination in the groundwater around brick kilns in Jammu and Kashmir, India

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A R T I C L E I N F O

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A B S T R A C T

The present investigation focuses on assessing the water quality of groundwater surrounding brick kilns in the Jammu district of Jammu and Kashmir (J&K). At 43 different brick kiln sites in both north and south regions of Jammu, concentrations of heavy metals were measured using established techniques. The elements zinc, copper, iron, lead, cadmium, nickel, and manganese were analyzed utilizing an Atomic Absorption Spectrophotometer (AAS). The pollution load index value was consistently below unity across all sites, suggesting an absence of pollution and making the water suitable for consumption. The average concentrations, listed in ascending order, were found to be 0.38 mg/L for copper, 0.31 mg/L for zinc, 0.01 mg/L for iron, and 0.09 mg/L for manganese. Notably, concentrations of lead, cadmium, and nickel were found below the detectable levels. Evaluation of contamination factors revealed the sequence Cu > Fe > Zn > Mn, while the geo accumulation index followed the sequence Cu > Fe > Mn > Zn. Comparison of these findings with the established standards of World Health Organization and Bureau of Indian Standards indicated that the recorded ranges were within permissible limits. The study's outcomes suggest that heavy metal emissions from brick kilns may not significantly impact the quality of groundwater. Elevated copper levels found near brick kilns were likely to result from plumbing materials in the study area. Iron and manganese in groundwater seems to have geogenic origin and not emission-related. This research represents a foundational step in examining groundwater contamination by heavy metals specifically in the neighborhood of brick kilns in Jammu district. It contributes to the establishment of a comprehensive database and serves as a reference point for future studies. Additionally, the study recommends regular monitoring of groundwater to ensure the maintenance of drinking water quality.

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1. Introduction

Groundwater serves as a fundamental necessity for the sustenance of all life forms on our planet. It stands as the primary reservoir catering to domestic and industrial water requirements, while simultaneously serving as the predominant source of irrigation [1]. In order to safeguard future quality of groundwater, it is imperative to engage in vigilant monitoring and conscientious management of this invaluable resource within a sustainable framework [2,3]. India faces a series of significant groundwater challenges, notably encompassing issues such as the overexploitation of groundwater, rapid depletion, and contamination from agricultural and industrial pollutants, among others [4,5]. According to global assessments by the United Nations, approximately 2.1 billion individuals currently lack access to uncontaminated water, and there is a projected shortage of safe drinking water by the year 2025 [6]. It is anticipated that water scarcity could potentially necessitate the relocation of around 700 million individuals by the year 2030 [7].

Pollution in India is primarily attributed to the rapid pace of industrialization, inadequately planned urban expansion coupled with inadequate management of sewage and waste disposal, inadequate focus on waste treatment and proper disposal methods, unsanitary waste disposal in proximity to water bodies, the utilization of chemical fertilizers and pesticides, and inadequate drainage systems in agricultural lands [8]. Groundwater pollution pertains to the alterations, both natural and induced that result from human activities, rendering the water unsuitable for its initial designated use. A contaminant signifies an entity that induces modification within the inherent composition of an environment; however, it is not classified as a pollutant unless it plays a significant role in the ecosystem. Trace metals like copper (Cu), lead (Pb), zinc (Zn), mercury (Hg), cobalt (Co), nickel (Ni), manganese (Mn), along with radioactive isotopes and various other elements, as well as pathogenic bacteria and viruses, emerge as primary pollutants capable of contaminating groundwater resources. Although groundwater pollution is notably less pronounced compared to surface water, it has grown into a substantial threat to public health [1,8].

Sixty percent of known elements are heavy metals having density greater than 5 g per cubic centimeters [9]. Lead, mercury, arsenic, cadmium, copper, chromium, zinc, and nickel are associated with prevalent human poisoning as they infiltrate the food chain, accumulating and magnifying within ecosystems, subsequently affecting organisms. Heavy metals exhibit harmful impacts at varying concentrations, and their existence in air, soil, and water originates from diverse sources including mining, vehicular emissions, and industrial activities. The existence of enduring, toxic amounts of heavy metals within the environment constitutes a substantial peril to human health [9,10].

Brick kilns stand as significant contributors to environmental pollution within their vicinity, impacting air, soil, and water resources, encompassing both surface and groundwater. An array of contaminants is introduced into the environment through brick kiln emissions, including carbon oxides (CO_x), sulfur compounds (SO_x), nitrogen compounds (NO_x), hydrocarbons (HCs), and particulate matter such as dust, soot, and smoke. India leads in brick production within South Asia, followed by Bangladesh and Pakistan [11].

India accounts for over ten percent of global clay-fired brick production. Boasting a staggering count of more than one hundred thousand active brick kilns across its expanse, the nation yields an estimated output of approximately 150–200 billion bricks annually. Notably, the dominant brick kiln type in operation is the Bull Trench Kiln (BTK), responsible for 74 per cent of the total brick output, whereas clamps contribute 21 per cent. Engaging approximately one crore individuals, the industry's primary fuel source for brick firing is coal, with an annual consumption of roughly 2500 lakh tonnes [12].

In addition to coal, brick kilns utilize a range of materials such as wood, tires, rubber, plastic waste, and sawdust as fuel sources. These fuel materials encompass diverse heavy metals, which subsequently deposit into surrounding land and water resources, posing a threat to human health through tainted food supplies. Given their persistent nature, heavy metals can accumulate to toxic levels through the process of bioaccumulation. When the soil utilized in brick production is irrigated with contaminated water, it becomes laden with heavy metals like nickel, manganese, cadmium, lead, zinc, and chromium. These metals are subsequently released during the firing process and redeposited onto soil, water, and plant surfaces [13].

In Jammu and Kashmir, brick manufacturing stands as a prominent industry that generates employment opportunities for both local residents and migrant labor. However, these establishments have led to significant air pollution, a subject explored by numerous researchers [14–17]. The emissions from brick kilns have far-reaching impacts, extending to the pollution of soil, vegetation, and water resources in the area. These harmful emissions, inclusive of heavy metals, adversely affect the surrounding areas. Notably, over a hundred operational brick kiln units are distributed throughout Jammu district, encompassing both industrial and non-industrial zones like agricultural lands, non-arable areas, and residential sectors. In light of the region's growing reliance on ground water resources for agricultural, domestic, and industrial needs, the issue of groundwater contamination has emerged as a substantial concern [18,19].

Human intervention and imprudent utilization have exerted an adverse impact on the quality and amount of groundwater resources [20].The brick kiln industry necessitates an uninterrupted supply of clean water, crucial both for the brick-making process and for the domestic requirements of the labor force involved. Moreover, local residents residing in proximity to brick kilns rely extensively on the region's groundwater resources for diverse purposes. It is hypothesized that the quality of groundwater of the studied area has been contaminated with heavy metal.

Numerous researchers have undertaken studies on heavy metals in the groundwater and reported important results [21–24]. The findings indicated presence of potential heavy metals which could be emanated from brick kilns [25–28]. Consequently, we have opted to include seven frequently encountered heavy metals in our study. The current study assesses the concentrations of zinc, copper, manganese, lead, nickel, cadmium and iron in groundwater neighboring brick kilns within the Jammu district. The calculation of indices like pollution load index and contamination factor, offers insight into the extent of contamination, thus contributing to the formulation of future management strategies. The findings of this research will contribute to an enhanced understanding of heavy metal contamination within the groundwater encircling brick kilns, thereby addressing relevant concerns and challenges.

2. Materials and methods

2.1. Study area

Jammu and Kashmir extends from 32.28°N to 37.06° N and 72.53°E to 80.32° E in the North-West region of Indian Himalayas. The entire population of Union Territory (UT) is 1.25 crores with population density of 124 persons per Km [2] (2011 Census, Government of India). The average literacy of the state is 67.16%. J&K has 81 reported urban areas and 86 towns. Jammu district (32° 17′ and 37° 5′ N and 72° 3′ and 80° 20′ E) was selected as the study area for present work. Jammu district is situated at the foothills of the Shivalik range with geographical area of 2336 K/m^2 and holds 12.20% of total population of UT. Average annual precipitation of 1100 mm is received in the city, major portion of which is received in form of monsoon rains from June to September. The average temperature in summers is 29.6 °C and average winter temperature is 17.1 °C (Source: https://jammu.nic.in/). Fig. 1 shows the study area.

2.2. Geology and hydrology of the study area

The geology of Jammu district predominately comprises of river sediments consisting of younger and older alluvium, characterized by unconsolidated, loose, clay, and silt-predominated soil of Holocene age which fall in the Tawi watershed of Chenab basin, north western Himalayas. Apart from this, Shiwalik rocks are exposed in the study area comprising lithologically of variety of sand and mudstone, while the upper Siwaliks are characterized by arenaceous sands and boulder conglomerates, referring to coarse grained rocks made up of sand and rounded stones. The upper shiwalik rocks occur as residual hills dissected by the various streams which flows into the river Tawi before it confluences with the river Chenab [29–31].

The study area is divided into three sections hydro geologically. The northern hilly area, served as a run-off zone and the Jammu alluvial plains from the Pleistocene epoch. Within the study region, the Jammu alluvial plains expanse occupies an elevation below 350 m above mean sea level. This flat alluvial terrain boasts a gradual incline and accommodates an extensive network of irrigation facilities such as tube wells and dug wells for diverse purposes, including domestic, irrigation, and industrial usage. Characterized by a shallow water table that experiences marginal seasonal shifts, it exhibits notable attributes of high discharge, minimal drawdown, and a substantial specific yield. Groundwater efflux transpires through diffused seepages, while some locations may channel flow through distinctly defined spring outlets [32].

2.3. Collection of water samples

Sampling was done in the month of March–April 2022 from the study area (Jammu district). Ground water samples were collected from sources present around brick kiln within a distance of 150 m. Bore wells (closed type with hand pump for the outlet) were found to be the main source of the water at most of the brick industries. The depth of bore well was 13.7–18.2 m. A total of 43 samples of groundwater were tested for heavy metal contamination. Fig. 2 represents the distribution of sampling points across the study area

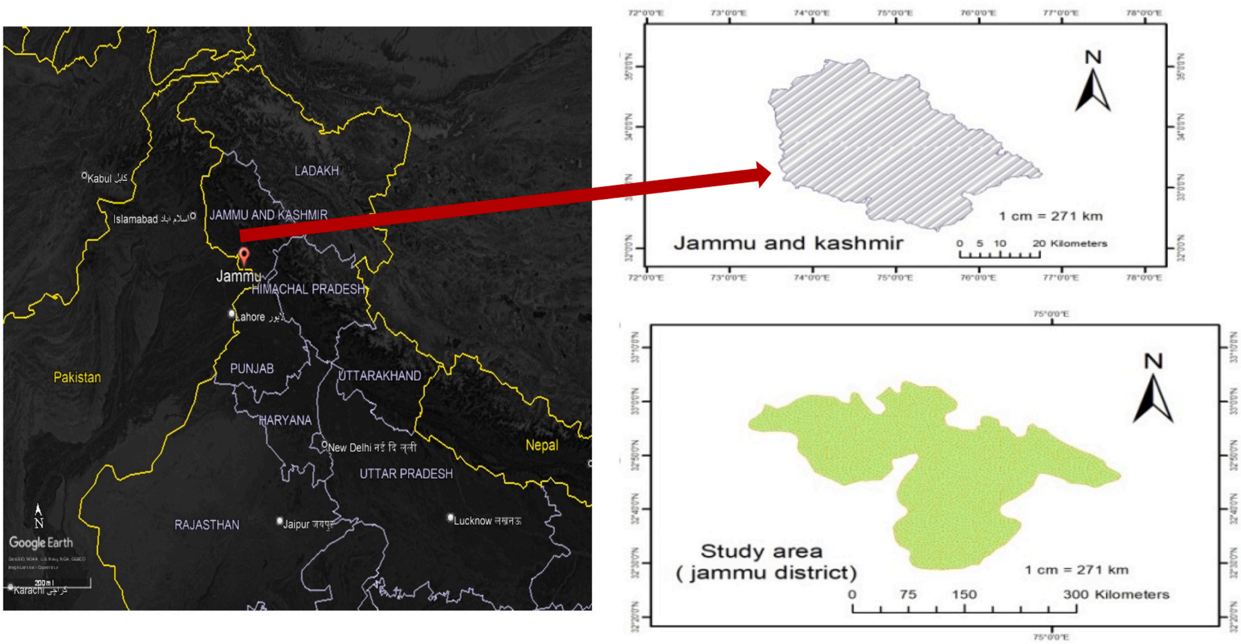

Fig. 1. Map showing study area.

plotted with the help of google earth application. The geo-coordinates were recorded using Garmin-etrex 10 GPS. Table S1 summarizes the details of sampling sites.

2.4. Quality assurance and quality control

All chemicals used were of analytical grade. Sample collection was adhered to the standard operating procedure (APHA, 2012) [33]. Appropriate labelling and coding was done on the sample bottles. All laboratory equipment was well maintained and calibrated. Manual calculations were avoided to minimize the errors. The mean of triplicate readings was used to interpret data. The calibration curve was obtained by mixing using 1000 mg/L standard solution (E-Merck) of the corresponding metal and dilutions were prepared using distilled water. Labolene washing reagent was used to clean storage bottles and glassware. Before sampling, storage bottles were rinsed with 10% Con. HNO3. Procedural blanks were also used. Triplicate values were taken to obtain the mean value used for further calculations. Heavy metals recovery rate was 85–95%.

2.5. Analysis

Water sample was collected from hand pump or outlet of the bore well and collected in plastic/polyethylene bottles as per sampling procedure and guidelines described in APHA, 2012. The collected samples were acidified using 1.5 mL conc. HNO_3 per litre. The samples were taken to laboratory and put in storage in refrigerator and then analyzed for heavy metals (zinc, copper, iron, lead, cadmium, nickel, and manganese) with the help of Atomic Absorption Spectrophotometer, AA-6880 (SHIMADZU).

2.6. Calculation of indices

2.6.1. Contamination factor (CF)

It estimates the amount of contamination due to presence of heavy metal and is obtained by dividing the obtained value (concentration) in the sample with the reference value. The acceptable limits for heavy metals prescribed by BIS drinking water specifications (2012) [34] available on the website of central pollution control board (CPCB) were used as reference values in the current study with respect to which the level of contamination is calculated by using the formula (Equation (1)):

$$CF = \frac{\text{Concentration of heavy metal in sample}}{\text{Reference value}} \quad (1)$$

Where, *CF* is the contamination factor. Reference value used for heavy metals: Zinc (5 mg/L), Copper (0.05 mg/L), Iron (0.3 mg/L) and Manganese (0.1 mg/L). The contamination is categorized as minor if the value of CF is less than 1; modest if it ranges from 1 to 3; considerable if it ranges from 3 to 6; and extreme if the value of CF is greater than 6 [27].

2.6.2. Pollution load index (PLI)

It can be used to check out how much pollution is caused by heavy metal contamination [35]. It shows how certain contaminants may have affected the natural properties. It is useful in determining quality of water and the level of pollutants present. The formula

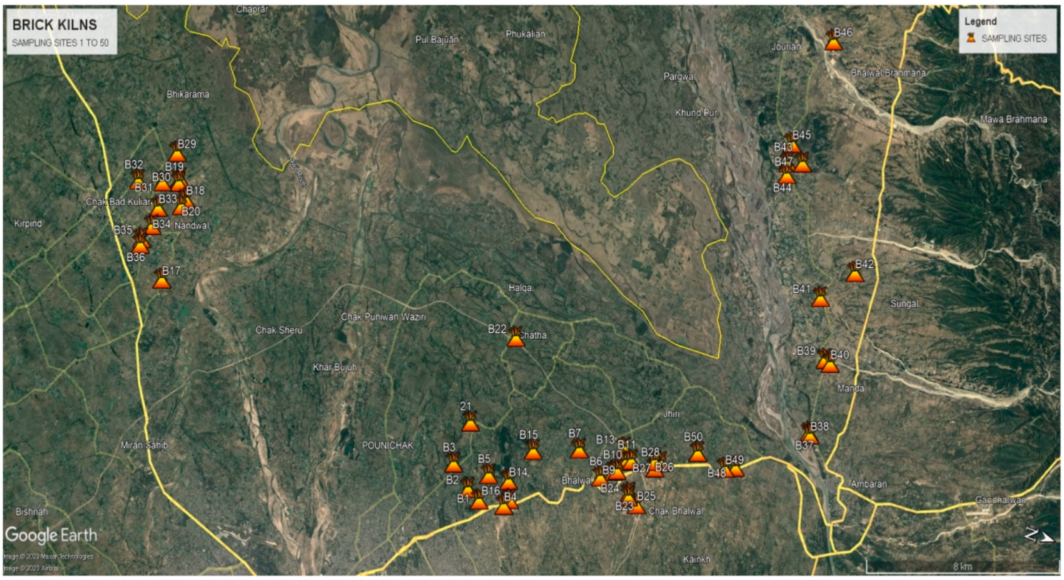

Fig. 2. Map showing locations of sampling sites in the study area.

used is (Equation (2)):

$$\text{PLI} = (CF1 \times CF2 \times CF3 \times CF4 \times \ldots . \times CFn)^{1/n} \tag{2}$$

Here, *CF* denotes Contamination Factor and *n* is the total number of samples.

It is classified in terms of pollution load: if PLI <1, there is superiority or there is no pollution; When PLI is equal to 1, pollution is under control; when PLI >1, pollution situation exists [27].

2.6.3. Geo-accumulation index (Igeo)

Igeo helps in determining the degree of anthropogenic pollution due to trace elements [27,36]. It is expressed as equation (3):

$$\text{Geo accumulation index} = \log_2\left(\frac{\text{Cm(sample)}}{1.5 * \text{Cm(background)}}\right) \tag{3}$$

Where, *Cm (Sample)* is the concentration of the metal in sample and *Cm (background)* is the concentration of the metal in the pre-industrial era [36]. This classification is divided into seven categories as shown in Table 1.

2.6.4. Co-efficient of correlation

The relationship of heavy metals with each other in the groundwater samples was observed by determining the coefficient of correlation (r). Assuming x and y as any two variables (here, heavy metals) and n = number of observations; then the coefficient of correlation (r) between x and y is given by the following mathematical formula (Equation (4)):

$$r = \frac{n\Sigma(x \times y) - \Sigma x \times \Sigma y}{[f(x) \times f(y)]^{0.5}} \tag{4}$$

Where $f(x) = n\ (x^2)\ \text{-}(\Sigma\ x)\ [2]$, $f(y) = n\ \Sigma\ (y^2)\ \text{-}(\Sigma\ y)\ [2]$ and all sums must be taken from 1 to n.

If the correlation between two variables x and y has a significant numerical value, it indicates that these two variables are correlated. The linear relationship can also be studied using the equation: $y = Ax + B$.

For determining the constants, A (Equation (5)) and B (Equation (6)), following equations can be implied.

$$A = \frac{n\Sigma(x \times y) - \Sigma x \times \Sigma y}{[n\Sigma(x - \bar{x})]^2} \tag{5}$$

$$\text{And } B = \bar{Y} - A\bar{x} \tag{6}$$

$\overline{X} = \frac{\Sigma x}{n}$ and $\bar{Y} = \frac{\Sigma y}{n}$. Following these relationships, the values for correlation coefficient was calculated with the help of Microsoft excel version 2010.

3. Results and discussion

Zinc, copper, iron, lead, cadmium, nickel, and manganese were analyzed in the samples of ground water from 43 different brick kiln sites of Jammu district. The concentration of heavy metals in water samples in the present study were reported in the range between 0.04 and 0.86, 0.2 and 0.44, 0.01 and 0.11, 0.01 and 0.33 mg/L for Zn, Cu, Mn and Fe, respectively. The concentrations of lead, cadmium, and nickel were found to be below the detection level, and as a result, they could not be utilized in the calculations of pollution indices. The average concentrations of Zn, Cu, Mn and Fe in ground water samples were reported to be 0.31, 0.38, 0.01 and 0.09 mg/L, respectively. Similar findings were reported earlier by Ghosh et al., 2018 [37] and Looi et al., 2019 [38]. Fig. 3 represents the radial diagram of heavy metal concentrations in water samples scattered around a particular range. It has been revealed that copper is more confined to a particular range of values as compared to other heavy metals. The examined heavy metals were found to have minimal contamination in the groundwater of the study area. Consequently, it was not possible to conduct a geospatial representation of their distribution.

The average concentrations (Fig. 4) of heavy metals were recorded in the order, copper > zinc > iron > manganese. The average

Table 1
Criteria for classification of Geo-accumulation index (Kaur et al., 2020).

Class	Igeo	Quality
0	Igeo ≤ 0	uncontaminated
1	0–1	uncontaminated to moderate contamination
2	1–2	moderate contamination
3	2–3	moderate to high contamination
4	3–4	high contamination
5	4–5	high to very high contamination
6	Igeo ≥ 5	extreme contamination

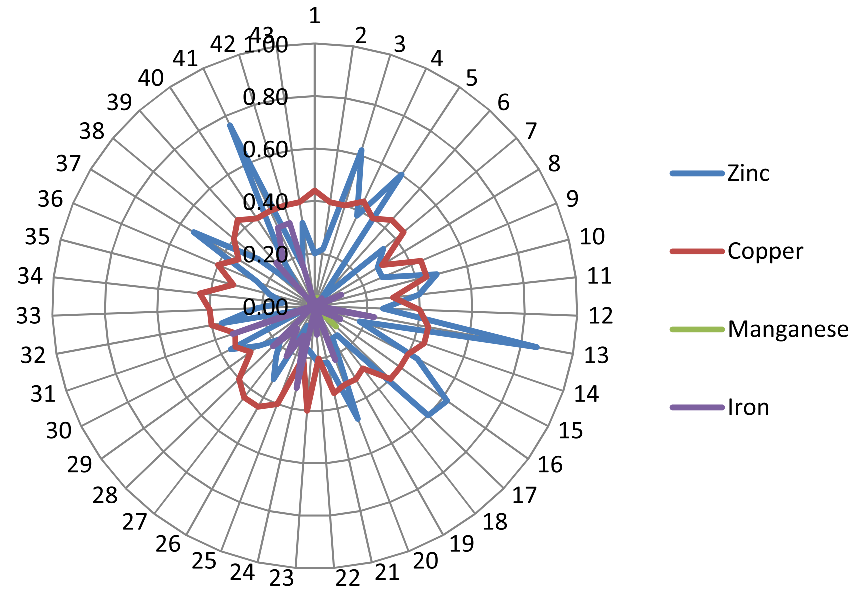

Fig. 3. Observed heavy metals concentrations in each water sample.

concentration of zinc, iron and manganese was found within both acceptable limit and permissible limit as per BIS, 2012 drinking water specifications and health-based guideline value recommended by WHO, 2022. For iron, no guideline value is specified by WHO, 2022. Chorol and Gupta, 2023 [39] conducted an assessment of groundwater contamination with heavy metal of Leh town in the Ladakh region, and reported elevated concentrations of iron. Prahraj et al., 2002 [40] found Zn as one of the major contaminants in ground water whereas, concentrations of iron in the groundwater might have been caused by steel containing iron present in residential discard (Nagarajan et al., 2012) [41] or by the occurrence of iron in weathered materials, responsible for reduction of ferric iron to ferrous iron (Raju, 2006) [42]. Greater use of this iron rich water could have resulted in hemosiderosis, a liver illness (Rajappa et al., 2010) [22]. Dipti et al., 2023 [43] conducted an assessment of pollution indices and concentrations of chromium, manganese, iron, nickel, copper, zinc, cadmium, and lead in various agro systems around the city of Lucknow, considering brick kilns as a potential source of contamination. The findings revealed a moderate level of contamination from manganese and nickel, while chromium, copper, zinc, and cadmium exhibited low levels of contamination. Higher levels of iron and manganese were stated by Vig et al., 2023 [44].

The amount of copper in the present investigation was found higher than the acceptable limit but less than the permissible limit of BIS, 2012; and less than guideline value recommended by WHO, 2022. Dogra et al., 2023 [45] also conveyed higher concentration of copper in the study conducted in Ranbir Singh Pura tehsil of Jammu. Table 2 shows the acceptable limits, permissible limits and health-based guideline values recommended by BIS, 2012 and WHO, 2022. George et al., 2023 [46] also reported higher levels of copper, iron and zinc as compared to other heavy metals analyzed in their study. Dheeraj et al., 2023 [47] recorded average values of

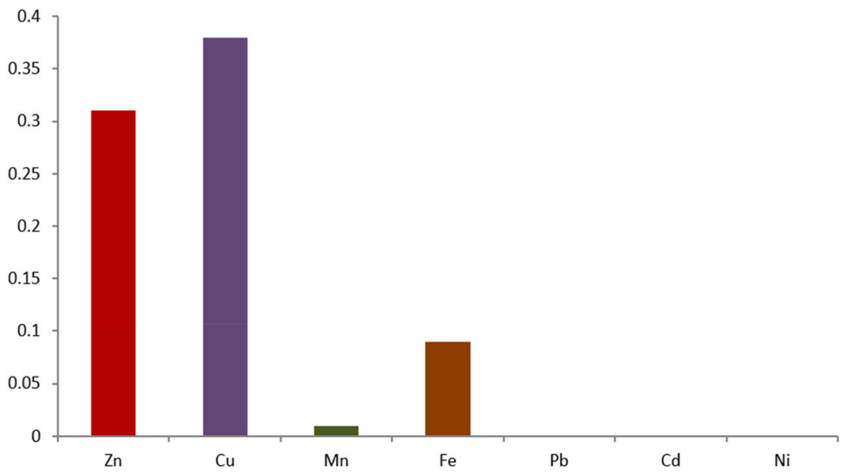

Fig. 4. Average concentrations of studied heavy metals in ground water of Jammu district.

iron, zinc and manganese exceeding from prescribed limits by WHO (2006) [48] & BIS 2012 (IS 10500). The comparative higher levels of copper reported in the present study cannot be attributed to brick kiln emission directly as brick manufacturing process does not involve release of copper related emissions at larger scale. It can be established that copper enrichment is probably due to associated plumbing materials like water fixtures, pipes, fitting, faucets etc. Elevated levels of zinc in the groundwater could be because of extensive use of fertilizer in agricultural fields and disposal of street dust in landfill areas (Ravindra and Mor, 2019) [49]. According to Davis et al., 2001 [50], roadside dust also serves as a significant contributor to toxic metal content. Moreover, the use of zinc as an additive in vehicle engines can lead to contamination due to leakage from drain pipes (Ravindra and Mor, 2019 [49]; Lawerence et al., 2016 [51]). The consumption of water with high concentrations of iron salts can negatively impact the quality of fabrics, fixtures, and kitchenware. Furthermore, iron can also affect the taste of cooked food when used in food preparation (Ravindra and Mor, 2019) [49]. The presence of iron and manganese in the groundwater seems to have geo-genic contribution rather than emission related inputs. The results obtained in the study have been equated with several recent national and international studies that explore quality of groundwater around brick kilns and similar industries.

3.1. Pollution indices

The reported values for contamination factor are summarized in Table 3. The value of contamination factor for zinc varied between 0.01 and 0.17, with an average value of 0.06. Similarly, the CF value for copper, manganese and iron ranged between 4.00 and 8.80, 0.06 and 1.12, and 0.03 and 1.10 with the average (mean) value of 7.62, 0.15 and 0.29, respectively. The mean CF value for zinc, manganese and iron was found less than unity indicating minor or low contamination. On the contrary, the average (mean) values of CF for copper were recorded to be higher than 6 that represented extreme level of contamination. The maximum level of contamination was reported for copper that exceeded the acceptable levels by large difference. The mean CF values were reported in the order Cu $>$ Fe $>$ Zn $>$ Mn.

The calculated values for pollution load index ranged between 0.16 and 0.68 with an average value of 0.31 (Table 3). The mean PLI value recorded was less than unity depicting absence of pollution. The pollution load index value was reported less than 1 for all water samples and hence, the results clearly stated that there is no problematic situation with respect to groundwater qualities. Vig et al., 2023 calculated pollution indices and the subsequent health risk assessment in the Rupnagar district of Punjab and indicated the necessity for consistent monitoring of groundwater quality within the investigated region.

The obtained results for geo accumulation index have been mentioned in Table 3. The mean Igeo value for Zinc, Copper, Manganese and Iron were calculated as -4.9, 2.32, -3.6 and -3.4 respectively. The Igeo value for zinc, Manganese and Iron fall into class 0 (Igeo ≤ 0) that indicates no contamination. The Igeo values for copper belonged to class 3 (i.e. Igeo = 2–3) and indicates medium to high contamination. The Igeo values were reported in the order Cu $>$ Fe $>$ Mn $>$ Zn. By observing the obtained results, it cannot be suggested that major groundwater pollution problem occurs in the study area thus, the null hypothesis is rejected.

3.2. Correlation

The correlation of analyzed heavy metals was also studied and is represented in the form of correlation matrix in Table 4. A weak positive correlation was perceived among all the four heavy metals except for two groups i.e., copper and iron; and manganese and iron which displayed negative correlation. The minimum correlation was observed for the above-mentioned pairs. Parallel positive correlation was perceived between three sets of heavy metals namely zinc and copper, zinc and manganese; and copper and manganese. No correlation was observed between zinc and iron. Only a handful of studies have been conducted concerning brick kilns to assess groundwater quality and the potential contamination of heavy metals. A comparative compilation is also presented in Table 5.

4. Conclusions and limitations

This study revealed that groundwater around brick kilns in the Jammu district is not contaminated with the analyzed heavy metals namely zinc, copper, manganese, iron, nickel, lead and cadmium. All the samples showed the levels under permissible limits. The concentration of lead, cadmium and nickel were found below detection level. The range of heavy metals varied between 0.04 and 0.86 for Zn, 0.2 and 0.44 for Cu, 0.01 and 0.11 for Mn, and 0.01 and 0.33 mg/L for Fe. Similarly, the average or mean concentration of Zn,

Table 2
Drinking water standards specified by different agencies.

Heavy metal	Avg. value (mg/l)	BIS 2012		WHO 2022
		Acceptable limit (mg/l)	Permissible limit (mg/l)	Health based guideline values
Zinc	0.31	5	15	3 mg/L
Copper	0.38	0.05	1.5	2 mg/L
Manganese	0.01	0.1	0.3	0.08 mg/L
Iron	0.09	0.3	No relaxation	No guidelines proposed
Lead	–	0.01	No relaxation	0.01 mg/L
Cadmium	–	0.003	No relaxation	0.003 mg/L
Nickel	–	0.02	No relaxation	0.07 mg/L

Table 3
Average values of Contamination Factor, Pollution Load Index and Geo-accumulation Index.

	Average value	
	CF	Igeo
Zinc	0.06	−4.9
Copper	7.62	2.32
Manganese	0.15	−3.6
Iron	0.29	−3.4
PLI	0.31	

Table 4
Correlation matrix of estimated heavy metals in groundwater of Jammu district, J&K.

	Zinc (ppm)	Copper (ppm)	Manganese (ppm)	Iron (ppm)
Zinc	1.00			
Copper	**0.16**	1.00		
Manganese	**0.29**	**0.07**	1.00	
Iron	**0.00**	−**0.11**	−**0.11**	1.00

Bold indicates the positive correlation whereas italics with bold represent negative correlation of the studied heavy metals.

Table 5
Comparison of results with different studies.

Heavy metals in groundwater found within permissible limits	Study area	Heavy metals in groundwater found above permissible limits	Organization	References
Cd and Zn		Cu (few samples)	WHO (1997)	Nouri et al., 2008 [21]
Fe, Zn, Cu, Pb and Cr	Karnataka, India	Cd, As and Ni	BIS (1998)	Rajappa et al., 2010 [22]
________	Maharashtra, India	.As, Ni, Hg, and Cd	WHO (2011)	Bhagure and Mirgane. 2011 [23]
Zn Fe Mn Co Cu and Cr	Pakistan	Ni, Pb and Cd	WHO (2011)	Nazeer et al., 2014 [24]
Zn, Cd, Cr, Fe, Mn, As, Hg and Cu	Jammu and Kashmir, India	________	WHO (2011)	Kumar et al., 2016 [25]
Cu, Zn, and Mn	Pakistan	As, Hg, Ni, Cd, Cr, Fe and Pb	WHO (2011)	Khanoranga and Khalid. 2018 [26]
Zn and Cu	Jammu and Kashmir, India	Pb and Cr	WHO (2011)	Kaur et al., 2020 [27]
Cu, Mn, Zn and Co	Tamil Nadu, India	Pb, Ni, Cr and Cd	WHO (2011)	Raja et al., 2021 [28]
Cr, Mn, Cd, Fe, Ni and Zn	Ladakh, India	Fe	WHO (2022)	Chorol and Gupta, 2023 [39]
Fe, Ba, Cu, Mn, S, Pb, V, and Zn	Orissa (now Odisha), India	Mn, Fe, and Pb	United States Environmental Protection Agency (USEPA)	Prahraj et al., 2002 [40]
Fe, Zn, Cd, Pb, Cu, Ni, As, and Cr	Jammu and Kashmir, India	Cu, Fe, Pb, and Cr	BIS (2012)	Dogra et al., 2023 [45]
Cu, Zn, Fe and Mn	Jammu and Kashmir, India	________	BIS (2012), WHO (2022)	Present study

Cu, Mn and Fe was found to be 0.31, 0.38, 0.01 and 0.09 mg/L, respectively. The average concentration of zinc, Manganese and iron was found within the prescribed limits except the values of copper which were found to be higher than the permissible limits. The mean contamination factor value for copper, manganese, and iron was 7.62, 0.15, and 0.29, respectively indicating minimal or low contamination. Among heavy metals the level of contamination for copper only was reported to be slightly higher than the permissible values but average PLI value was less than unity indicating least contamination. Igeo values for heavy metals belonged to class 0 (Igeo 0), denoting pollution less condition.

The pollution load index values recorded for all the water samples were found less than 1 and indicated minimal or no contamination of groundwater. Also, a weak positive correlation was recorded among all the four heavy metals excluding for copper and iron; and manganese and iron which displayed negative correlation. The data analysis revealed absence of any noticeable correlation between the levels of zinc and iron in the studied samples. The calculated values for pollution load index ranged between 0.16 and 0.68 with a mean of 0.31. The Igeo averages for zinc, copper, manganese, andiron were determined as −4.9, 2.32, −3.6, and −3.4, respectively. The Igeo values for zinc, manganese, and iron are classified as 0 ($Igeo \leq 0$), signifying an absence of contamination. The Igeo values for copper fall within class 3 (i.e., Igeo = 2–3), indicating a medium to high level of contamination.

The findings indicate that the ground water of the studied area is not contaminated due to heavy metals. Although the continuous analysis of the water quality around the brick kilns of the study area must be checked before public consumption.

The study primarily concentrated on heavy metal concentrations in groundwater near brick kilns presents several potential limitations for future researchers to consider, including the confined spatial scope within the immediate kiln vicinity, potential oversight of seasonal variations due to a limited timeframe, the need for advanced techniques to precisely identify contamination sources and the necessity of extended monitoring to capture long-term trends. Moreover, a broader assessment of multiple pollutants of groundwater including organic and inorganic contaminants can be done. Health risk assessment was not conducted in the present study as none of the analyzed heavy metals surpassed the permissible limits. However health risk assessment is suggested in case the concentration of toxic metals increase in future. Socio-economic implications on local communities and comparative analyses with other industrial sources would enrich the understanding of heavy metal contamination dynamics and contribute to a more comprehensive perception of the issue.

Ethical approval

It is not applicable.

Consent to participate

It is not applicable.

Consent to publish

It is not applicable.

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CRediT authorship contribution statement

Indica Mohan: Writing – original draft, Methodology, Investigation. **Rohit Jasrotia:** Writing – review & editing, Methodology, Supervision, Conceptualization. **Sunil Dhar:** Writing – original draft, Methodology, Data curation. **Brijmohan Singh Bhau:** Methodology, Data curation, Conceptualization. **Deepak Pathania:** Writing – review & editing, Methodology, Data curation, Conceptualization, Supervision. **Rohit Khargotra:** Review & editing, Funding. **Tej singh:** Review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on a reasonable request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e27869.

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