Potentially Harmful Metals, Water Toxicity, Source Apportionment, and Potential Health Risk in Groundwater of Sheikhupura, Pakistan

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Research Article

Keywords: Groundwater, Potential harmful metals, Mineral phases, Source apportionment, Health risk indices

Posted Date: April 11th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1527307/v1

Abstract

The presence of potentially harmful metals (PHMs) in drinking groundwater is a common environmental problem in Pakistan. Ingestion of PHMs polluted water, can cause a variety of harmful health impacts in humans. However, in Pakistan, only a little level of attention is given to quantitative and qualitative evaluation of groundwater utilized for ingestion motive. Therefore, this research was aimed for the first time to evaluate the levels of PHMs in drinking groundwater sources of Sheikhupura, Pakistan. A total of (n=243) samples were collected and subjected to analyze PHMs concentration like arsenic (As), manganese (Mn), lead (Pb), zinc (Zn), copper (Cu), nickel (Ni), iron (Fe), along with pH, total dissolved solids (TDS), and electrical conductivity (EC). The results show the concentration of PHMs such as As (91%), Mn (14%), Pb (97%), Fe (45%), Zn (15%), Cu (0%), and Ni (0%), samples were beyond the WHO recommended values for PHMs in drinking water. Saturation indices results shows that the aquifers of the study area are saturated for lead hydroxide, zinc hydroxide, and goethite minerals, indicating that these minerals have a vital role in the contamination of groundwater sources of the study area. Principal component analysis (PCA) results with total variability of (60.154%) reveal that the groundwater sources of the study area are contaminated due to (30.9%) geogenic sources, (31.3%) anthropogenic sources, and (37.6%) of mixed type including both geogenic and anthropogenic sources. Health risk exposure assessment results predicted potential health risk on the population of the study area.

Introduction

Potentially harmful metals (PHMs) in drinking groundwater water sources are commonly reported environmental issue[1]. Most of the PHMs contains arsenic (As), zinc (Zn), lead (Pb), mercury (Hg), manganese (Mn), iron (Fe), copper (Cu), nickel (Ni), [2], which is released in to groundwater sources as a result of natural and anthropogenic actions [3]. PHMs can negatively affect human health and is the common cause of various health ailments such as cancer, hyperkeratosis, melanosis, peripheral vascular diseases, lung diseases, and hypertension are some of the health outcomes associated with toxic metals ranging from acute to chronic effects [4, 5]. The important physicochemical structures or setups that contribute to PHMs mobility into the aquifers is either lowering or increasing of pH in the watershed [6]. The concentration of PHMs in groundwater can also rise due to a low hydrological slope, which causes lesser infiltration of water, or an arid climate, which causes evaporating accumulation [7]. Furthermore, the elevated concentration of PHMs in groundwater sources is due to mining actions, industrial waste-water recharge, agricultural pesticides, which may contribute PHMs mobility into groundwater sources [8, 9].

Groundwater is a key source of freshwater for ingestion motive, irrigation, and industries everywhere across the entire globe, especially in developing countries, but it is regularly challenged by environmental conditions and human activity [10]. Almost one-third of the population around the world drink from freshwater sources[11]. Groundwater is the only source of drinking water in certain dry and semi-arid regions. In recent decades, water supply has suffered an increase in challenges, especially quality control issues and the loss of fresh water sources [12].

Groundwater quality is affected by a variety of factors, including recharge sources, lithology, hydrodynamic setting, mineralization of watersheds, water-rock interaction, including mineral dissolution, ion exchange, redox, and human impacts [9, 13]. When it comes to addressing fundamental human requirements, water quality is definitely as vital as availability, because a lack of water and sanitation causes a litany of public health issues [14]. The reliability and sustainable alternative characteristics of aquifers within a region are often used to evaluate the consumption and accessibility of local water resources in recent decades [15].

Pakistan is also facing the problem concerning groundwater contamination and is severely water-stressed in terms of both surface and groundwater supplies, which is decreased significantly in recent decades. In contrast, household groundwater consumption is high [16, 17]. Over-exploitation has resulted in a considerable increase in groundwater quality problems in several parts of Pakistan, especially in Punjab Province. Groundwater with high levels of PHMs is a severe health concern, although research on the impacts is still limited [18]. Punjab groundwater vulnerability has increased in recent decades due to a variety of factors. In detained extremely contaminated groundwater, TDS levels of 400 – 20,000 ppm, As 0.5–200μg/L have been reported in many regions of Punjab province of Pakistan [10].

Previous information concerning PHMs pollution in drinking groundwater sources of Punjab Province, Pakistan, has addressed minor regions. To investigate a realistic situation of groundwater sources polluted with PHMs, it seems compulsory to conduct a detailed survey of drinking groundwater sources. Therefore, we aimed to determine not only the level of PHMs in the aquifers of Sheikhupura, but the exertion was made to determine the origins of groundwater contamination and its effects on health of human being through a multivariate statistical approach and geochemical modeling.

Study Area

2.1. Location and climate

The research was carried out in the Sheikhupura district of Punjab, Pakistan. The study area is located at 31º 27′ 48’ N, latitude and 74º ‘6’ 0’ E, longitude as shown in (Fig. 1), and is the semi-arid zone of Punjab, Province, Pakistan. The population of the study area is 3,321,029, of which 25% is urban. There is a hot semi-arid climate in the region, with hot and humid summers and dry, winters with a low level of precipitation in the winter. The average annual temperature and precipitation are 26.7 ºc and 412 mm, respectively. The main growing crops of the study area is wheat, rice, sugarcane, and vegetables.

2.2. Geological setting

The slope of the ground in the south-west is around 0.3 to 0.4 meters per kilometer of length. The surrounding flooding plains in the center of the plain are elevated to a height of 50 feet by terraces or bars. Exploratory drilling revealed that a 1500-meter-thick quaternary alluvium with scattered bedrock hills had overlain Precambrian basement rocks, breaking the plain's flat relief. The area is covered in meander-belt deposits, stream-belt deposits, and flood-plain deposits. The soils consist of the alluvial substance carried by the river Indus and its tributaries. Individual strata's vertical and horizontal continuity is limited in diverse alluvial deposits. The soil is generally medium-textured reddish-brown to grayish-brown, with a high percentage of fine to very fines and tiny amounts of clay and gravel. Fine to medium sand, silt, and clay make up the majority of the alluvial complex. Pebbles of silt stone and mudstone are found embedded in silty or clayey sand. The alluvial sediments constitute a coherent highly transmissive no artesian aquifer despite their variety. The strata above 300 feet are compacted but extremely productive. In the research region, the hydraulic head ranges from 129m to 171m (with average of 150 m)[19].

2.3. Groundwater samples analysis, and instrumentation

The groundwater samples were collected from various groundwater sources, such as tube wells, bore-hole, and hand-pumps in Sheikhupura, Punjab, Pakistan, following standard protocol adopted by [20]. A total of (n=243) drinking groundwater samples were collected for heavy metals detection and other physicochemical parameters. The sampling survey was performed in summer 2021. The groundwater samples were collected in contamination free polyethylene bottles having a capacity of 1.5L. Afore sampling the groundwater sources were pumped for several minutes to avoid the effect of stagnant water. The basic water quality parameters like pH, total dissolved solids (TDS), and electrical conductivity (EC) was measured in field by using a pH meter and electrochemical analyzer (Hac-44600-00, Loveland, USA). The samples for PHMs detection like As, Fe, Mn, Zn, Pb, Cu, were acidified with 3% HNO_3 to adjust the pH of the samples to less than 2, and kept in ice-box then instantly shifted to laboratory for further analysis. The concentration of PHMs were measured by Inductively Coupled Plasma Mass Spectrometry (ICPMS Agilent 7500-USA).

2.4. Quality assurance and quality control

Regular quality control checks, standards operating protocols, reagent blanks, standard calibration, and duplicate analyses were used to achieve accuracy and precision in the results of analytical data conferring to [21]. The reagents used for the analysis were bought from Germany (Merck Company). To eliminate the contaminants, all glassware was carefully cleaned with deionized water and a 30 percent HCl solution. Glassware was oven-dried after being washed.

After six samples, reagent blanks were used to monitor and examine contamination, with the concentration of the blank being subtracted from the groundwater concentration. As previously stated, PHMs were examined using an ICPMS (Agilent7500ICP-MS).

2.5. Face to face interview

In the study area questioner survey was conducted with the help of environmental experts and health workers following [22]. The head of expert team asked several questions concerning their age, profession, ingestion of drinking groundwater sources, education, source of income, and health status. After detail interview from inhabitants in the study area it was concluded that the most of them belong to poor families and can’t afford to buy mineral water and used groundwater sources for ingestion motive. Most of the peoples were affected from the ingestion of polluted groundwater with PHMs. The commonly reported ailments in the study area was hair loss, lung cancer, bladder, liver, and neuronal damages. To record the toxicity level of PHMs in drinking groundwater human health risk assessment was performed.

2.6. Human health risk assessment

Humans were exposed through three different routes: oral consumption, skin contact, and inhalation. Oral intake is still the most vulnerable among these three pathways. This study calculated PHMs exposure through oral ingestion using chronic daily intake (CDI Ingestion), Hazard Quotient (HQ Ingestion), and Hazard Index (HI Ingestion) formulas. These formulas aid in calculating and assessing the exposure level and ingestion rate (IR) of PHMs through groundwater consumption. Human health risk assessment was calculated using equations developed by the USEPA followed by [23].

$$\text{CDI}_{\text{ingestion}} = \frac{CPHMs \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

$$\text{HQ}_{\text{ingestion}} = \frac{CDI_{ingestion}}{RfD_{ingestion}} \quad (2)$$

$$CR = \text{CDI} \times \text{CSF} \quad 3)$$

Here in equations C_{PHMs} represents concentration of potentially harmful metals (mg/L), IR=ingestion rate (2L/day for adult and 1 L/day for children), EF=exposure frequency (365 days/year), ED=exposure duration 350 days, BW= body weight (72 kg for adult and 32 kg for children), AT= averaging time (72×365 days). Here CR represents cancer risk, CSF represent cancer slope factor for each metal following [24].

2.7. Statistical analysis

Statistical analysis plays a vital role for understanding the data set by representing various operations[25]. Descriptive statistics, such as mean, minimum, maximum, Principal component analysis, Pearson correlation matrix, Quantile-Quantile (Q-Q) plotting was calculated over SPSS software (Armonk, NY, USA). Mineral phases of groundwater sources were calculated through geochemical modeling program PHREEQC (version 3.1) for determination of tendency of groundwater dissolved minerals. Study area map was built over ARC-GIS software.

Rsults

3.1. Geochemical composition of groundwater

Table 1 shows the geochemistry of groundwater variables of samples (n = 243) collected from the study area. The pH value in groundwater samples were varied from 7.6–8.3 with an average value of 7.86 and was found in WHO recommended values indicates slightly alkaline nature of groundwater sources. Being as key water quality parameter pH determination is compulsory due to its vital role in water chemistry, alkalinity, solubility of groundwater variables [26]. The value of total dissolved solids (TDS) were recorded ranging from 209–3116 mg/L with mean value of 500 mg/L and were found in acceptable limit of WHO. The elevated value of TDS in groundwater sources is due to ion dissolution, which might be credited to progressively depleting salts and minerals over time [24]. The electrical conductivity (EC) value in groundwater samples were ranged from 249–865μs/cm having an average value of 511.23 μs/cm. The high (EC) water samples indicate aquifer constituent leakage or suspension, as well as other sources such as saline water bodies[11]. As concentration in groundwater samples varied from 1.04–92.30 μg/L with an average value of 39.49μg/L, 91% samples were recorded beyond the recommended value of 10μg/L recommended by WHO. The presence of high arsenic in drinking groundwater is a direct result of anthropogenic and geogenic sources, and it has been identified as a severe environmental concern. As can also be released into groundwater due to high salinity, alkalinity, and anoxic conditions [27]. Geogenic As pollution of groundwater is more widespread in alluvial aquifers. Gravel, sandstone, silt, and sand that have been in a river canal or food plain for a long time make up these aquifers [28]. In comparison to other areas of Punjab, Pakistan, the study area has a high concentration of arsenic, which could have negative health consequences for its residents. The concentration of Mn in groundwater samples ranging from 0.01–0.90 mg/L with an average value of 0.19 mg/L, 15% samples were beyond the permitted limit recommended by WHO. Mn is a naturally occurring mineral that is one of the most numerous metals on the planet's surface, in air, water, and soil. It can be found in natural sources of groundwater and surface water, as well as human activity such as mining and industrial wastes [29]. Mn is also utilized in a variety of sectors, including iron and steel alloys, batteries, glass, fireworks, cleaning supplies, fertilizers, varnish, fungicides, cosmetics, and livestock feed additions [30]. The Pb concentration in groundwater samples were in the range of 0.01–0.40 mg/L having an average value of 0.05 mg/L. Among (n = 243) groundwater samples 97% samples were beyond the permitted limit of WHO. Lead (Pb) can be found at varied degrees of solubility in rocks and mineral deposits. The elevated (Pb) concentrations in groundwater can result from the leaching of such rocks and minerals [28]. The concentration of Zn in groundwater samples ranges from 0.01-4 mg/L having a mean value of 1.07 mg/L, 15% samples were beyond the recommended value of WHO. The majority of zinc is introduced into water by artificial channels, such as by-products of steel manufacture or coal-fired power plants, or waste material combustion. Some fertilizers include zinc, which can seep into groundwater [31]. The concentration of Cu varied from 0.01–1.9 mg/L with an average value of 0.41 mg/L and all of the sample were in acceptable guidelines of WHO. The factors which may lead the elevated concentration of Cu in groundwater sources are corrosion of residential plumbing, faucets, and water fixtures. Copper leaches from plumbing materials including pipes, fittings, and brass faucets and is absorbed by water [21]. The concentration of Ni in groundwater samples were recorded ranges from 0.01–0.7 with an average value of 0.03 mg/L, and all of the samples were in WHO recommended guideline value. The prime cause of Ni in groundwater is leaching from metals in contact with drinking-water, such as pipes and fittings. Nickel, on the other hand, may be present in some groundwater sources due to dissolution from nickel ore-bearing rocks [32]. The Fe concentration in groundwater samples was detected ranges from 0.04–0.70 mg/L with an average value of 0.26 mg/L, among (n = 243) 45% samples were beyond the permitted limit recommended by WHO. Iron is the second most abundant metallic element in the earth's crust, while it has a low concentration in water. Whenever rainwater seeps, percolates, and flows down the soil and rocks, dissolved iron from the soil and rock formations dissolves in the groundwater [33]. The results of this research were compared with the study of [4] conducted in Vehari, Punjab, Pakistan and the comparison shows similarity with the above-mentioned research work.

3.2. Principal component analysis

To explore the association between groundwater variables, a principal component analysis (PCA) approach was employed to evaluate all of the geochemical processes occurring in the research area.

A total of five principal components were achieved for (n = 243) samples, such as PC1, PC2, PC3, PC4, and PC5, respectively with eigenvalues of 1.483, 1.321, 1.186, 1.028, and 0.998 respectively. A variability for each factor were calculated to be 14.826%, 13.207%, 11.86%, 10.285%, and 9.977% respectively with total variance of 60.54%.

PC1 was counted with 14.826% variability having an eigenvalue of 1.483 and shows strong and moderate loading for pH, TDS, EC, and Fe and their numerical values were calculated to be 0.723, 0.564, 0.577, respectively. PC1 suggested that geogenic input has a significant impact on groundwater physicochemical variables, and that pH and TDS play an important role in the saturation of water variables in this study [34]. PC2 was calculated with variability of 13.207% having an eigenvalue 1.321 which shows strong loading for Mn and Ni, their numerical values are 0.608, and 0.645 respectively. Manganese (Mn) is an element that can be found naturally in rocks and soil, as well as in subsurface pollution sources. Manganese is rarely found in a water source on its own. It's common in iron-bearing streams, but it's less common than iron. The primary source of nickel (Ni) are ore-bearing rocks, which can contribute pollution of Ni in groundwater sources [35]. PC2 also reflect for geogenic source of contamination in groundwater. PC3 was counted with variability of 11.86% with eigenvalue of 1.186 and shows strong negative loading for As and Pb having a loading value of -0.683 and − 0.515 respectively. The negative values of these two variables shows that they have no direct effect on each other. Arsenic (As) can enter groundwater and drinking water from a variety of natural sources as well as manmade acts. Geologic formations (e.g., sedimentary deposits/rocks, volcanic rocks and soils), geothermal activity, coal, and volcanic activities are all key natural sources. Anthropogenic activities such as mining, burning of fossil fuels, use of arsenical fungicides, herbicides, and insecticides in agriculture, and the use of wood preservatives are the main anthropogenic sources of As pollution of groundwater. Coal combustion has a significant impact on As pollution in the environment [36]. The origin of Pb in shallow groundwater systems may contain naturally occurring ores rich in various pollutants, which seep into waterbodies and pollute them. Groundwater contamination with high Pb levels has been related to these ores. Moreover, mining and smelting of ore, manufacturing of lead-containing products, coal and oil burning, and waste incineration are all anthropogenic sources of lead [37]. PC3 shows mixed type of contaminant which may contaminate groundwater sources. PC4 shows variability of 10.285% with eigenvalue 1.028 and shows strong loading for TDS and Pb with values of 0.511 and 0.640 respectively. Natural sources, sewage, urban and agricultural run-off, and industries of lead manufacturing products, wastewater all contribute to TDS and Pb in water systems. Salts used for de-icing roads can potentially contribute to TDS levels in water supplies [38]. PC4 shows mixed type of source that the aquifers of the study area are contaminated due to geogenic and anthropogenic actions. PC5 was counted with variability of 9.997% with eigenvalue 0.998 which shows strong negative loading for EC and positive for Cu and their values are − 0.522, 0.555, respectively, suggesting that these two variables had not direct effect on each other. The high electrical conductivity (EC) in groundwater sources is due conductive ions come from dissolved salts, and inorganic substances such as sulfides, chloride, and carbonate compounds, while copper (Cu) levels in surface and groundwater are typically relatively low. Copper contamination can occur in the environment as a result of mining, farming, manufacturing, and municipal or industrial effluent [39]. PC5 reflect for mixed type due to geogenic and anthropogenic source of contamination. As shown in Fig. 2 principal component analysis (PCA) results with total variability of (60.154%) reveal that the groundwater sources of the study area are contaminated due to (30.9%) geogenic sources, (31.3%) anthropogenic sources, and (37.6%) of mixed type including both geogenic and anthropogenic source of contamination.

3.3. Mineral phases of PHMs in groundwater

Saturation data is being used to estimate subsurface minerals. As shown in Fig. 3 the results of mineral phases for groundwater samples, such minerals include, hausmannite, zinc hydroxide, pyrochroite, lead hydroxide, goethite, pyrolusite, respectively. The Si value for hausmannite, zinc hydroxide, and pyrochroite were found in the range of (-7.6941 − 3.5589), (-1.3947 − 2.3741), and (-5.1547−-1.8704), and their mean values were recorded to be (-2.856880), (0.713146), and (-3.718981), respectively. The SI value for lead hydroxide, pyrolusite, and goethite, were found in the range of (1.7007 − 3.8798), (-8.1348−-3.4504), and (9.2632−10.1506), and their mean values were recorded to be (2.446345), (-6.168955), and (9.3142), respectively. The saturation indices result of mineral phases shows that the groundwater sources of the study area were saturated for goethite, lead hydroxide, and zinc hydroxide minerals, which indicates that these minerals had a significant role in the contamination of groundwater sources of the study area.

3.4 Quantile-Quantile (Q-Q) plotting

To obtain the outcome of Q-Q plotting, groundwater data for selected elemental composition were plotted in SPSS program. It's a graphical method for showing data from the first data set quantiles against the second data set. The expected normal values were shown in the first data set, whereas the observed values were shown in the second data set. At a 45° reference line, both values are sorted up and down in the form of scatter plot. The standard distribution outline is revealed by the values of quantiles, which can be found in a straight diagonal line. Figure 4 shows the Q-Q plotting result for selected groundwater variables. The quantiles R^2 values for As, Mn, Zn, Cu, Ni, and Fe in the normal Q-Q box plots were found to be (0.971), (1), (0.989), (0.991), (1), and (1), respectively.

3.5. Human health risk exposure assessment

For the purpose of estimating risk exposure in the research region, a human health risk exposure survey was done. In the study area, the research team visited several groups of people, including youngsters (1–16 years old) and adults (17–55 years old). The majority of the population, or 70% of local respondents, believe that the study area's industrial and commercial activities are to blame for the contamination of the groundwater and the study area's health situation. In the study area the common reported disorders were, irritability, constipation, sleep disorders, hearing loss, exhaustion, cramps, gastrointestinal disease, neurological damage, learning difficulties, low appetite, stunted growth, organ failure, flu, vomiting, coma, and convulsions were among the most prevalent diseases. The effects of PHMs in groundwater were examined in terms of chronic daily intake (CDI), Hazard Quotient (HQ), and Cancer Risk (CR), to better comprehend the exact environmental guidelines and increased health frustrates for the local people. In this investigation, CDI, HQ, and CR via oral ingestion route for two groups of populations, children and adults, were computed following USEPA criteria, and the findings are shown in Table 4. As a result of groundwater consumption, the majority of persons in the research region were highly exposed to PHMs.

As shown in Table 3 the average CDI value of As, Mn, Pb, Zn, Cu, Ni, and Fe, for children were calculated to be 4.73E-04, 2.35E-06, 5.76E-07, 1.29E-05, 4.96E-06, 3.59E-07, and 3.10E-06 respectively. Similarly, the average CDI value of As, Mn, Pb, Zn, Cu, Ni, and Fe, for adults were counted to be 6.01E-05, 2.98E-07, 7.31E-08, 1.63E-06, 6.3E-07, 4.55E-08, and 3.94E-07 respectively. The average non-carcinogenic risk of As, Mn, Pb, Zn, Cu, and Ni, for children were calculated to be 1.58E + 00, 1.68E-05, 3.61E-14, 4.28E-08, 1.34E-04, and 1.79E-05 respectively. Likewise, the non-carcinogenic value of the abovementioned PHMs for adults were calculated and their values are 2.00E-01, 2.13E-06, 2.09E-05, 5.44E-09, 1.70E-05, and 2.28E-06, respectively. The average carcinogenic-risk of As, Pb, and Ni for children were calculated and their values were found to be 3.16E-04, 1.48E-14, and 2.11E-07, respectively. Similarly, the average carcinogenic risk of As, Pb, and Ni, for adults were found to be 4.01E-05, 8.61E-06, and 2.68E-08, respectively as shown in Table 4, thus it was noticed from the result that PHMs in groundwater sources of the study area has an adverse effect on the population of the study area. The result of this study was compared with the study conducted by [37] and [40], the comparison showed that the results of this research was similar to the above mentioned research work.

Conclusion

This research looks at the prevalence and abundance of PHMs in Sheikhupura's groundwater sources. As of their increased concentrations, bioavailability, and stability, PHMs such as As, Pb, and Fe have been shown to be inappropriate for drinking and domestic use in the studied region. The increasing order of PHMs in groundwater sources was observed to be Pb > As > Fe > Zn > Mn > Cu > Ni. According to WHO guidelines value PHMs such as As (91%), Mn (14%), Pb (97%), Fe (45%), Zn (15%), Cu (0%), and Ni (0%), samples were beyond the permitted limit. Saturation indices results shows that the aquifers of the study area are saturated for lead hydroxide, zinc hydroxide, and goethite minerals, indicating that these minerals have a vital role in the contamination of groundwater sources of the study area. Principal component analysis (PCA) results with total variability of (60.154%) reveal that the groundwater sources of the study area are contaminated due to (30.9%) geogenic sources, (31.3%) anthropogenic sources, and

(37.6%) of mixed type including both geogenic and anthropogenic sources. Health risk exposure assessment results predicted potential health risk on the population of the study area. The study's findings highlighted the significance of using proper methods to remediate groundwater before it is used for drinking. Furthermore, various public awareness campaigns in the study area must be implemented as soon as possible to raise public awareness of the contamination of drinking groundwater, as well as the health risks linked with it.

Declarations

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Zahid Ullah], [Junaid Ghani], [Abdur Rashid,], [Asmat Ali], [Javed Iqbal], [Hamad Ur Rehman], The first draft of the manuscript was written by [Zahid Ullah] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Competent interest

The authors have no relevant financial or non-financial interests to disclose.

Funding

Not applicable

Data Availability

The data will be provided on request to corresponding author.

Ethics approval

Not applicable

Consent to participate

All authors reviewed and approved the final manuscript.

Consent to publish

All authors approved this for publication.

Acknowledgment

The authors would like to acknowledge Pakistan Council for Research on Water Resources for sample analysis and materials support.

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Tables

Table 1 Descriptive statistics of selected parameters in groundwater samples (n=243) collected from the study area

Parameters	Minimum	Maximum	Mean	SD	% Fit	% Unfit	WHO
pH	7.60	8.30	7.86	0.19	100	0	6.5–8.5
TDS mg/L	209.00	3116.00	500.15	279.66	100	0	1000
EC µs/cm	249.00	865.00	511.23	157.37	100	0	1000
As µg/L	1.04	92.30	39.49	20.31	9	91	10
Mn mg/L	0.01	0.90	0.19	0.24	85	15	0.50
Pb mg/L	0.01	0.40	0.05	0.08	3	97	0.05
Zn mg/L	0.01	4.00	1.07	1.06	83	17	3
Cu mg/L	0.01	1.90	0.41	0.52	100	0	2.0
Ni mg/L	0.01	0.70	0.03	0.07	100	0	0.07
Fe mg/L	0.04	0.70	0.26	0.15	56	44	0.30

Table 2 Principal component analysis of groundwater samples collected from the study area

Parameters	PC1	PC2	PC3	PC4	PC5
pH	**0.723**	-0.125	0.354	0.127	-0.076
TDS	**0.564**	0.004	0.191	**0.511**	-0.342
EC	**0.577**	0.193	-0.039	-0.222	**0.522**
As	0.135	0.382	**-0.683**	-0.031	0.008
Mn	-0.159	**0.608**	0.426	0.219	-0.206
Pb	-0.085	-0.113	**-0.515**	**0.640**	-0.089
Zn	0.159	0.273	0.081	0.395	0.486
Cu	0.010	-0.336	0.224	0.333	**0.555**
Ni	0.037	**0.645**	0.165	-0.063	0.045
Fe	**0.501**	0.367	-0.158	0.146	0.078
Eigenvalues	1.483	1.321	1.186	1.028	0.998
Variability %	14.826	13.207	11.86	10.285	9.977
Cumulative %	14.826	28.033	39.893	50.178	60.154

Table 3 Non-carcinogenic and carcinogenic risk of selected parameters

		As	Mn	Pb	Zn	Cu	Ni	Fe
CDI								
Ingestion	Children	4.73E-04	2.35E-06	5.76E-07	1.29E-05	4.96E-06	3.59E-07	3.10E-06
	Adults	6.01E-05	2.98E-07	7.31E-08	1.63E-06	6.3E-07	4.55E-08	3.94E-07
Non-carcinogenic risk								
Ingestion	Children	1.58E+00	1.68E-05	3.61E-14	4.28E-08	1.34E-04	1.79E-05	–
	Adults	2.00E-01	2.13E-06	2.09E-05	5.44E-09	1.70E-05	2.28E-06	–
Carcinogenic risk								
Ingestion	Children	3.16E-04	–	1.48E-14	–	–	2.11E-07	–
	Adults	4.01E-05	–	8.61E-06	–	–	2.68E-08	–

Table 4 is not available with this version.

Figures

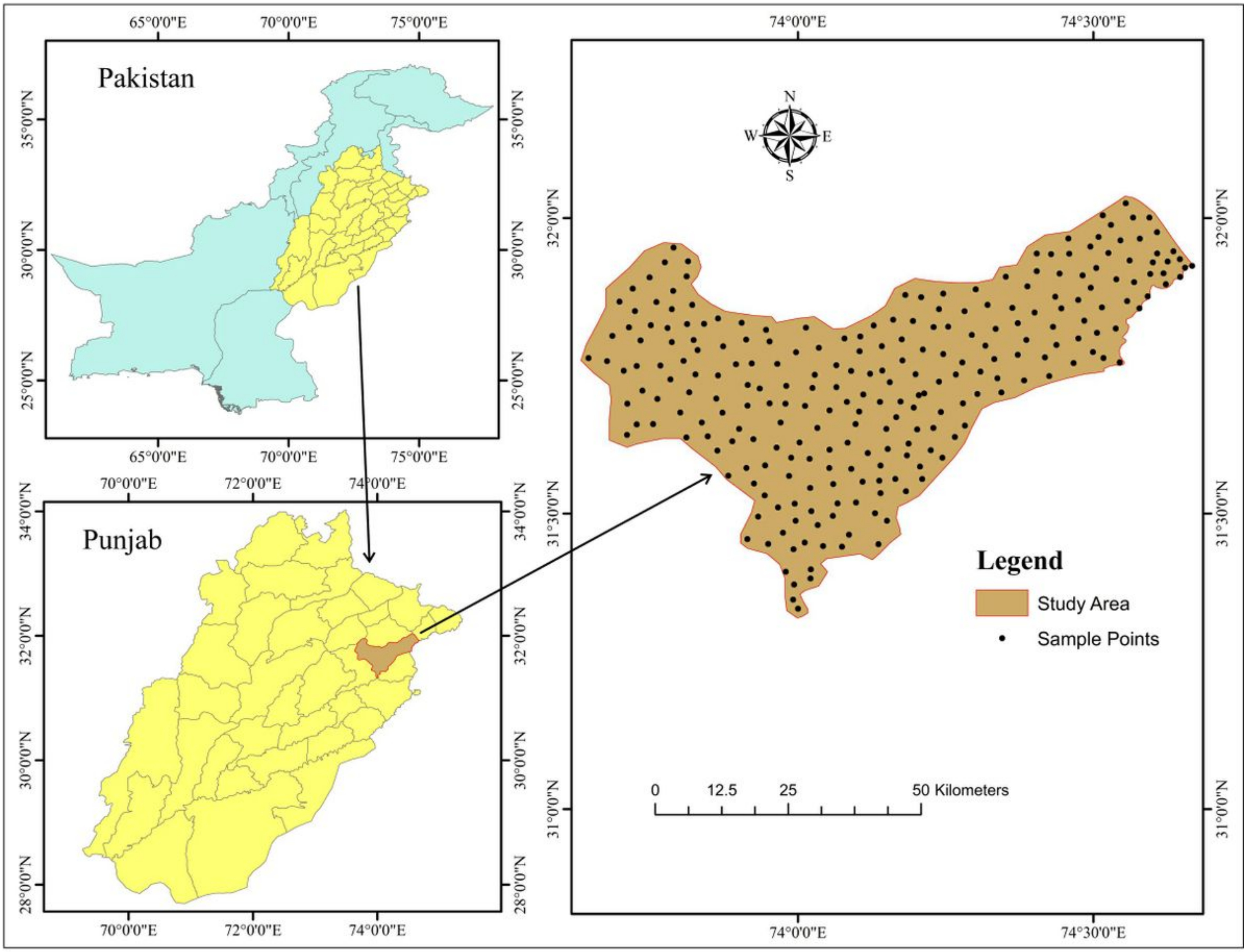

Figure 1

shows study area and sampling stations

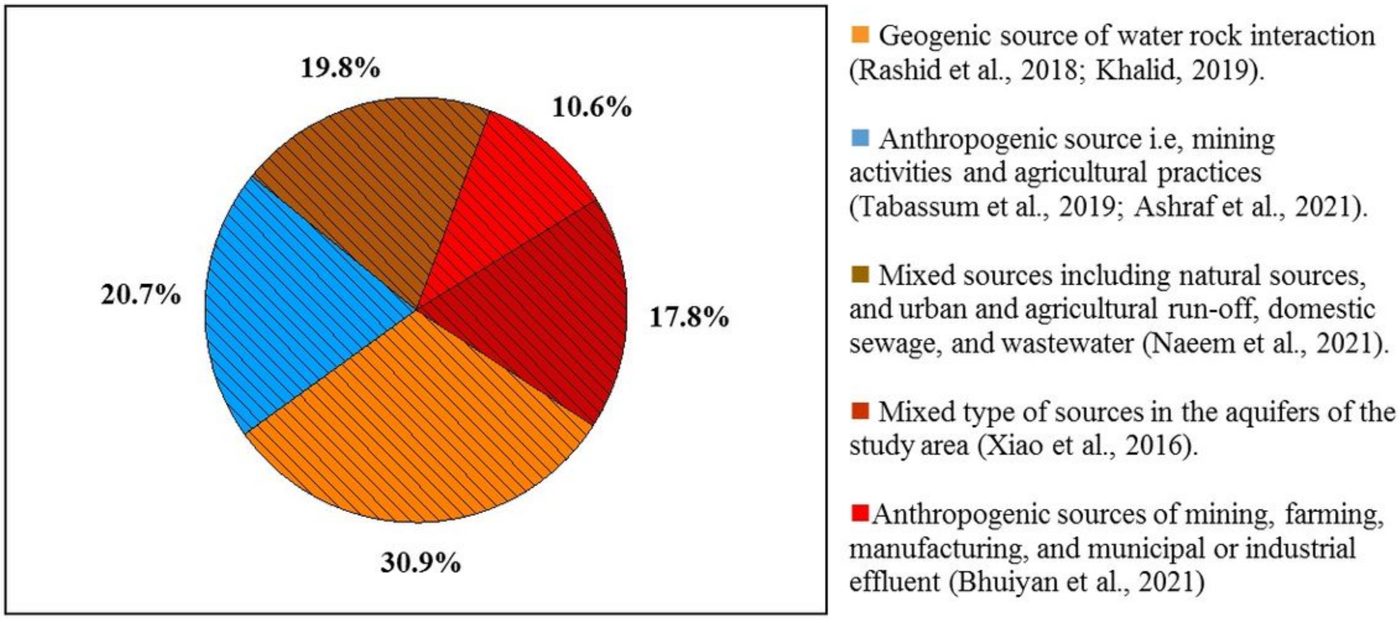

Figure 2

Contributions of pollution sources (%) in the groundwater of the study area

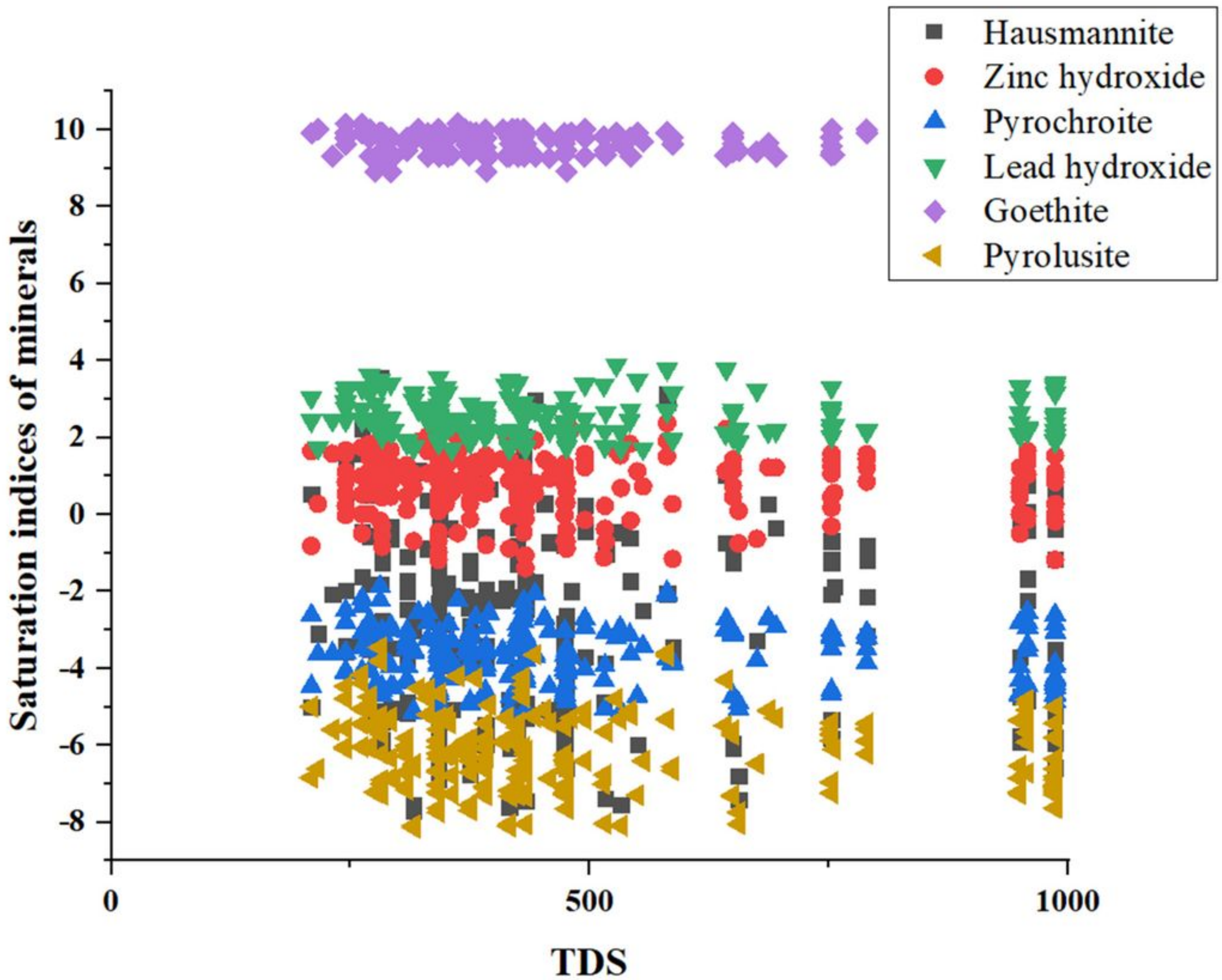

Figure 3

shows saturation of mineral phases in groundwater of the study area

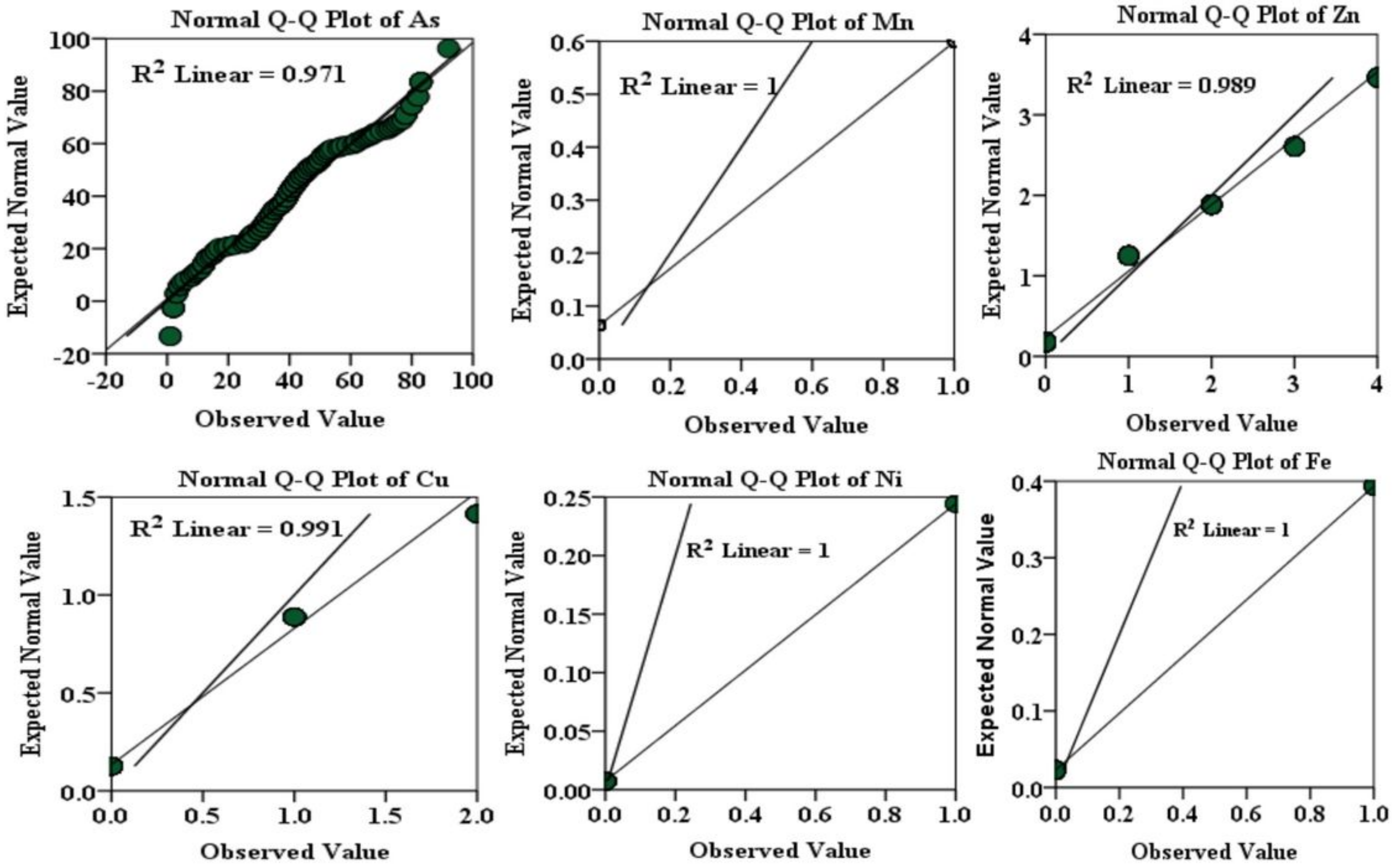

Figure 4

Quantile-Quantile (Q-Q) plotting shows distribution of the groundwater variables