Hydrochemical Characteristics of Groundwater for Drinking Purpose and Health Risk Assessment

Muhammad Ali[1*], Walaa F. Alsanie[2,3], Abdulhakeem S. Alamri[2,3], Majid Alhomrani[2,3], Wael S. Al-Rashed[4], Fahad Al-Asmari[5], Tolga İzgü[6], Özhan Şimşek[7], Sheikh Safeena Sidiq[8]

[1]*Institute of Agro-Industry & Environment, The Islamia University of Bahawalpur, 63100, Pakistan*

[2]*Department of Clinical Laboratory Sciences, The faculty of Applied Medical Sciences, Taif University, Taif, Saudi Arabia.*

[3]*Research Centre for Health Sciences, Taif University, Saudi Arabia*

[4]*Department of Civil Engineering, Faculty of Engineering, University of Tabuk P.O. Box 741, Tabuk 71491*

[5]*Department of Food and Nutrition Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia*

[6]*Institute for BioEconomy (IBE), National Research Council (CNR), 50019 Sesto Fiorentino, Florence, Italy*

[7]*Horticulture Department, Agriculture Faculty, Erciyes University, Kayseri 38030, Türkiye*

[8]*Women Health Care Center and Maternity Home, The Islamia University of Bahawalpur*

Corresponding email: muhammadali@iub.edu.pk

Abstract

Urbanization and industrialization in many parts of the world contaminate ground and surface water resources. The present study is designed to investigate the hydrochemical characteristics, spatial distribution of major cations/anions, heavy metal pollution and associated health risk assessment of groundwater. In total 30 groundwater samples were taken from different urban localities of Multan, suggesting an elevated level of EC and TDS. Major cations and anions except SO_4^{2-} and HCO_3^- in one area were below World Health Organization (WHO) guidelines for drinking purpose. Hydrochemical results also indicates groundwater pollution is attributed to rock-water interaction. Medium to low microbial concentration was also noted in groundwater by seepage of sewage water. Elevated heavy metal concentration (As, Cd, Cr & Fe) was recorded in most of the sampled groundwater. Piper plot indicates mixed water type with Na^+/K^+ and Na^+/HCO_3^- type. Water Quality Index (WQI) and Heavy metal Pollution Index (HPI) ranked

groundwater of Multan from very poor to hazardous posing health hazards. Total hazard quotient value by ingesting groundwater exceeds non-carcinogenic threshold HQ = 1.0 in half of groundwater samples. Potential cancer risk was obtained for children in selected areas. Therefore, an effective management and monitoring system is applied in study area to safeguard the local community from potential illness. Major response action require to restore groundwater quality is to cut off contamination sources such as industrial effluents, fertilizers and pesticides application. Installing water treatment plants in study area to reduce cancer risk for local community is an effective and tangible solution.

Key words: Hydrochemical, Water quality, Heavy metals, Non-carcinogenic, Cancer risk

Introduction

Water is fundamental compound essential to living organisms (Al-Rashed, 2024, 2025). Only 3% fresh water is available of which 67% is stored in glaciers, 30% in ground and 3% on surface (Ofosu et al. 2021; Hosseininia and Hassanzadeh, 2023). Groundwater is an important resource as one third population around the globe rely on it for drinking, domestic and irrigation purposes (Piyathilake et al., 2022). Only in South Asia around one billion people rely on groundwater to fulfill basic necessities (Adimalla et al. 2018). For decades, demand of fresh water resource is increasing for drinking purpose which otherwise polluted due to industrial effluents and sewage water. Therefore, groundwater quality is of great importance as is easy to pull up and access contamination (Adimalla et al. 2018a). Various researchers extensively investigated the groundwater quality for human consumption, domestic and irrigation purposes. Adimalla, (2019) did an extensive study in groundwater of South India with arid to semi-arid conditions and reported the potential health concern related to drinking poor quality of groundwater. Similarly, Ayadi et al. (2018) investigate the groundwater of Tunisia and found that weathering of rocks influence groundwater quality.

Presence of heavy metals in groundwater poses significant environmental concern. Toxic nature of heavy metal, persistence in the environment made them suitable candidate to persist in living organisms for years which poses health risk including skeletal, cardiovascular and infertility (Ali et al. 2023). Limited movement of water within the ground aquifer made the situation even worse and groundwater become contaminated over the period of time. Nitrate, fluoride, chloride and iron are also widely accepted ions which contaminate the groundwater with potential to risk public health in Southern Punjab (Iqbal et al. 2023).

Public health standard for a community largely relies on availability of pure drinking water. Potable groundwater is safe to drink without any health related concerns (Hossain et al. 2024). Safe groundwater for drinking purpose is scarce in developing countries like Pakistan which might be responsible for lot of diseases. Drinking contaminate water in developing countries is accountable for more than 80% of water borne diseases which ultimately leads to death (Xiao et al. 2022). Quality of groundwater is important for public health as ingesting tainted water could causes serious illness due to transmission of diseases throughout the world.

Groundwater contamination poses various health related challenges in various areas of Punjab, Pakistan. Toxic metals persistence in poorly urbanize and industrial cities of Punjab is of serious health concern according to the surveys and findings of Pakistan Council for Research in Water Resources (PCRWR). Previous research also provides preliminary estimates of groundwater quality in different areas of Punjab however water characterization associated with different factors to influence water quality has not been fully investigated. Under such prevailing conditions this study is designed with an aim to evaluate groundwater quality of Multan city for drinking purpose with predication of water quality index (WQI) and health risk assessment. Results from this study give essential insights for quality of groundwater quality with special reference to health risk in study area.

Material and method

Study area

Multan city (30.1864º N 71.4886º E) with an area of 3721 km^2, home to 2.2 million people is the 6th largest city of Pakistan. It is an ancient city along Chenab river in Southern Punjab with arid to semi-arid climatic conditions. Groundwater aquifer of Multan is not recharge for years as water is not flown except for the monsoon season where river flow is considerably high. Mean annual rainfall is between 175 and 86 mm is less enough to recharge groundwater aquifers therefore groundwater aquifers are present at the depth 25 and 40 meters. Although soil is sandy loam in nature but less rainfall doesn't recharge groundwater aquifers. Sediments of salt containing rocks were deposited in the alluvial plans of Multan by Chenab river for thousands of years ago therefore groundwater hydrological characteristics were largely depends upon geological changes. Mean annual temperature is 25.6 ºC. Therefore groundwater quality is poor for safe water consumption. Since Multan city is an urban area surrounded by industries therefore it is important to assess the health risk in terms of carcinogenic and cancer risk which haven't been done in recent past. Current work is novel in its type that it comprises water quality indices along with health risk assessment whereas pervious researcher only focuses on the groundwater quality with special reference to calculate salts, cations and anions as limiting factor. Moreover previous research were designed to only assess arsenic which is in abundant in the area with limited scope i.e., in city center or in a school while current work established a way by assessing other heavy metals including cadmium, chromium and iron not in city but also in city suburban's (Gul et al. 2020; Mahar et al. 2024).

Groundwater sampling

Thirty groundwater samples were collected from six different locations (Five samples from each area) on the basis of population density and water consumption of Multan city. Water sample was taken in a pattern that each sampling point is in the range of 500 meters in specific coordinates. Borehole electric pump with the depth between 25 and 40 meters was running for 5 minutes prior to sampling for homogeneity. Groundwater temperature, pH and electrical conductivity were recorded at the time of sampling. 1 liter groundwater sample was stored in pre-sterilized polythene container to assess the physicochemical properties, heavy metal and pathogenic microbial concentration. Coordinates of the water sampling site was also recorded at the time of sampling by using Global Positioning System (GPS) is shown in figure 1.

Groundwater quality assessment

Groundwater samples collected from different locations of Multan were analyzed for temperature from mercury thermometer, pH is noted by dipping glass electrode pH meter in water sample (Model: Mi-1700), Electrical conductivity of water sample was noted by dipping pre-calibrated EC meter (3100C) with KCL solution. Total dissolved solids (TDS) in the solution was determined by using following equation

$$\mathrm{TDS} = \mathrm{EC\ dS\ cm^{-1}} \times 650 \quad (1)$$

Groundwater hardness was determined in terms of calcium carbonates by forming complexes with calcium and magnesium ions through EDTA titration method. Calcium and magnesium was determined by treated with buffer solution and erichorme black until color changes from red to blue end point. Sodium and potassium was noted by flame photometer (Model: BWB technologies) by adapting standard protocol used for waste water evaluation (Rice et al. 2012). HCO_3^- was determined by titrimetric method by adding few drops of methyl orange indicator and titrated against 0.1 N H_2SO_4 while chloride ion concentration is noted by adding potassium chromate solution into water sample and titrated against 0.05 N $AgNO_3$ solution. NO_3^- is noted by cadmium reduction method and running the sample on UV-vis spectrophotometer at 540 nm. Similarly, F^- is also noted by colorimetric method by mixing SPADNS regent with water sample and subsequently run it on spectrophotometer (Model: CE7400S) at 570 nm. All physic-chemical parameters were done according to the protocol by American Public Health Association (APHA) (Greenberg et al. 2005). Microbial concentration in water sample was determined by filtering 100 ml of water through membrane having mesh size of 0.45 μm and subsequently incubate on selective media for 48 hrs at 37º C. Pathogenic bacterial colonies were counted by colony counter and expressed as colony per 100 ml of water (Forbes et al. 2007). Water quality index from the selected site was determined by computing parameters into equation;

$$\mathrm{WQI} = \sum_{i=1}^{n} \mathrm{Qi} \quad (2)$$

Where; n is the number of samples, i is parameter range and Qi is relative measure of water specific to each parameter.

All groundwater samples were analyzed for heavy metals. Among all arsenic was determined by molybdenum blue method as As (V) which reacts with ammonium molybdate under acidic condition to form arsenomolybdic acid. Thereafter, this complex was turned into molybdenum blue complex which then run into UV-vis spectrophotometer at 870 nm. Cd, Cr & Fe were detected in groundwater samples after digesting it in HNO_3 in digestion tubes until the sample become colorless and run it in Atomic Absorption Spectrophotometer (ASS) (Model: Shimadzu 7000F) at wavelength of 228 nm, 357 nm and 248 nm, respectively. Heavy metal pollution index (HPI) was calculated by using following formula;

$$\mathrm{HPI} = \frac{\sum_{i=1}^{n} \mathrm{WiQi}}{\sum_{i=1}^{n} \mathrm{Wi}} \quad (3)$$

Where; n is the number of samples to be analyzed, Qi is sub-index of ith parameter and Wi is ith unit parameter weight. Qi for HPI was calculated by using following equation;

$$\mathrm{Qi} = \sum_{i=1}^{n} \frac{\mathrm{Mi} - \mathrm{li}}{\mathrm{Si} - \mathrm{li}} \times 100 \quad (4)$$

Where; Mi is the concentration of ith metal, li is the ideal value and Si is the maximum value of ith metal.

Health risk assessment

Drinking poor/contaminated water for long time significantly affect human health by causing different diseases. Non-carcinogenic risk from ingesting contaminated drinking water is calculated by following formula;

$$\mathrm{Intake}_{\mathrm{Oral}} = \frac{\mathrm{C} \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \quad (5)$$

$$\mathrm{HQ}_{\mathrm{Oral}} = \frac{\mathrm{Intake}_{\mathrm{Oral}}}{\mathrm{RfD}_{\mathrm{Oral}}} \quad (6)$$

Inputs are;

$\mathrm{Intake}_{\mathrm{Oral}}$ is daily intake of contaminant ($mg/kg/day^{-1}$)

C is pollutant concentration (mg/L)

IR is daily ingestion rate of water (1.5 L/day for adult and 0.52 L/day for child)

EF is exposure frequency (365 day/year)

ED is exposure duration (year); in current study 60 years for adult and 6 years for child according to USEPA (1989, Washington, USA)

BW is average weight (60 kg for an adult and 15 kg for child)

AT is average exposure time (ED×365)

HQ is Hazard Quotient, RfD_{Oral} is reference dose of contaminant ($mg/kg/day^{-1}$). RfD_{Oral} for As, Cd and Cr are 0.0003, 0.0005 and 0.003 mg kg^{-1} day^{-1}.

Life time cancer risk (CR) assessment was calculated according to the equation;

$$\text{Cancer risk}_{\text{Oral}} = \text{Intake}_{\text{Oral}} \times \text{SF} \tag{7}$$

SF is cancer slope factor for As is 1.5 and for Cr is 0.5 according to USEPA (1989).

Results

Physiochemical properties of groundwater samples

Table 1 exhibit physiochemical properties of groundwater samples collected from different locations of Multan city. pH, electrical conductivity and total dissolved solids are the basic parameters to identify the groundwater property and their concentration for drinking purpose strictly within the limits set by World Health Organization (WHO). pH in drinking water must be 6.5-8.5, EC <400 µS cm^{-1} and TDS <1000 mg L^{-1}. pH form selected sites were within limits with highest value of 7.76. EC ranges between 1493-2558 µS cm^{-1} and TDS is 1206 mg L^{-1} to 2501 mg L^{-1}. 33% sample were above 2000 µS cm^{-1} while remaining sample were within the range of 1493 µS cm^{-1} and 2000 µS cm^{-1}. Similar trend was noted for TDS where also 33% samples exceed 2000 mg L^{-1} limit while other exhibit moderate to high TDS concentration. However, water from all sampling sites is unfit for drinking purpose according to WHO limits. Hardness of water samples were also within in the range of 306-543 mg L^{-1} having water samples only from one site exceeds WHO limits (500 mg L).

Major cations (Na^+, Ca^{2+}, Mg^{2+} & K^+) and anions (HCO_3^-, SO_4^{2-}, Cl^-, NO_3^- & F^-) were also calculated given in table 2. All parameters in sampled water were under recommended range as per WHO except HCO_3^-, which concentration in one sample exceeds which suggest its unsuitability for drinking purpose. Mixed concentration of cations and anions were widely distributed in selected area and is not coupled to any single pollution causing source.

Total coliform and E. coli in groundwater sample was recorded from lower to medium range usually brought about by seepage of sewage water into ground aquifers. Increased Colony

Forming Unit (CFU) might cause disease however according to WHO zero CFU was present in water used for drinking purpose.

As, Cd, Cr and Fe are heavy metal found in groundwater sample indicating its origin from industries. Since heavy metal in groundwater is in large concentration therefore its consumption for long time is lethal to public health. Arsenic usually derived into water through increased Al and Mo after increased pH therefore its anthropogenic origin in groundwater is not neglected.

Major water type in groundwater aquifers of Multan

Major water type in sampling site is sodium/potassium and sodium/bicarbonate type as given in piper plot (Figure 2). Among cations dominant one is Na^+ while other were in the sequence of $K^+ > Ca^{2+} > Mg^{2+}$. Among anions dominant is HCO_3^- with sequence of remaining anion is $Cl^- > SO_4^{2-} > CO_3^-$. Samples in diamond and lower triangle exhibit mixed water type originate from single aquifer. All cations and anions were evenly distributed with no dominant water type.

Water Quality Index (WQI)

Water quality index is complete set of water quality indices to estimate for drinking suitability by using physiochemical and heavy metal. Water quality index is scaled from 0-100 where 0-25 is good groundwater quality, 26-50 is good, 51-75 is poor, 76 to and 100 is hazardous. Results suggest that all samples exceed hazardous limit (100%) making water harmful to consume (Figure 3).

Heavy Metal Pollution Index (HPI)

Similar to WQI, heavy metal pollution index describe the groundwater contamination due to overall concentration of metal (As, Cd, Cr & Fe) (Figure 4). HPI is also divided in different categories < 25 excellent, 26-50 good, 51-75 poor, 76-100 very poor and >100 is hazardous. Case study explains that HPI of all water samples were hazardous which upon drinking causes serious health hazards. Almost 50% groundwater samples exhibit increasing trend in heavy metal which mentions its anthropogenic origin from industries.

Principle Component Analysis (PCA)

A score plot was generated by using Principle Component Analysis (PCA) between two factors (PC_1: 29.92%) and (PC_2: 24.84%) as depicted in figure 5. PC_1 & PC_2 together exhibit variance of 54.76% having significant portion of variability. Shershah town and Shraif Pura in upper quadrant have highest EC, TDS, nitrates and hardness suggested that groundwater is mineralized by high level of pollutants. Suraj Miani and Tariq Abad in lower quadrant exhibit increase bicarbonate, Chromium, Arsenic and sulphate which suggests its less association with variables of PC_1 and PC_2. Liaqat Abad and Basti Baghbanpura are clustered in the center of score plot indicating average value of measured parameters. Na, Cd, F and coliform is associated to middle of score plot indicating its influence to middle centered clusters. PCA score plot also indicate that Shershah town and Suraj Miani is less prevalent to overall distributed parameters.

Person correlation matrix for groundwater samples

A person correlation matrix for physicochemical, microbial and heavy metals characteristics of collected groundwater from Multan is given in table 2. Positive correlation is determined between number of parameters in water samples like pH and Mg^{2+} (r = 0.81), EC and TDS (r = 0.86), EC and hardness (r = 0.74), TDS and hardness (r = 0.80), hardness and NO_3^- (r = 0.61), HCO_3^- and Mg^{2+}/As (r = 0.66), Cl^- and NO_3^- (r = 0.69), Na^+ and Cd (r = 0.68), As and Fe (r = 0.91). Matrix indicates type of correlation among water parameters and potential contaminants. Person correlation is important in sampling, analyzing and ranking groundwater quality to carry out sustainable management measures.

Human health risk assessment

Non-carcinogenic risk

Tables 3 (CDI) and 4 (HQ) encompasses the non-carcinogenic risk of heavy metal through oral exposure of two population groups i.e., adult and children. Calculated CDI for ingestion in adult and children is in the following order Cd > Cr > Fe > As. Hazard Quotient was noted by calculating exposure risk to reference dose. HQ <1 is regarded as non-carcinogenic while >1 is carcinogenic in terms of environmental and toxicological risk analysis. Mean HQ for adult and children is found in following order As > Cd > Cr > Fe. HQ suggests that all heavy metals are potential risk to health in study area especially for children.

Cancer risk

Cancer risk for arsenic and chromium through ingestion is given in table 5. WHO recommends safe limit of cancer risk is 1 in 1,000,000 lifetimes. Across all sites, Sharif Pura exhibit highest arsenic/chromium level making it most at risk location in terms of potential cancer development by ingesting groundwater. Both age groups have potential cancer risk but children with higher ingestion intake to body ratio made it vulnerable to toxins during body development.

Discussion

Poor groundwater quality significantly hinders the economic growth and development of an area since both are interconnected (Wang et al. 2025). This led to the development of innovative enterprises for construction technologies that minimize water use or use of gray water for building purpose (Shen et al. 2025). Sustainable water management therefore, for agriculture and human health is important in water scarcity and contamination (Raveena and Surendran, 2024; Surendran and Krishnan, 2024). Environmental assessment is important for quality living standard for wellbeing of local community and sustainable economy (Wen et al. 2025). Assessment of groundwater quality is important for drinking and domestic purposes. Groundwater is important source easily accessible to inhabitants in arid areas. Groundwater analysis revealed that pH of groundwater is natural to slightly alkaline. Presence of HCO_3^- is the single possible reason of alkaline nature of water samples due to weathering of carbonaceous rocks. Elevated electrical conductivity of water samples indicates presence of dissolved solids which exceeds the maximum permissible range of WHO (2011) guidelines. It was noted that TDS is evenly distributed in overall study area attributed to ion exchange between soil minerals and soil water giving increased TDS and EC (Kurakalva et al. 2021). Water hardness is due to calcium carbonate rocks covering groundwater aquifers which upon weathering add into water. In most cases water hardness is due to dissolved form of calcium and carbonate containing ions as described by Mohsin et al. (2013).

Among tested cations and anions only HCO_3^- gives increased value in one study area attributed to the increased fertilizer and household waste input. Weathering of carbonaceous rock is another possible reason behind elevated HCO_3^- level in water (Li et al. 2019). Among other anions SO_4^{2-}, Cl^-, F^- and NO_3^- was also detected in groundwater samples. NO_3^- detected in water samples due to intensive agricultural activates by which synthetic fertilizers seeps through soil profile. NO_3^- is also added to groundwater through sewage water, feces and dead decaying plants. FAO (2004) reported that use of fertilizers has been increases in Pakistan, Punjab is the major agricultural province thus increasing trend in NO_3^- is common scenario (Akhtar et al. 2021). Moderate level of SO_4^{2-}, Cl^- and F^- is also present indicating anthropogenic input through sewage and bio wastes. Moreover study area is present in arid to semi-arid thus water naturally flows from North to South West helps increase in SO_4^{2-} and Cl^- concentration. It is important to note that increased SO_4^{2-} concentration gives bitter taste to water (Arshad and Umar, 2022). Cation occurrence in groundwater is similar to that of anions where Ca^{2+} and Na^+ was added to soil through infiltration of soluble salts from irrigation water. K^+ is mostly fixed with clay minerals and released with slow process. Mg^{2+} also increases in groundwater through industrial effluents and leachate from landfills (Jehan et al. 2023).

Moderate level of Total coliform and E. coli was also noted. Enrichment of T. coliform does indicate presence of pathogenic microbes while E. coli present in large intestine of human body excrete out by feces. Consuming such water may cause fatal illness. Microbial concentration was found in heavily populated areas (Vendrell and Atiles, 2013).

Piper plot describes mixed water type largely influenced by water/rock interaction with low rainfall and increased evaporation in arid areas. This is largely due to associated carbonate rocks precipitation and dissolution with groundwater (Pei-Yue et al. 2010). Water Quality Index (WQI) was executed to check overall water quality indicating hazardous nature of sampled water. The water samples collected from all sites were affected by domestic and industrial waste. Previous water quality reports from PCRWR also indicate the similar issue. Addition of agricultural waste is also reported which contain pesticides also pollute groundwater quality. According to Venkatraman et al. (2024) groundwater quality was predicated by a novel technique by using optimization driven deep differential recur flow net which indicates water quality assessment up to 98%. Similarly in another work by Maruthi et al. (2025) a real time quality data prediction is made based on Internet of Things (IoT) sensors which helps in protecting water bodies from pollution. Similar to it score plot for Principle Component Analysis (PCA) indicates least hydrochemical concentration in Tariq Abad and Shershah Town giving relatively good water quality than others (Su et al. 2020).

Spatial distribution of trace metals (As, Cd, Cr & Fe) with varying concentration in study area was done to assess its enrichment. Arsenic enrichment in groundwater is attributed to the nearby presence of iron, aluminum and manganese which also increase pH (Sharma et al. 2022). Cadmium, chromium and iron in water sample is due to geogenic processes which was enhanced by anthropogenic activities mainly due to industrial effluents, fertilizers application and transportation of weathered material (Wang et al. 2020). High concentration of heavy metal is summarized by the Heavy metal Pollution Index (HPI) indicates hazardous nature of all selected samples. It was concluded that the presence of iron and manganese rocks near groundwater systems gives enhanced Cd, Cr and Fe concentration after weathering. Use of agrochemicals, pesticides and tanneries increase trace metals in soil as well as in water. It was determined that increasing use of agrochemicals in Punjab province increases the amount of heavy metals in groundwater used for drinking purpose (NFDC, 2016).

Public health of the community lies in successfully conducting environmental assessment vital for living standards and welfare of the community, while encouraging growth of sustainable businesses in the region (Shen et al. 2025). Non-carcinogenic risk associated with the studied metal exhibits an increasing HQ trend in all water samples for both age groups i.e., adult and children. $HQ > 1$ is carcinogenic while $HQ < 1$ is non-carcinogenic for human health. Our results revels $HQ > 1$ for arsenic in most water samples, which are consistent with the work of Alves et al. (2014), which suggests anthropogenic activities and use of herbicides is the main problems. On the other hand, cadmium, chromium, and iron are non-carcinogenic for adults, while potentially carcinogenic for children. Only reason behind exceeding the potential risk is increased water intake as the study area lies in an arid climatic condition with relatively high humidity thus the daily average intake also increased. Prolonged exposure to low concentrations of heavy metals could potentially increase risk of cancer. Our results regarding health risk are also supported by Wongsasuluk et al. (2014), which suggests a high consumption ratio of groundwater to body weight poses cancer risk after prolonged time. Our results followed the work of Cao et al. (2014) where high cancer risk is detrimental to human health.

Conclusion

Study was conducted to determine physiochemical characteristics and health risk exposure to heavy metal in groundwater of Multan, Punjab, Pakistan. Hydrochemical study exhibit that major cations and anions in study area influenced by rock-water interaction. Piper plot exhibit mixed water type of Na^+/K^+ and Na^+/HCO_3^-. Water Quality Index (WQI) and Heavy metal Pollution Index (HPI) exceeds hazardous limit poses danger to health if consumed for long time. Heavy metal distribution in the study area is in the order As > Fe > Cr > Cd. Person correlation matrix and Principal Component Analysis (PCA) were performed to check the geochemical nature of groundwater. Potential risk assessment in the study area is computed by carcinogenic and non-carcinogenic risk of groundwater ingestion. Mean Hazard Quotient (HQ) indicates that most of the samples exceed the potential non-carcinogenic threshold for both age groups, i.e., adults and children. Among all studied heavy metals, arsenic has the highest risk of cancer. The present study provides an insight into groundwater quality deteriorating through anthropogenic inputs and geochemical weathering, which have a potentially harmful effect on human health. Health risk assessment also clarifies that consuming groundwater for a long time may affect the health and daily lifestyle of a person. Therefore, protective measures should be adapted, including the prohibition of discharge of effluents from industries, protected discharge of domestic waste, lining of landfills, surface runoff from agricultural areas, along with the installation of water filtration plants to reduce heavy metal input into groundwater resources, especially in urban areas. All this was adapted by strict monitoring of water quality as per WHO standards.

Conflict of interest: The authors declare no conflict of interest.

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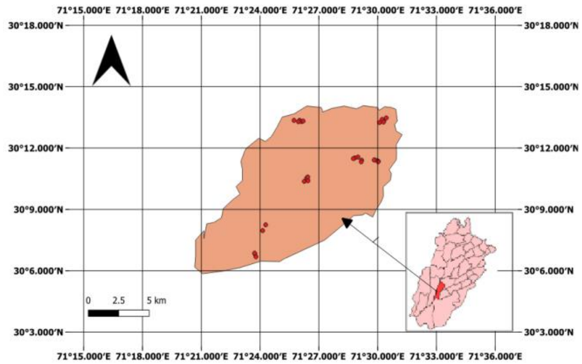

Figure 1. Map indicating water sampling sites from Multan city, Punjab, Pakistan

Table 1. Physiochemical properties of groundwater samples from Multan city, Punjab, Pakistan

Sampling Sites	Ph	EC (µS cm^{-1})	TDS (mg/L)	Hardness (mg/L)	SO_4^{2-} (mg/L)	F^- (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Ca^{2+} (mg/L)	Total Coliform (CFU)	E. coli (CFU)	As (µg/L)	Cd (µg/L)	Cr (µg/L)	Fe (µg/L)
Shershah Town	7.35	2369	2071	371	70	1.36	206	107	0.67	35.2	163.2	5.36	35.2	24	15	8.67	3.69	3.58	2.26
Suraj Miani	7.33	1547	1773	379	164	0.29	175	84	0.68	35	149.9	6.12	38.6	19	16	11.94	4.81	4.74	3.14
Liaqat Abad	7.76	1873	1889	360	169	0.66	312	122	0.86	51.4	159.6	5.61	49.8	17	16	12.65	3.82	3.07	2.48
Tariq Abad	7.41	1493	1206	306	123	0.75	550	96	0.47	47	119.8	6.74	43.2	20	16	15.95	2.28	4.49	5.11
Sharif Pura	7.34	2558	2501	543	85	0.56	320	125	0.89	39.8	127.1	8.26	54.8	19	17	16.44	3.01	3.65	5.07
Basti Baghbanpura	7.54	1898	1525	408	86	1.03	339	115	1.02	42	91.6	9.39	38.2	18	18	11.39	2.82	4.15	3.22
Maximum	7.76	2558	2501	543	169	1.36	550	125	1.02	51.4	163.2	9.39	54.8	24	18	16.44	4.81	4.74	5.11
Minimum	7.33	1493	1206	306	70	0.29	175	84	0.47	35	91.6	5.36	35.2	17	15	8.67	2.28	3.07	2.26
Mean	7.45	1956.57	1827.90	394.77	116.80	0.77	317.52	108.69	0.76	41.7	135.2	6.91	43.3	19.5	16.33	12.84	3.41	3.95	3.55
Standard Deviation	0.17	430.09	446.76	80.09	42.70	0.37	132.01	15.73	0.20	6.53	27.57	1.59	7.6	2.43	1.03	2.93	0.89	0.63	1.25
Coefficient of Variation	2.28	21.98	24.44	20.29	36.56	48.3	41.58	14.4	25.8	15.6	20.39	23.07	17.55	12.46	6.32	22.83	26.25	15.85	35.19
Median	7.38	1885	1831	375.4	105.3	0.70	316.5	111	0.77	40.9	138.5	6.43	40.9	19.0	16.0	12.29	3.35	3.90	3.19
Kurtosis	1.81	-1.45	0.20	3.12	-2.21	0.03	1.80	-0.9	-0.47	-1	-0.56	-0.8	-1.0	2.88	0.58	-0.85	0	-1.2	-1.8

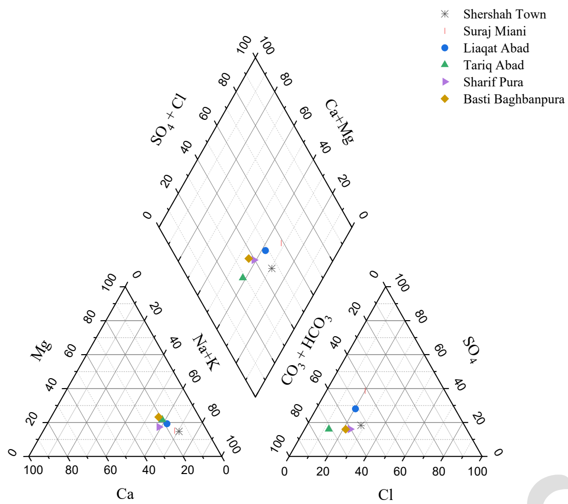

Figure 2. Piper plot representing groundwater type in Multan city, Punjab, Pakistan

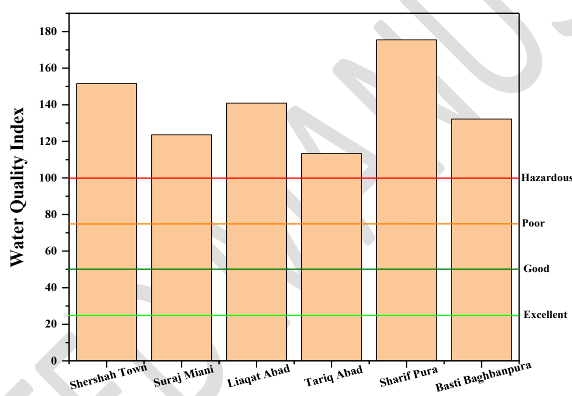

Figure 3. Groundwater quality index of Multan city, Punjab, Pakistan

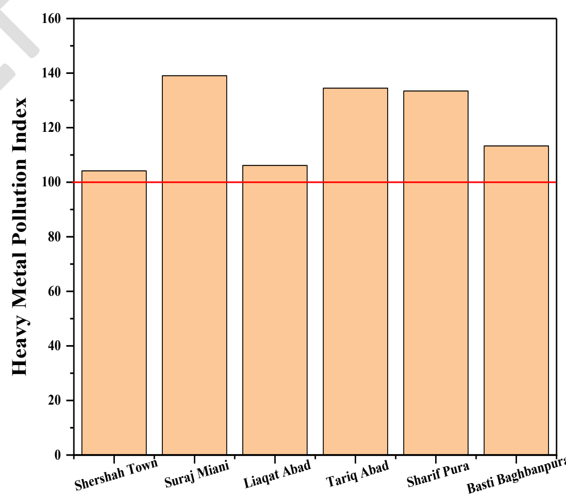

Figure 4. Heavy metal pollution index (HPI) of groundwater from Multan city, Punjab, Pakistan

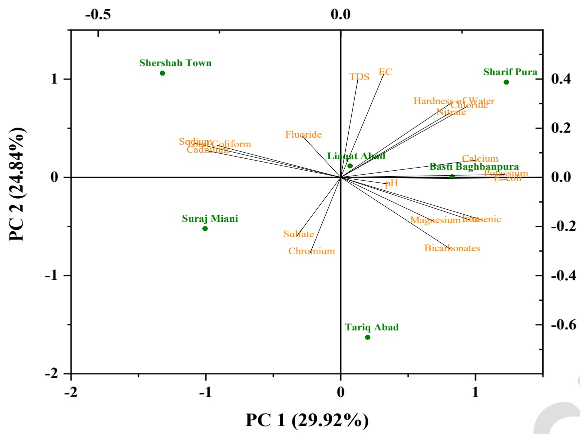

Figure 5. Principle component analysis (PCA) for groundwater samples collected from various locations of Multan city, Punjab, Pakistan

Table 2. Person correlation among different measured parameters of groundwater from Multan city, Punjab, Pakistan

	pH	EC	TDS	Hardness	F^-	HCO_3^-	Cl^-	NO_3^-	SO_4^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	Total coliform	E. coli	As	Cd	Fe	Cr
pH	1.00																		
EC	-0.19	1.00																	
TDS	-0.2	**0.86**	1.00																
Hardness	-0.27	0.74	**0.80**	1.00															
F^-	0.03	0.38	-0.05	-0.19	1.00														
HCO_3^-	0.17	-0.33	-0.57	-0.28	0.00	1.00													
Cl^-	0.49	0.69	0.53	0.55	0.26	0.06	1.00												
NO_3^-	0.41	0.43	0.40	0.61	0.05	-0.31	0.69	1.00											
SO_4^-	0.43	-0.69	-0.28	-0.4	-0.71	-0.03	-0.35	-0.20	1.00										
Na^+	0.02	0.14	0.40	-0.19	-0.05	-0.54	-0.11	-0.34	0.36	1.00									
K^+	-0.05	0.15	-0.04	0.53	-0.00	0.29	0.33	0.60	-0.44	-0.92	1.00								
Ca^{2+}	0.26	0.32	0.47	0.55	-0.49	0.28	0.61	0.26	0.17	-0.00	0.17	1.00							
Mg^{2+}	**0.81**	-0.31	-0.36	-0.31	-0.11	0.66	0.39	0.05	0.41	-0.13	-0.00	0.49	1.00						
T. coliform	-0.61	0.34	0.14	-0.15	0.62	-0.20	-0.26	-0.50	-0.57	0.35	-0.40	-0.52	-0.59	1.00					
E. coli	0.18	0.03	-0.07	0.48	-0.14	0.23	0.37	0.72	-0.20	-0.86	-0.95	0.23	0.15	-0.63	1.00				
As	-0.07	-0.08	-0.00	0.30	-0.58	0.66	0.14	-0.12	0.14	-0.36	0.34	0.76	0.42	-0.44	0.32	1.00			
Cd	-0.04	-0.09	0.31	-0.02	-0.35	-0.86	-0.34	0.02	0.51	0.68	-0.54	-0.22	-0.43	0.00	-0.40	-0.50	1.00		
Fe	-0.38	-0.02	-0.07	0.31	-0.38	0.68	-0.00	-0.23	-0.16	-0.52	0.47	0.51	0.14	-0.15	0.33	**0.91**	-0.63	1.00	
Cr	-0.56	-0.63	-0.56	-0.25	-0.33	0.15	-0.84	-0.41	0.12	-0.40	0.21	-0.46	-0.38	0.03	0.14	0.14	0.01	0.35	1.00

Table 3. Chronic daily intake of heavy metal (CDI) from drinking groundwater of Multan city, Punjab, Pakistan

Sampling Sites	As		Cd		Cr		Fe	
	Adult	**Children**	**Adult**	**Children**	**Adult**	**Children**	**Adult**	**Children**
Shershah Town	0.00021	0.030	0.000092	0.012	7.67143E-05	0.012	4.84286E-05	0.0078
Suraj Miani	0.00029	0.041	0.00012	0.016	0.00010	0.016	0.000078	1.08
Liaqat Abad	0.00031	0.043	0.000095	0.013	0.000076	0.010	0.000062	0.0085
Tariq Abad	0.00039	0.055	0.000057	0.0079	0.00011	0.015	0.00012	0.017
Sharif Pura	0.00041	0.056	0.000075	0.010	0.000091	0.012	0.00012	0.017
Basti Baghbanpura	0.00028	0.039	0.000070	0.0097	0.00010	0.014	0.000080	0.011

Table 4. Non-carcinogenic human health risk Hazard Quotient (HQ) by heavy metal in the groundwater of Multan city, Punjab, Pakistan

Sampling Sites	As		Cd		Cr		Fe	
	Adult	**Children**	**Adult**	**Children**	**Adult**	**Children**	**Adult**	**Children**
Shershah Town	0.72	100.18	0.18	25.58	0.02	4.13	0.01	2.61
Suraj Miani	0.99	137.97	0.24	33.34	0.03	5.47	0.02	2.84
Liaqat Abad	1.05	146.17	0.19	26.48	0.02	3.54	0.02	2.86
Tariq Abad	1.32	184.31	0.11	15.80	0.03	5.18	0.04	5.90
Sharif Pura	1.37	189.97	0.15	20.86	0.03	4.21	0.04	5.85
Basti Baghbanpura	0.94	131.61	0.14	19.55	0.03	4.79	0.02	3.72
Permissible limit	1.0		1.0		1.0		1.0	

Table 5. Life time cancer risk (LCR) of human health exposed to drinking water in Multan city, Punjab, Pakistan

Sampling Sites	As		Cr	
	Adult	Children	Adult	Children
Shershah Town	0.00014	0.020	0.00015	0.024
Suraj Miani	0.00019	0.027	0.00020	0.032
Liaqat Abad	0.00021	0.029	0.00015	0.021
Tariq Abad	0.00026	0.036	0.00022	0.031
Sharif Pura	0.00027	0.037	0.00018	0.025
Basti Baghbanpura	0.00018	0.026	0.00020	0.028