Physico-Chemical and Contamination Analysis of Ground Water: A Case Study of Shah Faisal Town, Karachi, Pakistan

Syed Wasi Haider,[1,2]* Anila Begum,[2] Iqra Kulsoom,[2] and Aiman Hussain[2]

[1] Institute of Space Science & Technology, University of Karachi, Karachi, Pakistan
[2] Department of Geology, University of Karachi, Karachi, Pakistan

KEYWORDS

Groundwater
Characterization
Drinking Quality
Shah Faisal Town

ABSTRACT

A comprehensive evaluation of groundwater quality in Shah Faisal Town, Karachi, was conducted to determine its suitability for drinking purposes. Sixteen groundwater samples were collected from various locations, revealing varied TDS concentrations (310-7650 mg/L) and comparable pH levels (6.32-7.88), which are within the WHO guidelines of 6.5 to 7.5. However, all samples exceeded WHO limits for hardness (>500 mg/L) and sodium content (>200 mg/L), with magnesium levels surpassing permissible limits by approximately fivefold. In contrast, bicarbonate content (120-400 mg/L) and nitrate levels (0.24-10.94 mg/L) were within WHO guidelines. Arsenic was detected in only three samples from the Malir River area, at a concentration of 0.005 mg/L, which is a significant concern for human health. After the end of monsoon rains of 2022, many ionic constituents were diluted, including arsenic, according to previous studies of the comparative appraisal of groundwater quality in lower and upper riparians of the Malir River system in 2019, where rainfall was less compared to the 2022 rainfall impact, which was 375 mm and 761.4 mm, respectively. The ionic correlation matrix indicates that both natural and anthropogenic factors are responsible for altering the groundwater characteristics of the study area. These findings, including the presence of arsenic even after the end of the monsoon rains of 2022, highlight concerns regarding groundwater quality in Shah Faisal town, emphasizing the need for effective management and treatment strategies, like a Reverse Osmosis plant, to ensure safe drinking water.

1 Introduction

The groundwater and surface water demand is widening with ever increasing population, especially in water starved regions. In case of groundwater, its over exploitation depletes the available water table of that well resulting in acceleration of contaminants, migration from land surface to shallow and deep aquifers. It shows vulnerability to such aquifers from good to unusable. Groundwater is vital for every habitat and living organisms. It appears to be one of the crucial resources available on Earth (El-Rawy *et al*., 2023). Since it is affected by manmade activities, pollutant sources like industrial and agricultural lands become the main source of its varying composition (Hu *et al*., 2025). The industrial and domestic effluents contribute towards an increasing concentration of different pollutants in surface and groundwater.

The change in climate variability also affects the migration of sedentary individuals as well as precipitation events in previous years within this semiarid region (Ali and Khan, 2021; Haider *et al*., 2023). This indefinitely also affects water quality and human activities with ever increasing urban sprawl. As a result, shallow and deeper wells as along with surface runoffs also change. Moreover, food and water demands will arise due to socioeconomic, demographic, cultural appearance (Sishodia *et al*., 2018). Similarly, the increase or decrease in precipitation events will definitely make more interdependence of consumers on water demand that may whether improve or decline water availability. In terms of wastewater reuse, it could meet plant requirements but on the other hand, it may contaminate natural resources which consequences in degraded crops.

Corresponding Author wasi110@hotmail.com

Groundwater availability is challenging in arid and semiarid environment where sparse rainfall and environmental sustainability is on a question of whether incoming years may support or deteriorate the presence of available water resources. The potability of groundwater appears to be more than 49% for global population (Connor, 2015) and replenished more than 39 % of irrigated areas (Siebert *et al*., 2010). As observed in many downstream in arid and semiarid regions, the over abstraction of groundwater also reflects the situation of groundwater at low elevated areas where downstream is often located. Such use of water from surface runoffs also leads to a decrease of water in available down streams (Wheater *et al*., 2010). From above scenarios, surface as well as groundwater both show crucial and irreplaceable role. For downstream, they gradually serve agricultural irrigation and potable water supply. But in this study area of semiarid environment, industrial sectors and its effluents creates unfavorable environment. There is more probability of less water and food security in this region. Moreover, sub-urban and urban cultivation are dependent on waste water irrigation in most of water deficit countries. Karachi city is expanding everyday with commercial and industrial sectors around the banks of Malir River (Haider *et al*., 2023) while Hub and Lyari rivers are also covered with exponential growth of urbanization. This study aims to assess (1) Groundwater quality assessment after previous 2022 monsoon rains. (2) Identify arsenic and its source whether from natural or anthropogenic sources. (3) Potability or non potability of available water from these available wells in Shah Faisal town. These studies will help in compare the current and future groundwater quality parameters as Malir motorway is yet to be established with removal of agricultural lands in upcoming years. In other words, it will be a baseline study for groundwater located in upper ridges of the Malir River.

1.1 Study Area

Shah Faisal Town, being located in the district of Malir with Malir River on its southern parts. Being a commercial along with residential area, it appears that its assigned geographical points in longitudes and latitudes are 67.1691°E and 24.9077°N, respectively. Moreover, it is adjacent to main Shahrah-e-Faisal, Jinnah International Airport, as well as with the Malir River, after Local Government Ordinance 2001, it was split into 11 union councils. The town is in between Bin Qasim town to the East, Malir Town to the northeast, Landhi and Korangi town to the South, and Malir and Faisal Cantonment to the Northwest and West, respectively. The Malir River is located at its Southern boundary whilst the Shahrah-e-Faisal highway also located at its Northern boundary. Finally, the Jinnah International Airport also located at the Northern side of this town.

Shah Faisal town appears to be in a vicinity of Malir River where it is greatly affected by storm water runoff in the form of floods also (Guriro, 2017). The climate appears to be semiarid as Karachi airport station holds weather station with average rainfall around 200 mm (PMD, 2022, Haider *et al*., 2023). The Shah Faisal town located beside the Malir River in its Northern parts such that most of the alluvial deposits are available as shown in (Fig.1) (JICA, 2013; Haider *et al*, 2023).

The Malir River carries sediments from upstream to downstream in a manner that meandering curves hold few or more deposits of upper mobile sediments, leaving more mineral traces on groundwater composition. The geological map is taken from (Haider *et al*., 2023). The Malir River catchment shows four Geologic formations, i.e., Alluvial deposits formation of Recent to sub-recent age, Gaj formation of Miocene age, Manchar formation of Mio-Pliocene age and Nari formation of Oligocene age. Localities which are situated along the bank of Malir River generally exposed silty and gravely sand. The geology is made up of primarily by the arenaceous composition followed by gravel in upstream and by silt in the downstream area. Although Manchar formation is primarily spread over the pediment lowland of the upper reach. Its main components are sandstone and conglomerate, with soft shale and mudstone being positioned between them. Gaj formation made up of limestone and sandstone which are widely distributed in the upper reach mountain (Haider *et al*., 2023).

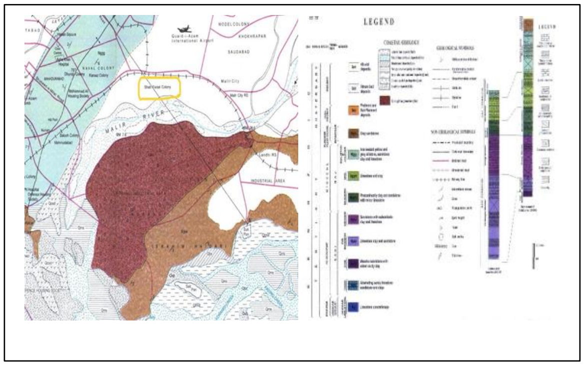

Fig..1. Geological map of Shah Faisal town with Legends

2 Materials and Methods

2.1 Sample Collection

The sampling of groundwater was carried out at the onset of rainy season. About 16 groundwater samples were collected from Shah Faisal Karachi (Malir River basin).

Field studies included the collection of groundwater samples from wells at a depth range of 4.6-61 m. The water samples were collected from boring wells after pumping for at least 5-10 min to get representative samples of the groundwater.

Water samples were not filtered so that accurate value of arsenic and other elements could be obtained as that would be consumed by well users. Location of the wells was marked with the Global Positioning System (GPS). Groundwater samples were collected in plastic bottles (1-L capacity) for physico-chemical analysis and bottles with few drops of boric acid for nitrate testing. These bottles were washed properly and rinsed thoroughly with deionized water and then with the groundwater.

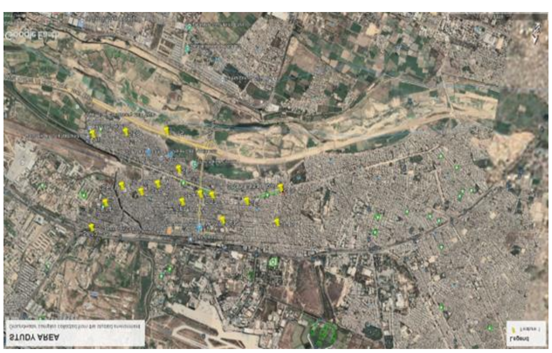

Fig..2. Groundwater sampling points collected from the study area as Shah Faisal town.

Table 1. Location of sites for sample collection

S. No.	Sample Code	Coordinates	Site
1	SF-1	24°52'55.28"N, 67° 9'10.43"E	Shah Faisal Colony #3, Noor Mosque
2	SF-2	24°52'39.68"N, 67° 9'9.32"E	Shah Faisal Colony #3, Reta Plot, Jamia Masjid Sehra
3	SF-3	24°52'39.29"N, 67° 8'49.28"E	Shah Faisal Colony #2, Reta Plot
4	SF-4	24°53'3.28"N, 67° 8'42.07"E	Shama Shopping Centre
5	SF-5	24°52'48.07"N, 67° 8'31.66"E	Shah Faisal Colony #1, Madina Masjid
6	SF-6	24°52'40.67"N, 67° 8'16.11"E	Shah Faisal Colony #4, Khokhar Club area
7	SF-7	24°52'31.85"N, 67° 8'28.00"E	Reta Plot Shah Faisal Colony #1
8	SF-8	24°52'16.97"N, 67° 7'55.08"E	Roshanabad, Shah Faisal Colony #5
9	SF-9	24°52'20.07"N, 67° 7'35.57"E	Qadria Mosque, Shah Faisal Colony #5
10	SF-10	24°52'45.63"N, 67° 8'6.50"E	Pak Colony
11	SF-11	24°52'43.89"N, 67° 7'54.65"E	Sadat Colony
12	SF-12	24°53'0.81"N,67° 8'12.81"E	Natha Khan Goth
13	SF-13	24°53'7.29"N, 67° 7'37.99"E	Hanfia Masjid, Drigh Road
14	SF-14	24°52'53.62"N, 67° 7'45.53"E	Azeemabad, Drigh Road
15	SF-15	24°53'5.49"N, 67° 9'17.85"E	Al-Falah Society
16	SF-16	24°52'52.46"N, 67° 9'30.07"E	Green Town, Pathar Road

2.2 Sample Analysis

Electrical conductivity, temperature, and pH were measured after sampling using a portable meter. Arsenic concentration in groundwater was determined at each site using a Merck field testing kit (Cat No. 1.17926.0001, Germany, 0.005-0.25 mg/l). The concentration of arsenic was measured by visual comparison of the reaction zone of the analytical test strip with the fields of color scale.

Table 2. Showing Parameters and their methods

S-No.	Parameters	Instruments/Methods
1	Odour and taste	Aesthetically
2	Eh(mv)/ORP and pH	ADWA(AD111) pH meter
3	Colour	Visual observation
4	Temperature	ADWA(AD111) pH meter with temperature probe
5	Turbidity	Hanna Portable HI-93102 meter
6	TDS/EC	ADWA(AD330) TDS/EC/T°C mete
7	Hardness	EDTA titration method
8	Chloride	Argentometric titration method
9	Bicarbonate	Titration method
10	Nitrate	Genesys 10s Uv-Vis spectrophotom
11	Sulfate	HACH DR-2800 spectrophotometer
13	Sodium	JENWAY PFP7 Flame Photometer
14	Potassium	JENWAY PFP7 Flame Photometer
15	Calcium	EDTA titration method
16	Magnesium	Standard formula; Mg=[(Hardness-(Calcium.2.5)]x0.243
17	Arsenic	Merck Arsenic Test Kit based on colorimetric method

3 Result & Discussion

3.1 Physical Parameter

Table 3a. Physical parameters of the studied groundwater samples and their comparison with standards listed in WHO (2017)

Sample No.	Turbidity (NTU)	Temp. (°C)	Eh (mv)	pH	TDS (mg/L)
1	0.01	28.1	120	7.01	2243
2	0.21	28.0	110	6.99	3120
3	0.32	28.1	98	7.23	1600
4	0.06	28.1	102	8.11	1110
5	3.00	16.2	114	7.21	1430
6	0.00	26.4	118	6.32	310
7	2.66	25.6	184	7.12	1870
8	4.13	26.4	105	6.87	1150
9	0.20	26.7	111	7.88	316
10	0.06	26.3	121	7.54	1450
11	0.05	26.8	134	7.06	2822
12	0.09	27.0	121	6.77	7650
13	0.00	26.9	114	7.07	2110
14	5.76	27.0	123	7.02	1210
15	0.67	26.7	136	7.08	875
16	0.15	26.6	127	7.06	1190
Minimum	0.00	16.2	98	6.32	310
Maximum	5.76	28.1	184	8.11	7650
Mean	1.085625	26.30625	121.13	7.15	1903.5
WHO limit	05	15-25	-	6.5-8.5	500
Std. Dev	1.791248982	2.794391705	19.795	0.42	1719.1358

The electrical conductivity and total dissolved solids (TDS) of collected groundwater samples were measured with an EC meter (Eutech Cyber Scan CON II). pH were measured by pH meter and Eh by Eh meter. Sodium (Na^+) and potassium (K^+) were measured by flame photometer. Calcium (Ca^{2+}) magnesium (Mg^{2+}) was measured through the titration method proposed by (APHA, 2005).

3.1.1 Temperature

Groundwater temperature varied in the range of 16-28 °C. The temperature of groundwater is one of the most important parameter that may cause many alterations in water chemistry such as corrosion problem, bacterial growth, color, taste and odor (WHO, 2011). From descriptive statistics (Table.3a), the mean temperature is 26.3°C, maximum 28.1°C, minimum 16.2 °C and standard deviation of 2.79 °C. Many anthropogenic sources so called human activities are responsible for higher temperature of groundwater on long-term basis as higher TDS, cation and anion content also elevate chemical reactions with temperatures (Haider *et al.*, 2023).

3.1.2 pH and Eh/ORP

The pH value varies from acidic to basic (6.32 to 8.11). Generally, groundwater pH is within the permissible range (6.5-8.5) of (WHO, 2011). Most of the shallow well groundwater samples were found neutral to slightly alkaline, while a few have shown acidic values. The pH of water appears to show no explicit impact on human health, but its greater values may increase the scale formations in water heating apparatus (Gebremikael and Dawod, 2021). Moreover, the pH is an important parameter causing dissolution of minerals (Zhang *et al.*, 2011; Haider *et al*, 2023). The mean of pH value from (Table.3a) appears to be 7.15, maximum is 8.11, minimum 6.32 and standard deviation is around 19.795. The variation in pH values indirectly affects the quality of groundwater such as solubility of heavy metal ion and microbial growth. Eh of the samples lie in the range of 98-184 mv. Such values of Eh/ORP shows recharge rate of groundwater as freshwater through surface or storm water runoff contributes in recharging mechanism. Moreover, it also shows extent of metallic ions (Haider *et al.*, 2023). The mean value of Eh/ORP was 121.13mv, maximum is 184 mv, minimum is 98 mv and a standard deviation is 19.79 mv.

Table.3b. Chemical parameters of studied groundwater samples and their comparison with standards listed in WHO (2017).

Samples No	Hardness	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	NO3 (mg/L)	HCO3 (mg/L)	As (mg/L)	SO4 (mg/L)
1	800	915	13	12	187	1450	5.44	370	0.000	300
2	900	1200	19	190	103	1190	6.45	360	0.005	200
3	400	550	14	12	90	540	4.87	320	0	500
4	200	320	10	12	41	249	6.66	400	0	350
5	700	1000	14	21	157	1210	6.54	430	0	380
6	200	40	11	12	41	97	1.01	120	0	80
7	400	901	13	24	83	1100	10.94	430	0	220
8	300	598	13	12	66	787	3.65	390	0.005	560
9	200	90	12	14	40	85	0.24	120	0	590
10	300	520	11	14	64	246	4.49	240	0	400
11	900	790	21	68	177	1147	4.45	300	0	680
12	1500	1260	15	220	231	2345	0.23	200	0	890
13	1100	1000	13	66	227	989	4.44	210	0	510
14	500	760	10	24	107	998	2.1	300	0.005	610
15	300	120	12	12	66	112	4.32	200	0	590
16	400	565	12	23	83	656	5.67	320	0	300
Minimum	200	40	10	12	40	85	0.24	120	0	80
Maximum	1500	1260	21	220	231	2345	10.94	400	0.005	890
Mean	600	664.3125	13.3125	53.7777	113	868.3889	4.593333	290.5556	0.001111	451.6667
WHO limit	500	200	12	75	50	250	10	30-400	10	250
Std. Dev	378.9789	382.4114	2.9825	64.8084	64.95251	610.0715	2.727132	102.3698	0.002016	207.2197

3.1.3 Total Dissolved Solids (TDS)

The variable values of TDS content were determined in the studied environment that ranges between 310-7650 mg/L. The mean value of TDS (mg/L) according to (Table.3a) is 1903.5, maximum 7650, minimum 310 and standard deviation is 1719.1358. The TDS estimation is very important for suitability of water for drinking purpose, agriculture and industrial uses as it expresses organic as well as inorganic salts (WHO, 2011). The elevated TDS contents in groundwater of study area may be due to higher concentration of chemical parameters including major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}), anions (Cl^-, NO_3^-, HCO_3^-, SO_4^{2-}). WHO and Pakistan guideline values for TDS are 500 and 1000 mg/L for drinking purpose, respectively. A very important source for higher values of TDS in collected groundwater samples may be due to the influx of anthropogenic matter especially sewage drainage effluents coming from its Western as well as from Eastern side where highly populated sewage flows from different towns.

3.1.4 Turbidity

Turbidity of collected groundwater samples ranges between 0.00-5.76 NTU. All samples were found under permissible limit <5 NTU by (WHO, 2011). According to (Table.3a), the mean value of Turbidity (NTU) is 1.085, maximum is 5.76, and minimum is 0 and a standard deviation of around 1.791.

3.2 Chemical Parameters

Please see Table 3a.

3.2.1 Major Cations

3.2.1.1 Sodium

The concentration of sodium in some of the collected samples from Shah Faisal Malir River was found objectionable against the permissible limit (200mg/L) prescribed by (WHO, 2011) for drinking purposes. The higher values of sodium concentration were observed in sample numbers SF3, 6, and loc13, 14 which were above 1000 mg/L. According to (Table 2b), the mean concentration of sodium (mg/L) is 664.3125, maximum value is 1260, minimum value 40 and a standard deviation of 382.4114. The higher salinity of groundwater in these areas has already been reported by seawater intrusion (Khan and Bakhtiari., 2017; Mashiatullah *et al*., 2002). The sources of high sodium include dissolution from subsurface strata or anthropogenic activity. The use of fertilizers and irrigation practices in the surrounding area may contribute to increased sodium concentrations in the river water (Katz & Bullen, 1996). Industrial processes, such as textile manufacturing or oil refining, may release sodium-rich effluents into the river (US EPA, 2004). The surrounding soil may have high sodium concentrations, which can leach into the river water (Appelo & Postma, 2005).

3.2.1.2 Potassium

A wide range of potassium concentration occurs on all the samples except sample SF4,6 LOC 4,8 all the samples are higher than the WHO guidelines for drinking purpose (WHO, 2011), prescribed limit of potassium (12mg/L) for drinking purposes. According to (Table 2b), the mean value of potassium (mg/L) is 13.3125, the maximum value is 21, and minimum value is 10 and a standard deviation of around 2.98. The potassium concentrations may be influenced by the geological formations in the area. Potassium-rich minerals, such as potassium feldspar or mica, can release potassium ions into the water (Hem, 1985). Weathering and erosion of potassium-rich rocks and soils can contribute to increased potassium concentrations in the water (Langmuir, 1997). The use of potassium-based fertilizers in agricultural practices can lead to increase potassium concentrations in the water (Katz & Bullen, 1996). The surrounding soil may have high potassium concentrations, which can leach into the water (Appelo & Postma, 2005).

The possible sources of potassium in groundwater include precipitation, weathering of existing minerals of potash silicate, excessive use of potash fertilizer (Jain *et al*., 2018; Deshpande and Aher, 2012). Since Malir River downstream is an agricultural belt before construction of Malir motorway, it shows elevated values of potassium which later diluted due to storm water runoffs.

3.2.1.3 Calcium

Like other ions, variable calcium concentration is also reported in the groundwater of the study area. The Ca^{2+} content ranges from 12-220 mg/L. Only sample number SF2 and loc 6 are found above the permissible limit of Ca^{2+} content (75 mg/L) by (WHO, 2011) for drinking water. According to (Table 2b), the mean value of calcium (mg/L) appears to be 46, a maximum value of 220, a minimum value of 12, and a standard deviation of around 64.80. The surface water that flows through limestone may contain a greater concentration of calcium ions. The variable calcium concentration in the groundwater of the study area can be attributed to the geological formations and interactions with surface water. As mentioned, surface water flowing through limestone can lead to higher concentrations of calcium ions (Srivastava and Pandey, 2012). Calcium concentrations can be higher in areas where groundwater flows through limestone, dolomite, or gypsum formations, as these rocks are rich in calcium minerals (Hem, 1985). Weathering and erosion of calcium-rich rocks and soils can release calcium ions into groundwater (Langmuir, 1997). Agricultural runoff and fertilizers can contribute to increased calcium concentrations in groundwater, particularly in areas with intensive farming practices (Katz and Bullen, 1996). Ion exchange processes between groundwater and aquifer materials can also affect calcium concentrations. For example, calcium ions can exchange with sodium or potassium ions in clay minerals, leading to increased calcium concentrations (Appelo and Postma, 2005). Calcium concentrations can also be influenced by pH and redox conditions in the aquifer. For example, under acidic conditions, calcium minerals can dissolve, leading to increased calcium concentrations (Stumm and Morgan, 1996).

3.2.1.4 Magnesium

Extremely variable magnesium concentrations is found in the samples of Shah Faisal area that varied between 40-227 mg/L. Nine samples are found under the permissible limit for magnesium content (150 mg/L) by (WHO, 2011) for drinking purposes. According to (Table 2b), the mean concentration of magnesium (mg/L) appears to be 110.1875, a maximum of 231, a minimum of 40, and a standard deviation of 64.95. Higher values of Mg^{2+} may create kidney stones (WHO, 2011). The Shah Faisal area might have diverse geological formations, leading to variations in magnesium-rich minerals and subsequent differences in magnesium concentrations (Klein and Hurlbut, 1993). The interaction between groundwater and rocks can release magnesium ions, causing variability in concentrations (Appelo and Postma, 2005). Fertilizers and pesticides used in agricultural activities can contaminate groundwater, leading to increased magnesium levels (WHO, 2011). Improper disposal of domestic and industrial waste can also contribute to magnesium contamination (USEPA, 2017).

3.2.1.5 Chloride

Very high variation in chloride concentration has been found in the samples ranging between 85-2345 mg/L. are above the WHO permissible limit. High concentrations of Cl- are because of seawater intrusion in the area. As mentioned, seawater intrusion is a likely cause of high chloride concentrations in the area. This occurs when seawater flows into freshwater sources, increasing the chloride concentrations (Todd, 1980). The geological formations in the area may also contribute to high chloride concentrations as they are [paved roads as well as untreated sewage lines that directly affect chloride concentrations, as chloride is conservative (Haider *et al*., 2023). For example, chloride-rich minerals like halite or sylvite can release chloride ions into the water (Hem, 1985). The use of chloride-based fertilizers or irrigation practices can lead to increased chloride concentrations in the water (Katz & Bullen, 1996). Industrial processes, such as textile manufacturing or oil refining, can release chloride-rich effluents into the environment (US EPA, 2004).

3.2.1.6 Nitrate

Nitrate great variation is found in the range of 0.23-10.94 mg/L almost all the samples are in the permissible limit (10 mg/L), except loc1 which is 10.94 mg/L. About 99 % of samples are found with NO3 concentration <10 mg/L Possibly the fecal bacteria are accelerating the nitrate reduction process by oxidation of organic matter, which results in a decrease of nitrate content in groundwater and causing reducing conditions in the aquifer. The presence of fecal bacteria can accelerate the nitrate reduction process by oxidizing organic matter, leading to decreased nitrate concentrations (Tiedje, 1994). The use of nitrogen-based fertilizers in agricultural activities can lead to increased nitrate concentrations in groundwater (Spalding and Exner, 1993). The type of soil and underlying geology can affect the movement and occurrence of nitrates in the groundwater system (Appelo and Postma, 2005). Improperly functioning septic systems and wastewater from domestic and industrial sources can contribute to nitrate contamination (USEPA, 2017). Atmospheric deposition of nitrogen oxides can also contribute to nitrate concentrations in groundwater (Galloway *et al*., 2003).

3.2.1.7 Bicarbonate

Bicarbonate concentrations are found in the range of 120-430 mg/L and only 40 % are above the permissible limit of 300 mg/L (WHO, 2011). Naturally, bicarbonate is mainly derived from soil zone CO_2 during the weathering of parent rock (Kenneth *et al*., 2014). Dissolution of silicate minerals and reaction between feldspar minerals and carbonic acid in the presence of water are possible sources of HCO_3. The geological formations in the area may be rich in bicarbonate-bearing minerals, such as limestone or dolomite, which can release bicarbonate ions into the water (Hem, 1985). The surrounding soil may have high bicarbonate concentrations, which can leach into the groundwater (Appelo & Postma, 2005). The presence of vegetation and organic matter in the area can contribute to increase bicarbonate concentrations in the groundwater through decomposition and root respiration (Langmuir, 1997). and absorption of atmospheric CO2 by the groundwater can also contribute to increased bicarbonate concentrations (Stumm & Morgan, 1996). High bicarbonate concentrations in drinking water can cause gastrointestinal problems and may also contribute to the formation of kidney stones (NRC, 2007).

3.2.1.8 Sulphate

High variation in sulphate content was determined which is in the range of 80-590 mg/L. 70 % of samples show a higher value than the prescribed limit (250 mg/L) by WHO (2011). High sulphate content in the groundwater of the study area suggests the dissolution of gypsum from gypsiferrous shale of the

Gaj Formation, use of SO_4 fertilizer may increase sulphate concentration in groundwater. Sulphate-rich geological formations, such as gypsum or limestone, can release sulphate ions into the water (Hem, 1985). The use of sulphate-based fertilizers or irrigation practices can contribute to increased sulphate concentrations in the water (Katz & Bullen, 1996). Industrial processes, such as mining or paper manufacturing, can release sulphate-rich effluents into the environment (US EPA, 2004). Sulphate can also be deposited into the water through atmospheric processes, such as acid rain (Langmuir, 1997; Haider *et al*., 2022).

3.2.1.9 Arsenic

Arsenic concentration was found in only 3 samples of Shah Faisal adjacent to Malir River which is 0.005 mg/L in the sample numbers SF2, loc2, and 8. All the samples are within the WHO limit of 10 μg/L. higher concentration of arsenic can cause skin manifestations were observed mainly in rural parts other than the study area within Sindh province (Rubab *et al*., 2014; Ali *et al*., 2019a; Ali *et al*., 2019b; Shahab *et al*., 2019). Some other clinical manifestations, such as weakness (Mukherjee *et al*., 2003), muscle cramps (Khuda-Bukhsh *et al*., 2005) and gastrointestinal problems like hepatitis (Goel *et al*., 2016) and stomach disorders (Khan and Husain, 2021) were also observed in arsenic-affected regions. The geological formations in the area may not be rich in arsenic-bearing minerals, resulting in low arsenic concentrations in the water (Smedley & Kinniburgh, 2002; Haider *et al*., 2023). The area may have low human activities, such as mining or industrial processes, which can release arsenic into the environment (US EPA, 2004; Haider *et al*., 2023) because of residential and commercial area as shown in (Figure 1). Natural attenuation processes, such as adsorption or precipitation, may be occurring in the aquifer, reducing the arsenic concentrations in the water (Appelo & Postma, 2005). Low arsenic concentrations in drinking water are generally not considered a health risk. However, long-term exposure to low levels of arsenic can still cause health problems, such as skin discoloration or cardiovascular disease (NRC, 2007).

3.3 Hardness

The hardness of about 200-1500 mg/L in the collected samples, some are above the WHO permissible limit (500 mg/L) for drinking purposes. According to (Table.3b), the mean value of hardness (mg/L) is 600, the maximum is 1500, and the minimum is 200, and a standard deviation of around 378.98. There appears to be permanent hardness as calcium, magnesium, bicarbonates, as well as sulfate concentration uplifts such hardness values (WHO, 2011) as different carbonates, bicarbonates combination with cations increases permanent hardness.

Through the correlation matrix (Table.4), a brief detail in the form of associations between one or more than one variable can easily be estimated such that overall data set coherence can be visualized.

Also, each individual parameter can also be seen as influencing factors (Helena *et al*., 2000; Haider *et al*., 2022; Haider *et al*., 2023). The groundwater samples collected from the Shah Faisal town were analyzed for physical (Eh, pH, temperature, turbidity, TDS) as well as for chemical (K^+, Ca^{2+}, Na^+, Mg^{2+}, Hardness, As^{3+}) along with anions like (SO_4^{2-}, HCO_3^-, NO_3^-, Cl^-).

For assumption, values from (0.50 to 0.60) are named significant, (0.61 to 0.70) are named strong whilst (0.71 to 0.99) are given as a very strong correlation. From the ionic correlation matrix (Table.4), turbidity shows a moderately strong correlation with arsenic (0.63), indicating that arsenic mobility in the form of colloidal particles (insoluble) exists within shallow wells of groundwater (Haider *et al*., 2023). Moreover, Eh/ORP shows a significant correlation between nitrate (0.50) that represents sewage effluents and fertilizer carrying nitrate into these collected groundwater wells as surface/storm water runoff also carries nitrate that penetrates into these aquifers (Lasagna, 2016; Haider *et al*., 2023).

The correlation of TDS shows its interaction as very strong with hardness, Na^+, significant with K^+, strong with Ca^{2+}, $Mg^{2+,}$ and Cl^- significant with arsenic. This correlation partially shows anthropogenic and water rock interaction (Haider *et al*., 2023). Furthermore, Hardness comes as a part of very strong correlation with Na^{+}, Mg^{2+}, Cl^{-}, whilst significant with potassium as sodium feldspar from local geology and anthropogenic sources like sewage carries chloride content in these alluvial aquifers from surface runoff. Na^{+} appears to show a significant correlation with K^{+} as well as from HCO_3^{-} and a strong to very strong correlation occurs with Mg^{2+}, Ca^{2+}, and Cl-, respectively. This is still supported partially by geological settings from the area as alluvial deposits are available. The same exists with Ca^{2+} and Mg^{2+} correlations with each other along with Cl^{-} as shown in (Table.4). NO3- and HCO3- also show strong correlation with each other indicating anthropogenic influence (Ali and Khan, 2021, Haider *et al*., 2023)

4. Conclusion

The comprehensive assessment of groundwater quality in Shah Faisal, Karachi, reveals significant concerns regarding its suitability for drinking purposes. While pH levels and bicarbonate content were within WHO guidelines, excessive levels of hardness, sodium, and magnesium were detected, exceeding recommended limits. The presence of arsenic in three samples from the Malir River area further exacerbates the issue as after end of Monsoon rains of 2022 (average 761.4 mm rain fall) perhaps reduced the concentration of arsenic to some extent as compared to recent studies of the Malir River system after stormwater runoffs in 2019 (average rain fall 375 mm). These findings underscore the need for effective groundwater management and treatment strategies to ensure safe drinking water for the residents of Shah Faisal Town. Biological parameters should be addressed for detailed water analysis. Furthermore, regular monitoring and assessment of groundwater quality are essential to mitigate potential health risks associated with the consumption of contaminated water. Ultimately, a multidisciplinary approach involving policymakers, water management authorities, and local communities is necessary to address the challenges of groundwater quality in Shah Faisal and ensure a sustainable and safe drinking water supply.

Table.4. Correlation matrix related to groundwater data of Shah Faisal Town

	Turbidity (I	Temperatu	Eh (mv)	pH	TDS (mg/L	Hardness (	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	NO3 (mg/l	HCO3	As (mg/L)	SO4 (mg/L)
Turbidity (NTU)	1														
Temperature	-0.35009	1													
Eh (mv)	0.166635	-0.07703	1												
pH	-0.14443	0.025088	-0.18759	1											
TDS (mg/L)	-0.19657	0.1129	0.062201	-0.27048	1										
Hardness (mg/L	-0.17286	-0.03002	-0.00033	0.3435	0.867315	1									
Na (mg/L)	0.14876	-0.17579	0.131938	-0.25709	0.717148	0.835166	1								
K (mg/L)	-0.23544	-0.01225	0.060269	-0.23866	0.484287	0.581316	0.533849	1							
Ca (mg/L)	-0.23055	0.154022	-0.04744	-0.28306	0.86732	0.800998	0.669535	0.592525	1						
Mg (mg/L)	-0.10529	-0.13586	0.028274	-0.31532	0.703671	0.931897	0.777943	0.464844	0.529525	1					
Cl (mg/L)	0.131114	-0.12316	0.162055	-0.37531	0.853871	0.880818	0.904538	0.489146	0.695247	0.827063	1				
NO3 (mg/L)	0.08108	-0.19366	0.476094	0.202387	-0.1554	-0.11189	0.292051	0.13373	-0.17311	-0.05359	0.049541	1			
HCO3	0.406576	-0.2793	0.14315	0.158301	-0.01032	-0.00311	0.457226	0.1699	-0.095	0.05312	0.304096	0.78772	1		
As (mg/L)	0.631801	0.146871	-0.212	-0.22116	-0.02217	-0.00273	0.24437	0.114362	0.22456	-0.13992	0.13549	-0.07315	0.269588	1	
SO4 (mg/L)	0.125891	0.080044	-0.13498	0.092978	0.498035	0.427629	0.163987	0.187956	0.305594	0.4209	0.350471	-0.51057	-0.26972	0.021947	1

5. Acknowledgements

We are extremely thankful to Dr. Adnan Khan, Associate Professor, Department of Geology, University of Karachi for providing us lab facilities through Environmental geology lab for physico-chemical analysis of collected groundwater samples from the studied environment.

References

Ali, W., Rasool, A., Junaid, M., & Zhang, H. (2019a). A comprehensive review on current status, mechanism, and possible sources of arsenic contamination in groundwater: a global perspective with prominence of Pakistan scenario. *Environmental Geochemistry and Health*, 41: 737-760.

Ali, W., Aslam, M. W., Feng, C., Junaid, M., Ali, K., Li, S., Chen Z., Yu Z, Rasool A, & Zhang, H. (2019b). Unraveling prevalence and public health risks of arsenic, uranium and co-occurring trace metals in groundwater along riverine ecosystem in Sindh and Punjab, Pakistan. *Environmental Geochemistry and Health*, 41: 2223-2238.

Ali, S. F., & Khan, A. (2021). Physicochemical and microbiological characterization of groundwater along the banks of Malir River in Karachi, Pakistan. *International Journal of Earth Sciences Knowledge and Applications*, 3(1): 37-52.

APHA (2005) Standard Methods for the Examination of Water and Wastewater. 21st Ed. American Public Health Association, Washington DC.

Appelo, C. A. J., & Postma, D. (2005). Geochemistry, groundwater and pollution. 2nd. *Ed. Balkema, Rotterdam*. Ben Akkerman collection Stedelijk Museum, Amsterdam

Connor, R. (2015). The United Nations World Water Development Report 2015: Water for a Sustainable World (Vol. 1). UNESCO Publishing, Paris.

Deshpande, S. M., & Aher, K. R. (2012). Evaluation of Groundwater Quality and its Suitability for Drinking and Agriculture use in Parts of Vaijapur, District Aurangabad, MS, India. *Research Journal of Chemical Science.* 2: 25-31. ISSN, 2231, 606X.

El-Rawy, M., Fathi, H., Abdalla, F., Alshehri, F., & Eldeeb, H. (2023). An Integrated Principal Component and Hierarchical Cluster Analysis Approach for Groundwater Quality Assessment in Jazan, *Saudi Arabia. Water*, 15(8): 1466.

Galloway, J. N., Aber, J. D., Erisman, J. W., Seitzinger, S. P., Howarth, R. W., Cowling, E. B., & Cosby, B. J. (2003). The Nitrogen Cascade. *Bioscience*, 53(4): 341-356.

Gebremikael, G. H., & Dawod, A. H. (2021). Assessment of Corrosion and Sacale Forming Potential of Groundwater Resources: Case Study of Dire Dawa City, Ethiopia. *Momona Ethiopian Journal of Science*, 13(1): 110-133.

Goel, A., Christudoss, P., George, R., Ramakrishna, B., Amirtharaj, G. J., Keshava, S. N., Ramachandran, A., Balasubramanian, K. A., Mackie, I., Fleming, J. J., Elias, E., & Eapen, C. E. (2016). Arsenicosis, Possibly from Contaminated Groundwater, Associated with Noncirrhotic Intrahepatic Portal Hypertension. *Indian Journal of Gastroenterology*, *35*(3): 207–215.

Guriro, A. (2017, September 7). Exploring why Karachi's rainwater has nowhere to go. *Dawn*. https://www.dawn.com/news/1355990

Helena, B., Pardo, R., Vega, M., Barrado, E., Fernandez, J. M., & Fernandez, L. (2000). Temporal Evolution of Groundwater Composition in an Alluvial Aquifer (Pisuerga River, Spain) by Principal Component Analysis. *Water Research*, 34(3): 807-816.

Hem, J. D. (1985). *Study and interpretation of the chemical characteristics of natural water* (Vol. 2254). Department of the Interior, US Geological Survey.

Hu, W., Zhao, Z., Zhang, Y., Xiao, Y., Qin, G., Wang, J., & Zhao, D. (2025). Groundwater in Arid and Semi-arid Regions: Issues of Scarcity and Quality. In Sustainable Groundwater and Environment: Challenges and Solutions . Cham: Springer Nature Switzerland 115-136.

Haider, S. W., Kazmi, S. J. H., Arsalan, M., Naseem, S., & Kanwal, H. (2022). Spatial Evaluation of Precipitation Patterns in the Catchment Area of Malir River during Monsoon Spells of 2019 through Geospatial Techniques. *Arabian Journal of Geosciences*, 15(17): 1435.

Haider, S. W., Kazmi, S. J. H., Alamgir, A., Khan, A., & Arsalan, M. (2023). Comparative Appraisal of Groundwater Quality in Lower and Upper Riparians of Malir River System through Geospatial Techniques. *Arabian Journal of Geosciences*, 16 (10): 578.

Jain, C. K., Sharma, S. K., & Singh, S. (2018). Physico-chemical characteristics and hydrogeological mechanisms in groundwater with special reference to arsenic contamination in Barpeta District, Assam (India). *Environmental Monitoring and Assessment*, 190: 1-16.

Japan International Cooperation Agency (JICA), (2013). Preparatory survey (II) on Karachi Circular Railway Rrevival Project in Islamic Republic of Pakistan, final report, volume 1(2) Main report.

Katz, B. G., & Bullen, T. D. (1996). The combined use of 87Sr/86Sr and carbon and water isotopes to study the hydrochemical interaction between groundwater and lakewater in mantled karst. *Geochimica et Cosmochimica Acta*, 60(24): 5075-5087.

Khan, A., & Husaın, V. (2021). Groundwater arsenic contamination and its health impacts in Tando Muhammad Khan District, Sindh, Pakistan. *International Journal of Earth Sciences Knowledge and Applications*, 3(3): 263-272.

Khan, A., Eghbal Bakhtiari, A., Fengjiao, C., Jichao, S., Sadeghian, M., Daneshkhah, M., & Khan, S. (2017). Groundwater assessment of coastal aquifers in Karachi: impact of seawater intrusion. *International Journal of Ground Sediment & Water*, 6: 248.

Khuda-Bukhsh, A. R., Pathak, S., Guha, B., Karmakar, S. R., Das, J. K., Banerjee, P., & Mandal, B. (2005). Can homeopathic arsenic remedy combat arsenic poisoning in humans exposed to groundwater arsenic contamination?: a preliminary report on first human trial. *Evidence-Based Complementary and Alternative Medicine*, 2(4): 537-548.

Kenneth, K. Y., Crew, A. B., Messingham, K. A., Fairley, J. A., & Woodley, D. T. (2014). Omalizumab therapy for bullous pemphigoid. *Journal of the American Academy of Dermatology*, 71(3): 468-474.

Kinzelbach, W., Brunner, P., Von Boetticher, A., Kgotlhang, L., & Milzow, C. (2010). Sustainable water management in arid and semi-arid regions. In H. Wheater, S. Mathias, & X. Li (Eds.), *Groundwater Modelling in Arid and Semi-Arid Areas* 119–130.

Klein, C., Hurlbut, C. S., & Dana, J. D. (1993). Manual of mineralogy: (after James D. Dana).

Langmuir, D. (1997). *Aqueous Environmental Geochemistry*. New Jersey.

Lasagna, M., De Luca, D. A., & Franchino, E. (2016). Nitrate contamination of groundwater in the western Po Plain (Italy): the effects of groundwater and surface water interactions. *Environmental Earth Sciences*, 75: 1-16.

Mashiatullah, A., Qureshi, R. M., Ahmad, E., Tasneem, M. A., Sajjad, M. I., & Khan, H. A. (2002). Groundwater salinity in coastal aquifer of Karachi, Pakistan. Science Vision,7: 185-207

Mukherjee, S. C., Rahman, M. M., Chowdhury, U. K., Sengupta, M. K., Lodh, D., Chanda, C. R., … & Chakraborti, D. (2003). Neuropathy in arsenic toxicity from groundwater arsenic contamination in West Bengal, India. *Journal of Environmental Science and Health, Part A, 38*(1): 165–183

National Research Council, Division on Earth, Life Studies, Board on Environmental Studies, & Toxicology Committee on Fluoride in Drinking Water. (2007). *Fluoride in drinking water: a scientific review of EPA's standards.* National Academies Press.

Pakistan Meteorological Department. (2022). Annual climate report 2022 Report . Government of Pakistan. http://www.pmd.gov.pk/reports/annual2022.pdf

Rubab, G., Naseem, S., Khan, A., Husain, V., & Arain, G. M. (2014). Distribution and sources of arsenic contaminated groundwater in parts of Thatta district, Sindh. *Journal of Himalayan Earth Sciences*, 47(2): 175-183.

Shahab, A., Qi, S., & Zaheer, M. (2019). Arsenic contamination, subsequent water toxicity, and associated public health risks in the lower Indus plain, Sindh province, Pakistan. *Environmental Science and Pollution Research*, 26: 30642-30662.

Siebert, S., Burke, J., Faures, J. M., Frenken, K., Hoogeveen, J., Döll, P., & Portmann, F. T. (2010). Groundwater use for irrigation–a global inventory. *Hydrology and Earth System Sciences*, 14(10): 1863-1880.

Sishodia, R. P., Shukla, S., Wani, S. P., Graham, W. D., & Jones, J. W. (2018). Future irrigation expansion outweighs groundwater recharge gains from climate change in semi-arid India. *Science of the Total Environment*, 635: 725-740

Smedley, P. L., & Kinniburgh, D. G. (2002). A review of the source, behaviour and distribution of arsenic in natural waters. *Applied Geochemistry*, 17(5): 517-568.

Spalding, R. F., & Exner, M. E. (1993). Occurrence of nitrate in groundwater—a review. *Journal of Environmental Quality*, *22*(3): 392-402.

Srivastava, R. K., & Pandey, D. (2012). Physico-chemical and microbiological quality evaluation of groundwater for human domestic consumption in adjoining area of Omti Nallah, Jabalpur (MP), *India. International Journal of Environmental Sciences*, 3(3): 1089-1096.

Stumm, W., & Morgan, J. J. (1996). Water chemistry. *Encyclopedia of Environmental Science*, 3: 1142-1161.

Tiedje, J. M. (1994). Denitrifiers. *Methods of Soil Analysis: Part 2 Microbiological and Biochemical Properties*, 5, 245-267.

Todd, A. H. (1980, April). *Water Harvesting: Soil/Water Impacts of Salt Treatment*. In *Water Harvesting Proceedings*, Arizona-Nevada Academy of Science 163-169. USDA Tahoe National Forest, Nevada City, CA.

U.S. Environmental Protection Agency, Region 9. (2004). *Abandoned Uranium Mines and the Navajo Nation: Northern Arizona. EPA Region screening assessment report* (Document No. P101HJKK). United States Environmental Protection Agency. Retrieved from https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P101HJKK (Accessed September 4, 2007)

Wheater, H. S., Mathias, S. A., & Li, X. (Eds.). (2010). *Groundwater modelling in arid and semi-arid areas*. Cambridge University Press.

WHO (2011) Guidelines: for Drinking-water Quality Geneva. World Health Organization, 104-108.

Zhang, F., Luo, W., Parker, J. C., Brooks, S. C., Watson, D. B., Jardine, P. M., & Gu, B. (2011). Modeling uranium transport in acidic contaminated groundwater with base addition. *Journal of hazardous materials*, 190(1-3): 863-868.