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Groundwater Contamination and its Impact on Health and Dentition in Malir District Pakistan

Dr Almas Rahim Balouch[1], Dr Sadaf Rasool Baloch[2], Dr Farha[3], Sassi[4], Dr Uzma Zareef[5], Dr. Rabail khero[6]

[1]Women Medical Officer at Health Department Government of Sindh, MBBS, MPH, Baqai Medical University. Email: almassrahim@gmail.com
[2]Designation LRMO, Institute SESSi ITC Landhi wing. Email: drsadafbaloch4@gmail.com
[3]House Officer, Zaiuddin Dental College. Email: farahabrish118@gmail.com
[4]Representative of SDG Youth Organisation. Email: rbsassi918@gmail.com
[5]BDS.MCPS, MDS, Professor, Liaquat College of Medicine and Dentistry, Karachi. Email: uzmaz_3@hotmail.com
[6]BDS, RDS, Dentist (MD Resident Oral Pathology), Liaquat College of Medicine and Dentistry, Karachi. Email: kherorabail@gmail.com

1. Abstract:

1.1 Background: Concern over groundwater pollution in Pakistan's Malir District is developing as a result of the area's fast industrialization and urbanization. Hazardous amounts of pollutants, such as microbiological pathogens and heavy metals, have been found; these pollutants pose serious health hazards, such as gastrointestinal disorders and dental fluorosis, which can result in serious dental issues.

1.2 Methods: We took twenty samples from the Right Bank (RB) and twenty from the Left Bank (LB) of the Malir River, drawing from wells that ranged in depth from twelve to three hundred feet, to examine the quality of the groundwater. Several physical characteristics were measured for these samples: pH, electrical conductivity (EC), total dissolved solids (TDS), oxidation-reduction potential (ORP), hardness, alkalinity, salinity, specific gravity, temperature, taste, color, and odor. Additionally, we examined chemical components such as fluoride (F^-), nitrate (NO_3^-), bicarbonate (HCO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), and chloride (Cl^-). We also took measurements of iron levels and looked for fecal coliforms. According to our research, both banks' groundwater salinities are noticeably high, with the Right Bank exhibiting a mean TDS of 8983 mg/L, which is higher than the Left Bank's mean TDS of 3163 mg/L.

1.3 Results: It was found that the groundwater on both banks of the Malir River was polluted.Specifically, the right bank (RB) had higher levels of pollution than the left bank (LB). After the water was analyzed, it was discovered that harmful bacteria were present in around half of the samples from RB and slightly more than half from LB. This suggests that the groundwater in this vicinity has probably been contaminated by sewage.

1.4 Conclusions: The research area's groundwater properties are altered by both natural and anthropogenic causes, as indicated by the five major components that were found by Principal Component Analysis (PCA). It has been determined that the groundwater near the Malir River is unsafe to drink on both sides, with the condition being worse on the right bank.
Keywords:Groundwater Pollution, Health Effects, Dental Health, Water Quality Index, Malir River Contamination

2. Introduction:

Water quantity is important, but so is water quality for ecosystems and humans. Having an adequate and safe supply of drinking water is essential for a country's development. Although groundwater is a great supply of fresh water, authorities nevertheless face several obstacles in ensuring its sustainable usage. The region's geology, geochemical processes, and land use patterns are some of the variables that affect groundwater chemistry. Therefore, both naturally occurring (geogenic) and artificially generated (anthropogenic) processes have a major influence on the composition of groundwater.Groundwater is becoming more and more in demand as a result of urbanization, industry, and population increase. Part of the reason for this growing need is the widespread use of fertilizers and pesticides. Because of this, scientists have been concentrating more on researching groundwater quality, underscoring its rising importance in the last several years. As a result, groundwater reserves are currently thought to be among the most important worldwide.
Surface water and nearby groundwater are linked and have a great deal of influence on one another. Aquifers that have surface water seeping into them frequently see changes in the quality of their groundwater. For example, changes in surface water levels throughout the year have a significant impact on groundwater quality. This dynamic is seen in regions along the Mekong River, such as Cambodia, where the river is replenished by river water during the rainy season and is supplied by groundwater during the dry seasons. The Arikaree River in North America serves as an example of an inverse relationship between river stream flow and surrounding groundwater levels, where excessive groundwater pumping results in lower water table levels.It has been demonstrated that contaminated water from India's Kham River seeps into the groundwater of neighboring communities, raising serious issues for the environment and human health. In a similar vein, Orlikowski and colleagues' 2002 study demonstrated how river water had a detrimental impact on the groundwater quality in Lobau, Vienna's metropolitan neighborhoods. Groundwater is frequently utilized for agricultural field irrigation in the Malir River watershed. Regretfully, studies show that several plant species are negatively impacted by Malir's tainted groundwater and river water.

These findings suggest that groundwater pollution on both sides of the Malir River's banks may be caused by the river's contaminated waters. Unfortunately, because there isn't much municipal water available, most of the low-income residents who live near the banks rely mainly on groundwater. The water table is dropping as a result of this over-reliance on groundwater, which puts pressure on the river to refill the aquifers.Additionally, studies have demonstrated that pollution has influenced the quality of the groundwater in a number of locations along the Malir River (Siddique et al., 2012; Khattak and Khattak, 2013; Farooq et al., 2010).
Particularly on both sides, the Malir River watershed remains largely unexplored in terms of groundwater quality. In the future, the residents may face serious health hazards as a result of this knowledge gap.Conducting a comprehensive analysis is crucial in evaluating the quality of

groundwater in the vicinity of the Malir River in Karachi. This study employs techniques to examine the water's microbiological and chemical composition to achieve precisely that goal.

3. Literature review:

3.1 Overview of Groundwater in Pakistan:

Groundwater in Pakistan is a critical resource that plays a fundamental role in sustaining agriculture, industry, and domestic water supply across various regions. These are the salient features of Pakistani groundwater:

- Groundwater supports about 50% of Pakistan's drinking water needs and is essential for irrigating approximately 70% of the country's agricultural land.
- It is particularly crucial in areas where surface water availability is limited or unreliable, such as Balochistan and parts of Sindh.
- The Indus Basin aquifer is the primary groundwater source, covering extensive areas of Punjab and Sindh. This basin is among the largest and most productive aquifers globally, supporting intensive agriculture through an irrigation system.
- .Groundwater availability varies across Pakistan. While Punjab and Sindh benefit from shallow aquifers that are easier to access. Other regions, like Balochistan and Khyber Pakhtunkhwa, have more isolated and deeper aquifers, making groundwater extraction challenging and costly.

3.2 Groundwater Quality in Malir District:

The search results indicate that the groundwater quality in Malir District, Karachi, Pakistan is poor and contaminated:

- According to research, groundwater samples from the Malir River region had high mean concentrations of main chemical elements such as calcium, magnesium, sodium, potassium, chloride, and sulfate, which defined the water as "hard".
- Nitrate levels were found to be higher than the permissible WHO guidelines.
- High levels of total dissolved solids (TDS) were attributed to the percolation of industrial wastes into the groundwater.
- An additional study article said that 35 out of 104 districts in Pakistan, including Malir, have arsenic pollution in their drinking groundwater supplies according to a nationwide survey conducted in 2001.

Groundwater contamination in Malir District, located in Karachi, Pakistan, due to various anthropogenic activities and natural factors.

3.2 Causes of Groundwater Contamination:

I. The main causes of contaminated groundwater:

- **Industrial Pollution:** The presence of industrial zones in and around Malir District contributes to groundwater contamination. Industrial effluents containing heavy metals, organic pollutants, and toxic chemicals seep into the groundwater, impacting its quality.
- **Agricultural Runoff:** Intensive agricultural practices in the area result in the use of fertilizers and pesticides. These chemicals leach into the soil and eventually contaminate the groundwater, affecting both quality and safety.
- **Urbanization and Domestic Waste:** Rapid urbanization and inadequate waste management systems lead to the discharge of untreated sewage into open drains and landfills. This untreated wastewater infiltrates groundwater aquifers, introducing pathogens and pollutants.
- **Saltwater intrusion** from the nearby Arabian Sea causes high salinity in groundwater.
- **Anthropogenic** activities in the area.
- **Illegal sand** and gravel mining is decreasing groundwater levels.
- **Disposal waste** of human and animal from nearby localities and cattle pens.

II. Types of Contaminants:

Heavy Metals: Industrial activities release heavy metals such as lead, cadmium, and chromium into the groundwater, posing risks of long-term health effects, including organ damage and neurological disorders .

Nitrate and Pesticides: Agricultural runoff introduces nitrates and pesticides into the groundwater, which are harmful to human health, particularly affecting infants and young children .

Microbial Contamination: Poor sanitation practices and inadequate sewage disposal lead to microbial contamination in the groundwater, causing diseases such as diarrhea, typhoid, and cholera.

3.3 Groundwater Quality Issues:

1. High levels of total dissolved solids (TDS), hardness, salinity, and specific gravity in groundwater samples.
2. Higher than normal amounts of key ions such as sulfate, calcium, magnesium, sodium, potassium, and chloride.
3. Nitrate levels exceed WHO permissible limits in many groundwater samples.
4. The presence of fecal coliforms indicates microbiological contamination.
5. Shallow groundwater's brackish and unfitness for human consumption.

3.4 Impacts on the Local Population:

1. Villagers in the Malir district have to travel long distances (up to 1 km) to obtain potable water.
2. Consumption of contaminated groundwater has led to the spread of diseases like hepatitis, with 70% of the population in Malir, Gadap, and Bin Qasim areas lacking access to clean tap water.
3. Farmers are facing challenges in growing crops due to declining groundwater levels and poor water quality.

4. Malir, once known as the fruit and vegetable basket of Karachi, is now losing its agricultural productivity and biodiversity.

Hence the groundwater in Malir district is severely contaminated due to various anthropogenic and natural factors, posing significant health risks to the local population and threatening the agricultural productivity of the area. Urgent measures are needed to address this critical issue.

3.5 Health Impacts:

- **Waterborne Diseases:** Contaminated groundwater in Malir District poses significant health risks, contributing to outbreaks of waterborne diseases such as cholera, typhoid, and hepatitis.
- **Chronic Health Effects:** Long-term exposure to contaminants like heavy metals (e.g., arsenic, lead) and high nitrate levels can lead to chronic health issues, including neurological disorders and cancers .

3.6 Regulatory and Management Challenges:

- Weak Regulatory Enforcement: Inadequate enforcement of environmental regulations allows industries to discharge pollutants freely, exacerbating groundwater contamination
- Lack of Monitoring: Limited groundwater monitoring infrastructure in Malir District hinders early detection of contamination and effective mitigation measures.

3.7 Mitigation Strategies:

- **Improved Sanitation:** Upgrading sanitation systems to prevent sewage seepage into groundwater can reduce microbial contamination.
- **Pollution Control:** Implementing stringent regulations and monitoring mechanisms to control industrial discharge and agricultural runoff.
- **Community Awareness:** Educating local communities about the importance of groundwater quality and promoting sustainable water use practices.

Addressing groundwater contamination in Malir District requires concerted efforts from regulatory bodies, industries, and the community to mitigate sources of pollution and ensure sustainable management practices. Effective governance, enhanced monitoring, and public awareness are essential to safeguarding this vital resource for future generations.

4.Material and method

4.1 Study Area:

In Karachi, Pakistan, Abbasi Shaheed Hospital plays a vital role in treating the health problems caused by contaminated groundwater in the neighborhood, especially in the Malir District. This region's groundwater quality is severely degraded by a variety of toxins, which causes a host of health issues.

I.Groundwater Contamination in Abbasi Shaheed Hospital Area:

Groundwater Pollution in the Hospital Area of Abbasi ShaheedImportant information on groundwater contamination issues surrounding Karachi, Pakistan's Abbasi Shaheed Hospital may be found in the search results:

One of Karachi's biggest public hospitals, the Abbasi Shaheed Hospital, has reportedly been using its grounds and the neighboring neighborhoods as dumping sites for unprocessed medical waste. There is a significant risk of groundwater pollution in the area due to this medical waste, which may contain infectious agents, dangerous chemicals, and other toxins.

Investigations have revealed that many trash dumps, both on hospital property and in the surrounding area, are used to dispose of various types of medical waste. The improper disposal of medical waste can cause pollutants to seep into the soil and groundwater over time.

Experts have issued a warning, stating that the disposal of medical waste is a "volatile source of infection" that can infect a huge number of people in the vicinity by spreading via a variety of routes such as wind, rain, animals, and even car tires. The hospital's inadequate waste management procedures have put the public's health at risk.

The problem of groundwater pollution at Abbasi Shaheed Hospital is a subset of Karachi's more widespread issue of improper medical waste disposal. Hazardous medical waste is carelessly dumped into municipal hospitals due to a lack of infrastructure and appropriate waste disposal methods.

II.Potential Health Impacts of Groundwater Contamination:

The search results also highlight the potential health impacts of groundwater contamination in the Abbasi Shaheed Hospital area:

- Consuming tainted groundwater can cause poisoning from exposure to hazardous materials that have seeped into the water supply, as well as major health problems including diarrhea and hepatitis.
- Consumer health may be in danger if hazardous materials such as heavy metals build up in crops due to contaminated groundwater used for irrigation.
- Long-term consequences of groundwater pollution exposure may include an elevated chance of developing certain cancers.
- The health impacts of groundwater pollution, which might include "blue baby syndrome" due to high nitrate levels, are more severe for children and babies.
- Additionally harmful to the environment are surface water pollution, soil deterioration, and ecological disturbance caused by groundwater contamination.

In conclusion, the local populace is seriously in danger of serious health problems due to the Abbasi Shaheed Hospital's improper medical waste management and the ensuing groundwater pollution in the neighborhood. To solve this problem and guarantee the security of the environment and water supplies, immediate action is required.

4.2 Groundwater sampling:

As of right now, groundwater tests are being taken in advance of the monsoon season, namely between November 2023 and February 2024, to avoid any potential chemical changes in the groundwater brought on by precipitation seeping in. Twenty samples are being taken from the right bank (RB) and twenty from the left bank (LB) of the groundwater in total. An electrical pump is used to pull groundwater from drilling wells for two to three minutes to guarantee representative samples. In a similar vein, 50–80 pumps are used to extract samples from hand pump wells. The Global

Positioning System (GPS) is used to identify the sampling sites on the map and indicate the location of the wells on Google Maps. The following symbols are used to identify the four samples from each well: (A) for physicochemical analysis, (B) for bacterial analysis, (C) for nitrate measurement, and (D) for iron determination. Each sample is collected independently for various parameters. For physicochemical analysis, one to one-and-a-half-liter sanitized polystyrene vials are used to collect groundwater samples. In 200 ml sterilized bottles, samples are collected and stored in an icebox to detect bacteria (Coliform). Samples are collected in 200 ml plastic bottles and each sample is mixed with 2 ml of boric acid solution to measure the nitrate concentration.
After that, the samples were put in an ice box to keep their temperature at 4 °C. Samples were collected in 100ml clean plastic bottles to measure the iron concentration. As a preservative, two to three drops of hydrochloric acid were applied.

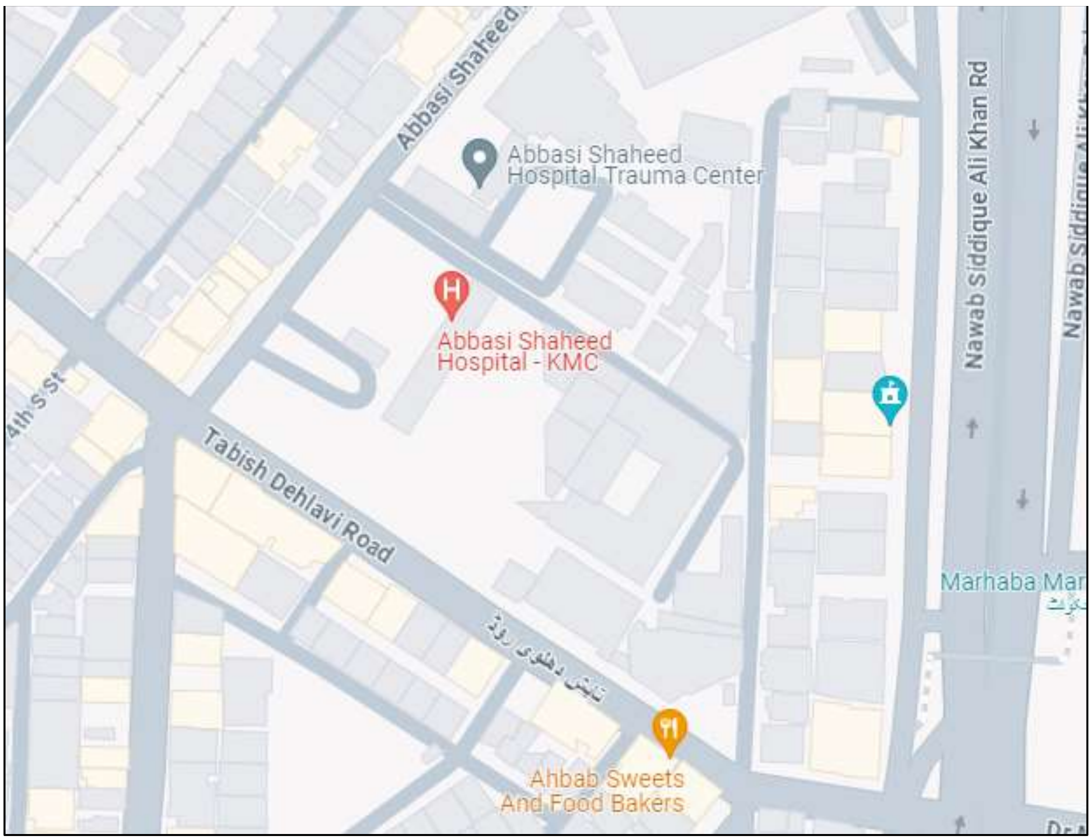


Fig. 1. Location map of the study area

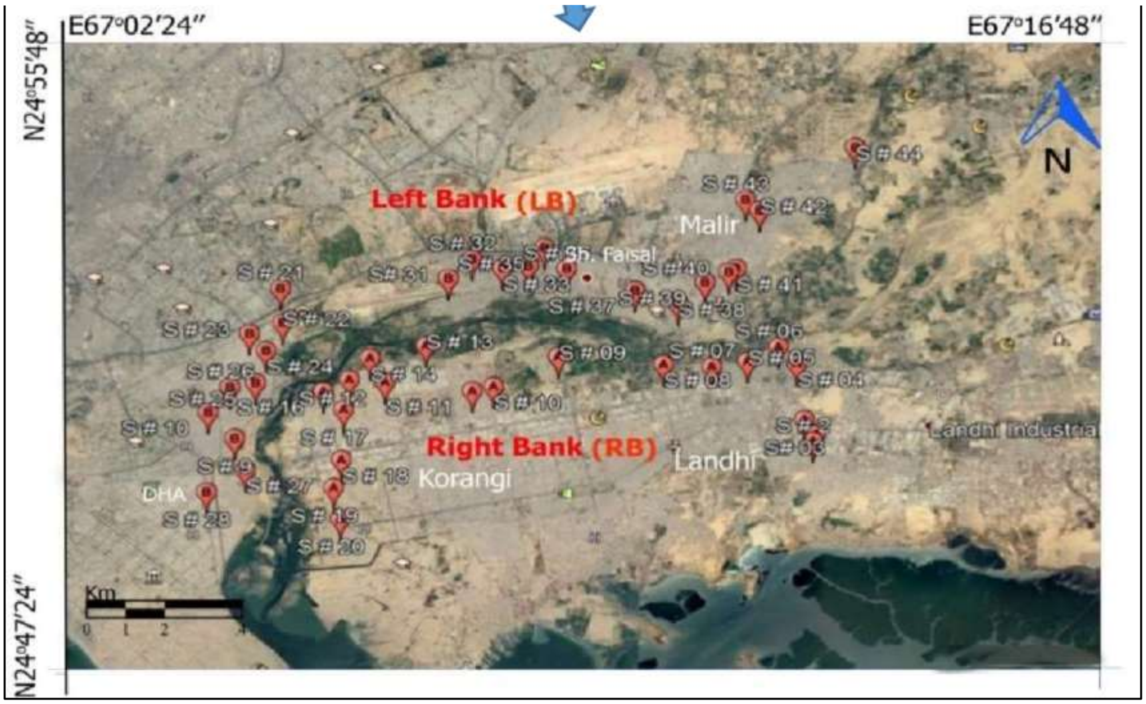


Fig. 2. collected groundwater samples

4.3 Analytical methods:

The current analytical techniques used to ascertain the physicochemical characteristics of groundwater samples are described in Table 1. These factors are examined in the University of Karachi's Department of Geology laboratory. The samples are transmitted to the Pakistan Council of Research in Water Resources (PCRWR) laboratory for the precise measurement of fluoride concentrations.

I.Microbiological and statistical analysis:

To determine if E. coli is present in groundwater samples that have been obtained, the Membrane Filter (MF) technique is employed. Principal Component Analysis (PCA) data and ionic correlations are assessed using SPSS software (Version 16.00).

5.Results and Discussion:

5.1 Aesthetic characteristics (color, taste, and odor):

Except for samples 1 and 5, which were taken from the right bank (RB) and left bank (LB), respectively, all of the current samples that were taken from both sides of the Malir River are colorless and odorless (see Tables 2 and 3). The light yellow color of these six samples is caused by the presence of suspended particles, dissolved iron, and organic materials. The sources of the pollutants in the study region are probably home effluents, household sewage, and industrial operations.

The research region may be separated into two distinct zones based on taste: a freshwater zone in the north and a salty zone in the south. Near coastal areas, such as DHA Phase VII, Manzoor Colony, Akhtar Colony, Kashmir Colony, and Qayyumabad, are where most of the salty samples are found in the LB, as well as the southern parts of Korangi along the RB of the Malir River. In the research region, samples from the right bank (RB) and left bank (LB) had around 55% and 33%, respectively, of salty to bitter tastes. These samples, which were taken at different depths (12 to 300 feet), show that the salinity of the groundwater in the area is not affected by changes in depth. This implies a consistent distribution of the saline source from shallow to deeper wells.

The main cause of the salty flavor is seawater infiltration, a process that past scholars have extensively studied. In addition, sewage mixing probably makes the high salt levels worse. The Malir River serves as the primary route for sewage infiltration, and industrial pollution from the Landhi and Karachi Industrial Trading Estates (LITE) and KITE additionally considerably raises the salinity in the area. This persistent problem emphasizes how urgently comprehensive groundwater management plans are needed to stop the spread of salt and safeguard the area's water quality.

Table 1. Equipment/methods used to analyze physicochemical parameters of groundwater samples

Sample no	Parameters	Equipment /Methods

1	Color	Visual observation
2	Odor and Taste	Aesthetically
3	Temperature	Thermometer
4	pH and Eh	pH meter, ADWA (AD 111)
5	Turbidity	Turbidity meter, Lamotte, model 2008, USA
6	Electrical Conductivity/TDS	EC meter, ADWA (AD 330)
7	Salinity and Specific gravity	Portable Refractometer
8	Hardness as CaCo3	EDTA Titration Standard Method (1992).
9	Alkalinity	APHA 2320 Standard Method (1992)
10	Bi-Carbonate	Titration Method (USSL, 1954)
11	Calcium	EDTA Titration Method
12	Chloride	Argentometric Titration Method
13	Carbonate	Titration Method, (USSL, 1954)
14	Fluoride	Spectrophotometer, SPADNS (HACH)
15	Iron	Atomic Absorption Spectrometer
16	Magnesium	Titration Method
17	Nitrate	Spectrophotometer, HACH-8171
18	Potassium	Flame photometer (JENWAY PFP7)
19	Sodium	Flame photometer (JENWAY PFP7)
20	Sulphate	Spectrophotometer (DR 2800)

5.2 Physical parameters:

I.Groundwater Temperature:

- **Current Temperature Range:** The Malir River's groundwater temperatures range from 26°C to 32°C on both banks at the moment. On the right bank (RB) and left bank (LB) of the river, the measured mean temperatures are 31°C and 29°C, respectively.
- **Temperature** is an important factor that affects many elements of water quality, such as the development of bacteria, color, taste, odor, and corrosion potential. Groundwater temperature is one such parameter. High temperatures can encourage the growth of bacteria and cause

unfavorable alterations in the qualities of water, such as problems with taste and odor and a higher risk of corrosion [WHO, 2008].

- **Anthropogenic Impact:** Human activity is frequently the cause of long-term rises in groundwater temperature. The right bank's greater mean temperature (+30°C) is probably caused by the mixing of contaminated water from the Malir River, which raises the temperature of the groundwater in this area [Gunawardhana and Kazama, 2009].

II. Groundwater pH

- **Current pH Range:** Groundwater has a pH range of 6.3 to 8, ranging from basic to acidic. On the right bank, the mean pH is 7.3, whereas on the left bank, it is 7.4. While some groundwater samples have indicated somewhat acidic values, the majority of samples show neutral to slightly alkaline pH readings.
- **Permissible Range:** The pH of groundwater often complies with health criteria overall, falling between 6.5 to 8.5 on the World Health Organization's list of acceptable values [WHO, 2011].
- **pH's Effect on Water Quality:** Although pH has no direct effect on human health, higher pH values can cause more scale to accumulate in water heating systems. Furthermore, pH has a big impact on how minerals dissolve, which can change how soluble heavy metal ions are and promote microbial growth in the water [Zhang et al., 2009].
- **Sewage Infiltration:** The pH readings of the wells closest to the Malir River are marginally higher than those farther away. This is probably because sewage seeps into shallow groundwater, altering the pH balance and, as a result, the groundwater's quality [Narsimha et al., 2013].

This information is especially pertinent to the continuing research and health evaluations, which are being carried out by organizations like Abbasi Shaheed Hospital and center on the effects of groundwater pollution on public health in Karachi, Pakistan's Malir District.

The redox potential of groundwater varied considerably along the research area's left and right banks (RB and LB) in the current investigation. With mean values of +74.45 mV and +96.3 mV, respectively, the redox potential varied from -62 to +255 mV along RB and from -70 to +219 mV along LB (Tables 2 and 3). On both banks, the oxidation-reduction potential (ORP) readings were generally positive. Tables 2 and 3 indicate that a small number of samples four from RB and three from LB exhibited negative ORP values.A diminishing environment inside saline aquifers was indicated by the samples with negative ORP values, with the exception of sample number 2 .
Because of biological degradation processes, the existence of landfills containing organic matter probably affected the redox potential (Christensen et al., 2000; Atlas, 1981). With a mean difference of 21 mV, groundwater samples from RB had greater redox potential values in comparison. This disparity could suggest elevated bacterial activity as a result of sewage mixing from the neighboring Malir River or adjacent sources.

These results highlight the intricate relationships that exist in the research region surrounding Abbasi Shaheed Hospital between microbial activities, land use practices, and groundwater quality.

1. Total dissolved solids (TDS) concentration is very variable in the Abbasi Shaheed Hospital region along both sides of the Malir River. The TDS concentrations vary greatly:

2. TDS on the right bank (RB) has a mean value of 8,983 mg/L and a range of 216 mg/L to 48,442 mg/L.
3. TDS on the left bank (LB) had a mean value of 3,163 mg/L and a range of 1,242 mg/L to 9,408 mg/L (Tables 2 and 3).
4. The RB's higher average TDS value, which differs by 5,820 mg/L from the LB's, is mostly due to samples taken from southern Korangi's coastal regions, namely RB-16, RB-17, and RB-18.

These results underline the necessity for management plans and monitoring programs to reduce health concerns associated with high TDS levels by highlighting the notable regional heterogeneity in groundwater quality along the Malir River.

III. Current Results on Groundwater Quality:

Total Dissolved Solids (TDS) levels in groundwater samples are alarming, according to recent investigations done close to Abbasi Shaheed Hospital. TDS levels in the research area's two banks are higher than the 500 and 1000 mg/L drinking water guidelines recommended by Pakistan and the WHO, respectively. The TDS values of the right bank (RB) are notably greater than those of the left bank (LB), suggesting a notable degree of fluctuation that is probably impacted by both geological processes and human activity.

The elevated TDS content is primarily attributed to:

- **Geochemical Processes:** Natural processes within the aquifers contribute to the mineralization of groundwater, increasing TDS levels.
- **Human Activities:** Activities such as sewage water infiltration and industrial discharge introduce higher concentrations of major cations (Na, K, Ca, Mg) and anions (Cl, NO3, HCO3) into the groundwater. This contamination is exacerbated by bacterial presence, indicating potential sewage contamination .

Along the river banks (RB and LB), the turbidity levels of groundwater samples taken at Abbasi Shaheed Hospital range from 0.7 to 4.9 NTU, with a steady mean value of 1.4 NTU. These measurements indicate relatively low pollution levels during the dry season, as they are significantly below the WHO (2011) permitted limit of 5 NTU. The reduced turbidity levels can be attributed to the lack of notable siltation in the clay beds and soil .

The RB samples range from 230-10,000 mg/L (mean: 1946 mg/L) and the LB samples from 200-3,000 mg/L (mean: 872 mg/L). These ranges represent considerable differences in the hardness of the groundwater samples. Eighty-four percent of LB samples and over sixty percent of RB samples are beyond the 500 mg/L WHO drinking water acceptable limit. The very high levels of hardness in samples RB-16 and RB-18 are explained by their high calcium and magnesium content, which is most likely the result of groundwater interacting with mineral-rich rocks like limestone.

Table 2. Summary of physical parameters along RB of Malir River

Sample No	Coordinates		Locality	Place	Well dept (ft)	Well life	Color	Taste	Odor	pH	Eh (mv)	TDS (mg/L)	EC (mS/cm)	Temp. (°C)	Turbidity (NTU)	Salinity (%)	Specific gravity (mm)	Hardness (mg/l)	Alkalinity as $CaCO_3$ (mg/l)
	Latitude	Longitude																	
RB-01	24.83'66.572"	67°21'67.43"	Bilal Colony Landhi	House	40	3 years	Colorless	UO	UO	7.25	125	1216	1.90	29	0.8	0	1	370	250
RB-02	24.83'49.882"	67°21'61.15"	Bilal Colony Landhi	Street	35	10 months	Colorless	UO	UO	7.90	-62	1171	1.83	30	1.2	0	1	230	200
RB-03	24.84'03.36"	67°21'39.92"	Mehmood Nagar Landhi	Masjid	40	3 years	Colorless	UO	UO	7.34	164	1254	1.96	31	0.6	0	1	320	100
RB-04	24.84'43.02"	67°21'20.71"	Qaidabad	Masjid	120	>12 years	Colorless	UO	UO	7.14	157	979	1.53	30	0.8	0	1	410	150
RB-05	24.84'49.52"	67°20'10.61"	Future Colony	Shope	110	10 months	Colorless	UO	UO	7.25	151	928	1.45	30	1.2	0	1	420	250
RB-06	24.84'58.48"	67°20'76.98"	Murghi Khana	House	160	3 days	Colorless	UO	UO	7.33	128	1568	2.45	31	3.5	0	1	450	250
RB-07	24.51'11.9772"	67°11'31.68"	Korangi	Service station	120	+20 years	Colorless	UO	UO	8.00	255	1114	1.74	28	2.5	0	1	460	200
RB-08	24.51'12.808"	67°10'51.056"	Murtaza Chowrangi	Masjid	750	3-4 months	Colorless	Salty	UO	7.85	163	6611	10.33	27	1.9	2	1.002	1475	100
RB-09	24.51'18.910"	67°9'22.820"	Allah Bukhs Goat	Masjid	120	1 year	Colorless	UO	UO	7.77	181	3821	5.97	29	0.8	0	1	980	200
RB-10	24.50'50.64"	67°8'28.651"	Gulshane Bilal, Korangi	Masjid	180	1 year	Colorless	UO	UO	7.45	155	3392	5.3	30	0.5	0	1	910	500
RB-11	24.50'46.43"	67°8'10.94"	Bilal Colony, Kongari	Masjid	200	+15 years	Colorless	Bitter	UO	7.21	124	9856	15.4	30	0.6	15	1.012	3440	25
RB-12	24.50'52.95"	67°6'57.44"	Mehran Town, Kongari	Masjid	80	+5 years	Colorless	Salty	UO	7.33	120	10643	16.63	29	0.7	8	1.005	2020	100
RB-13	24.51'26.69"	67°7'31.20"	Kongari Sector 7A	Factory	300	7 months	Colorless	Salty	UO	7.03	98	3795	5.93	28	2	10	1.01	700	180
RB-14	24.51'14.71"	67°6'44.37"	Mehran Town, Kongari	Masjid	117	6 months	Light yellow	Salty	UO	7.11	38	3846	6.01	30.08	0.4	8	1.005	3000	170
RB-15	24.50'55.00"	67°6'27.40"	Kongari Sector 6	Masjid	88	9 years	Colorless	Bitter	UO	7.00	-65	9847	13.98	30.5	0.4	11	1.011	900	100
RB-16	24.50'43.96"	67°6'5.77"	Kongari Sector 5	Home	150	6 months	Colorless	Bitter	UO	6.77	-126	38784	60.6	30.1	1.1	20	1.015	10000	360
RB-17	24.50'27.78"	67°6'23.08"	Kongari Sector 6	Masjid	100	7 years	Colorless	Bitter	UO	6.38	86	25459	39.78	31.1	2.9	19	1.014	500	220
RB-18	24.49'42.22"	67°6'22.16"	Allahwala Town Sector A	Masjid	30	3 years	Colorless	Bitter	UO	6.51	-180	48442	75.69	30	0.7	25	1.024	10000	210
RB-19	24.49'16.92"	67°6'16.16"	Bhitai Colony	Masjid	15	15 days	Colorless	Bitter	UO	7.10	16	6394	9.99	31.3	0	8	1.005	1300	150
RB-20	24.48'49.00"	67°6'22.51"	Bhitai Colony	Home	25	2 years	Colorless	Bitter	UO	7.28	-101	1440	2.25	30.1	1.4	5	1.001	1400	190
Min	-	-	-	-	-	-	-	-	-	6,28	-180	928	1.45	27	0	0	1	230	25
Max	-	-	-	-	-	-	-	-	-	8	255	48442	75.69	31.3	4.9	25	1.024	10000	500
Mean	-	-	-	-	-	-	-	-	-	7,3	71.4	8983	14.0	29.8	1.4	6.6	1	1964.3	195.5
WHO	**-**	**-**	**-**	**-**	**-**	**-**	**Colorless**	**UO**	**UO**	**6.5-8.5**	**-**	**500**	**-**	**-**	**0**	**0**	**-**	**500**	**500**

Table 3. Summary of physical parameters along LB of Malir River

Sample No	Coordinates		Locality	Place	Well dept (ft)	Well life	Color	Taste	Odor	pH	Eh (mv)	TDS (mg/L)	EC (mS/cm)	Temp. (°C)	Turbidity (NTU)	Salinity (%)	Specific gravity (mm)	Hardness (mg/l)	Alkalinity as $CaCO_3$ (mg/l)
	Latitude	Longitude																	
RB-21	24.52'16.42"	67°5'27.90"	Karsaz	Home	252	1 year	Colorless	Salty	UO	6.82	76	3904	6.1	32	0.8	10	1.01	600	150
RB-22	24.51'45.34"	67°5'30.34"	Falcon Complex Faisal	Masjid	25	15 years	Light yellow	Salty	UO	7.01	57	5325	8.3	32	0.72	5	1.001	1200	170
RB-23	24.51'35.14"	67°5'2.47"	KAEHS Block 8	Home	128	3 years	Colorless	UO	UO	6.45	38	2752	4.3	29	0.01	0	1	1500	200
RB-24	24.51'19.94"	67°5'16.85"	Manzor Colony Sec I	Masjid	43	25 years	Colorless	Salty	UO	6.32	97	4173	6.5	30	0.6	5	1.001	800	190
RB-25	24.50'50.60"	67°5'8.60"	Manzor Colony Sec E	Home	15	20 years	Colorless	Salty	UO	7.21	16	1126	1.8	30	1.2	5	1.001	900	260
RB-26	24.50'46.40"	67°4'47.18"	Junaijo Town	Home	26	3 years	Light yellow	UO	UO	7.52	40	5280	8.3	31	0.6	0	1	1100	100
RB-27	24.49'31.66"	67°5'1.80"	Qayyumabad	Masjid	37	3 years	Colorless	Salty	UO	6.91	51	9408	15	30	1.2	15	1.012	3000	100
RB-28	24.49'11.15"	67°4'29.35"	DHA phas 7	Masjid	25	dna	Light yellow	Salty	UO	7.42	-70	1613	2.5	30	1.6	15	1.012	400	110
RB-29	24.49'59.98"	67°4'52.01"	DVHS	House	102	dna	Light yellow	Salty	UO	7.62	-20	5107	8	26	2.01	5	1.001	920	230
RB-30	24.50'23.38"	67°4'29.22"	Akhtar Colony	House	36	dna	Light yellow	Salty	UO	6.50	125	1267	2	26	2.26	10	1.01	620	185
RB-31	24.52'28.3944"	67°7'65.52"	Shah Faisal No: 05	Masjid	110	3 years	Colorless	UO	UO	7.76	107	3014	4.7	29	1.2	0	1	440	50
RB-32	24.52'45.685"	67°8'8.196"	Shah Faisal No: 04	Masjid	100	3 years	Colorless	UO	UO	8.03	169	1242	1.9	29	0.8	0	1	200	150
RB-33	24.52'37.9164"	67°8'34.3284"	Shah Faisal No: 1 Rita Plot	Masjid	75	3 years	Colorless	UO	UO	7.70	109	3046	4.8	28	0.6	0	1	500	175
RB-34	24.52'40.1556"	67°8'55.8024"	Shah Faisal No: 2 Rita Plot	Masjid	90	4 years	Colorless	UO	UO	7.64	146	3130	4.9	30	0.7	0	1	540	500
RB-35	24.52'56.2416"	67°9'8.8992"	Shah Faisal No: 3	Masjid	75	10 years	Colorless	UO	UO	7.65	130	3846	6	30	1.1	0	1	1020	100
RB-36	24.52'38.0496"	67°9'27.342"	Shah Faisal No: 3	Masjid	120	1 month	Colorless	UO	UO	7.72	80	5069	7.9	29	1.2	0	1	1040	250
RB-37	24.52'19.8804"	67°10'25.9716"	Gulhane Ghazali	Home	140	2 years	Colorless	UO	UO	7.6	92	1888	3	28	1.5	0	1	580	250
RB-38	24.52'8.4864"	67°11'2.238"	Muhammad Ali Shaheed	Home	120	2 years	Colorless	UO	UO	7.57	100	1760	2.8	31	2.9	0	1	640	100
RB-39	24.52'28.0092"	67°11'24.8928"	Baghe Ibrahim	Home	150	3-4 months	Colorless	UO	UO	7.83	85	1869	2.9	30	3.5	0	1	700	40
RB-40	24.52'37.4088"	67°11'44.5776"	Chatai Ground, Asu Goth	Masjid	150	2 years	Colorless	UO	UO	7.40	160	1933	3	29	2.2	0	1	960	75
RB-41	24.52'40.7712"	67°11'50.8632"	Bakra Piri, Asu Goth	Masjid	120	10 years	Colorless	UO	UO	7.27	174	3174	5	30	2.6	0	1	1300	250
RB-42	24.53'34.2348"	67°12'09.1404"	Jafar-e-Tayyar	Masjid	150	16 years	Colorless	UO	UO	7.96	148	1536	2.4	27	1.5	0	1	300	20
RB-43	24.53'43.5372"	67°11'56.814"	Urdu Nagar, Malir Colony	Masjid	220	2 years	Colorless	UO	UO	7.35	219	2598	4.1	28	0.7	0	1	900	125
RB-44	24.54'32.0688"	67°13'28.2576"	Aram Goth	Masjid	130	6 years	Colorless	UO	UO	7.41	189	1862	2.9	31	1.1	0	1	780	100
Min	-	-	-	-	15	-	-	-	-	6,32	-70	1126	1.8	26	0.01	0	1	200	20
Max	-	-	-	-	252	-	-	-	-	8.03	219	9408	15	32	3.5	15	1.012	3000	500
Mean	-	-	-	-	-	-	-	-	-	7.4	96.3	3163	4.9	29.4	1.4	2.9	1	872.5	161.7
WHO	**-**	**-**	**-**	**-**	**-**	**-**	**Colorless**	**UO**	**UO**	**6.5-8.5**	**-**	**500**	**-**	**-**	**0**	**0**	**-**	**500**	**500**

Fig. 3. Relationship between salinity and ORP of groundwater samples

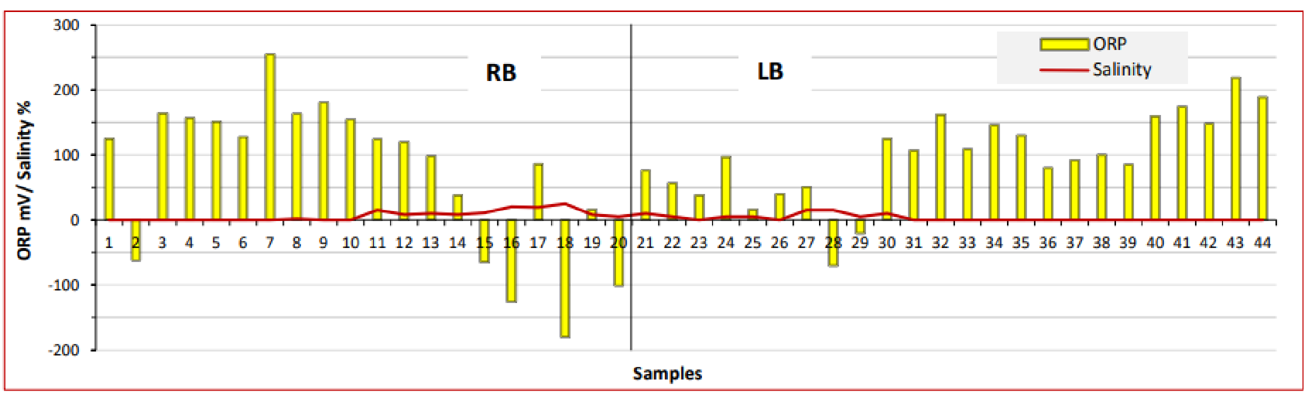


Fig.4. Distribution pattern of hardness of groundwater samples along banks of Malir River

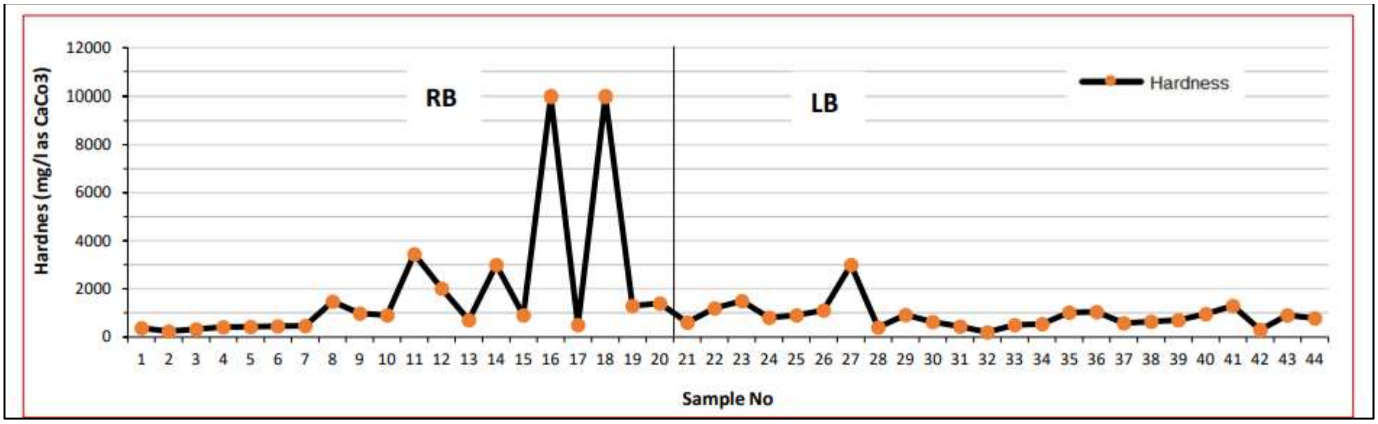
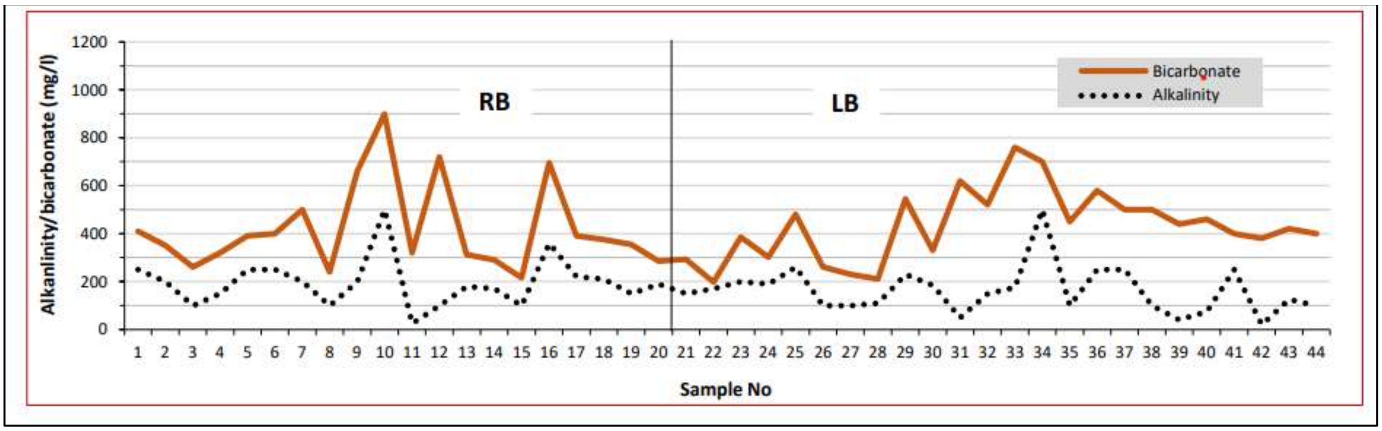


Fig. 5. Direct relationship between alkalinity and bicarbonate of groundwater samples along banks of Malir River



5.3 Chemical parameters:

I. Major cations:

Recent measurements of salt levels in groundwater from the Malir River's two banks reveal values that are far higher than the 200 mg/L WHO drinking water permitted standard from 2011. On the right bank (RB), the sodium concentration ranged from 272 to 14,809 mg/L, whereas on the left bank (LB), it ranged from 986 to 2,221 mg/L. On average, RB had twice the sodium content of LB. This suggests that RB is being impacted by significant industrial contamination and saltwater incursion. Due presumably to agricultural operations, potassium levels are also above the WHO's recommended range of 12 mg/L, with RB and LB concentrations ranging from 17 to 160 mg/L and 13 to 130 mg/L, respectively. The serious health hazards posed by this contamination highlight the necessity of efficient water management techniques, especially in the vicinity of residential areas like Korangi and DHA Phase VII. The excessive salinity of groundwater further degrades the quality of the water. Abbasi

Shaheed Hospital is noteworthy because it emphasizes how urgent it is to take steps to protect these areas' public health.

In the Malir District, near Abbasi Shaheed Hospital, groundwater exhibits variable calcium and magnesium concentrations. On the right bank (RB) of the Malir River, calcium levels range from 201-750 mg/L, with a mean of 206 mg/L. In contrast, on the left bank (LB), levels are between 8-348 mg/L, averaging 94 mg/L. Only 35% of RB and 45% of LB samples meet the WHO's 2011 permissible limit of 75 mg/L for calcium. The higher calcium levels on the RB are likely due to the limestone of the underlying Gaj Formation, while lower levels on the LB are due to the Manchar Formation's shale and sandstone.

Magnesium concentrations also vary widely RB values are between 36-2219 mg/L, averaging 370 mg/L, while LB values range from 44-669 mg/L, with an average of 165 mg/L. Only 35% of RB and 41% of LB samples are within the WHO's permissible limit of 150 mg/L. Higher magnesium levels on the RB may not be due to seawater intrusion, as areas like Qayyumabad and DHA Phase VII on the LB show lower values. Instead, sewage mixing is likely the cause of elevated magnesium levels, which can act as a laxative when present in drinking water.

Key Points:

- **Calcium:** High on RB (due to limestone); low on LB (due to shale and sandstone).
- **Magnesium:** High on RB (due to sewage mixing); low on LB (seawater intrusion not a factor).

II. Major anions:

Chloride (Cl-) Concentration:

- Range: 177-30,666 mg/L on the right bank (RB) and 175-7,801 mg/L on the left bank (LB) of Malir River.
- Mean Values: 3,891 mg/L (RB) and 1,963 mg/L (LB).
- Exceedance: 85% (RB) and 88% (LB) of samples exceed WHO limits.
- Source: Seawater intrusion near Qayyumabad and Gizri Creek, anthropogenic activities.

Sulphate (SO4) Concentration:

- Range: 342-2,123 mg/L (RB) and 69-1,536 mg/L (LB).
- Mean Values: 4 times (RB) and 3 times (LB) higher than the WHO limit (250 mg/L).
- Source: Gypsum dissolution from Gaj Formation, SO4 fertilizers, sewage, industrial discharges, and fossil fuel smoke.

Nitrate (NO3) Concentration:

- Range: 2.5-27.7 mg/L (RB) and 2.4-18.9 mg/L (LB).
- Mean Values: 10 mg/L (RB) and 11 mg/L (LB).
- Exceedance: 40% of samples above the permissible limit (10 mg/L).
- Source: Fecal bacteria, organic matter oxidation, reducing conditions.

Bicarbonate (HCO3) Concentration:

- Range: 215-900 mg/L (RB) and 198-760 mg/L (LB).
- Mean Values: 419 mg/L (RB) and 432 mg/L (LB).
- Exceedance: 80% of samples exceed the WHO limit (300 mg/L).
- Source: Soil zone CO2, silicate mineral dissolution, organic matter decomposition.

Fluoride (F-) Concentration:

- Range: 0.9-5.6 mg/L (RB) and 0.8-3.8 mg/L (LB).
- Mean Value: 2 mg/L.
- Exceedance: 45% (RB) and 67% (LB) of samples exceed the WHO limit (1.5 mg/L).
- Source: Industrial discharge, minerals like mica, amphibole, and apatite.

Table.4 Summary of chemical parameters along RB of Malir River

Sample No	Cation				Anions					Minor Element
	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Chloride (Cl)	Sulphate (SO4)	Bicarbonate (HCO3)	Nitrate (NO3)	Fluoride (F)	Iron (Fe)
RB 1	72	46	440	32	355	342	410	2.5	1.01	BDL
RB 2	20	44	535	17	284	961	350	3.6	1.01	BDL
RB 3	68	36	272	32	177	814	260	3.88	1.02	BDL
RB 4	60	63	385	30	284	969	320	9.85	0.98	BDL
RB 5	80	53	341	57	213	1331	390	10.69	0.9	BDL
RB 6	70	67	547	23	567	1237	400	5.10	1.11	BDL
RB 7	72	68	418	69	319	794	500	11.97	1.25	BDL
RB 8	200	237	1282	30	3901	1729	240	9.34	1.35	BDL
RB 9	96	182	955	23	2021	1280	660	11.26	1.5	BDL
RB 10	84	170	907	62	1525	889	900	12.88	1.89	1
RB 11	720	399	5060	160	9574	1368	320	9.56	1.98	BDL
RB 12	84	440	1250	86	6737	2123	720	13.50	1.74	BDL
RB 13	74	125	1515	37	198	678	312	27.69	2.4	6
RB 14	275	562	1290	48	1002	2012	290	25.21	1.5	40
RB 15	104	156	1830	105	3020	739	215	7.6	1.9	46
RB 16	348	2219	14809	140	1998	2049	695	8.66	5.54	79
RB 17	590	237	8615	139	12720	490	390	8.42	5.51	260
RB 18	750	1974	979	158	30666	505	375	16	5.55	19
RB 19	159	219	2606	102	1998	370	355	11.67	2.52	90
RB 20	195	250	375	70	258	675	285	3.37	1.05	65
WHO	75	150	200	12	250	250	300	10	1.5	300

Samples above Permissible limit	**13**	**12**	**2O**	**2O**	**17**	**2O**	**15**	**9**	**11**	**O**

Health Impacts:

- **High Chloride:** Gastrointestinal irritation.
- **High Sulphate:** Laxative effects, catharsis at high doses.
- **High Nitrate:** Methemoglobinemia in infants, reducing conditions in aquifers.
- **High Bicarbonate:** Indicators of organic matter decomposition, potential gastrointestinal issues.
- **High Fluoride:** Dental and skeletal fluorosis, severe skeletal damage at high concentrations.

Table 5.Summary of chemical parameters along LB of Malir River

Sample No	Cation				Anions					Minor Element
	Calcium (Ca)	**Magnesium (Mg)**	**Sodium (Na)**	**Potassium (K)**	**Chloride (Cl)**	**Sulphate (SO4)**	**Bicarbonate (HCO3)**	**Nitrate (NO3)**	**Fluoride (F)**	**Iron (Fe)**

LB 21	124	7O	855	25	1O98	22O	292	8.O3	1.6	1O
LB 22	149	2O1	13O5	85	1695	981	198	13.8	1.9	BDL
LB 23	222	153	561	38	458	659	385	4.O1	1.7	6
LB 24	1O4	6O	1O69	11O	175	321	3O2	18.88	2.7	BDL
LB 25	119	156	2O3	74	165O	1O5	48O	4.6	1.86	BDL
LB 26	98	195	1449	13O	598	255	261	1O	2.62	2O
LB 27	82	669	435O	129	195	645	23O	9.O6	3.1	1O
LB 28	2O1	47	222	8O	2O5	118	21O	12.9	1.56	1O6
LB 29	79	1O1	1198	1O4	21O8	121	545	8.48	2.55	285O
LB 3o	44	1O3	258	69	599	69	33O	4.19	1.23	776
LB 31	8	8O	895	32	994	125O	62O	11.12	2.99	1O
LB 32	32	44	58O	16	355	1371	52O	11.4O	1.4	BDL

LB 33	4O	1O2	1OOO	24	1383	1273	76O	11.42	3.1	BDL
LB 34	48	1O7	1O1O	25	1418	997	7OO	11.84	3.12	BDL
LB 35	8O	219	1582	27	195O	8O6	45O	1O.88	2.9	BDL
LB 36	6O	2O4	162O	23	312O	733	58O	9.15	3.8	19
LB	64	1O4	6OO	21	745	512	5OO	9.5O	1.33	BDL
LB 38	52	117	938	25	7O9	924	5OO	2.38	1.27	BDL
LB 39	56	139	1143	18	887	1319	44O	1O.13	1.79	BDL
LB 4O	1OO	199	5OO	19	5851	558	46O	7.89	2.1	BDL
LB 41	24	255	633	21	78O1	83O	4OO	2.4	1.O1	16
LB 42	88	58	589	15	3O14	711	38O	18.9	1.85	BDL
LB 43	4O	165	757	14	6O28	941	42O	1O	O.84	BDL
WHO	75	15O	2OO	12	25O	25O	3OO	1O	1.5	3OO
Samples above Permissible limit	**13**	**11**	**24**	**24**	**21**	**2O**	**2O**	**12**	**16**	**2**

Analyze quality:

- **Location:** Malir District, Karachi, Pakistan.
- **Institution:** Abbasi Shaheed Hospital.
- **Findings:** Significant variations in groundwater quality parameters indicate severe contamination primarily due to seawater intrusion, anthropogenic activities, and industrial discharges.

III. Trace element:

High fluctuation may be seen in the amounts of iron present in groundwater from both sides of the Malir River. Levels vary from 1 to 460 µg/L on the right bank (RB) and from 6 to 2850 µg/L on the left bank (LB). With an average of 51 µg/L, the mean iron content on the LB is about three times higher than that on the RB. The anomalously high amounts in samples LB-29 and LB-30 are the main cause of the increased mean on the LB (see Tables 4 and 5). Except for RB-15, LB-29, and LB-30, the majority of samples are below the 300 µg/L WHO acceptable level. Except for a few possible anomalies caused by reducing or iron-rich local sources, the typically low iron content indicates an oxidizing climate along both banks.

IV. Microbiological analysis:

Significant pollution, most likely from sewage infiltration, has been found in groundwater samples from the Malir District, including the area around Abbasi Shaheed Hospital, according to a qualitative investigation. Fecal coliform was present in around 50% and 62% of samples from the Malir River's right and left banks, respectively. Sewage infiltration from the Malir River was indicated by the higher amounts of sodium, potassium, chloride, sulfate, and fluoride ions detected in contaminated wells, which were also observed at shallow depths.

The primary source of fecal contamination is latrine leakage, leading to high levels of nitrates and E. coli bacteria in groundwater. This poses serious health risks to the residents of the area, including patients and staff at Abbasi Shaheed Hospital.

5.4 Statistical analysis:

I.Ionic correlation:

The ionic correlation between physicochemical parameters including physical parameters, well depth, temperature, pH, Eh, salinity, specific gravity, TDS, EC, hardness, and alkalinity while chemical parameters include major cations (Na, K, Ca, Mg), anion (Cl, NO3, SO4, HCO3) of collected groundwater samples was done for RB and LB.

II. RB:

Groundwater at Abbasi Shaheed Hospital shows strong correlations between Total Dissolved Solids (TDS), salinity, specific gravity, and electrical conductivity (EC) with major cations (Ca, Mg, Na, and K). This indicates that these cations contribute significantly to the elevated TDS and salinity levels in the groundwater [1]. Hardness also correlates strongly with Ca2+, Mg2+, Na+, and K+, with Mg showing the strongest correlation (r=0.90) followed by Ca (r=0.6), suggesting their influence on groundwater hardness along the RB of Malir River [2].

Moderate correlations exist between sulfate (SO4) and Mg (0.4), indicating leaching from evaporitic sediments rich in gypsiferous shale, consistent with local geology [3]. Bicarbonate (HCO3) shows a strong correlation with alkalinity (r=0.67), influenced by redox processes and organic matter oxidation in aquifers [4]. Fluoride showed a strong correlation with TDS (r =0.9), salinity (r =0.8), hardness (r

=0.7), EC (r =0.9), Ca (r =0.7), Mg (r =0.58), Na (r =0.94,) and K (r =0.7) suggesting the dissolution with major salts from sediments.

III.LB:

The relationship between pH and total dissolved solids (TDS) is perfect (r = 1). TDS is mostly regulated along LB, as seen by its significant correlation (r = 0.9) with Mg and moderate correlation (r = 0.6) with Na. Na ions indicate seawater incursion in the region because they closely correlate with TDS, salinity, specific gravity, EC, and Mg. Na likewise has a negative correlation (r = -0.69) with depth, indicating that shallow aquifers close to the coast may have seawater intrusion. Fecal coliform presence supports a weak negative association between temperature and TDS (r = -0.23), which may be caused by sewage pollution. Strong positive connections have been found between fluoride and pH (r = 0.61), TDS (r = 0.61), and magnesium (r = 0.57), with the former coming presumably from clays, weathering of mica, and agricultural practices.

Table 6 Summary of microbiological characterization of groundwater samples of the study area

RB			RB			Total	
No. of Samples with +ve E. Coli	**Samples**	**%age**	**No. of Samples with +ve E. Coli**	**Samples**	**%age**	**No Samples**	**%age**
1O	1, 2, 3, 4, 8,11 15, 18, 19 and 20	5O%	11	21, 23, 24, 25, 26 28, 30, 34, 35, 38 and 40	45%	21	47.5%

conclusion:

It is concluded that groundwater along both banks of the Malir River is unfit for drinking purposes, but the situation is worse on the RB as compared to the LB. High salinity and hardness are the key factors in deteriorating the groundwater quality along both banks. Most of the physicochemical parameters exceed the permissible limits of WHO. The main parameters in deteriorating the groundwater quality are TDS, Na+, Mg2+, Ca2+, K+, Cl-, SO4 2-, HCO3 -, NO3 -, and F- along both banks of the river. Major cation varied in the order of Na+ (mean: 2221mg/L) > Mg2+ (376mg/L) > Ca2+ (206mg/L) > K+ (71mg/L) and anions Cl- (mean: 3891mg/1) > SO4 2- (1068mg/L) > HCO3 - (419mg/L) > NO3 - (11mg/L)> F- (2mg/L, 2mg/L) along RB while to the LB as Na+ (mean: 986mg/L) > Mg2+ (155mg/L) > Ca2+ (94mg/L) > K+ (47mg/L) and anions Cl- (1963mg/L) > SO4 2- (722mg/L) > HCO3 - (432mg/L) > NO3 - (10mg/L), F- (2mg/L). About 50% and 60% of samples each from RB and LB have pathogenic bacterial occurrence, which suggests that sewage contamination is common in the ground waters of the study area. PCA revealed five significant factors that indicate that both geogenic and anthropogenic factors are responsible for altering the groundwater characteristics of the study area.

References

Anawar, H.M., Tareq, S.M., Ahmed, G. (2024). Is organic matter a source or redox driver or both for arsenic release in groundwater? *Physics and Chemistry of the Earth*, 58-60, 49-56.

Atlas, R.M. (2024). Microbial degradation of petroleum hydrocarbon: An environmental perspective. *Microbiological Reviews*, 45, 180-209.

Babu, P., Linga, P., Kumar, R., Englezos, P. (2024). A review of the hydrate-based gas separation (HBGS) process for carbon dioxide pre-combustion capture. *Energy*, 85, 261-279.

Banning, R.O.B. (2024). Analysis of groundwater and surface water interactions in the Arikaree river basin of Eastern Colorado. MS Thesis, Department of Civil and Environmental Engineering, Colorado State University.

Bhatnagar, P.D. (2024). Study of hardness of water due to the presence of high dissolved minerals calcium and magnesium. *Environmental Monitoring and Assessment*, 15, 209.

Bhattacharya, P., Chatterjee, D., Jacks, G. (2024). Occurrence of As-contaminated groundwater in alluvial aquifers from the Delta Plains, Eastern India: Options for safe drinking water supply. *Water Resources Development*, 13, 79-92.

Blount, C.W., Dickson, F.W. (2024). Gypsum-anhydrite equilibria in systems CaSO4, H_2O and $CaCO_3$-NaCl-H_2O. *American Mineralogist*, 58, 323-331.

Canters, K.J. (2024). Habitat Fragmentation and Infrastructure: Proceedings of the International Conference on Habitat Fragmentation, Infrastructure and the Role of Ecological Engineering, 17-21 September 2024, Maastricht and The Hague, The Netherlands. Ministry of Transport, Public Works and Water Management, Delft, The Netherlands.

CGWB. (2024). Annual report and other related reports on groundwater quality. Central Ground Water Board, New Delhi.

Christensen, T.H., Bjerg, P.L., Banwart, S.A., Jakobsen, R., Heron, G., Albrechtsen, H.J. (2024). Characterization of redox conditions in groundwater contaminant plumes. *Journal of Contaminant Hydrology*, 45, 165-241.

Cigna, A. (2024). Some remarks on phase equilibria of evaporites and other karstified rocks. *Le Grotte d'Italia*, 4, XXII, 201-208.

Cocchetto, D.M., Levy, G. (2024). Absorption of orally administered sodium sulfate in humans. *Journal of Pharmaceutical Sciences*, 70, 331-333.

McArthur, J.M., Ravenscroft, P., Safiulla, S., Thirlwall, M.F., 2024. Arsenic in groundwater: testing pollution mechanisms for sedimentary aquifers in Bangladesh. *Water Resources Research*, 37, 109-117.

McCreadie, H., Blowes, D.W., Ptacek, C.J., Jambor, J.L., 2024. Influence of reduction reactions and solid-phase composition on porewater concentrations of arsenic. *Environmental Science and Technology*, 34, 3159-3166.

Mohamadi, M., Mohamadi, G.M., Ebrahimi, K., 2024. Temporal and spatial variation of groundwater quality in Qazvin. *Journal of Iran Water Research*, 5(8), 41-52.

Momba, M.N.B., Malakate, V.K., Theron, J., 2024. Abundance of pathogenic *Escherichia coli*, *Salmonella typhimurium*, and *Vibrio cholerae* in Nkonkobe drinking water sources. *Journal of Water and Health*, 4, 289-296.

Morris, M.E., Levy, G., 2024. Absorption of sulphate from orally administered magnesium sulphate in man. *Journal of Toxicology - Clinical Toxicology*, 20, 107-114.

Mukherjee, A., Fryar, A.E., Thomas, W.A., 2024. Geologic, geomorphic, and hydrologic framework and evolution of the Bengal basin, India, and Bangladesh. *Journal of Asian Earth Sciences*, 34, 227-244.