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Integrated Surface and Groundwater Planning for Sustainable Water Security in Ghotki District, Sindh

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ABSTRACT

Groundwater quality in Ghotki district faces severe degradation, with a substantial proportion of sampled wells exceeding permissible limits for key physicochemical parameters, including electrical conductivity, total dissolved solids, hardness, sodium, calcium, and fluoride. While high saline and sodium concentrations negatively impact soil characteristics, crop yields, and long-term agricultural sustainability, elevated fluoride and hardness levels provide serious hazards to public health, particularly dental and skeletal fluorosis. Surface water from the Guddu Barrage on the Indus River is an essential supplemental and alternative water source in this situation. Built in 1962, the barrage regulates river flows to important irrigation canals, such as the Ghotki Feeder Canal, thereby supporting industrial water supply, large-scale dry-season cropping, flood management, and irrigation of more than one million hectares throughout northern Sindh and portions of Baluchistan. However, ongoing rehabilitation and effective management are necessary to ensure the barrage's continued operational effectiveness. To address water quality issues, this study emphasizes the need to integrate surface water from the Guddu Barrage with improved groundwater management and advanced treatment methods, such as reverse osmosis. To improve water security, protect public health, maintain agricultural production, and promote long-term socioeconomic development in Ghotki District, an integrated approach to water resources management is crucial.

Introduction

Water is the most essential and significant natural resource for life, including both surface water and groundwater, which are used for irrigation, industry, and domestic purposes [1]. Water is

widely distributed and an abundant source found in nature[2]. Public health is closely linked to the quality of the water used. Groundwater quality depends on several factors, including chemical, hydrological, geological, physical, and biological [3]. Groundwater pollution from anthropogenic activities is increasing and affecting both quality and quantity. In recent decades, there has been a rise in demand for freshwater [4]. It is necessary to identify parameters that exceed acceptable limits and are susceptible to pollution.

In Pakistan, groundwater is a major source of drinking water in several cities and accounts for approximately one-third of the total water resources. In Pakistan, 30% of the urban and 23.5% of the rural population have access to safe drinking water. [5] [6]. Several studies have reported concentrations of cations, anions, heavy metals, and biological and organic pollutants in groundwater in Sindh Province, which may pose health concerns. [7]. The water quality of the groundwater in District Ghotki is facing high variability. Groundwater quality is also affected by human activities, including industrialization. The study area, Ghotki, is predominantly agricultural, with limited industrial activity.

The contaminated water may cause serious health concerns, including high death rates in developing countries. Many cities in Sindh province rely on contaminated groundwater for daily use. Diarrhea is common in Pakistan; it is due to drinking polluted water. It is expected that Pakistan will face challenges related to drinking water in the future. [9].

Most of the irrigation water in Ghotki district is provided from the Guddu Barrage, on the left bank of the Indus River, through the Ghotki Feeder Canal. Data from March 2025 shows that the Ghotki Feeder Canal has a discharge of approximately 2,521 cusecs (cubic feet/second), which is a large quantity of canal water used for irrigation in the Ghotki district. Approximately 0.35 million farming households and 3 million rural population benefit from the Guddu Barrage, along with irrigating 1.05 million hectares of agricultural land across multiple districts, including Ghotki.

Groundwater is extensively used in the Ghotki district as an alternative source, especially when canal water is insufficient or during periods of scarcity; however, direct groundwater-extraction figures, which are usually precise, do not provide volumetric data. Groundwater available for use, compared with canal water, is limited in Sindh, including the Ghotki district, because groundwater is mostly saline, except near the Indus River. Groundwater is extracted from several tubewells throughout Sindh, and the aquifers have moderate yield potential; tubewell installation is commonplace but varies in density across districts. Annually, Pakistan extracts approximately 53.07 million acre-feet of groundwater [10].

In addition to irrigation, water from the Guddu Barrage canal is used for industrial processing and as drinking water in some villages, particularly in areas where groundwater is unsuitable or saline.

Most of the groundwater samples evaluated in Ghotki district are usable for human consumption, according to Water Quality Index (WQI) criteria. Approximately 74% of Ghotki groundwater samples categorized as 'excellent' drinking water were contaminated, often with arsenic levels exceeding limits. Groundwater from boreholes, tube wells, and hand pumps serves as a valuable source of drinking or household water in Ghotki. Groundwater in Ghotki can be found at depths approachable in many locations (5.24 meters on average).

The present research compares results with World Health Organization (WHO) standards by analyzing physicochemical characteristics and trace metal ions in groundwater from the relevant area, to conclude groundwater quality and potential health risks to humans. Ghotki has received a very poor water supply from the Guddu Barrage. The undersupply of water is primarily due to aging infrastructure and its operational dysfunction. The construction of the Guddu Barrage,

completed more than 50 years ago, presents serious safety concerns and operational issues related to gate corrosion, lifting mechanisms, electrical wiring, power supply and distribution, and the lack of backup. These issues have raised significant concerns about the operational efficiency and reliability of water delivery to Ghotki within the irrigation systems of Southern Sindh province, which are heavily relied upon. While the Guddu Barrage is an integral part of the region's water and irrigation supply, the age of machinery and outdated infrastructure have significantly contributed to undersupplying water for agricultural needs, livestock, and human consumption.

Effectively, there is an urgent need for reconditioning and reconstruction of the Guddu Barrage to enhance the water quality and quantity for Ghotki, as well as the surrounding areas. The data support the current limitations in water quality and infrastructure for groundwater use in Ghotki, as well as the continued reliance on aging water management and delivery systems at the Guddu Barrage. The objective of the study is to analyze the physicochemical characteristics of groundwater samples and identify and assess the safety of safe and unsafe groundwater sources.

Study Area

Sindh is the second most populous province in Pakistan, located in the southern region. Sindh is the third-largest province of Pakistan by total area. Sindh is the third-largest province of Pakistan by total area and the second-most populous province, after Punjab. It has an area of 140,914 square km. It shares its borders with Baluchistan and Punjab to the north, and with the Indian states of Gujarat and Rajasthan to the east. Also bounded by the Arabian Sea to the south. It comprises 30 districts; this study focused on three of these districts (Fig. 1.4) with the highest levels of contamination and poor water quality, which have received insufficient attention.

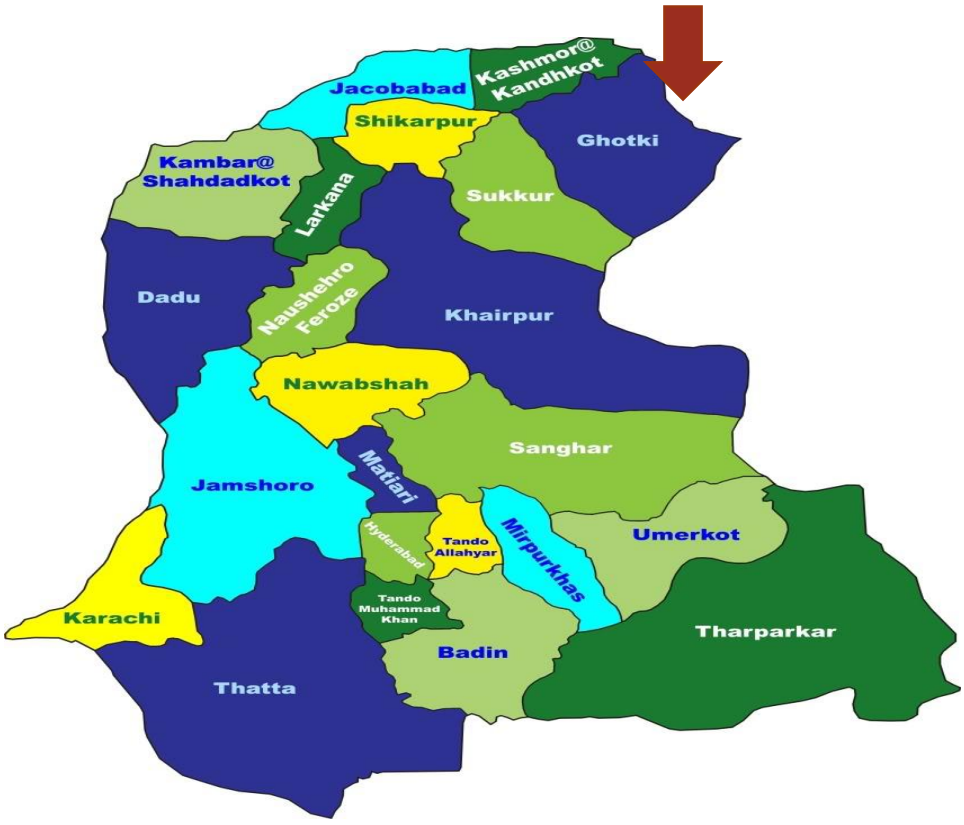


Fig. 1: Map of Sindh province shows the selected study areas

Literature Review

Water Quality Standards

Water quality standards are the foundation of a water quality-based control program. WQS (Water Quality Standards) are provisions of the state approved by the EPA (Environmental Protection Agency) that describe the desired conditions of a water body and the actions by which those conditions will be protected. To protect human health and aquatic life in these waters, the state develops WQS. Standards are fundamental parameters that help maintain. A standard can consist of a numeric or narrative limit for a specific physical or chemical parameter.

Previous Study on Water Quality Assessment of Different Districts of Sindh Province

In 2012, Pathak Hemanth assessed the physicochemical quality of groundwater in rural areas near Sagar city, M.P., India. In this study, groundwater quality in the selected 02 villages near Sagar city was analyzed. Forty groundwater samples were collected from the entire village. They assessed their physical and chemical parameters across the pre-monsoon, monsoon, and post-monsoon seasons from June 2007 to July 2010. 30 groundwater samples collected for physicochemical analysis of Gambhiria and Baheria villages. It can be concluded that the parameters exceed the highest desirable limits; therefore, the samples cannot be considered suitable for drinking. Some essential treatment is required to render it potable. People in these areas are therefore at a higher potential risk of contracting various waterborne diseases. It is recommended that water analysis be carried out periodically to monitor the rate of contamination. [11].

This study, conducted by Aamir Alamgir in 2016, aimed to assess groundwater quality in the coastal areas of Sindh province. The study focused on two subdistricts of Thatta, Keti Bandar and Shah Bandar. Forty-six samples of groundwater were taken at depths ranging from 30 to 50m. Physicochemical and Biological analyses were performed during 2012 and 2013. The results indicate that almost all samples were unsuitable for drinking. Unfortunately, people consume this water. Levels of Ni and Pb also exceeded the desirable limit. Groundwater pollution from organic and fecal materials can be addressed only through improvements in irrigation, sanitation, and sewage infrastructure. This paper identifies locations where such infrastructure is needed. [12]

Wali Muhammad Daudpota et al. (2016). Presented a study to evaluate the quality of groundwater taken from different Talukas of the district Tando Muhammad Khan for drinking and agricultural purposes. Physical and chemical parameters, including pH, EC, Turbidity, Color, and 14 others, were measured [13]. The results demonstrated that pH and odor were within permissible limits in most samples, whereas Arsenic (As), Hardness, Na, TDS, taste, and Cl exceeded the WHO permissible limits. In this study of groundwater status in the Tando Muhammad Khan district, TDS (50%), chloride (54.16 %), sulfate (44.8%), calcium (38.5%), sodium (54.16%), and hardness (21.8%) exceeded the limits in 50%, 54.16%, 44.8%, 38.5%, 54.16%, and 21.8% of the samples, respectively. Such water must not be used for drinking or irrigating crops. Without testing from a recognized soil and water testing laboratory, the groundwater must not be used for drinking purposes [14].

Nadeem ul Kareem Bhatti conducted a comparative study that examined the physicochemical properties of Daur in Shaheed Benazir Abad in 2018. All collected samples were brought to the laboratory and tested with the American Public Health Association (APHA) Standards. The results showed that 25 percent of samples were microbiologically contaminated, and other parameters that exceeded safe limits included TDS, Cl, sulfate, sodium, hardness, and taste. [15]Click or tap here to enter text.

Another study, conducted by Muhammad Farooque Lanjwani in 2018, examined three talukas of Qambar district (Qubo Saeed Khan, Sijawal Junejo, and Shahdadkot Sindh). The study examines the water quality of Shahdadkot, Qubo Saeed Khan, and Sijawal Junejo, which were less affected by industrial contamination. 28 parameters were analyzed and compared with the WHO drinking water standards [15]. The total dissolved solids (57.8%) for 57.8% of the samples exceeded the WHO limits. The concentration of cations and anions was also high. The concentration of fluoride in 50% of the samples was higher than the permissible limits. The high concentration of Ni, Cr, Pb, and Cd may be due to drainage wastewater and the geological nature of the area. The Cl, K, Na, Ca, and Mg concentrations were higher than acceptable limits in half of the samples. Although water was not suitable for human consumption in the study area [16].

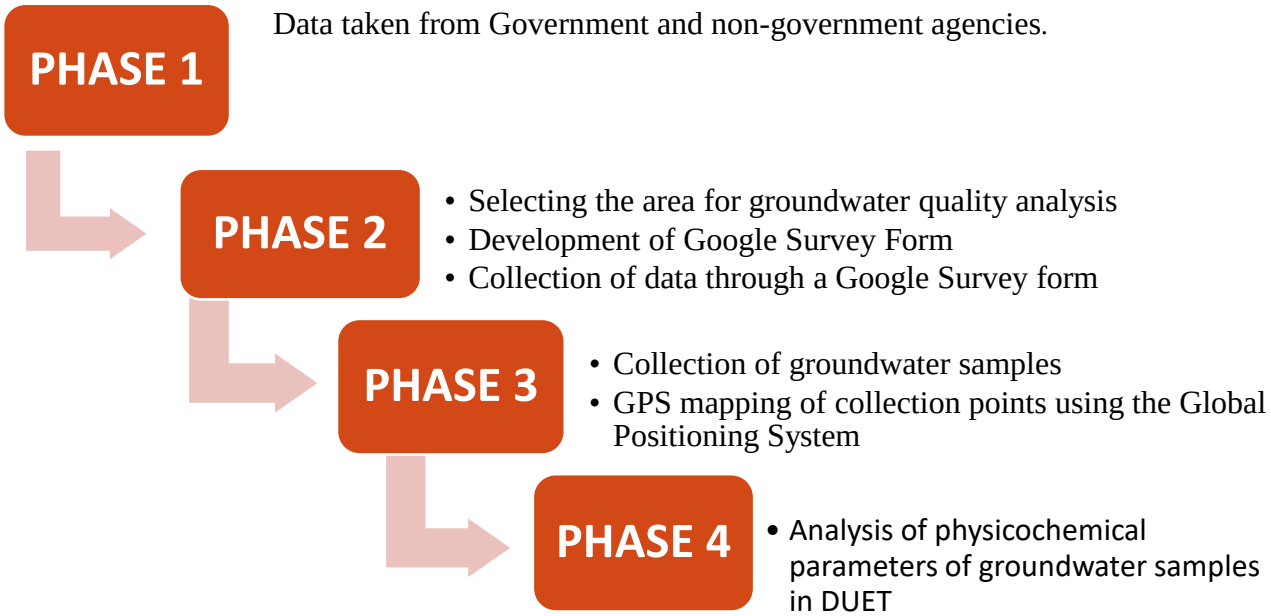
Muhammad Jahangir Khan's 2019 study assesses groundwater quality in the Sindh Industrial and Trading Estate (SITE) area of Karachi, Sindh. Twenty-four groundwater samples were collected from boring wells, at different depths ranging from 100 to 150 ft., and tested for various physical and chemical parameters. This study provides substantial information on water-quality parameters, including dissolved ions, minor and trace elements, and physicochemical characteristics. Data indicate that groundwater quality is primarily affected by the discharge of untreated municipal and industrial effluents into water bodies [17]. This adversely affects water quality, indicating that the Motorville area has elevated concentrations of sodium, chloride, calcium, potassium, sulfate, and zinc in groundwater. Other areas, including Qasba Colony and Islamia Colony, were also affected [18].

Zafarullah Jamali (2020) conducted a study in the Taluka of Larkana, Sindh Province. Because most of the population relies on groundwater for domestic use, about 43 groundwater samples were collected from hand pumps and electric-motor bores installed at various sampling stations across the study area [19]. Water samples were analyzed in a laboratory for physical and chemical analysis. Results indicate that approximately 53.48%, 83.72%, 20.93%, and 83.72% of groundwater samples exceeded the WHO [20] prescribed limits for pH, EC, TH, and TDS, respectively. Studies indicate that groundwater samples collected from local areas were unsuitable for human consumption [21][22].

Methodology

Project Methodology

This study was conducted to assess water supply and demand in the Ghotki district and groundwater quality in selected districts to meet our objectives promptly. We proposed a methodology to conduct our assessment more accurately and with fewer errors. For this, we divided our research methodology into three phases mentioned below:
The following are the phases of methodology as described below



Selecting the area for groundwater quality analysis

Selecting an area for groundwater quality analysis is a critical component of the research. Although water quality in Sindh province is not suitable for human consumption, we selected specific areas for water-quality analysis. Our study focuses on these districts. In the Ghotki district, due to significant concerns about groundwater quality, residents in these areas are experiencing waterborne diseases. We will focus on analyzing the most vulnerable areas in these districts.

Collection of groundwater samples

For the respective study, our team members adopted rigorous criteria for sample collection. A total of 20 groundwater samples were collected from different union councils in the district of Ghotki. Majorly, ground water was consumed for drinking by residents; samples were collected between June and July 2025 from handpumps having depth up to 50-70 feet, and handpumps were drained for five minutes to remove impurities.

Sampling Techniques

- For the analysis of physical parameters such as pH, turbidity, other trace metals, and organic and inorganic contaminants, the groundwater samples were collected in 500 ml sterilized bottles from running handpump water.
- The bottles were labeled carefully with numbers like 1,2,3. The coordinates of each sample were collected using GPS mapping.

Table 1: Coordinates and sample ID of samples

Sample ID	Y latitude	X longitude
01	28.0127	69.5456
02	27.9031	69.5586
03	27.9031	69.5579
04	27.9024	69.5578
05	27.9156	69.5488
06	27.8892	69.5384
07	27.8992	69.5311
08	27.9055	69.5363
09	27.9079	69.5469
10	27.9089	69.5456
11	28.9254	69.5696
12	28.9199	69.5522
13	28.9170	69.5450
14	28.9233	69.5666
15	28.9279	69.4700
16	27.9406	69.4590
17	27.9408	69.4413
18	27.9484	69.4432
19	27.9470	69.4332
20	27.9419	69.4332

Table 1 shows the Coordinates and sample ID of samples collected from Taluka Mirpur Mathelo and Khangarh total of 20 samples were collected; the first fifteen samples were collected from 3 union councils of Taluka Mirpur Mathelo (Dangra, Garhi Chakar, and Sahib Khan), and the remaining five samples from Taluka Khangarh (UC Beriri).

Results

Groundwater samples were analyzed for physical and chemical parameters, and the results were compared with the drinking water quality standards of the Pakistan Standards & Quality Control Authority and the World Health Organization (WHO) Guidelines.

The field observation indicates that the water samples were colorless, odorless, and clear. The lab measurements of pH, TDS, Electrical conductivity, hardness, and other parameters of the water samples are presented in Table 2. The pH in the study area in Ghotki ranged from 7.2 to 7.9. It shows that the pH of all samples of the three districts was within the limits of (PSQCA) and WHO, and this shows that the nature of most of the groundwater in the study area is alkaline. Turbidity of all the samples of the study area was in the permissible range. The electrical conductivity EC of Ghotki was found between 714 and 1618 mg/l, while in Ghotki, 9 samples of (Dangra, Garhi, and Sahib Khan union councils) exceeded the permissible limit. This may be due to the geological nature of the study area; EC measures the concentration of soluble salts in water as ions, which increase with the presence of salts. The high EC of water samples corresponds to the presence of ions (HCO_3^-, SO_4^{2-}, $Ca^{2+,}$ and Mg^{2+}) in higher concentrations, which resulted from the solubility of rocks and the ion exchange process in aquifers. Total dissolved solids (TDS) of seven samples from Ghotki exceeded the permissible limit (1000 mg/l). The elevated TDS concentration in the study area may be due to the presence of high levels of natural minerals in the soil. A detailed

survey of problems requires an epidemiologic survey of the District and Ghotki to identify health risks associated with excessive TDS in drinking water.

Concentration of chloride was found from 19 to 205 mg/l in 30 samples (from Ghotki). Only one Ghotki sample exceeded the standard limit. Chloride is not harmful to humans at low levels, but it could change the taste of groundwater at a concentration higher than 250 mg/l.

The bicarbonate concentration was in the range of 130 to 450 mg/l in district Ghotki. The samples collected from UC Gather and Ber Sharif, along with UC Dangra, Garhi, and Beriri in the district of Ghotki, are within the desirable limit.

Hardness is an important parameter for minerals dissolved in water and is often expressed as calcium carbonate concentration. Three samples of Ghotki exceeded the permissible limit out of 20 samples. The result of Nitrate was in the permissible range. The concentration of sodium of the study area was found from 14-485 mg/l in Ghotki 6 samples of (Dangra and Sahib Khan) Union councils of Taluka Mirpur Mathelo exceeded the PSQSA limit.

The result of potassium (K) in Ghotki district, only the sample of the taluka Mirpur Mathelo Dangra Union council exceeded the given limit. Calcium and magnesium concentrations in samples were found in the range of 70-120 mg/l and 18 – 38.88 mg/l. The Ca results varied from 24-136 mg/l; the Ca value of 5 samples of taluka Mirpur Mathelo crossed the desirable limit for drinking.

Table 2a: Physicochemical parameters of Ghotki district samples

S.ID	pH	EC uS/cm	Sulfate mg/l	Hardness Mg/l	Ca mg/l	Mg mg/l	Nitrate Ppm
1	7.63	1843	293	620	124	75	3.151
2	7.59	780	103	350	96	27	2.215
3	7.43	1803	289	490	116	48.6	3.149
4	7.86	752	28	200	40	24.3	0.890
5	7.67	1409	265	230	68	14.58	0.798
6	7.73	512	24	240	48	29	0.859
7	7.41	1790	256	560	136	53.5	1.015
8	7.66	556	25	310	64	36.5	1.296
9	7.64	500	23	240	52	26.7	0.723
10	7.88	344	17	150	28	19.44	0.812
11	7.96	1589	110	150	24	21.87	0.957
12	7.66	1090	108	210	60	14.58	0.798
13	7.95	1260	155	140	24	19.44	0.598
14	7.66	2131	430	390	72	51.03	0.636
15	7.62	731	10	270	52	34	0.444
16	7.45	1695	125	550	116	63	0.671
17	7.56	479	18	250	56	27.7	0.794
18	7.59	463	17	230	60	19.44	0.691
19	7.31	630	21	340	92	27	1.947
20	7.43	787	29	300	72	29	1.858

Table 2b: Physicochemical parameters of Ghotki district samples

S.ID	Na mg/l	K mg/l	Fluoride mg/l	Bicarbonates mg/l	Chloride mg/l	TDS mg/l	Arsenic Ppm
1	230	18.6	0.48	410	185	1173.76	0.007
2	43	9.1	0.34	290	45	499.2	0.0056
3	270	17.8	0.61	420	155	1153.92	0
4	53	10.16	0.06	150	40	289.3	0
5	205	55	0.52	370	110	902	0
6	33	9.0	0.84	180	37.5	327	0.0051
7	115	37	0.53	340	13	1145.6	0.0052
8	36	9.0	0.77	220	30	355.8	0.0058
9	28	9.2	0.41	200	30	320	0.0054
10	14	4.0	0.49	130	25	220.2	0.0059
11	315	9.5	1.68	450	42.5	1017	0.00521
12	119	9.7	1.01	330	45	697	0.005
13	315	17.5	0.69	380	50	1300	0.005
14	486	23	1.64	390	205	1363.8	0.006
15	86	3.7	1.4	270	32.5	476	0.0061
16	112	16	1.20	220	47.5	1084	0.0055
17	40	8.7	1.52	200	30	307	0.0057
18	35	5.5	1.74	190	30	296	0.0058
19	59	8.6	1.3	310	27.5	403	0.00553
20	43	7.5	1.79	250	35	504	-

The table above presents the results obtained from the Qambar Shahdadkot district, Taluka Qambar. Sample ID 1 to 5 shows the results of the Union Council Ber Sharif, and sample ID 6 to 10 shows the results of the Union Council gathering.

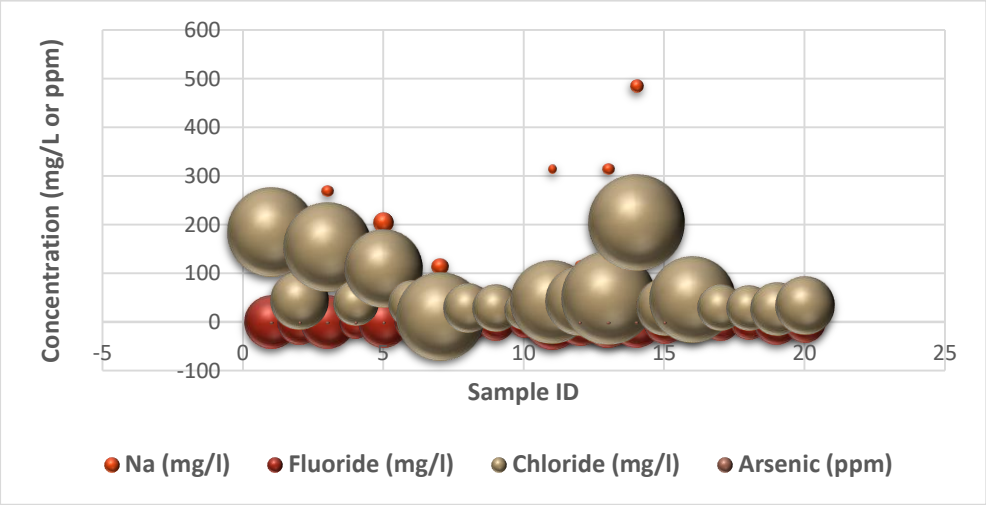


Figure 2: Water quality parameters w.r.t. sample IDs

In samples 13 and 14, elevated sodium, chloride, and total dissolved solids could be attributed to either natural geological sources or human contributors such as agricultural runoff or industrial sources, consistent with other findings from regional water studies. The elevated fluoride

concentrations exceeding the WHO and EFSA recommended limits in samples 11, 14, 17, 18, and 20 are likely attributable to the solubility of fluoride-bearing minerals, as reported in groundwater quality studies. Most parameters comply with WHO drinking water recommendations, except for fluoride in certain instances, as shown in Graph 1. Some samples exhibit high total dissolved solids (TDS) concentrations, consistent with similar studies of groundwater in urban and semi-urban areas. Sodium and chloride enrichment suggests that salinization or pollution is occurring, a phenomenon that has also been observed in similar hydrogeological settings.

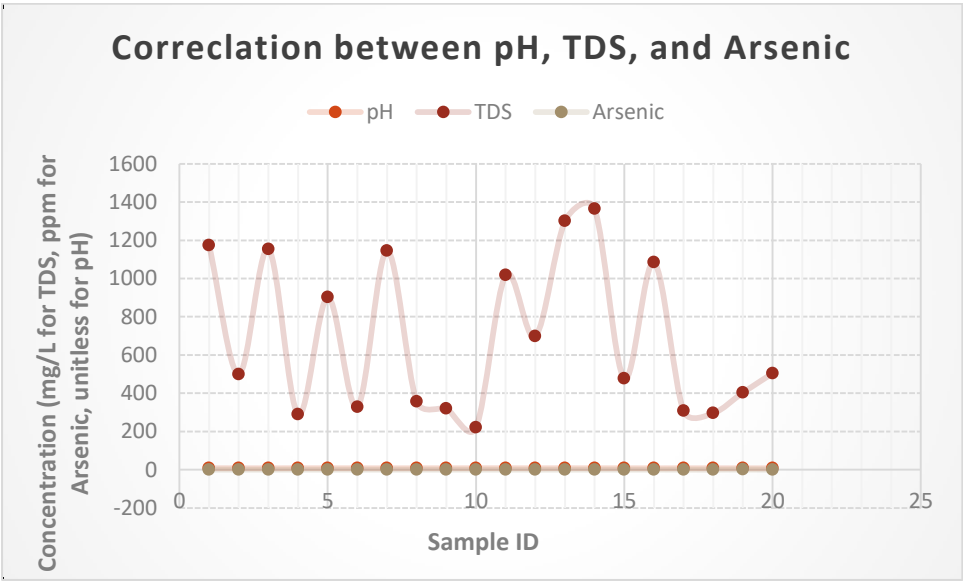


Figure 3: Correlation between pH, TDS, and arsenic with respect to. Sample IDs.

Most water samples met the WHO drinking water standards for pH and TDS. However, there is one highly concerning area with an extremely high arsenic concentration, posing a serious risk of contamination. This sample requires immediate action to protect public health through monitoring, alternative drinking-water provision, and decontamination. Therefore, regular water quality monitoring and targeted investigations into arsenic sources will be necessary to avoid chronic health impacts in affected communities.

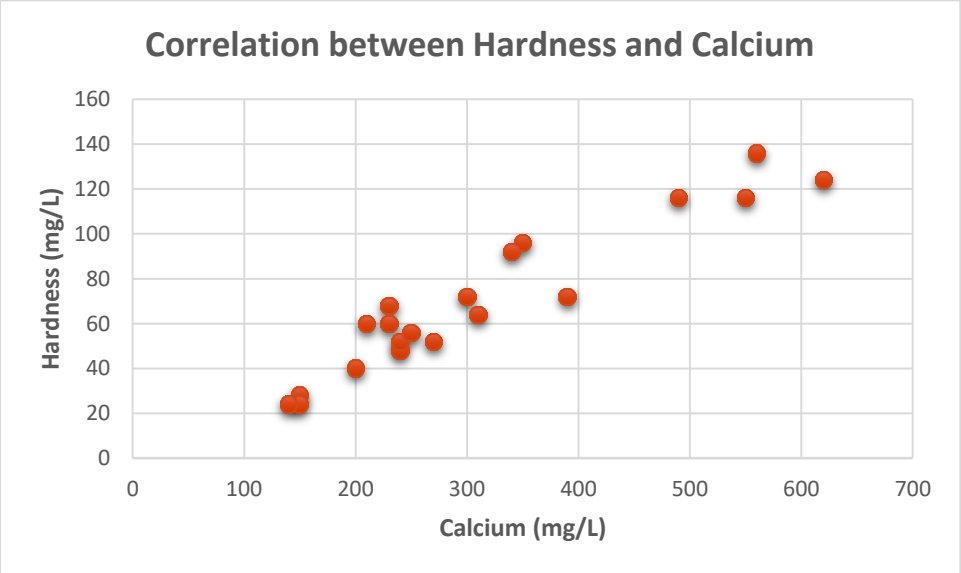


Figure 4: Correlation between hardness and calcium with respect to. Sample IDs.

Calcium usually has a larger role in the hardness level than magnesium, based on the higher concentration of calcium over magnesium in many natural waters, and because of its chemical characteristics.(14). Hardness as $CaCO_3$ can be calculated using

$$TH\ (mg/L\ as\ CaCO3)=2.5(Ca)+4.1(Mg)$$

where Ca and Mg are the concentrations of calcium and magnesium in mg/L, respectively; 2.5 and 4.1 are the conversion factors for the relative molecular weights of Ca and Mg relative to $CaCO_3$. Some of the data shown have total hardness values ranging from 140 to 620 mg/L, corresponding calcium values from 24 to 136 mg/L, and magnesium values from 28 to 350 mg/L.

Most of your water samples are classified as very hard or hard, indicating they contain high mineral content. Hard water provides calcium and magnesium, both essential for human nutrition. Some studies suggest that hard water may exert protective effects against cardiovascular disease due to the presence of minerals, although evidence remains conflicting. Excessive hardness can lead to scaling in pipes and appliances, but it is generally not known to cause adverse human health effects. Click or tap here to enter text. The maximum hardness of 620 mg/L is likely due to high calcium (124 mg/L) and magnesium (350 mg/L) concentrations, indicating very hard water. The proportions of calcium and magnesium varied among samples, which influenced both the hardness composition and the potential effects on the chemistry and usability of the water. Perceived water hardness, along with the table's related taste or scaling potential, can also increase at magnesium levels above 50 mg/L. All of this data suggests that the water samples have different constituent supplies or geological origins, leading to variability in mineral types.

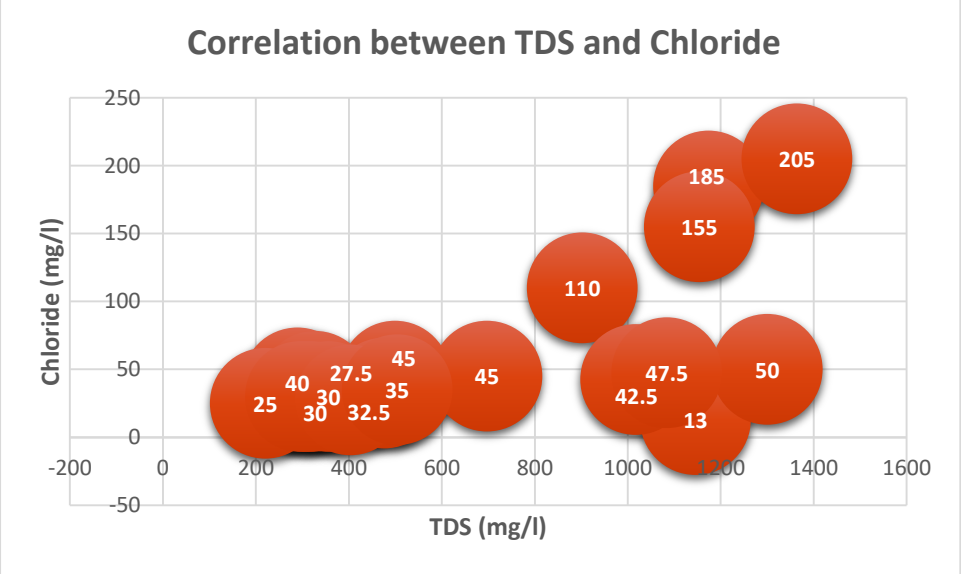


Figure 5: Correlation between TDS and chloride w.r.t. sample IDs.

The high positive correlation between TDS and chloride is related to the fact that, as chloride concentrations increase, they significantly add to the total dissolved solids load and thus raise TDS. Correlation coefficients between TDS and chloride are often in the vicinity of +0.8 to +0.9 and demonstrate that for many water sources, chloride is a primary factor in TDS variability. This is supported by data showing that TDS values are significantly elevated alongside high chloride concentrations. Some samples are shown in graph 3a. TDS can be monitored more simply and rapidly (via conductivity measurements) and can be used as an indirect indicator of chloride, given its strong association with chloride. Higher chloride concentrations can produce more corrosive

water and affect taste, infrastructure, and aquatic life; thus, higher TDS has implications for water quality.

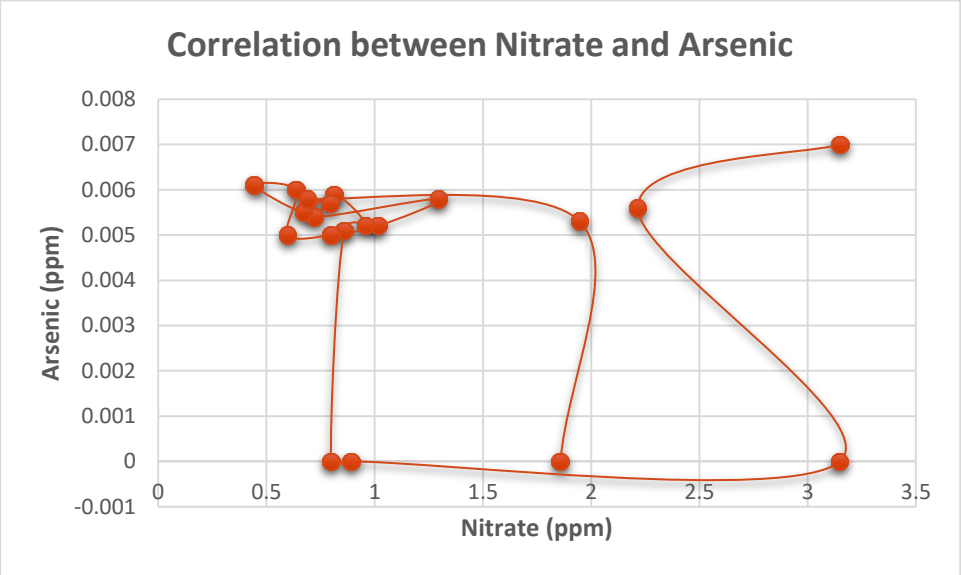


Figure 6: **Correlation between nitrate and arsenic with respect to. Sample IDs.**

Nitrate contamination is commonly associated with agricultural runoff, fertilizer use, and sewage inputs. Ghotki is agricultural land, and there are fertilizer industries in Ghotki, with greater potential for nitrate contamination in the groundwater. Conversely, arsenic is most often sourced from geogenic mineral dissolution or industrial pollution. This is reflected in your data, where modest nitrate levels are observed and minuscule arsenic levels per sample, suggesting that both parameters result from distinct contaminant pathways or geochemical controls. Both parameters should be monitored not only for their independent health risks but also to provide a comprehensive water quality profile. Graph 5 likely depicts a fairly stable, low-level trend for arsenic concentration in samples, which indicate overall safe water quality and a few potentially non-detect or zero detections figure 6 depicted no significant changes in nitrate values, some variability but all below levels that might cause harm; they are below potentially harmful thresholds and suggest moderate nitrate levels likely from diffuse agricultural or environmental sources.

The Ghotki Canal is part of the Sindh Water Sector Improvement Project, aimed at rehabilitating and modernizing the main and branch canals, including Ghotki. The project has improved conveyance efficiency at canal heads from approximately 52% to around 58%, exceeding their subproject target. Reliability of water distribution and delivery has improved from 53% to 60% through infrastructure divisions, including the replacement and rehabilitation of canal regulators. Sedimentation remains a major challenge in the left-bank pocket immediately downstream of the divide wall at the Guddu Barrage. If sedimentation is not carefully managed, ecological or sedimentation-driven processes could reduce the canal's available capacity by 44% within the next 25 years. Completed in 1962, the Guddu Barrage is a major hydraulic structure that regulates water supply to the Ghotki Canal and other feeders to parts of Sindh and the province of Balochistan. Limited funding has constrained progress on repair and maintenance work, resulting in incomplete completion of the planned tasks. Recent efforts to promote sustainable fishing practices in the Ghotki Canal focus on improving water management and securing the water supply through decentralization and the use of institutions such as the Sindh Irrigation and Drainage Authority (SIDA), Area Water Boards (AWBs), and cooperatives called Farmer Organizations (FOs) through participatory irrigation management approaches.

Canal water is the primary source of irrigation in dry-crop cultivation areas in Sindh and parts of Balochistan. Supplementary water may be drawn from tube wells in the surrounding areas, particularly in areas where canal water is insufficient. Scheduled maintenance closures will result in temporary reductions in canal water availability, such as a 30-day closure at the Guddu Barrage in 2025. Water shortages are a persistent problem, as available water has declined, with shortages reaching approximately 50% in Sindh as of early 2025. Further limiting the ability to meet irrigation demands.

Discussion

Exceedances of electrical conductivity and TDS in a considerable fraction of samples (45% and 30%, respectively) indicate increased concentrations of dissolved minerals and ions in the water, which can have implications for taste, infrastructure, and health. High EC and TDS often indicate high mineralization, which can lead to the classification of the water as hard or very hard. Hardness that exceeded the criteria and was in more than 10% of the samples may reflect high concentrations of both calcium and magnesium ions [23][24]. Hard water can cause scaling on pipes and appliances, reduce the effectiveness of soap, and hurt skin and hair. High levels of sodium (30%) raised health concerns, particularly for individuals with hypertension or kidney disease, because exposure to excess sodium in drinking water increases overall sodium intake. The use of calcium exceeding thresholds in 20% of samples indicates hardness and potential health issues. Calcium is fundamental for bones but is associated with scaling and hardness problems when levels are high. Fluoride contamination is a significant public health risk that contributes to dental and skeletal fluorosis. At high levels, fluoride can cause mottling and discoloration of teeth, whereas skeletal fluorosis affects bones and joints. The most common source of fluoride is natural geological sources in water, which can exceed the WHO guideline value of 1.5 mg/L [25]. Regular monitoring, awareness, and remediation are required to address issues of fluoride contamination effectively. Remediation interventions include identifying contaminated water sources, adopting a safe water supply, utilizing treatment-based techniques when applicable, stakeholder and community awareness of existing health risks, and monitoring exposure levels. Overall, successful management of fluoride contamination requires a coordinated approach to monitoring, public health interventions/risk education, and treatment (26).

The Sindh Water Sector Improvement Project (WSIP) restored and upgraded approximately 775 km of main and branch canals, and over 1,000 km of distributaries and minor canals. The works included the replacement and rehabilitation of numerous cross-regulators and head-regulators, thereby improving the regulation and distribution of water flow at the canal and distributary levels in Ghotki and surrounding regions.(27). Modernizing the system increased conveyance efficiency from approximately 52% to approximately 58%, exceeding our project targets. The reliability of water delivery improved from 53% to 60%, thereby enabling the distribution of irrigation deliveries, particularly in tail-end areas, thereby increasing agricultural performance overall.(28). The improvements implemented through these projects have systematically addressed key issues, including sedimentation, inefficiencies in water delivery, ageing infrastructure, and institutional deficits. The physical improvements and focus on building local management capacity have increased conveyance water-delivery efficiency, improved flow regulation, and enhanced reliability of the regional irrigation supply in the Ghotki Canal system [29]. These improvements are vital to sustaining agricultural productivity in the Ghotki command area, particularly given sedimentation and ongoing water shortages [30].

Conclusion

The groundwater quality assessment identifies potential issues arising from water quality parameters exceeding the limits set by the standards. More specifically, electrical conductivity (EC) and total dissolved solids (TDS) are above standard limits for 45% of the samples and for 30%, respectively. EC and TDS indicate the dissolved minerals and salts in the water. Elevated salinity and high concentrations of dissolved minerals can affect the usability of drinking and irrigation. Hardness concentration exceeds the permitted limit in 10% of samples and could affect taste and pipe scaling due to mineral precipitation. Sodium concentrations are elevated in 30% of samples, posing a potential hazard to soil health and crop quality if used for irrigation. High concentrations of sodium also raise concerns about toxicity in human health. Elevated concentrations of calcium in 20% samples, with equally elevated fluoride in 20% of the same samples, raise health concerns in the general population for dental fluorosis, skeletal fluorosis, and cardiovascular damage. Groundwater quality issues underscore the importance of groundwater monitoring and public education on public health concerns. Each of these considerations calls for, or at least a modified, water treatment strategy or protocol to manage quality issues and ensure a safe supply. The groundwater management project in Drumheller should focus on controlling salinity, minimizing fluoride exposure, and reducing hardness and sodium where possible to mitigate impacts on human health and agricultural productivity. Aging infrastructure necessitates rehabilitation to ensure the safety and functionality of the barrage, thereby safeguarding the water supply to Ghotki and other districts.

Recommendation

The diagram depicts an integrated groundwater and surface-water management framework designed to improve water quality, environmental sustainability, and public health. At the center, “Recommendation” signifies a holistic approach in which multiple interlinked strategies collectively address groundwater contamination and water resource challenges.

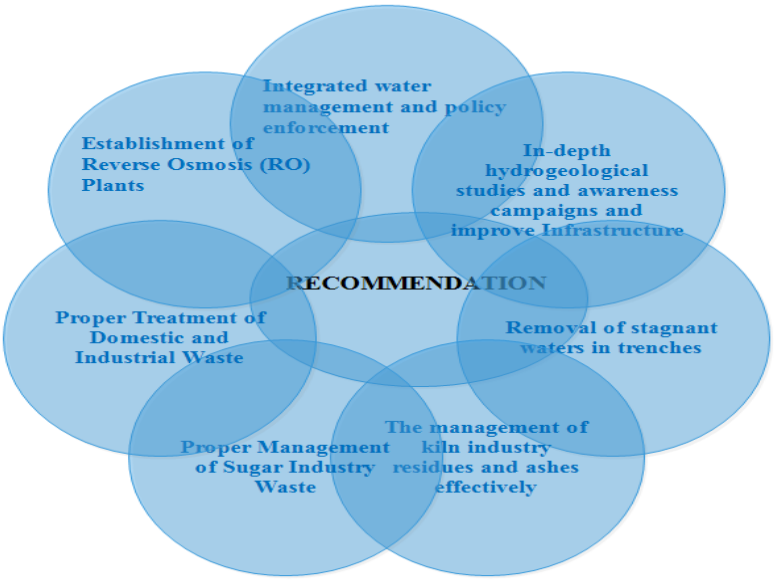


Figure 7: This figure shows recommendations to improve groundwater quality and the supply of water in Ghotki.

Establishment of Reverse Osmosis (RO) Plants

The reverse osmosis (RO) process is highly effective for reducing dissolved salts, fluoride, arsenic, and other contaminants in groundwater. Therefore, the installation of community and domestic RO units would go a long way toward improving potable water quality in affected areas. This technology remains particularly useful when fluoride, hardness, TDS, and arsenic exceed acceptable limits.

Proper Treatment of Domestic and Industrial Waste

Untreated domestic wastewater and industrial wastewater are serious concerns in groundwater pollution because they contribute to organic and inorganic pollutants in aquifers. Establishing a wastewater treatment facility or enforcing standards and parameters for effluent discharges from treatment plants are both options for limiting further deterioration of groundwater resources.

Proper Management of Sugar Industry Waste

Disposal of waste from the sugar industry has, for decades, been a point source (e.g., disposal ponds) and a nonpoint source of water pollution. Discharging effluents directly into the environment causes severe water pollution. Establishing effluent management schemes and treatment facilities would reduce leachate infiltration into aquifers.

The management of kiln industry residues and ashes effectively

Kiln-industry residues that have not been managed are permitted to remain and form a slurry that will eventually reach the base and contaminate groundwater. Proper disposal and treatment protocols must be established for these industrial wastes to reduce the risk of groundwater contamination.

Removal of stagnant waters in trenches

Stagnant areas, such as large bodies of water, are sites where contamination occurs and disease develops. Trenches should therefore be drained and managed to limit contaminated waters from infiltrating the groundwater table.

In-depth hydrogeological studies and awareness campaigns, and improve Infrastructure

In-depth studies on groundwater contamination sources, aquifer vulnerability, and water chemistry would provide a basis for intervention. Raising public awareness is necessary with a campaign to educate local communities about the risks of water pollution, preventive measures, and water conservation and hygiene.

Integrated water management and policy enforcement

Local governments, regulatory agencies, and stakeholders must coordinate efforts for sustainable groundwater management and pollution control.

The overall structure indicates that, particularly in groundwater-stressed areas such as Sindh, Pakistan, combined technical, regulatory, environmental, and social interventions are necessary for sustainable water resource management and long-term socioeconomic development.

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