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Water quality assessment of groundwater resources in rural areas of Karachi, Pakistan

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ABSTRACT

The quality of drinking water directly controls many diseases and affects the growth of the human body. The provision of quality water is a major concern around the world, especially for developing countries that have poor environmental rules, insufficient water supply, and poor drainage systems. Considering these issues, this research was undertaken to assess drinking water quality in the rural areas surrounding Karachi, Pakistan. Samples were collected in the monitoring of the Pakistan Council of Research in Water Resources (PCRWR) and tested for physicochemical and bacteriological parameters (PCB) using geographical information system (GIS). Further, the results were compared with World Health Organization (WHO) standards for human consumption. An analysis of 35 drinking water samples revealed that 14% exceeded the permissible ranges for physical parameters. Moreover, 60% of the samples were deemed unsafe for consumption as the levels of inorganic substances surpassed permissible ranges outlined by WHO. All water samples contained coliform bacteria, making them unsafe, and 46% were contaminated with E. coli, highlighting the urgent need for improved sanitation and water treatment infrastructure in the area.

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1. INTRODUCTION

Water is a vital necessity for sustaining all life on Earth, also, other human activities such as electricity production, gardening, cultivation, and industries, as well as ultimately rely on water resources [1]–[4]. Pakistan's per capita availability of portable water has significantly declined, falling from around 5,600 cubic meters annually to approximately 1,038 cubic meters per annum due to population growth and economic development [5]. Human activity produces a massive amount of waste, including home, industrial, agricultural, hospital, and other types of waste. Due to the lack of a sustainable wastewater disposal infrastructure, wastewater is frequently released into natural water bodies and water storage, damaging water resources [6]. High levels of contaminants like microorganisms, chemicals, pesticides, fertilizers, heavy metals, and wastewater render water unsuitable for drinking and household use, while wastewater from municipal, agricultural, and industrial sources can contaminate groundwater [7]. In Pakistan, a major health concern is the accessibility of quality drinking water. In Pakistan, the water scarcity and contamination brought on by poor water resource management by the government and relevant bodies pose a serious threat to human survival [8]. Water pollution in Pakistan is a major concern, causing environmental damage and health issues, including chronic conditions linked to contaminated water [9]. As per the World Health Organization (WHO), 80 million people in Pakistan lack appropriate access to safe drinking water. According to Murtaza *et al.* [10], 97900 people die each year because of drinking contaminated water, primarily in Pakistan's rural areas, the majority of whom are children. Moreover, 20-40% of hospital beds in Pakistan are filled by patients suffering from water-related diseases such as cholera, typhoid, dysentery, and hepatitis B or C. One-third of all deaths are caused by them [5]. Elevated concentrations of arsenic in drinking water present a significant health risk to nearly 60 million individuals in Pakistan [11]. Furthermore, in the previous four years, water-borne illnesses and drought have claimed the lives of about 1832 children [12].

In Sindh, surface and groundwater serve as the main drinking water sources, but improper disposal of various wastes into surface water has caused severe pollution [13]. According to Waqas *et al.* [14], because of the semi-arid climate, seawater intrusion, and a high rate of evapotranspiration due to high average annual temperatures, most groundwater in Sindh Province is found in shallow aquifers that are very saline. Groundwater quality in Sindh is degraded by iron, fluoride, arsenic, nitrates, high dissolved solids, and microbial contamination from geological factors and human activities. Rural communities rely on this contaminated water for drinking, domestic use, and irrigation, with 70-80% of water supply schemes non-functional [13]. The Pakistan Council of Research in Water Resources (PCRWR), a government organization established in 1964, conducts research to enhance both the quantity and quality of groundwater, focusing on groundwater management and recharge [13].

Karachi, the largest metropolis, is geographically divided into six districts: Central, South, West, East Korangi, Malir, and Keamari. Karachi is home to approximately 15 million people, accounting for about 10% of Pakistan's total population [13]. Karachi, located on the coast, has a moderate climate with warm summers, mild winters, and high humidity. The Arabian Sea borders Malir district, the study area, where inadequate freshwater supply and non-functional schemes cause excessive groundwater extraction, leading to seawater intrusion [15]. The residents in these places are unable to afford the costs of a private water delivery system, such as bottled water [11]. This study project involves assessing various physicochemical and bacteriological parameters (PCB).

This study investigates the influence of PCB characteristics on drinking water quality in rural Malir district (DMK), Karachi. It analyzes physicochemical (e.g., pH, turbidity, hardness, dissolved solids) and bacteriological (E. coli and total coliform) parameters in 35 water samples and assesses health risks. Samples were collected in polystyrene bottles of three capacities and preserved for physicochemical and microbial testing. Contaminated water can cause skin rashes, eye infections, diarrhea, kidney issues, and other waterborne diseases.

2. METHODOLOGY AND MATERIALS

2.1. Details of the study area and the sampling locations

The current study was conducted in the Malir district, located in Karachi, which is an industrial-cum-agricultural area in Karachi, Pakistan. The study covers both urban and rural areas of the district where most of the population resides. An aggregate of 35 drinking water samples were collected from various locations throughout the district, as shown in the map given in Figure 1. The distribution for the sample source is given in Figure 2.

2.2. Sample collection and preservation

Drinking water samples of 100, 500, and 1000 ml were collected in polystyrene bottles. For a bacteriological evaluation, sterilized 100 ml water bottles were kept in an ice container and delivered to the laboratory within 2 hours, in compliance with WHO guidelines 2011 [4]. The samples collected in 500 ml bottles were used for nitrate-nitrogen determination. Boric acid (1 M) was used to preserve the samples. The samples collected in 1 L bottles were subjected to the determination of various chemical characteristics.

2.3. Physicochemical and microbial analysis

The collected drinking water samples were subjected to various physicochemical analyses including color, odor, taste, pH, total dissolved solids (TDS), hardness, chloride, carbonate, bicarbonate, calcium, magnesium, sulfate, nitrate-n, potassium, sodium, arsenic, fluoride, and iron. The color, odor, and taste were assessed by performing sensory tests. pH and TDS were determined by using a glass electrode pH meter (Model6230N, JENCO) and an EC meter (EuTech, CON11, Singapore). Water turbidity was measured with a turbidity meter (Lamotte, Model 2008, USA). Chloride concentration was determined using the argentometric method, while calcium, magnesium, and $CaCO_3$ hardness were assessed using the ethylenediaminetetraacetic acid (EDTA) titrimetric method. Carbonates and bicarbonates in water samples were quantified by the H_2SO_4 titration method. Fluoride in water samples was measured using the (4500-F-D, SPADNS) method using a colorimeter (DR-2800 HAFCH). Iron was determined by the (HACH 8008 method). Arsenic determination in water samples was performed by Kit method using the Merck Test Kit (1.17927.0001) [16]. Microbial analysis of the water samples for E. coli and total coliforms was conducted using 3M™ Petrifilm according to OMA #991. 14 [4].

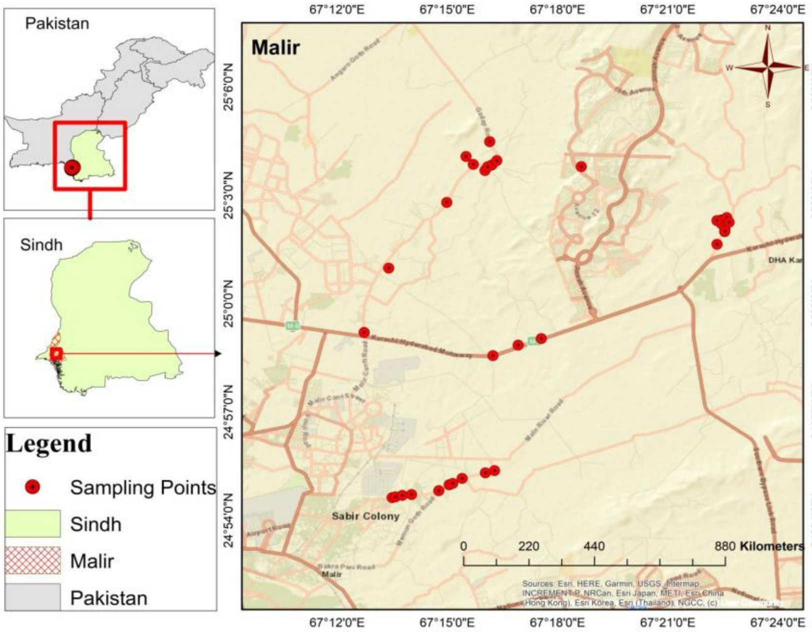

Figure 1. Map of sampling sites

2.4. Health risk assessment

For elevated chemical concentrations in groundwater, a health risk assessment (R) was conducted by comparing the values of chronic daily intake (CDI) with acceptable daily intake (ADI) levels, as defined by WHO guidelines for different chemical concentrations. CDI through water ingestion was calculated using (1) [17], [18].

$$CDI = C \times \frac{DI}{BW} \tag{1}$$

Where C denotes as parameters measured concentration in (mg/l), DI is the daily intake at (2l/day) and BW is body weight at (72 kg). Upon deriving the CDI from the equation, the Risk (R) is subsequently determined using (2):

$$Risk(R) = \frac{CDI}{ADI} \tag{2}$$

Equation (2) denotes the ratio of CDI to ADI, where CDI signifies the chronic daily intake, and ADI represents the maximum permissible limit prescribed by the WHO. This ratio offers a qualitative assessment rather than an exact risk measure. A value under 1 indicates no theoretical risk to the population, while a value above 1 suggests potential toxic effects without quantifying the likelihood [18].

2.5. Statistical calculation

The mean values of all quality parameters were calculated using Microsoft Excel. Statistical analysis, including linear regression, was performed to understand the relationships between chloride (Cl) concentration, TDS, and the combined concentration of calcium and magnesium (Ca+Mg). This analysis helped clarify the complex interactions among these environmental factors.

3. RESULTS AND DISCUSSION

The results presented here are based on tests performed for physicochemical parameters. The analytical data was then contrasted with the prescribed levels set by WHO standards. The findings cover a range of physicochemical and bacteriological water quality parameters, providing insights into the complex composition and properties of the substances analyzed.

3.1. Physicochemical characteristics of collected water samples (color, odor, and taste)

Figure 2 presents the sample collection by two sources hand pump and motor pump. The proportion of samples collected by hand pump was 74% whereas the proportion of samples collected by motor pump was only 28%. All the water samples were found to be odorless and tasteless. However, 14% (5 samples) were unsafe for drinking due to color. The occurrence of color in underground water is worrisome as it suggests the possible presence of hazardous substances. Colored water serves as an indication of potential contaminants that can jeopardize the consumers' health. Consequently, it becomes imperative to identify and rectify the sources of color contamination through the implementation of suitable water treatment methods.

3.2. Turbidity

Turbidity measures how water loses transparency due to suspended particles. Water sample turbidity was measured in Formazine Turbidity Units (FTU) and Nephelometric Turbidity Units (NTU) using a Lamotte Turbidity Meter (Model 2008, USA). Results showed that 6 samples (17%) had turbidity levels above the safe limit of 5 NTU. High turbidity affects water clarity and can harbor harmful germs and pollutants, posing a risk to human health, underscoring the need for regular water quality monitoring [19].

3.3. Total dissolved solids

The TDS levels of feed, filtered, and rejected water were measured using a TDS meter, with results expressed in mg/L. TDS levels ranged from 280 to 3725 mg/L, with 60% (21 samples) exceeding WHO standards. TDS under 600 mg/L is considered acceptable, while levels above 1000 mg/L are unsuitable for consumption due to taste issues. High TDS can result from natural sources like bedrock or human activities such as urban runoff, posing significant health risks and rendering the water unsafe for drinking.

3.4. pH

pH is a key water quality indicator, reflecting its acidity or alkalinity, particularly at extreme hydrogen ion concentrations. Using a pH meter (Model 6230N, JENCO), pH was measured by immersing the probe in a 20 mL water sample and shaking it to obtain the reading. The pH values of the potable water samples observed between 7.11 and 8.2, are within the WHO's acceptable range of 6.5 to 8.5, confirming the water quality in the study area meets the standards for safe human consumption.

3.5. Electrical conductivity

Water conductivity was measured using an electric conductivity meter (EuTech, CON11, Singapore) by placing its probe into a beaker containing the sample. Electrical conductivity (EC) ranged from 643 to 4600 µS/cm, with over half of the samples (22) exceeding WHO's acceptable limits, indicating significant contamination. High EC levels reflect a high concentration of dissolved salts, which can cause health issues such as hypertension. Thus, discontinuing the use of such water sources is essential for public health protection in the area.

3.6. Hardness

Calcium and magnesium were determined using the EDTA titration method (APHA, 2-34). Total hardness was first measured by taking a 20 ml sample, adding a small amount of Eriochrome black T, and adjusting the pH with ammonia, turning the solution pink. The sample was then titrated with 0.01N EDTA, and total hardness was calculated using (3).

$$Hardness = V_1 \times E \times \frac{1000}{V_2} \quad (3)$$

Where V_1 is the volume of the EDTA titrant, E=1, and V_2 is the volume of the sample.

The hardness of water samples ranged from 130 to 1610 mg/L, with 51% (18 samples) exceeding WHO limits. While hard water, rich in calcium and magnesium, isn't harmful to health, it can dry skin and hair [15]. It can also affect skin pH, reducing its effectiveness as a microbial barrier, particularly for eczema patients.

3.7. Calcium, magnesium, sodium, potassium, chlorides, sulfates nitrates, iron, fluoride, and arsenic

A wide variation was observed for the Ca contraction in water samples where the values ranged from 16 to 244 mg/l. Calcium was determined by (4) (EDTA Titration Method, APHA, 2-34).

$$Ca = Total\ hardness \times 0.4 (mg/l) \quad (4)$$

Remarkably, when comparing these values to the water guidelines set by the WHO, it was determined that 11% (4 samples) surpassed the established standard calcium concentration levels. Calcium, a vital mineral for the human body, acts as fundamental role in numerous physiological processes, including skeletal development, muscle contraction, and nerve function [20]. However, excessive calcium intake from water can have potential health implications, including an increased risk of kidney stone formation and potential effects on cardiovascular health [21].

In collected water samples, the values for magnesium ranged from 17 to 267 mg/l. Magnesium was determined by (5).

$$Mg = Total\ Haerdness - Ca (mg/l) \quad (5)$$

Only one sample had magnesium levels above WHO standards, likely due to natural variations [22]. Excess magnesium in drinking water poses no health risks and can help meet dietary needs [23]. The study revealed that 15 water samples (43%) were deemed unfit for human consumption levels surpassing the WHO's recommended limit of 200 mg/l, with concentrations ranging from 38 to 710 mg/L. High sodium intake can increase the risk of hypertension and cardiovascular diseases. Potassium (K) levels in all samples were within WHO limits, ranging from 3.5 to 21.4 mg/L, posing no health risk to the local population.

The drinking water analysis showed high chloride levels as shown in Figure 3, ranging from 33 to 1667 mg/L, indicating potential contamination from wastewater or other sources. Chlorides can enter groundwater from rocks, agricultural runoff, or wastewater. Sulfate levels in the samples ranged from 22 to 590 mg/L, with 26% (9 samples) exceeding WHO's recommended limits. Sulfate ions ($SO4^{2-}$) are naturally found in water, often due to leaching from sodium or magnesium sulfate deposits. While high sulfate levels can affect water taste and have mild laxative effects, they generally do not pose a significant health risk.

The nitrate concentration in the sample was measured using a nitrate ion-selective electrode (ISE) meter (Thermo Scientific Orion 4-Star Plus Ion-Selective Electrode Meter). The procedure began with instrument calibration using at least two standard solutions, adjusting the meter to measure the potential of the nitrate ISE for each standard. After calibration, samples were prepared by filtering to remove suspended solids if present. The nitrate electrode was rinsed with deionized water and then the sample before immersing it in the solution to measure nitrate concentration. Nitrate levels in water samples ranged from 0.97 to 23.61 mg/L, with two samples exceeding the WHO recommended limit of 10 mg/L. The increased nitrate concentrations may be linked to the improper disposal of municipal and industrial waste, as well as the leaching of nitrate into groundwater.

Iron concentrations in three drinking water samples (9%) surpassed the WHO-recommended limit of 0.3 mg/L, with concentrations ranging from 0.02 to 5.24 mg/L. Fluoride concentration was measured using a Thermo Scientific Orion 4-Star Plus Ion-Selective Electrode Meter. Like sodium measurements, the meter was calibrated using at least two standard fluoride solutions to ensure accurate readings. After calibration, the electrode was rinsed with deionized water and the sample, then immersed in the sample solution. Once the reading stabilized, the fluoride concentration was recorded.

Fluoride concentrations in three samples (9%) surpassed the WHO-recommended limit of 1.5 mg/L, ranging from 0.44 to 1.83 mg/L. This excess may result from factors like local geology, land composition, and minerals.

Arsenic concentration was measured using a 230 ATS atomic absorption spectrometer. A 60 mL sample was prepared by adding two drops of reagent As-1, swirling, and then adding a spoonful of reagent As-2 and another reagent. After sealing the bottle and inserting a test strip, the solution was left for 20 minutes. The strip was then removed, and its color was compared to a reference chart to determine arsenic concentration in mg/L. The analysis of water samples showed arsenic levels ranging from 0 to 5 ppb, indicating no contamination. Despite arsenic being a major pollutant in Pakistan’s groundwater. Notably, there was no evidence of such contamination in the studied area, which goes well for the development of future water treatment strategies Figure 4.

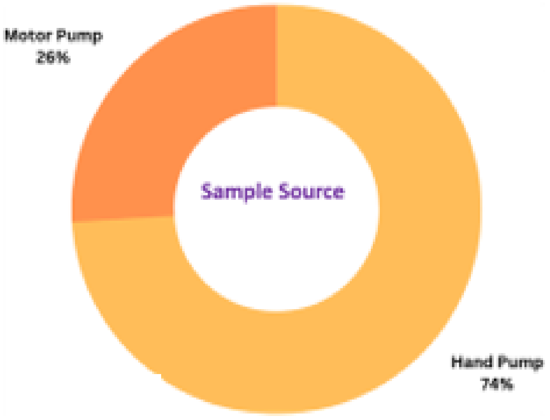

Figure 2. Sample sources

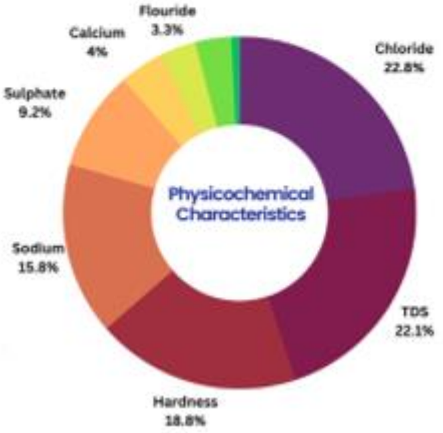

Figure 3. Physicochemical characteristics

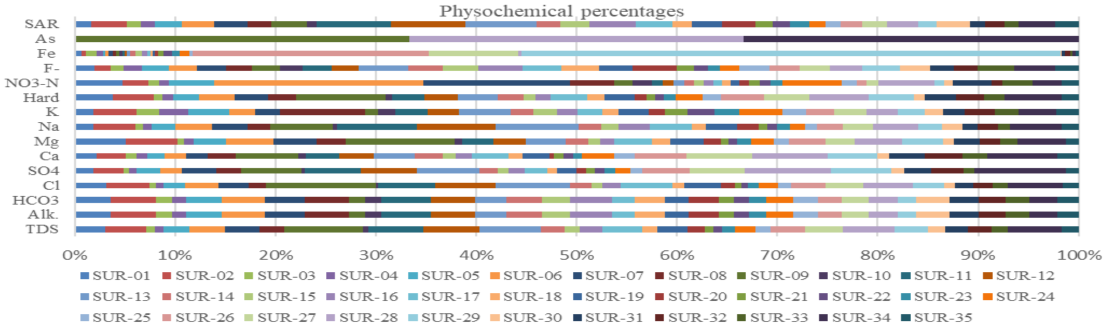

Figure 4. Physicochemical properties

3.8. Microbiological contamination in water samples

The results of the microbial analysis were concerning, as shown in Figure 5. None of the samples met the safety standards for human consumption because they contained an excessive number of total coliforms, surpassing the limit set by the WHO. Particularly concerning is the fact that 45% of the samples were contaminated with fecal matter, as indicated by E. coli levels exceeding the recommended limit. Groundwater contamination with total coliforms and E. coli likely resulted from sewage mixing with shallow groundwater near hand pumps [24], [25]. These findings highlight the urgent need to ensure access to safe drinking water to prevent health risks from contamination.

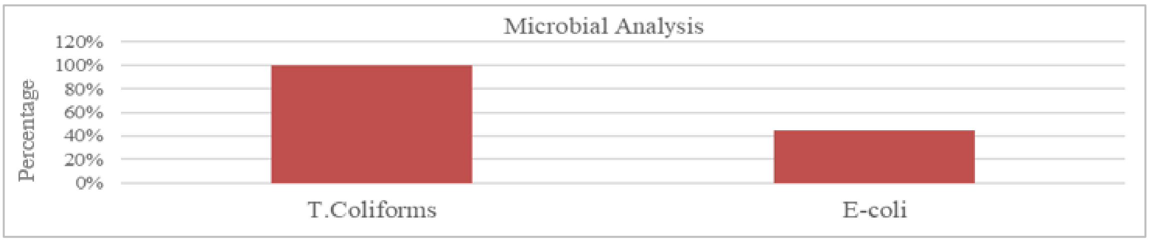

Figure 5. Microbial characteristics

3.9. Health risk assessment

A qualitative assessment of the impact of water quality on human health was conducted using a risk assessment factor (R) for distinct chemicals. R values for these chemicals were as follows: TDS (0.28–3.72), Cl (0.13–6.66), Fe (0.06–17.47), SO4 (0.08–2.36), Na (0.19–3.55), hardness (0.26–3.22), NO3-N (0.096–2.36), Ca (0.07–1.21), Mg (0.11–1.78) and F (0.29–1.22). R for drinking water samples should fall within these ranges, the risk level is categorized as: “R<1 (Low), R=1(Moderate), and R>1(High)”. Almost all 35 samples pose some risk to health as they show a higher value of R factor as shown in Figure 6.

3.10. Correlation analysis

The study examined correlations between pump depth and TDS, chloride and TDS, and combined concentration Ca+Mg and chloride. A positive linear relationship was identified between pump depth (m) and TDS (mg/L), though the coefficient of determination was low. i-e, R2=0.217, as shown in Figure 7. TDS levels are influenced by rainwater percolation and domestic sewage. High TDS can cause corrosion and increase water density, making it unsuitable for consumption.

The scatter plot in Figure 8 illustrates linear regression was performed for chloride concentration (mg/L) with TDS (Figure 6) and for combined calcium and magnesium concentrations against chloride (mg/L) (Figure 9) had R^2 values of 0.951 and 0.737, respectively. This suggests a strong linear relationship between the parameters, likely indicating a common geological origin or rock composition.

Figure 6. Risk assessment

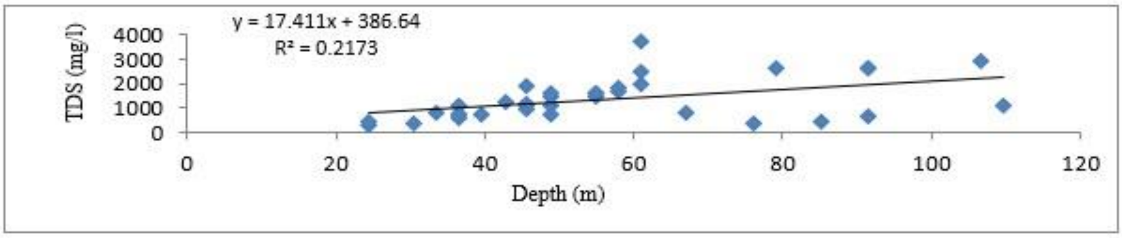

Figure 7. Linear regression analysis between groundwater depth (m) and TDS (mg/L) in samples collected from rural regions of Malir district, Karachi

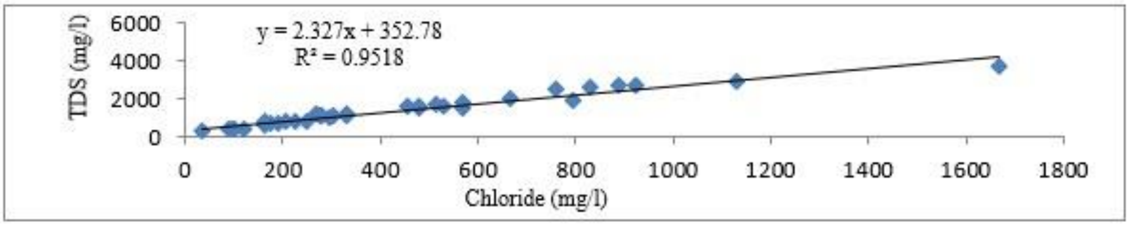

Figure 8. Linear regression analysis of TDS (mg/L) and chloride (mg/L) concentrations in samples collected from rural regions of Malir district, Karachi

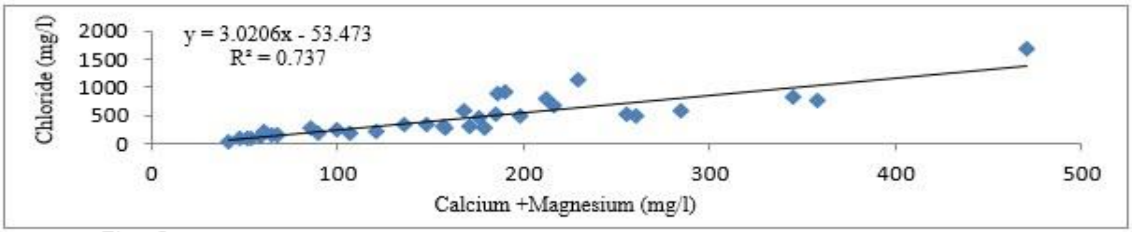

Figure 9. A linear regression analysis was carried out between the combined concentrations of calcium and magnesium (mg/L) and chloride (mg/L) in groundwater samples

4. CONCLUSION

In rural areas of Malir district, Karachi, groundwater is consumed by the populace without treatment because of insufficient access to potable water. The study area's water quality has not been previously reported. This study examined 35 groundwater samples for 22 PCB parameters. The findings revealed that 60% of the samples were unsuitable for drinking due to TDS levels, and 71% were potentially unsafe based on other physicochemical parameters. All samples were microbiologically contaminated. Contamination sources could be geological or anthropogenic, such as improper waste disposal and agrochemical use leading to high nitrate levels. The study highlights that contaminated groundwater poses health risks, as demonstrated by the calculated risk assessment factors. This suggests a need for treatment methods such as boiling, chlorination, filtration, UV disinfection, and reverse osmosis. It's crucial to raise awareness about safe water practices and improve sanitation infrastructure, including proper wastewater disposal and separation of drainage and water supply lines. Industrial contamination can be controlled by enforcing national environmental quality standards (NEQS). Upon the comprehensive conclusion of the groundwater quality evaluation in rural areas of Karachi, Pakistan, it is essential to provide recommendations for future research carried out in this life-threatening field. It is necessary to perform longitudinal analysis to obtain periodic changes in the quality of groundwater and to recognize the dynamic nature of hydrological systems. It is important to examine the major source of contamination, for example, whether it is agricultural runoff or it is industrial discharge; after determining the major source of contamination, it is very necessary to obtain improving approaches.

REFERENCES

[1] M. S Gaya *et al.*, "Estimation of turbidity in water treatment plant using Hammerstein-wiener and neural network technique," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 5, no. 3, p. 666, Mar. 2017, doi: 10.11591/ijeecs.v5.i3.pp666-672.

[2] M. H. H. Ichsan, W. Kurniawan, and M. Huda, "Water quality monitoring with fuzzy logic control based on graphical programming," *TELKOMNIKA (Telecommunication Comput. Electron. Control.*, vol. 14, no. 4, p. 1446, Dec. 2016, doi: 10.12928/telkomnika.v14i4.3505.

[3] O. Onigbogi and O. Ogunyemi, "Effect of storage containers on quality of household drinking water in urban communities in Ibadan, Nigeria," *Int. J. Public Heal. Sci.*, vol. 3, no. 4, p. 253, Dec. 2014, doi: 10.11591/ijphs.v3i4.4700.

[4] A. Ahmed, T. M. Noonari, H. Magsi, and A. Mahar, "Risk assessment of total and faecal coliform bacteria from drinking water supply of Badin City, Pakistan," *J. Environ. Prof. Sri Lanka*, vol. 2, no. 1, p. 52, Jul. 2013, doi: 10.4038/jepsl.v2i1.5750.

[5] M. K. Daud *et al.*, "Drinking water quality status and contamination in Pakistan," *Biomed Res. Int.*, vol. 2017, pp. 1–18, 2017, doi: 10.1155/2017/7908183.

[6] H. Kanwal *et al.*, "Analysis of physical chemical drinking water quality parameters in Sialkot," *J. Appl. Eng. Sci.*, vol. 12, no. 1, pp. 47–52, May 2022, doi: 10.2478/jaes-2022-0008.

[7] H. Ghazanfar, S. Saleem, S. Naseem, A. Ghazanfar, and U. K. Khattak, "Safe drinking water and sanitary measures: a cross sectional study in peri-urban community of Islamabad," *J. Pak. Med. Assoc.*, vol. 67, no. 2, pp. 220–224, 2017.

[8] Z. T. Ebrahim, "Is Pakistan running dry?," in *Water Issues in Himalayan South Asia*, Singapore: Springer Singapore, 2020, pp. 153–181. doi: 10.1007/978-981-32-9614-5_7.

[9] B. Gintamo, M. A. Khan, H. Gulilat, R. K. Shukla, and Z. Mekonnen, "Determination of the physicochemical quality of groundwater and its potential health risk for drinking in Oromia, Ethiopia," *Environ. Health Insights*, vol. 16, p. 117863022210960, Jan. 2022, doi: 10.1177/11786302221096051.

[10] F. Murtaza, M. Muzaffar, T. Mustafa, and J. Anwer, "Water and sanitation risk exposure in children under-five in Pakistan," *J. Fam. Community Med.*, vol. 28, no. 2, p. 103, 2021, doi: 10.4103/jfcm.jfcm_149_21.

[11] M. Latif *et al.*, "Assessment of drinking water quality using water quality index and synthetic pollution index in urban areas of mega city Lahore: a gis-based approach," *Sci. Rep.*, vol. 14, no. 1, p. 13416, Jun. 2024, doi: 10.1038/s41598-024-63296-1.

[12] G. Nabi, M. Ali, S. Khan, and S. Kumar, "The crisis of water shortage and pollution in Pakistan: risk to public health, biodiversity, and ecosystem," *Environ. Sci. Pollut. Res.*, vol. 26, no. 11, pp. 10443–10445, Apr. 2019, doi: 10.1007/s11356-019-04483-w.

[13] M. A. Kahlown, A. Majeed, M. Ashraf, and M. A. Tahir, "Drinking water quality in Pakistan: a case study of Islamabad and Rawalpindi Cities," in *Proceedings of the seminar on strategies to address the present and future water quality issues*, Islamabad, Pakistan: Pakistan Council of Research in Water Resources, 2005.

[14] M. M. Waqas *et al.*, "Evaluating the impact of climate change on water productivity of maize in the semi-arid environment of Punjab, Pakistan," *Sustainability*, vol. 12, no. 9, p. 3905, May 2020, doi: 10.3390/su12093905.

[15] A. Alamgir *et al.*, "Physico-chemical and bacteriological characteristics of drinking water of Malir Town, Karachi, Pakistan," *Am. J. Agric. Environ. Sci.*, vol. 15, no. 5, pp. 896–902, 2015, doi: 10.5829/idosi.aejaes.2015.15.5.12658.

[16] E. W. Rice, L. Bridgewater, A. P. H. Association, A. W. W. Association, and W. E. Federation, *Standard methods for the examination of water and wastewater*. in Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 2012. [Online]. Available: https://books.google.co.id/books?id=dd2juAAACAAJ

[17] S. Muhammad, M. T. Shah, and S. Khan, "Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan Region, Northern Pakistan," *Microchem. J.*, vol. 98, no. 2, pp. 334–343, Jul. 2011, doi: 10.1016/j.microc.2011.03.003.

[18] E. Emmanuel, M. G. Pierre, and Y. Perrodin, "Groundwater contamination by microbiological and chemical substances released from hospital wastewater: health risk assessment for drinking water consumers," *Environ. Int.*, vol. 35, no. 4, pp. 718–726, May 2009, doi: 10.1016/j.envint.2009.01.011.

[19] N. Hassan Omer, "Water quality parameters," in *Water Quality - Science, Assessments and Policy*, IntechOpen, 2020. doi: 10.5772/intechopen.89657.

[20] M. F. Lanjwani, M. Y. Khuhawar, and T. M. Jahangir Khuhawar, "Assessment of groundwater quality for drinking and irrigation uses in Taluka Ratodero, District Larkana, Sindh, Pakistan," *Int. J. Environ. Anal. Chem.*, vol. 102, no. 16, pp. 4134–4157, Dec. 2022, doi: 10.1080/03067319.2020.1780222.

[21] K. Mahmood, A. Alamgir, and M. A. Khan, "Seasonal variation in water quality of lower Sindh, Pakistan," *Fuuast J. Biol.*, vol. 4, no. 2, pp. 147–156, 2014, [Online]. Available: https://fuuastjb.org/index.php/fuuastjb/article/view/163/149

[22] G. Vespasiano, F. Muto, and C. Apollaro, "Geochemical, geological and groundwater quality characterization of a complex geological framework: the case study of the coreca area (Calabria, South Italy)," *Geosciences*, vol. 11, no. 3, p. 121, Mar. 2021, doi: 10.3390/geosciences11030121.

[23] A. Jabbar Kandhro, "Physico-chemical assessment of surface and ground water for drinking purpose in Nawabshah city, Sindh, Pakistan," *Am. J. Environ. Prot.*, vol. 4, no. 1, p. 62, 2015, doi: 10.11648/j.ajep.20150401.19.

[24] A. A. Elnazer, S. A. Salman, Y. M. A. Mohamed, J. Stafford, P. Davies, and H. A. El Nazer, "Siwa oasis groundwater quality: factors controlling spatial and temporal changes," *Environ. Monit. Assess.*, vol. 195, no. 1, p. 61, Jan. 2023, doi: 10.1007/s10661-022-10646-z.

[25] J. Ahmed, L. P. Wong, Y. P. Chua, and N. Channa, "Drinking water quality mapping using water quality index and geospatial analysis in primary schools of Pakistan," *Water*, vol. 12, no. 12, p. 3382, Dec. 2020, doi: 10.3390/w12123382.

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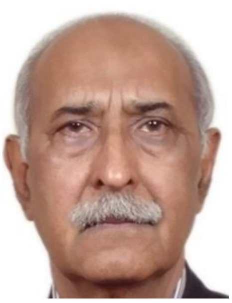

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