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GROUNDWATER QUALITY ASSESSMENT IN DISTRICT SANGHAR, SINDH, PAKISTAN USING MULTIVARIATE STATISTICS

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ABSTRACT

The present study investigates the groundwater quality of various Union Councils in Sanghar District, Sindh, Pakistan, with a focus on evaluating its suitability for human consumption. A total of 99 groundwater samples were collected and analyzed for key physicochemical parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), hardness, chloride, fluoride, sulphate, nitrate, and arsenic. Comparative assessment with World Health Organization (WHO) drinking water standards revealed that while the average concentrations of most parameters remained within permissible limits, approximately 20.20% of the samples exceeded the recommended TDS threshold of 1000 mg/L, indicating potential health risks. EC values ranged from 450 to 4980 µS/cm, with an average of 1764.4 µS/cm. A strong positive

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correlation (r > 0.75) was observed between TDS and EC, chloride, hardness, and sulphate, likely due to the dissolution of salts originating from similar geological formations. Additionally, EC showed a positive correlation with both hardness and chloride. Multivariate statistical approaches, including cluster analysis, coefficient of determination, and principal component analysis (PCA), were employed to interpret spatial patterns and interrelationships among the parameters. Cluster analysis effectively grouped sampling locations with similar water quality characteristics, aiding in the identification of zones requiring targeted monitoring and intervention. The findings highlight the necessity for continuous water quality surveillance and the implementation of appropriate mitigation strategies in areas where groundwater contains elevated salt and fluoride levels. Long-term consumption of such water may contribute to adverse health outcomes, underscoring the importance of sustainable water resource management in the region.

INTRODUCTION

Drinking water contamination is a serious environmental issue across the globe. High concentrations of heavy metals in water supplies pose significant health risks to humans. Consumption of water containing elevated levels of metals can lead to various adverse health effects, ranging from shortness of breath to certain types of cancers (1). Worldwide, billions of people still lack access to safe drinking water. There are two primary sources of drinking water: surface water and groundwater. Glaciers, lakes, reservoirs, and rivers serve as the main contributors to both. However, these water bodies are often contaminated through unsafe anthropogenic activities such as the disposal of chemicals, pesticides, open dumping of solid waste, and untreated sewage. In some cases, naturally occurring substances also contribute to water contamination. Developed countries have established centralized water quality monitoring systems to detect and manage contamination. Unfortunately, many developing nations including Pakistan, Bangladesh, Mexico, India, and Chile lack such infrastructure. There is an urgent need for centralized facilities for the treatment of raw water, coupled with public awareness campaigns about the presence of contaminants and their health impacts.

The quality of drinking water is determined by both microbiological and physicochemical parameters (2). These factor either individually or in combination are responsible for numerous public health issues. Key physicochemical indicators that influence water quality include pH, temperature, total dissolved solids (TDS), turbidity, alkalinity, and dissolved oxygen Nduka et al.,. In countries such as Bangladesh and Pakistan, the presence of arsenic in drinking water above the WHO-recommended limit is a critical concern. Soluble arsenic, when absorbed through the large intestine, has been linked to cancer following long-term exposure, particularly over a span of 20 years (3). Moreover, arsenic contamination is not limited to water; it can also be found in crops irrigated with contaminated sources (3). Recognizing this threat, the Government of Pakistan launched the National Action Plan for Arsenic Mitigation (2007–2011) to identify high-arsenic groundwater areas, provide alternative sources of safe drinking water, introduce arsenic removal technologies, and continuously monitor affected regions (4). In Pakistan, especially in rural and urban areas, most people rely on groundwater for drinking, often extracted using hand pumps and boreholes. However, excessive groundwater extraction can alter water quality, increasing concentrations of minerals and toxic metals. Additionally, groundwater contamination can result from nearby land pollution caused by industrial and urban activities. According to a PCRWR report, approximately 81,996 disease cases in northern Punjab were linked to the consumption of unsafe drinking water. UNICEF estimates that nearly 40% of hospital patients in Pakistan suffer from waterborne illnesses (5).

MATHODOLOGY

Study Area

Sanghar District is located in the Sindh Province of Pakistan, lying between latitude 25°58′13″N and longitude 69°24′04″E. The total area of the district is approximately 9,874 square kilometers, with a population of 2,049,873. Sanghar District comprises six talukas: Sanghar, Khipro, Sinjhoro, Tando Adam, Jam Nawaz Ali, and Shahdadpur, and includes 70 Union Councils (Figure 1). The district shares its borders with Mirpurkhas, Matiari, Nawabshah, Tando Allahyar, Khairpur, and Umerkot districts.

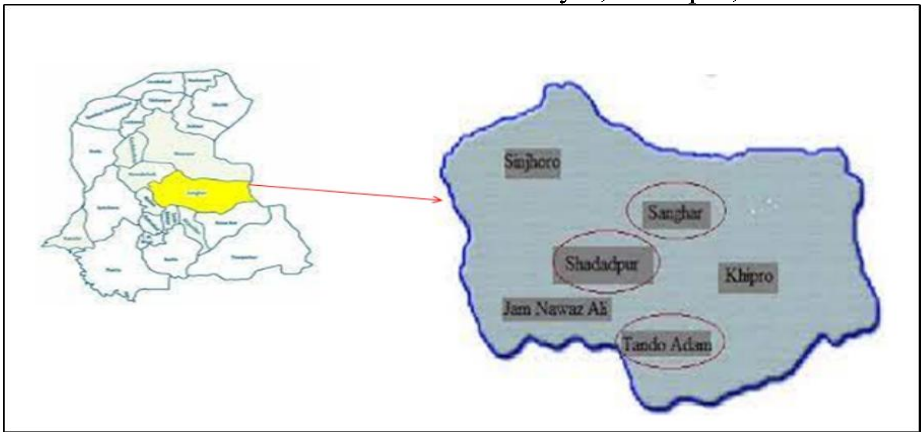

Figure 1: Study Area (District Sanghar)

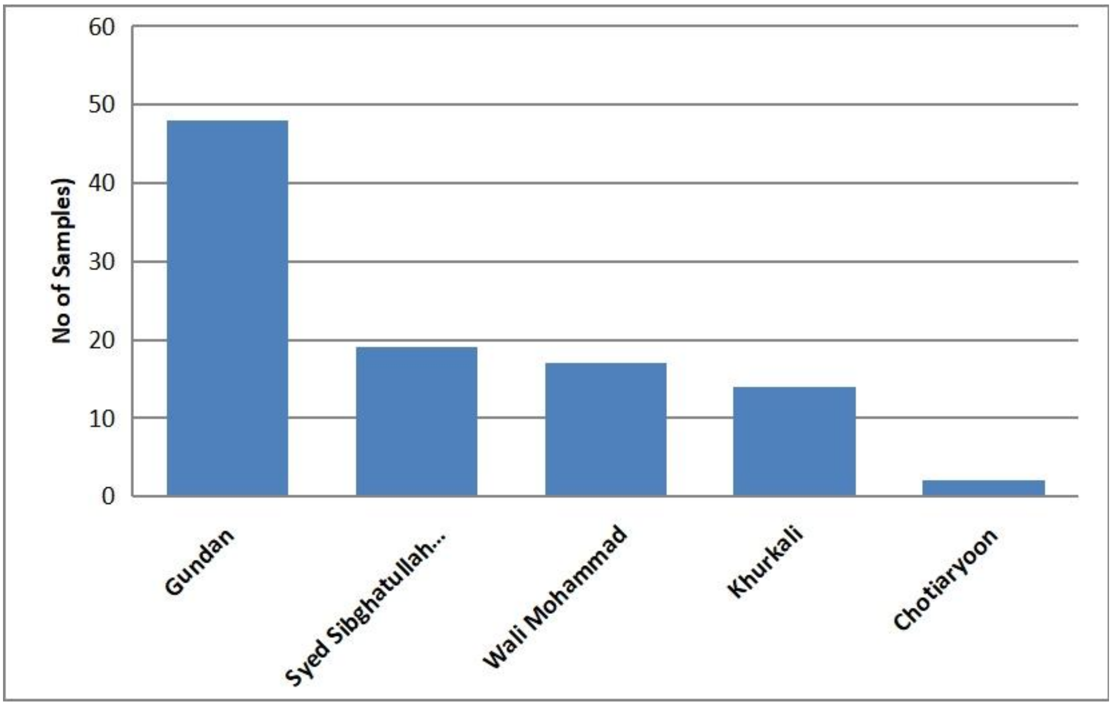

Figure 2: Number of samples collected from each Union Councils of District Sanghar

Sample Collection

Sanghar District was selected as the study area due to its remote location in Sindh Province and the limited availability of previous groundwater quality assessments. Over the course of one year, from January 2022 to December 2022, a total of 99 groundwater samples were collected. These samples were obtained from the taluka of Sinjhoro, specifically targeting five Union Councils: Chotiaryoon, Gundan, Kurkuli, Syed Sibghatullah Shah Shaheed, and Wali Mohammad. The selected sites aimed to provide comprehensive coverage of villages where groundwater is a primary source of drinking water (Figure 2).

Water samples were collected in clean, sterilized 1-liter plastic bottles from a variety of drinking water sources, including hand pumps, open wells, and public water supply schemes across more than 36 villages and households throughout the district. A total of nine physicochemical parameters were analyzed to assess water quality. These included pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, and arsenic. The pH of the samples was measured using a Hanna pH meter (HI 8417, Italy), while EC and TDS were determined with a Conductivity Meter (Orion 115, Inc., Boston, USA). Turbidity was measured using a Turbidity Meter (Model PC Chekit, Lovibond, Germany). Arsenic concentrations were analyzed using the Arsenic Test Kit (Merck 64271, Germany), which can detect levels ranging from 0.01 to 0.5 mg/L. The arsenic test operates by generating arsine gas, which reacts with mercury bromide present on an analytical strip to produce a yellow-brown arsenic-mercury halide complex. The arsenic concentration is then visually estimated by comparing the color intensity of the reaction zone on the strip with a pre-defined reference color scale, as described by (6).

Statistical analysis

The collected data, basic statistical analyses including the calculation of minimum, maximum, mean, and standard deviation were performed using Microsoft Excel 2013. In addition, multivariate statistical techniques were employed to better understand the relationships among the measured parameters. Hierarchical cluster analysis and Pearson correlation coefficients were computed using SPSS version 22 (SPSS Inc., Chicago, IL, USA). These statistical methods helped to identify trends, groupings, and correlations, thereby enabling a comprehensive assessment of the groundwater's suitability for human consumption.

RESULTS

In the present study, nine water quality parameters were analyzed from 99 groundwater samples collected across various Union Councils in Sanghar District. The number of samples varied across locations, with the highest number collected from Union Council Gundan, followed by Syed Sibghatullah Shah Shaheed. The lowest number of samples was collected from Chotiaryoon, as illustrated in Figure 1.2. The consumption of arsenic-contaminated water can result in serious health issues. Arsenic exposure is known to reduce the production of both white and red blood cells, cause irregular heart rhythms, damage blood vessels, and lead to paraesthesia in the hands and feet. Furthermore, long-term exposure is linked to various cancers, including urinary bladder, lung, and skin cancer (7-9). Additionally, arsenic exposure has been associated with characteristic skin lesions, such as melanosis and keratosis (10). The pH of the water samples ranged from 7.2 to 8.0, indicating that all samples were within the World Health Organization (WHO) recommended range of 6.5 to 8.5 for drinking water. Electrical conductivity (EC) values ranged from 450 to 4980 µS/cm, while total dissolved solids (TDS) were found between 288 and 3187 mg/L. Total hardness was observed in the range of 180 to 510 mg/L, expressed as $CaCO_3$. Nitrate was not detected in any of the samples. Sulphate concentrations ranged from 30 to 250 mg/L, with an average value of 96 mg/L. Arsenic levels varied from 0.0 to 5.0 µg/L, with an average concentration of 0.1 µg/L. Overall, the results for parameters such as pH, EC, TDS, hardness, chloride, fluoride, sulphate, nitrate, and arsenic in groundwater across different villages of Sanghar were found to be within WHO permissible limits for safe drinking water. These findings are consistent with the WHO's definition of potable water, which states that drinking water should be colorless, odorless, and tasteless, as also reported by (11).

Table 1: Mean value of parameter of drinking water samples of different Union councils of Taluka and District Sanghar

Union councils	pH	EC µS/cm	TDS mg/L	Hardness mg/L	Chloride mg/L	Fluoride mg/L	Sulphate mg/L	Nitrate mg/L	Arsenic µg/L
Chotiaryoon	7.3	1010.0	490.0	282.0	70.1	0.7	180.0	0.0	0.0
Gundan	7.5	1348.5	621.2	317.7	150.0	0.8	103.3	0.0	0.0
Kurkali	7.2	1141.0	575.1	349.0	108.9	0.8	70.5	0.0	0.0
Syed Sibghatullah Shah	7.3	1176.2	591.2	344.3	117.5	0.9	75.1	0.0	0.0
Wali Mohammad	7.4	962.8	488.6	321.7	80.6	0.6	110.0	0.0	0.01

Table 2: Minimum, maximum, mean and standard deviation values of parameters of Different Union councils at Sanghar

Parameters	Minimum	Maximum	Mean	Standard deviation	WHO Limit
PH	7.2	8.0	7.41	0.26	6.5-8.5
EC (µS/cm)	450.0	4980.0	1236	623.1	1500 µS/cm^3
TDS (mg/L)	288.0	3187.2	791.01	398.77	1000 mg/L
Total Hardness (mg/L)	180.0	510.0	333.15	100.1	500 mg/L
Chloride (mg/L)	40.0	800.0	129.0	122.0	250 mg/L
Fluoride (mg/L)	0.7	1.5	0.79	0.37	1.5 mg/L
Sulphate (mg/L)	30.0	250.0	96.0	53.0	250 mg/L
Nitrate (mg/L)	0.0	0.0	0.0	0.0	10 mg/L
Arsenic (µg/L)	0.0	5.0	0.1	0.0	10 µg/L

Table 3. Correlation determination of parameters

Parameters	TDS	pH	EC	Hardness	Cl	F	NO3	SO4	As
TDS	**1.000**								
pH	-0.062	**1.000**							
EC	**0.982**	0.041	**1.000**						
Hardness	**0.806**	-0.361	**0.767**	**1.000**					
Cl	**0.786**	0.124	**0.842**	0.419	**1.000**				
F	0.509	-0.107	0.458	0.198	0.325	**1.000**			
NO3	-0.06.	-0.21	0.03.	0.002.	0.032.	0.032.	**1.000**		

SO4	**0.763**	0.186	0.619	0.381	0.574	0.154	0.065	**1.000**	
As	-0.079	-0.101	-0.078	0.032	-0.068	-0.137	0.087	-0.097	**1.000**

Correlation Determination

The correlation coefficients (r) among nine water quality parameters namely electrical conductivity (EC), pH, total dissolved solids (TDS), chloride (Cl^-), sulphate (SO_4^{2-}), total hardness, and nitrate (NO_3^-) were evaluated using SPSS version 22 (Table 3). The correlation values were calculated based on the mean values of the samples and were used to measure the strength and direction of the relationships between pairs of variables. A high correlation between two parameters indicates that the value of one can be predicted based on the value of the other (5). The results revealed a strong positive correlation between TDS and several other parameters, including EC, chloride, total hardness, and sulphate ($r > 0.75$). This strong association is likely due to the common geological origin and similar salt dissolution processes influencing these parameters. Electrical conductivity was also positively correlated with both total hardness and chloride concentrations, further supporting the hypothesis of shared mineral sources contributing to groundwater composition.

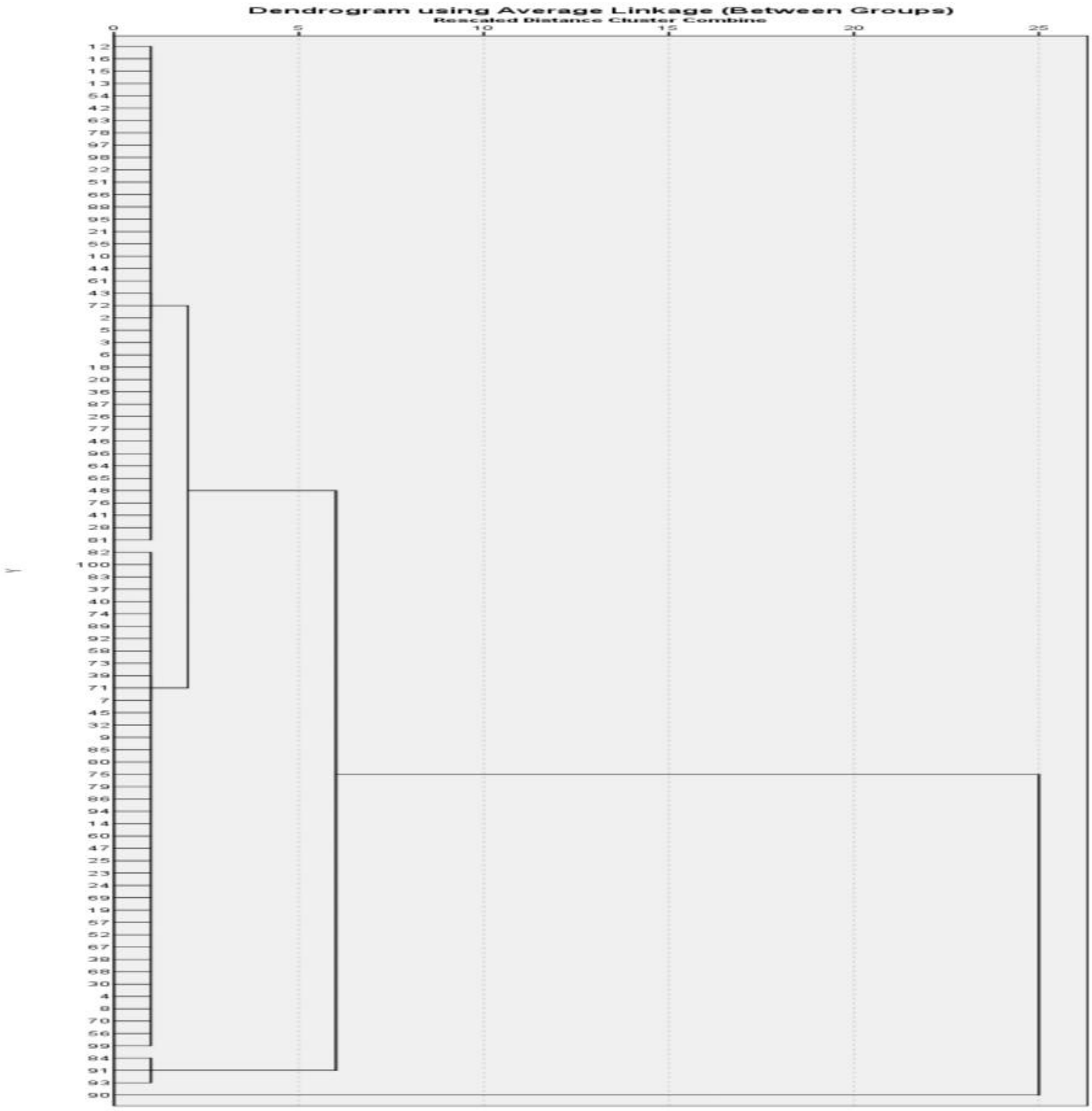

Figure 3. Cluster analysis of parameters

Cluster Analysis
Cluster analysis was performed to classify the sampling locations based on similarities in water quality parameters. This statistical technique groups locations that share similar characteristics, using distance measures and aggregation procedures to build a hierarchical structure. The goal is to identify clusters with internal similarity and external dissimilarity (12). The analysis was conducted on a normalized dataset using the Ward's method of hierarchical clustering (11). The dendrogram resulting from the analysis revealed three main clusters: Cluster 1, Cluster 2, and Cluster 3 (Figure 3). Cluster 1 included 41 samples, all of which demonstrated similar parameter values. Cluster 2 also comprised 41 samples with comparable characteristics. Cluster 3 consisted of only 4 samples, located at the lower end of the dendrogram, indicating distinct parameter values from the other clusters. Upon comparison, Cluster 3 exhibited the highest concentrations across most parameters, suggesting more severe water quality issues in those locations. Cluster 2 showed moderately high values, while Cluster 1 represented the locations with relatively lower parameter values. This hierarchical grouping helps in identifying

areas with similar contamination profiles and can assist in prioritizing intervention and treatment strategies.

DISCUSSION

The average values recorded in the study were: EC at 1236 µS/cm, TDS at 791 mg/L, pH at 7.41, total hardness at 333.15 mg/L, chloride at 129 mg/L, fluoride at 0.79 mg/L, sulphate at 96.0 mg/L, nitrate at 0.0 mg/L, and arsenic at 0.1 µg/L. However, it is worth noting that in some locations, EC levels were significantly higher, ranging from 484 to 6875 µS/cm, with an average of 1764.4 µS/cm. The lowest EC value was found in sample no. 96, while the highest was observed in sample no. 73. Although arsenic levels in this particular study remained below the WHO guideline of 10 µg/L, arsenic contamination of groundwater is a widespread issue in Pakistan. Studies have reported that over 40% of the population in Pakistan is exposed to arsenic-contaminated water (13). In Punjab Province, more than 20% of residents are affected by high arsenic concentrations in both surface and groundwater, particularly in industrial areas. In East Punjab, arsenic levels have been found as high as 1900 µg/L (14). Similarly, in Sindh Province, 16% to 36% of the population has been exposed to arsenic levels exceeding 315 µg/L in surface and groundwater sources (15). Groundwater arsenic concentrations have even reached up to 1100 µg/L in certain regions, far exceeding the WHO limit (16). A study in the districts of Matiari and Khairpur reported that 15% of samples had arsenic levels above 250 µg/L, while 37% exceeded 50 µg/L (17).

Conclusion

This study comprehensively evaluated the groundwater quality across five Union Councils of District Sanghar by analyzing 99 samples for key physicochemical parameters relevant to human health. Comparison with World Health Organization (WHO) guidelines revealed that, although the average values for electrical conductivity (EC) and total dissolved solids (TDS) were within acceptable limits, a notable proportion of individual samples exceeded these thresholds posing potential risks to consumers relying on untreated groundwater. To enhance understanding of the dataset, multivariate statistical techniques, including Pearson correlation and hierarchical cluster analysis, were employed. These tools effectively revealed the interdependence of various water quality parameters and identified clusters of areas with similar contamination profiles. The strong correlations observed, particularly between TDS and parameters such as EC, chloride, hardness, and sulphate, point toward shared geochemical processes influencing groundwater composition. The findings underscore the urgent need for continuous groundwater quality monitoring and the introduction of appropriate treatment and management strategies in affected areas. Addressing these water quality issues is essential to safeguarding public health and ensuring access to safe drinking water in rural regions of Sindh.

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CONFLICT OF INTEREST

Authors have no conflict of interest

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