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Analysis of Drinking Water Quality and Associated Human Health Risks. A Case Study of Rawalpindi- Pakistan

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Water is essential for the survival of all living beings, but the rapid increase in population is causing a significant decline in water quality. Access to safe and hygienic drinking water is crucial for human health, yet approximately 44% of Pakistan's population lacks access to clean drinking water. In Rawalpindi, a densely populated area, the challenges associated with drinking water are further exacerbated by industrialization and rapid population growth. This study aims to analyze the spread of waterborne diseases, identify sources of water pollution, and propose preventive measures specifically for the Mareer Hassan Saddar area within the Rawalpindi cantonment. The study assessed various water quality parameters, including aesthetic factors such as taste, odor, and appearance; chemical factors like pH, Total Dissolved Solids (TDS), hardness, nitrates, and turbidity; as well as heavy metals such as zinc, chromium, lead, and arsenic. Biological parameters, including the presence of total coliform bacteria, were also evaluated. Water samples were collected from different endpoints within the Rawalpindi district and compared against the drinking water quality standards established by the World Health Organization (WHO). The findings revealed that while the chemical quality of the water was within acceptable ranges according to WHO and national standards, the biological content was highly problematic. The presence of total coliform and fecal coliform bacteria in the water samples was particularly concerning, as these bacteria are known to cause various diseases in humans. This highlights the urgent need for improved water quality management in the study area to protect public health.

Keywords. Drinking Water Quality, Waterborne Diseases, Water Pollution, Rawalpindi Cantonment, Biological Contamination.

Introduction.

Water is essential for human life, serving as a critical component for survival and a medium for transporting microbial pathogens that can lead to serious illnesses. Extensive research has documented the global burden of waterborne diseases, which pose significant risks, particularly to children and women. In arid and semi-arid regions, groundwater is a primary resource for drinking, domestic use, and irrigation, especially for rural communities [1]. Contaminated water can lead to numerous health issues, including diarrhea, vomiting, gastroenteritis, dysentery, and kidney problems, as seen in the Badin and Thar districts of southern Sindh, Pakistan [2]. Technological advancements in water quality monitoring and data analysis are essential for identifying and mitigating risks. The integration of computer science with environmental technology facilitates real-time water quality assessments, predictive modeling of contamination trends, and the creation of smart water management systems.

In developing countries, many water sources are compromised by dangerous physical, biological, and chemical contaminants, leading to high rates of waterborne diseases such as diarrhea, cholera, typhoid, and skin and eye infections [3]. Emerging technologies such as IoT-based sensors, cloud computing, and Artificial Intelligence (AI) provide innovative solutions for continuous water quality monitoring, data-driven decision-making, and early warning systems. These technologies enable remote data collection, allowing for efficient and precise detection of pollutants. Machine learning algorithms can analyze water quality patterns to predict potential contamination events, offering valuable insights for public health authorities to implement preventive measures. Additionally, data visualization and GIS mapping improve the understanding of spatial variations in water quality, supporting targeted interventions [4].

Sources of heavy metal contamination include mining, agricultural activities, industrial production, untreated sewage, and pollution from smelters, chemical industries, oil refineries, and metal piping, as well as by-products of coal combustion and power plants. In Pakistan, drinking water is frequently contaminated with hazardous substances, including turbidity, bacterial infections, dissolved solids, nitrates, and arsenic [5]. The proximity of water channels and sewage pipes often leads to contamination upon corrosion of pipes (WWF Pakistan, 2010). It is estimated that 200,000 children in Pakistan die annually from diarrheal diseases, which contribute to national economic losses of $380-883 million (USD), or approximately 0.6-1.44% of the GDP [6]. Pakistan ranks 80th out of 122 countries in water quality, and the situation is deteriorating at an alarming rate.

The growing integration of technological solutions in environmental science highlights the need for multidisciplinary approaches to water quality management. Advanced data analytics and cloud-based platforms can significantly improve the accuracy and timeliness of water quality assessments, ensuring that interventions are precise and based on current scientific insights [7]. This study utilizes technology-driven methods to analyze the spread of waterborne diseases, pinpoint sources of water pollution, and recommend preventive measures for the Rawalpindi cantonment area, specifically Mareer Hassan Saddar. By incorporating technology, this research aims to support a more sustainable approach to water quality management and public health protection [8].+

Application of Computational Models and Data Analysis Techniques.

Emerging technologies such as IoT-based sensors, cloud computing, and Artificial Intelligence (AI) provide innovative solutions for continuous water quality monitoring, data-driven decision-making, and early warning systems. Computational models and data analysis techniques are increasingly employed to evaluate water quality and predict contamination events, enabling more effective water resource management [15]. Methods like machine learning, statistical modeling, and geospatial analysis have transformed the collection, analysis, and interpretation of environmental data.

Machine learning algorithms, including regression models, neural networks, and decision trees, are used to create predictive models that forecast water quality parameters based on historical and real-time data [16][14][17]. These models uncover complex patterns and correlations that traditional analysis methods often miss, allowing for the prediction of contamination events before they occur. For example, time-series analysis can predict trends in water quality indicators such as pH, turbidity, and heavy metal concentrations, offering crucial information for timely interventions and risk reduction.

GIS enables the visualization and spatial analysis of water quality data. Mapping the distribution of contaminants helps identify pollution hotspots and examine the spatial relationship between contamination sources and impacted communities. This spatial analysis supports the strategic placement of monitoring stations and prioritizes areas for remediation. Additionally, spatial interpolation techniques like Kriging estimate water quality parameters at unsampled locations, providing a detailed overview of the contamination landscape [18].

Objective of Study.

- To assess the types of diseases caused by contaminated water.
- To assess biological content in drinking water of Mareer and civil lines Saddar Rawalpindi.
- To compare the water quality parameters of the present study with National Drinking Water Quality Standards (2008) and WHO (2011) Guidelines.

Study Area.

The study area, Rawalpindi, is a metropolitan city with a population of approximately 2.098 million. Commonly referred to as "Pindi," it is the fourth largest city in the country and forms a closely integrated urban area with Islamabad, together known as the twin cities. Positioned on the Potohar Plateau, Rawalpindi is characterized by its distinctive geographical and urban features [9]. To the south of Rawalpindi's central areas, and across the Lai Nullah, lies the expansive Rawalpindi Cantonment. This study specifically focused on the Civil Lines and Mareer Hassan districts within Rawalpindi [10].

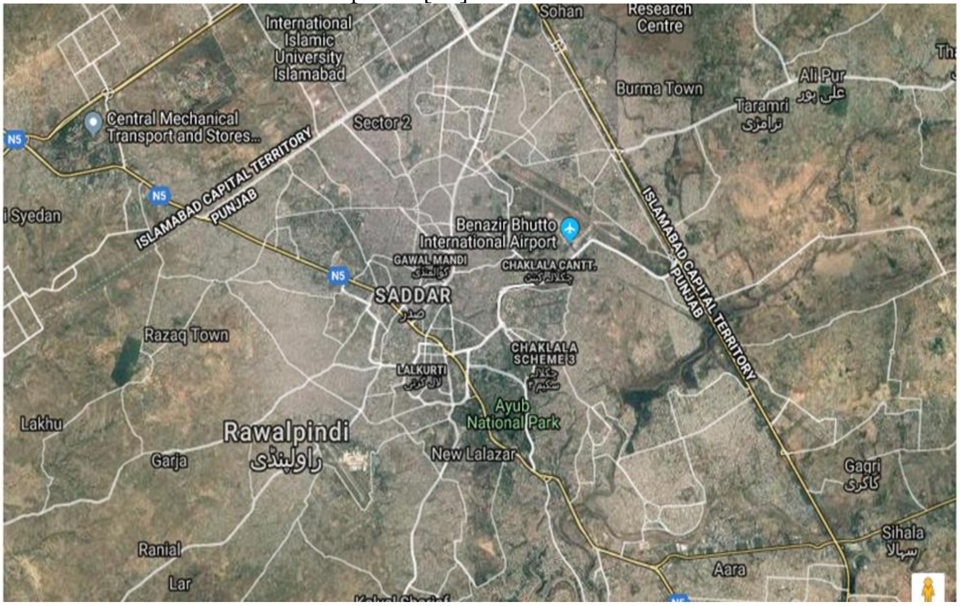

Figure 1. Map of Rawalpindi

Materials and Methods.

Study Type.

The study employed a qualitative approach to investigate the impact of contaminated water on human health. It assessed the pattern of increasing waterborne diseases by collecting and analyzing water samples from both the source points and the tail ends of areas most affected in Rawalpindi.

Data Collection and Sampling.

The study utilized multi-stage approaches to collect data Initially, hospital data was gathered to identify patterns in waterborne diseases. In the final stage, water sampling and quality analysis were conducted. Samples were collected from Mareer Hassan Saddar, Rawalpindi, and analyzed for parameters including pH, TDS, turbidity, hardness, calcium, magnesium, nitrates, chlorides, and heavy metals. Advanced instrumentation and IoT-based sensors were used for real-time data collection. Data was managed using Microsoft Azure SQL Database while cleaning and preprocessing were conducted using Python libraries like Pandas and NumPy.

Predictive Modeling.

GIS software like ArcGIS were used to map contamination sources and analyzed spatial patterns. Sampling sites in Rawalpindi were accurately planned to ensure thorough coverage of the city's critical areas [11][12]. Key factors were considered to achieve a representative overview of water quality. Sites were strategically selected across various zones residential, commercial, and industrial to capture the city's geographical diversity and potential water quality differences. Special attention was given to locations near potential contamination sources, including industrial zones, sewage discharge points, and densely populated regions, to assess their impact on water quality.

High-population areas like Saddar and Civil Lines were prioritized to examine the water quality experienced by the majority of residents, while areas with vulnerable populations, such as low-income neighborhoods, were also included, recognizing their potentially limited access to clean water [13]. Historical water quality data and previous studies were reviewed to identify sites with known issues, ensuring these areas were monitored for any changes over time. Government and municipal reports further informed site selection, particularly in regions flagged for water quality concerns [14].

Sampling Technique.

Water samples were collected from both the source point, where the community initially receives water, and the endpoint, where the water is used [19]. The sampling followed standard procedures, with collections conducted in March and April 2019. Before sampling, plastic bottles were sterilized in boiling water for 15 minutes. To eliminate bacteria around the tap, a candle flame was used, and the water was allowed to flow for 5 minutes before sampling (APHA, 2005). A total of 20 samples were collected from various endpoints in Rawalpindi, each properly labeled with sample code, date, time, and collection site [20][21]. Aesthetic parameters such as pH, temperature, taste, color, and odor were examined at the sampling sites. Chemical parameters (including sulfates, chlorides, nitrates, heavy metals, carbonates, bicarbonates, and dissolved oxygen) and biological contents (total coliform and fecal coliform) were analyzed by the Public Health and Engineering Department [22].

Analytical Methods for Chemical and Biological Testing.

The gathered information was analyzed with the help of SPSS, frequency, and percentages. The results were compared with established water quality standards to assess the relationship between water quality, water handling practices, and the incidence of waterborne diseases. Specifically, the collected data were evaluated against the WHO drinking water quality guidelines [23].

To thoroughly assess water quality, a combination of chemical and biological testing methods was employed, ensuring accurate detection of contaminants and compliance with health standards. Below is an overview of the methods and equipment used in this study.

Chemical Testing.

pH Measurement. The acidity or alkalinity of the water samples was measured using a digital pH meter, which was carefully calibrated with standard buffer solutions before each use to ensure accuracy. This method provided a precise assessment of the pH levels. The equipment utilized included a digital pH meter, specifically the Hanna Instruments HI 98107 model.

Turbidity.

Turbidity, an indicator of water clarity, was assessed using a turbidity meter. This method involved directing a light beam through the water sample and measuring the light scattered by suspended particles. The results offered insights into the concentration of particulates in the water. A Hach 2100N turbidity meter was employed for this analysis.

Total Dissolved Solids (TDS).

The concentration of TDS was determined using a TDS meter, which measures the water's electrical conductivity. This correlates with the concentration of dissolved ions and provides a comprehensive measure of both inorganic and organic substances present in the water. The Myron L Ultra Meter II was utilized in this study.

Heavy Metals.

The presence of heavy metals, including lead, arsenic, and cadmium, was detected using Atomic Absorption Spectroscopy (AAS). For this analysis, water samples were treated with concentrated acids to break down organic matter, allowing the metals to be accurately quantified. The PerkinElmer Analyst 400 was the Atomic Absorption Spectrometer employed for this purpose.

Chloride and Sulfate Ions.

Ion chromatography was used to measure the concentration of chloride and sulfate ions in the water samples. This method involves separating ions based on their interaction with an ion exchange resin, followed by detection with a conductivity detector. The Metrohm 883 Basic IC Plus ion chromatograph was used for this analysis, providing detailed information on the water's ionic composition.

Nitrate and Phosphate Levels.

Nitrate and phosphate concentrations were analyzed using spectrophotometric methods. The water samples were reacted with specific reagents to form colored complexes, and the intensity of the resulting color was measured at specific wavelengths to quantify these nutrients. A UV-visible spectrophotometer, such as the Shimadzu UV-1800, was employed for these measurements.

Biological Testing.

Total Coliforms and E. Coli.

To detect the presence of total coliforms and E. coli, the Most Probable Number (MPN) method was used. This involved inoculating multiple tubes with water samples and observing any gas production or color change, which would indicate bacterial contamination. The method was essential for evaluating the microbiological safety of the water. Equipment used included an incubator like the Memmert IN30, MPN tubes, and lactose broth media [24]. The Heterotrophic Plate Count (HPC) method was employed to estimate the bacterial population in the water. Samples were spread onto nutrient agar plates and incubated, allowing bacterial colonies to grow. The colonies were then counted to determine the level of heterotrophic bacteria. A Thermo Scientific Heratherm incubator was used for this process, along with Petri dishes and nutrient agar media.

Results and Discussion.

Aesthetic Quality Parameters

The analysis of aesthetic parameters revealed that all water samples had unobjectionable taste and odor, with color ranging from clear to the presence of suspended particles in one sample (DW-4), which exhibited an earthy odor. The majority of samples (19 out of 20) were clear and free from any undesirable taste or odor (Table 1).

Table 1. Aesthetic Parameters of Dug Well Water Samples

	Aesthetic Parameters

Sr No.	Sample Code	Taste	Color	Odor
1	DW-1	Unobjectionable	Clear	Unobjectionable
2	DW-2	Unobjectionable	Clear	Unobjectionable
3	DW-3	Unobjectionable	Clear	Unobjectionable
4	DW-4	Unobjectionable	Suspended particles	Earthy odor
5	DW-5	Unobjectionable	Clear	Unobjectionable
6	DW-6	Unobjectionable	Clear	Unobjectionable
7	DW-7	Unobjectionable	Clear	Unobjectionable
8	DW-8	Unobjectionable	Clear	Unobjectionable
9	DW-9	Unobjectionable	Clear	Unobjectionable
10	DW-10	Unobjectionable	Clear	Unobjectionable
11	DW-11	Unobjectionable	Clear	Unobjectionable
12	DW-12	Unobjectionable	Clear	Unobjectionable
13	DW-13	Unobjectionable	Clear	Unobjectionable
14	DW-14	Unobjectionable	Clear	Unobjectionable
15	DW-15	Unobjectionable	Clear	Unobjectionable
16	DW-16	Unobjectionable	Clear	Unobjectionable
17	DW-17	Unobjectionable	Clear	Unobjectionable
18	DW-18	Unobjectionable	Clear	Unobjectionable
19	DW-19	Unobjectionable	Clear	Unobjectionable
20	DW-20	Unobjectionable	Clear	Unobjectionable

Figure 2. Aesthetic parameters

Chemical Quality Parameters

pH Levels.

The pH of the water samples ranged from 7.1 to 7.4, with an average value of 7.25. All samples fell within the WHO recommended range of 6.5 to 8.5, indicating no significant acidity or alkalinity that could adversely affect water quality or health (Figure 3).

Total Dissolved Solids (TDS).

TDS levels varied from 361 mg/L to 728 mg/L. The highest value observed was 728 mg/L in sample 3, and the lowest was 361 mg/L in sample 13. These values are within the WHO and NSDWQ acceptable limits of <1000 mg/L (Figure 4).

Turbidity.

The turbidity values ranged from 0.46 NTU to 3.92 NTU. All samples were below the WHO and NSDWQ guideline limit of 5 NTU, indicating acceptable water clarity and low risk of pathogen presence (Figure 5).

Hardness.

Water hardness ranged between 280 mg/L and 490 mg/L, with an average of 385 mg/L. These values reflect a moderate level of hardness, which can cause scaling in plumbing systems but is not typically harmful to health (Figure 6).

Calcium and Magnesium.

Calcium levels ranged from 48 mg/L to 96 mg/L, with an average of 72 mg/L, while magnesium levels varied between 30 mg/L and 63 mg/L, with an average of 46.5 mg/L [25]. Both parameters are within the recommended guidelines, suggesting that the levels are suitable for dietary intake and do not pose significant health risks (Figures 7 and 8).

Nitrates.

Nitrate concentrations in all samples were recorded as 0 mg/L. This result is well below the WHO and NSDWQ limit of ≤50 mg/L, indicating no significant risk of "blue baby syndrome" or other nitrate-related health issues.

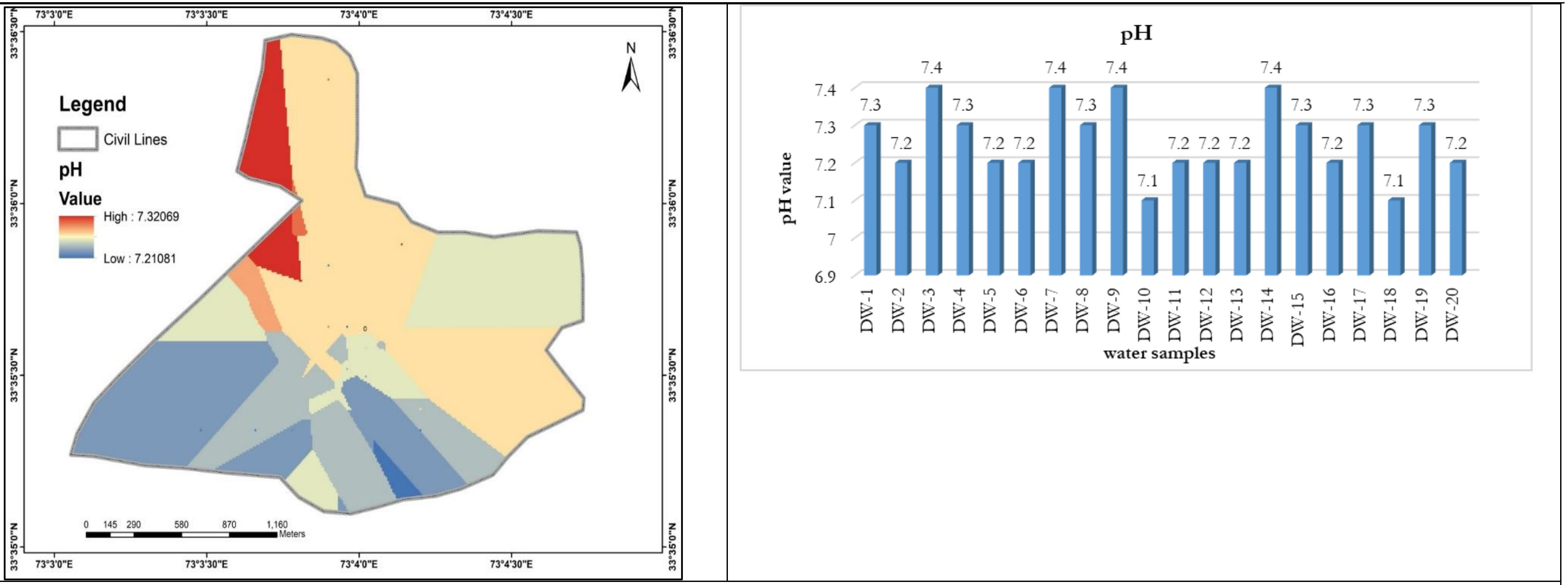

Figure 3. Value of pH throughout the study site.

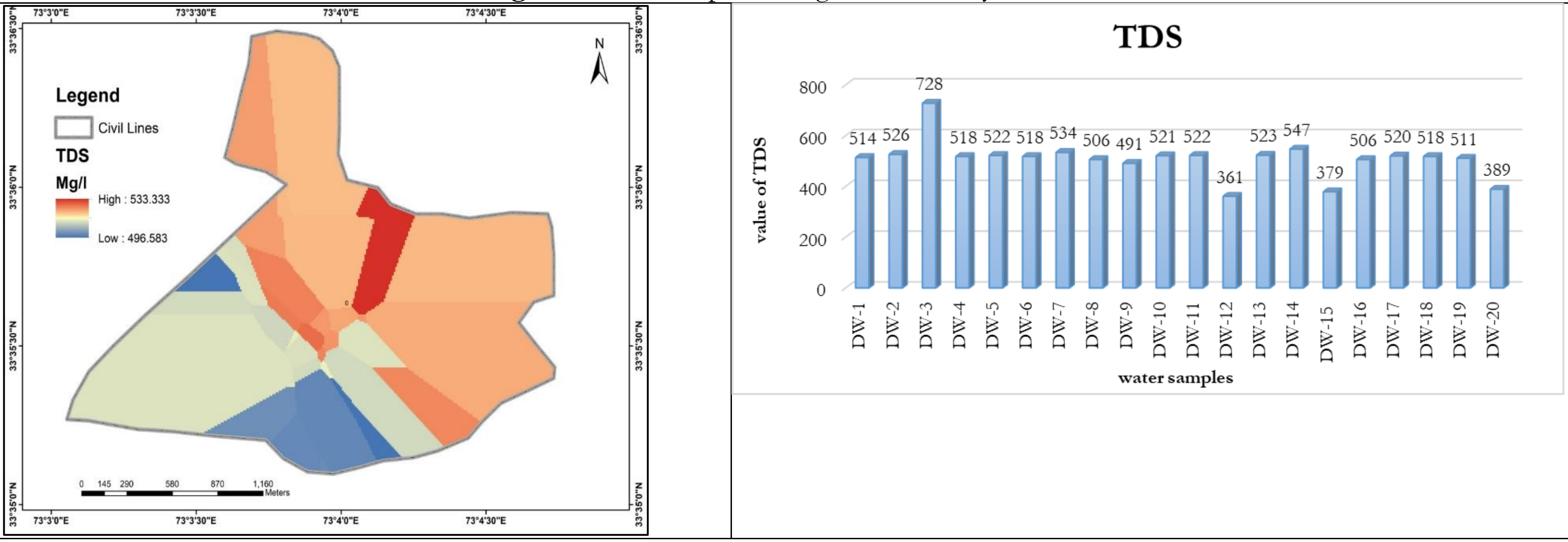

Figure 4. Value of TDS throughout the study site.

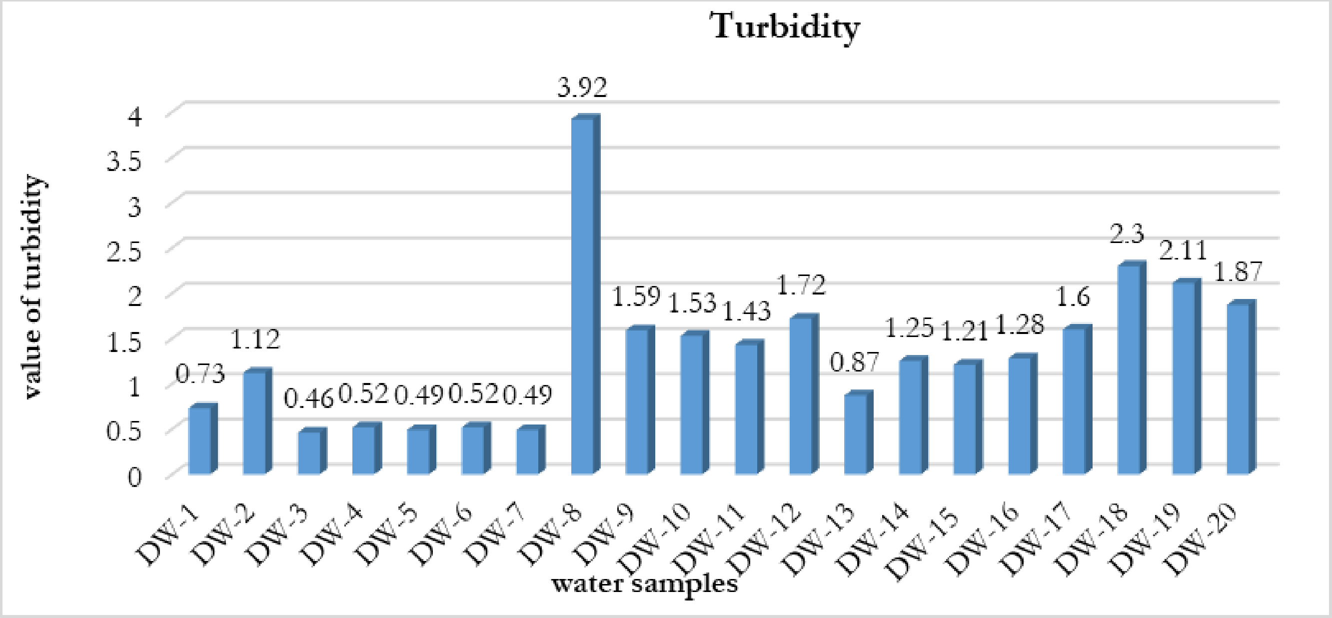

Figure 5. Value of turbidity

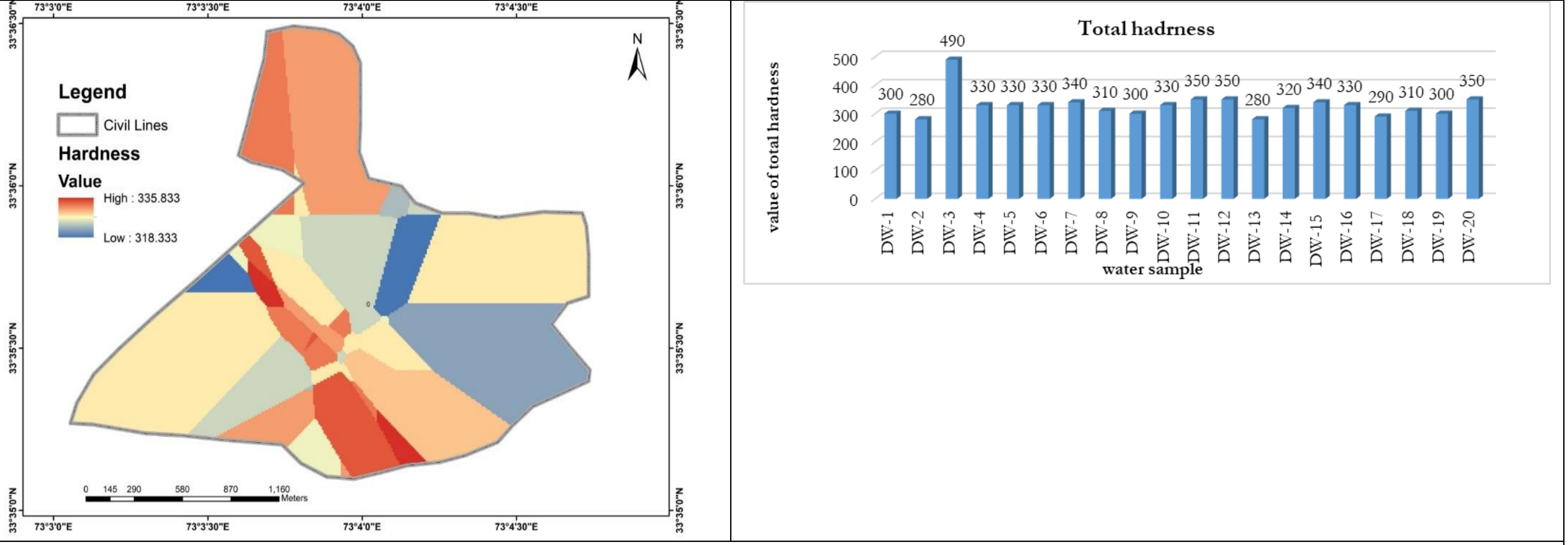

Figure 6. Value of total hardness

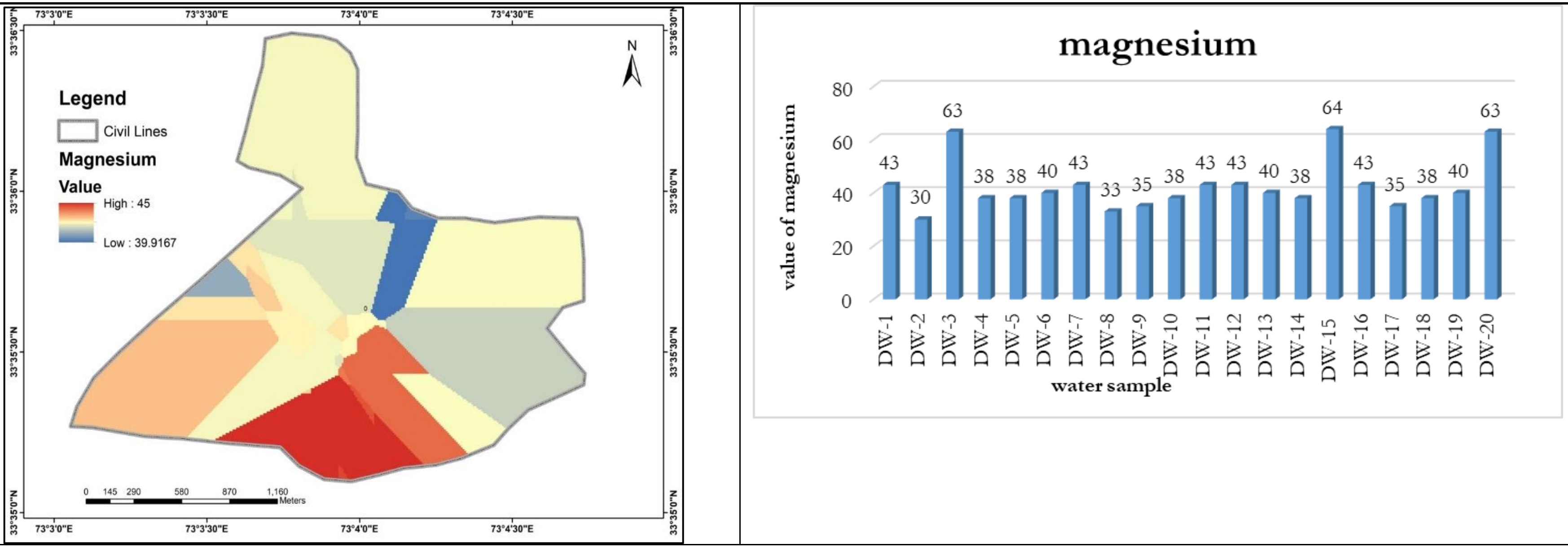

Figure 7. Value of magnesium

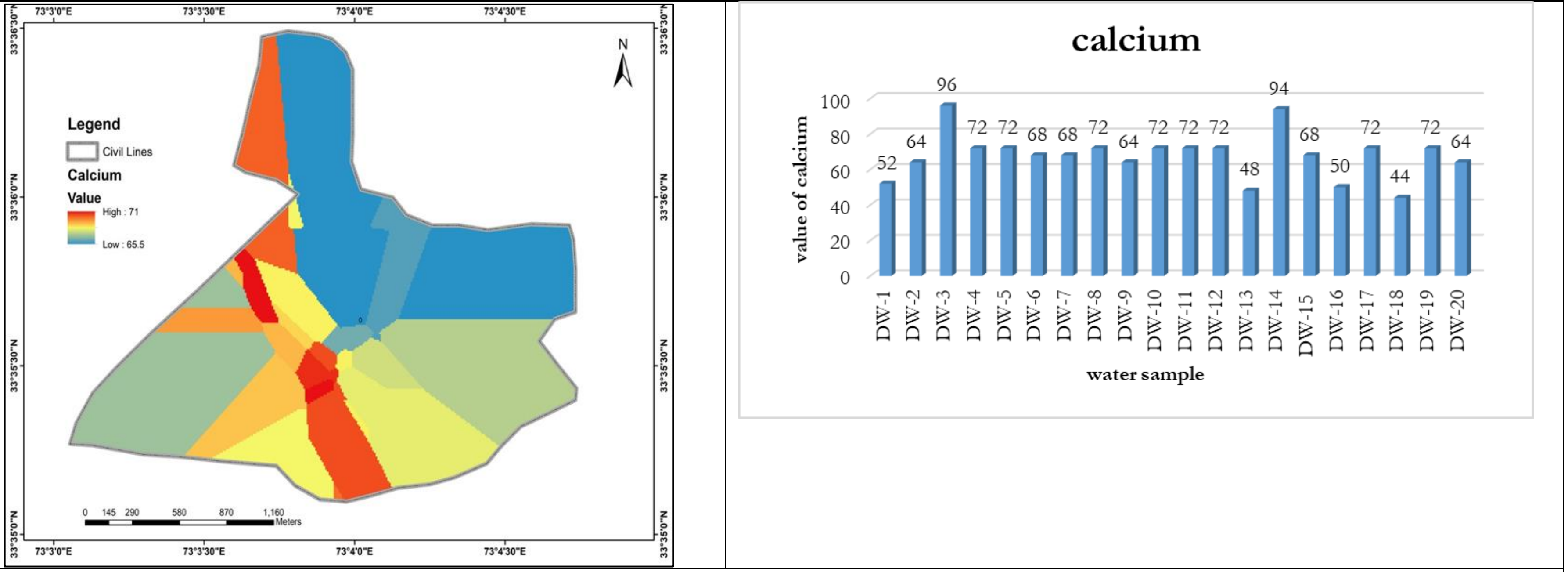

Figure 8. Value of calcium

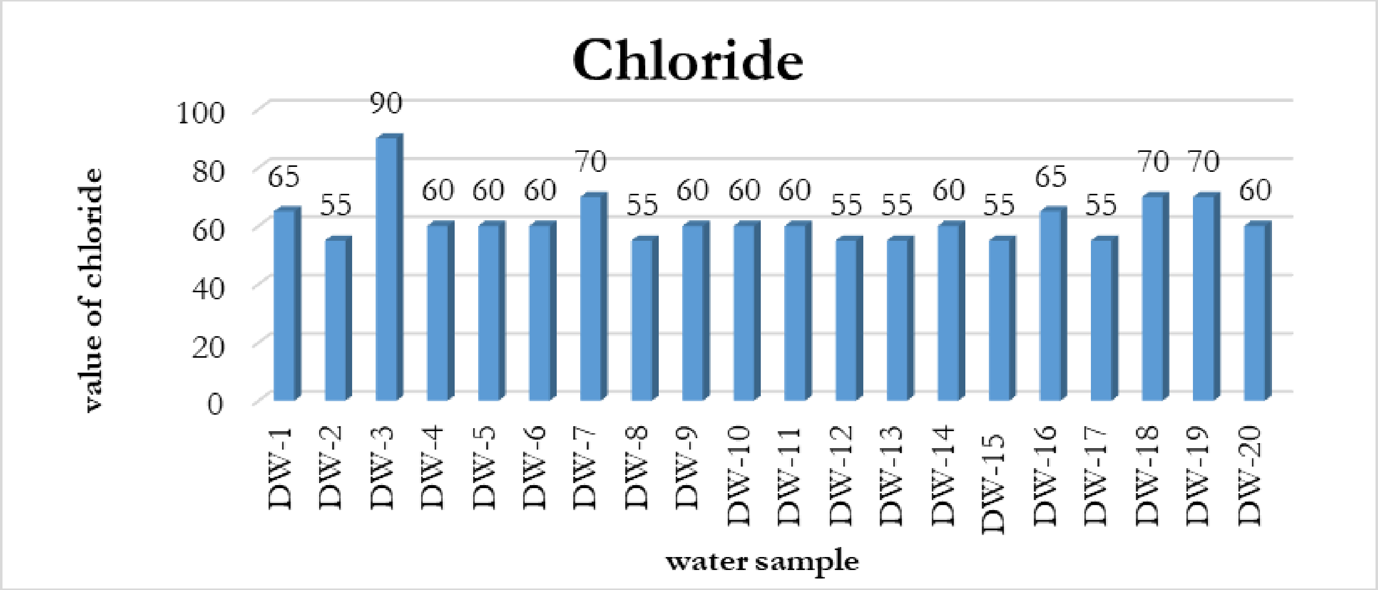

Figure 9. Value of Chloride

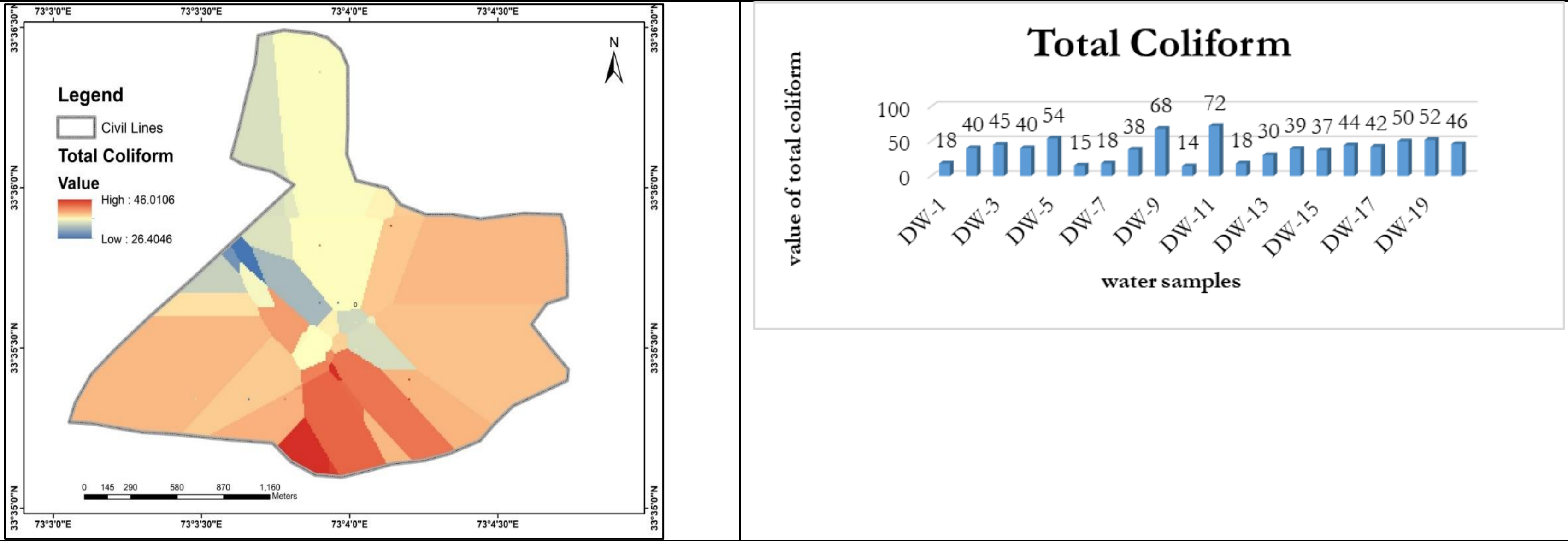

Figure 10. Value of total Coliform

Chlorides.

Chloride levels ranged from 55 mg/L to 90 mg/L, with a mean value of 72.5 mg/L. These levels are within the acceptable range of <250 mg/L, indicating no adverse impacts on taste or potential for corrosion (Figure 9).

Heavy Metals.

Lead and zinc were found to be below detection limits in all samples, while iron levels were also undetectable. Nickel, chromium, and other heavy metals analyzed were within permissible limits set by WHO and NSDWQ guidelines, ensuring no significant health risks from these contaminants.

Biological Quality Parameters

Total Coliforms.

Total coliform counts ranged from 14 to 72 per 100 mL. Although these levels are higher than the ideal standard of non-detectable coliforms in 100 mL of water, they are lower than many common thresholds, indicating a moderate level of biological contamination (Figure 10).

Comparison with Standards.

The results of this study were compared with the national and international standards for drinking water quality. The aesthetic parameters, chemical parameters (except for hardness), and biological indicators were within or close to the recommended limits set by WHO and NSDWQ (Table 2) [26][27]. Notably, while all chemical parameters were generally within acceptable ranges, the total coliform counts highlight a need for improved water treatment or disinfection measures to ensure microbiological safety [28].

In summary, the water quality in the studied areas of Rawalpindi generally meets the recommended standards, with some areas showing elevated biological contamination. The integration of advanced digital tools, such as IoT sensors and GIS, could further enhance real-time monitoring and management to address these issues effectively.

Comparison between WHO Standards and Present Study Results.

Table 2. Comparing results of the present study with National Standards for Drinking Water Quality and WHO Guidelines for drinking water quality.

Sr. No	Parameter Assessed	Result in Present Study	NSDWQ	WHO Guidelines
	Aesthetic Parameters			
1	Color	Clear	≤ 15 TCU	≤ 15 TCU
2	Odor	Non-objectionable	Non-objectionable	Non-objectionable
3	Taste	Non-objectionable	Non-objectionable	Non-objectionable
	Chemical			
4	Turbidity	0.46-3.92 NTU	<5 NTU	< 5 NTU
5	TDS	361-728	<1000	<1000
6	pH	7.1-7.4	6.5-8.5	6.5-8.5
7	DO	5.6-6.7	-	<5 mg/l
8	EC	611-1228	-	-
9	Hardness	280-490	-	-
10	Nitrates	0	≤50 mg/l	≤50 mg/l
11	Chlorides	55-90	<250 mg/l	<250 mg/l
12	Calcium	48-96	-	-
13	Magnesium	33-63	-	-
14	Nickle	BDL	0.02	0.02

15	Iron	0	300	300
16	Zinc	BDL	5	3
17	Lead	BDL	0.3	0.01
18	Chromium	BDL	0.01	0.05
	Biological			
19	Total coliform	15-72	Must not be detectable in 100mg/l	Must not be detectable in 100mg/l

Discussion.

The assessment of physiochemical and biological parameters in water sources, such as tube wells and dug wells, is critical for understanding water quality and identifying potential health risks. The presence of various contaminants can significantly impact both human health and the environment[13][29]. This discussion integrates findings from aesthetic analyses, chemical parameters, and emerging digital tools for water quality monitoring, highlighting their implications for water safety and public health.

Physiochemical Characteristics and Health Implications.

Water quality is influenced by multiple physiochemical parameters, each of which plays a role in determining its suitability for consumption and other uses. The analysis of pH levels is crucial, as deviations from the recommended range of 6.5 to 8.5 can lead to significant health and environmental concerns [30]. Acidic water (low pH) can cause corrosion of plumbing systems, leading to the leaching of toxic metals such as lead and copper into the water supply. This contamination poses severe risks, including neurological damage and developmental issues in children [16]. On the other hand, alkaline water (high pH) may cause skin irritation, and gastrointestinal discomfort, and reduce the effectiveness of disinfection processes, which can increase the risk of microbial contamination [31].

Turbidity is another critical parameter, indicating the clarity of water. High turbidity levels often suggest the presence of suspended particles that can harbor pathogens, thereby elevating the risk of waterborne diseases such as diarrhea, cholera, and typhoid [32]. These risks are particularly pronounced for vulnerable populations, including children, the elderly, and individuals with compromised immune systems [33]. High turbidity not only affects water safety but also necessitates additional filtration, increasing household maintenance costs and affecting the overall palatability of water. The presence of heavy metals, such as lead, arsenic, and cadmium, in water sources is alarming due to their toxicity and potential for bioaccumulation in the human body. Chronic exposure to these metals can lead to severe health issues, including cancer, neurological disorders, and damage to vital organs [34][35]. Regular monitoring and treatment are essential to mitigate these risks, though the associated costs and psychological stress related to health concerns can be burdensome for affected individuals.

Biological contaminants, such as coliforms and E. coli, serve as indicators of fecal contamination and the potential presence of harmful pathogens. The detection of these microorganisms highlights the need for immediate corrective actions, such as boiling water or utilizing alternative sources. Persistent contamination underscores the necessity for improved sanitation and waste management practices to prevent further pollution [36][37].

Application of Digital Tools in Water Quality Monitoring.

The integration of digital tools and technologies has revolutionized water quality monitoring and disease prediction. Internet of Things (IoT) devices, machine learning algorithms, and GIS are transforming how water quality is assessed and managed. IoT devices equipped with sensors offer real-time monitoring of water quality parameters such as pH, turbidity, T), nitrates, and heavy metals. These sensors, connected to cloud platforms, facilitate continuous data collection and rapid detection of contamination events. Real-time alerts enable prompt responses to potential contamination, enhancing overall water safety [38].

Machine learning algorithms play a pivotal role in predicting waterborne disease outbreaks by analyzing historical and real-time water quality data. Models such as regression, neural networks, and decision trees identify complex correlations between contaminants and disease incidence, aiding in targeted public health interventions and optimizing preventive strategies. GIS tools are invaluable for spatial analysis and mapping of contamination sources. By visualizing spatial data, GIS helps in identifying pollution hotspots and understanding the relationship between contamination and affected communities. Heat mapping and other spatial analysis techniques support more effective water resource management and decision-making.

Chemical Parameters and Their Implications.

TDS and hardness are additional important parameters in water quality assessment. While elevated TDS levels may not pose direct health hazards, they can affect the taste, color, and odor of water, potentially making it less desirable for consumption. Hard water, characterized by high concentrations of calcium and magnesium, may not pose significant health risks but can cause scaling in plumbing systems and reduce the effectiveness of soap.

Calcium and magnesium levels in water contribute to dietary intake but may also have implications for plumbing and appliance maintenance. High levels of magnesium can lead to a laxative effect, while excessive calcium can result in scale formation.

Nitrates, commonly found in agricultural runoff and septic systems, pose significant health risks, especially to infants. High nitrate levels can cause methemoglobinemia, also known as "blue baby syndrome," and long-term exposure may contribute to cancer and other health issues (Kahlown et al., 2014). Chlorides, originating from waste emissions, industrial effluents, and urban runoff, generally do not pose direct health risks at typical concentrations but can cause a salty taste and corrosion of metal pipes.

Conclusion.

The study aimed to generate standard data on the drinking water quality in Civil Lines and Mareer Hassan, Rawalpindi, to assess water quality and associated waterborne diseases, and to compare the water quality from the source (head) to the end-point (tail end). The physical and chemical properties of the water samples were within the limits proposed by the National Standards for Drinking Water Quality (NSDWQ) and the WHO. However, the total coliform values in samples from the study area were alarmingly high. Compared to chemical parameters, microorganisms, and coliform bacteria pose a greater risk of causing waterborne diseases in humans. These bacteria are responsible for illnesses such as diarrhea, typhoid, and various gastrointestinal conditions. Hepatitis A and E, common waterborne diseases, were also prevalent among the population.

The high bacteriological content in Mareer Hassan and Civil Lines can be attributed to inadequate sanitation and poor sewerage systems. The water supply pipelines were old, corroded, and had multiple leakages, and the water storage systems were outdated. Consequently, many diseases in the study area resulted from the consumption of contaminated potable water and infected well water. Diarrhea and skin diseases were the most prevalent waterborne diseases, with diarrhea being the most common according to the survey. To mitigate water pollution and its associated health risks, securing water sources and reservoirs should be a priority. Cost-effective methodologies should be developed for managing water sources and monitoring water quality. Water distribution systems and treatment plants must collaborate to effectively implement drinking water quality standards.

Author contribution.

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Anam Khurshid. The first draft of the manuscript was written by Anam Khurshid and Samiullah Khan commented on it for its improvement. Both authors read and approved the final manuscript.

Conflict of Interest. The authors declare no competing interests.

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