Research Article

Evaluation of Well Water Quality of District Bajaur, Pakistan

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Abstract | This research study focuses on the assessment of physicochemical parameters in the open well water of selected Tehsils (Khar, Mamund, and Salarzai) in District Bajaur, Pakistan. A total of 21 samples of well water were collected from the study area, with seven samples obtained from each Tehsil. The research analysis focused on various parameters, including pH, turbidity, electric conductivity, total hardness, sodium, potassium, calcium, magnesium, carbonates, bicarbonates, chlorides, and fluorides. The recorded average value ranges for each parameter provided insights into the characteristics of the well water samples. For example, pH values ranged from 6.87 to 7.53, indicating acidity or alkalinity levels. Turbidity, a measure of water clarity, varied from 0.5100 NTU to 45.633 NTU. Electric conductivity fell within the range of 261.00 µS/cm to 614.67 µS/cm, reflecting the water's ability to conduct electricity. Total hardness exhibited values ranging from 180.67 mg/L to 636.67 mg/L, indicating mineral content. These comprehensive data sets contribute to a deeper understanding of the physicochemical properties of the well water in the selected Tehsils, aiding in the evaluation of water quality and potential health risks. The recorded values were compared to guidelines established by prominent regulatory bodies such as the World Health Organization (WHO, 2011), the United States Environmental Protection Agency (US-EPA, 2018), and the Pakistan Environmental Protection Agency (Pak-EPA, 2008). By aligning the recorded values with these standards, the researchers aimed to assess compliance with recommended thresholds and evaluate potential health implications. Unfortunately, based on the guidelines set by the World Health Organization (WHO, 2011), the majority of the well water samples collected, except for those from Kharkai, Malangy, Laradagai, Raghagan, and Zubandar, were found to be unsuitable for human consumption. The researchers hope that this study will increase public awareness in the studied areas and encourage people to avoid using contaminated open well water for drinking and other domestic purposes to reduce the associated health risks.

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1. Introduction

Water is an essential element in our surroundings, required for the sustenance of all living beings. The right to access clean and uncontaminated drinking water is a fundamental human right, and it is the primary responsibility of the state to ensure its provision (Israr, 2017). The water supply in Pakistan is reported to be approximately 79%, according to the Pakistan National Conservation Strategy (Daud *et al*., 2017). As per the Pakistan Agriculture Scientists Association (PASA), it was reported that the per capita water availability in Pakistan during the period of its liberation was approximately 5,600 cubic meters. This figure, cited from the source (Hussain, 2012), indicates the amount of water available per person in Pakistan at that particular period. It serves as a reference point for understanding the changes in water availability over time and highlighting the potential challenges and implications related to water resources in the country. According to the Chairman of the PASA, the per capita water availability in Pakistan has significantly declined over the years. This substantial decline raises concerns about the accessibility and availability of water resources in Pakistan. Furthermore, if this trend continues, projections indicate a further decrease in water accessibility by 2050 to 575 cubic meters (Mustafa et al., 2012). These predictions highlight the urgent need for sustainable water management practices and conservation efforts to address the growing water scarcity challenges in the country. Indeed, water quality is influenced by a multitude of physicochemical factors. These factors include turbidity, total hardness, pH, electrical conductivity, total solids, bicarbonates, carbonates, heavy metals, microorganisms, and many others. Each of these parameters plays a crucial role in determining the overall quality, safety, and suitability of water for human consumption. By considering and evaluating these various physicochemical factors, researchers and water quality experts can gain insights into the potential health risks and the overall suitability of drinking water sources. The study by Daniel et al. (2013) likely provides further details and analysis on the impact of these factors on the quality of drinking water. Assessing water quality relies on the thorough evaluation of groundwater's physicochemical characteristics. The analysis of these characteristics is vital in determining the suitability and safety of groundwater for human consumption. Consequently, investigating the quality of groundwater for drinking purposes is highly important in this case. The presence of toxic metals in groundwater has emerged as a significant global concern, alongside the assessment of physicochemical properties. Disturbing findings reported by various agencies have raised alarming concerns regarding this issue, highlighting its importance in water quality evaluations. The study by Farmaki et al. (2016) likely delves deeper into the subject, shedding light on the presence and potential impacts of toxic metals in groundwater across different regions.

In less developed countries, polluted drinking water is a major cause of illnesses, particularly in children, which could have been avoided. Various viral, bacterial, and protozoan agents, when found in drinking water, cause widespread diarrheal diseases and result in about 2.5 million fatalities every year (Daud *et al*., 2017).

District Bajaur is a region located in the northern and remote areas of Pakistan, spanning a total area of 1290 square kilometers. It is geographically characterized by its proximity to Afghanistan, sharing a border of 52 kilometers with the neighboring country. Positioned at an elevation of 1126 meters above sea level, District Bajaur is situated at coordinates E 71° 30′ latitude and N 34° 41′ longitude. These geographical details provide insights into the location and topography of the district, highlighting its distinct characteristics within the broader context of Pakistan (Abdul *et al*., 2017).

Taking into account the information provided earlier, the goal of this investigation is to observe various physicochemical parameters of well water in District Bajaur.

2. Materials and Methods

2.1 Selection of points for sampling

The sampling points were selected based on several criteria such as population density, anthropogenic activities, and areas affected by war. The war-affected areas were considered because they are likely to have a high concentration of inorganic materials and heavy metals, which can pose potential health hazards. (Yousaf *et al*., 2013). Samples of water were gathered from 21 different open wells situated in different locations as chosen by the researchers.

2.2 Samples collection

To collect water samples from 21 wells in District

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Bajaur, 1-liter capacity Poly-ethylene terephthalate (PET) cans that were sterilized, clean, and transparent were used. Care was taken to collect water from each well at the time of sampling, and the bottles were carefully filled. The water from each well was collected in three replicates to ensure data accuracy, and the average value derived from the replicates was considered the standard for each sample. The bottle's opening was then covered with tape to make it airtight. To ensure proper identification and traceability, each bottle containing the water samples was labeled with unique codes, locations, and water sources.

The water samples in PET cans were promptly brought to the Government Public Health and Food Analysis (GPHFA) Laboratory located in Hayatabad Phase 5, Peshawar, without any delay. Upon arrival, the bottles were put in a refrigerator, Subsequently, the samples underwent comprehensive analysis to assess their physicochemical quality parameters and microbial load count. This analysis aimed to evaluate various aspects of the water samples, including but not limited to turbidity, pH, electrical conductivity, total hardness, total solids, and the presence of microorganisms.

2.3 Analysis of samples

The physic-chemical properties and microbial burden of water samples gathered from the Bajaur District were subjected to analysis using the methods and tools specified by the AOAC (2012) as listed in Table 1. The analytical methods recommended by these organizations are recognized and widely accepted in the field of water quality assessment. The study was conducted within the postgraduate laboratories of Food Science and Technology at the University of Agriculture Peshawar, Pakistan. These dedicated laboratory facilities provided the necessary infrastructure and resources for the researchers to carry out their investigations effectively.

In addition to the postgraduate laboratories at the University of Agriculture Peshawar, certain experiments were also conducted at the GPHFA laboratory situated in Hayatabad, Peshawar. These external laboratories provided specialized facilities and expertise necessary for specific experiments and analyses related to the study. By utilizing the advanced equipment and expertise available within these laboratories, the researchers were able to perform various analyses and experiments related to the physicochemical properties and microbial load of the well water samples.

Table 1: The Techniques, instruments with names, and model with references used for analysis of the physicochemical parameters of the collected water samples.

Parameters	Technique	Instrument Make and Model	Reference
pH	pH-meter	pH 200 Senso direct	AOAC, 2012
EC	Conductivity meter	Jenway, UK model 4510	APHA, 2016
Turbidity	EDTA titrimetric method (2340, C)	Wag-WT-300	AOAC, 2012
Total Hardness	Flame photometry and EDTA titrimetric method (3500-Ca, B)	-	APHA, 2016
Na^+, K^+, Ca^{+2}, Mg^{+2}	Flame photometry and EDTA titrimetric method (3500-Ca, B)	Flame Photometer model DV, 710W	AOAC, 2012and APHA, 2016
CO_3^{-2}, HCO_3^-, Cl^-, F-	Titration method 2320-B and by argentometric method (4500-Cl^-B)	Fluorides meter model DR 2800	APHA, 2016 AOAC, 2012

2.4 Statistical analysis

The data obtained from the twenty-one well water samples collected from different areas were analyzed using SPSS software and CRD one-way ANOVA. The averages were separated using the LSD test with a significance level of P-value less than 0.05 (Steel and Torrie, 1997).

3. Results and Discussion

3.1 Physico-chemical parameters of well water samples from Bajaur District

The analysis results of specific physicochemical parameters, having turbidity, pH, electrical conductivity, and total hardness, for the well water samples collected from District Bajaur are presented in Table 2. This table provides a comprehensive overview of the measured values for these selected parameters, allowing for a detailed measurement of the water quality in the studied region.

3.2 pH

The average pH values of all 21 well water samples (S1 to S21) collected from District Bajaur ranged from 6.87 to 7.53, with the highest average value of 7.53 found in S9 (Raghagan) and the lowest average value of 6.87 found in S15 (Umary). The values obtained for the analyzed physicochemical parameters in Table 2 were found to be within the permissible limits established by regulatory authorities, including the WHO (2011), the US-EPA (2018), and the Pak-EPA (2008). These guidelines provide reference values that ensure the water meets the required standards for safe consumption.

3.3 Turbidity

The average turbidity concentrations of the well water samples collected ranged from 0.510 NTU to 45.633 NTU, as indicated in Table 2. Among the samples, the highest average turbidity concentration of 45.6 NTU was observed in the water sample from S4 (Loi Sum), while the lowest average turbidity values of 0.510 NTU were observed in water samples from S20 (Amanatha), S11 (Pashat), and S1 (Zubandar).

However, it is important to note that the average turbidity concentrations in the drinking water from S3, S7, S8, S9, S13, S15, S16, and S21 areas were found to exceed the guideline limit of 5 NTU set by the WHO (2011), the US-EPA (2018), and the Pak-EPA (2008).

3.4 Electrical conductivity

The average values of electrical conductivity (EC) in the well water samples collected varied from 261.0µS/cm to 614.670µS/cm, as depicted in Table 2. Among the samples, the water sample from S3 (Sheikh Kaly) exhibited the highest average EC value of 614.670µS/cm, while the water sample from S18 (Malangy) had the lowest average EC value of 261.0 µS/cm.

It is worth noting that the average EC values of the water samples from areas S1, S2, S5, S6, S10, and S20 fell within the allowed limits (400 µS/cm) established by the WHO (2011), the US-EPA (2018), and the Pak-EPA (2008). This suggests that the EC levels in these particular well water samples comply with the recommended guidelines, indicating their suitability for consumption.

3.5 Total hardness

The average values of total hardness in the collected well water samples from various areas exhibited a range of 180.67 mg/L to 636.67 mg/L, as presented in Table 2. Notably, the water sample from S3 (Sheikh Kaly) recorded the highest average total hardness value of 636.67 mg/L, while S18 (Malangy) had the lowest average value of 180.67 mg/L.

However, it is important to highlight that the average total hardness values in the drinking water samples from S7, S4, and S3 exceeded the recommended guidelines (500 mg/L) established by the WHO, the US-EPA, and the Pak-EPA. This indicates that the total hardness levels in these specific well water samples exceeded the recommended limits, potentially impacting the quality and usability of the water for consumption.

Table 2: The Physicochemical properties of well water samples assessed for pH, electrical conductivity (EC), Turbidity, and total hardness (TH).

Samples code	Area name	Electrical conductivity µS/cm	Turbidity NTU/L	Total hardness mg/L	pH
S1	Zubandar	279.00n	0.510n	238.67o	7.363d
S2	Tangi	285.00m	0.770lm	259.33n	7.153i
S3	Sheikh Kaly	614.67a	39.500b	636.67a	7.513ab
S4	Loi Sum	591.33b	45.633a	580.67b	7.493ab
S5	Inayat kaly	320.00j	2.430j	362.67j	7.486b
S6	Patak	346.00h	4.686h	383.00g	7.310e
S7	Khar	567.00c	29.60d	534.67c	7.416c
S8	Taly	404.00e	24.520e	401.33d	7.030lm
S9	Raghagan	401.67e	4.160i	401.33d	7.530a
S10	Derakai	320.00j	1.133k	378.67i	6.950n
S11	Pashat	293.67l	0.510n	313.33m	7.253fg
S12	Laradagai	270.00o	0.550n	217.33p	7.086jk
S13	Ridawan	325.00i	6.223g	379.33hi	7.126ij
S14	Kotki	382.33g	2.596j	388.67f	7.430c
S15	Umary	325.00i	13.643f	381.33gh	6.876o
S16	Sewai	318.00f	24.520e	392.33e	7.010m
S17	Dabar	318.00j	0.840l	349.33k	7.283ef
S18	Malangy	261.00q	0.600mn	180.67r	7.056kl
S19	Kharkai	264.00p	0.550n	201.33q	7.230gh
S20	Amanatha	306.00k	0.510n	330.67l	7.2000h
S21	Nakhtar	414.33d	37.70c	378.67i	7.0900jk
WHO standards (WHO, 2011)		400	5	500	6.5-8.5
US-EPA limits (USEPA, 2009)		400	5	500	6.5-8.5
Pak-EPA (Pak-EPA, 2008)		400	5	500	6.5-8.5

Values that have the same letter(s) in each column are not significantly different from each other at a significance level of $p < 0.05$.

3.6 The chemical properties of the cations present in the water samples were assessed for sodium, potassium, calcium, and magnesium

3.6.1 Sodium

The average values of Sodium concentration in the well water samples collected from S1 to S21 ranged from 25.00 mg/L to 94.00 mg/L, as observed in Table 3. Among the samples, the highest average Sodium concentration value of 94.00 mg/L was found in the drinking water sample from area S3 (Sheikh Kaly), while the lowest average value of 25.00 mg/L was observed in the drinking water sample from area S18 (Malangy).

However, it is important to note that the average value of Sodium concentration in all the samples (S1 to S21) fell within the standard value (200 mg/L) prescribed by the WHO, the US-EPA, and the Pak-EPA. This indicates that the Sodium concentration levels in all the well water samples were within the normal range and complied with the recommended guidelines.

3.6.2 Potassium

The average Potassium concentrations in the analyzed well water samples were determined to range from 3.4333 mg/L to 14.800 mg/L, as indicated in Table No. 4. Notably, the drinking water sample from treatment S3 (Sheikh Kaly) recorded the highest average Potassium concentration value of 14.800 mg/L, while treatment S18 (Malangy) exhibited the lowest average value of 3.4333 mg/L.

It is worth mentioning that the average value for Potassium (K+) concentration in the drinking water samples from treatments S4 (Loi Sum) and S3 (Sheikh Kaly) exceeded the permissible limits (12 mg/L) established by the WHO, the US-EPA, and the Pak-EPA. This indicates that the Potassium concentrations in these specific well water samples surpassed the recommended limits, potentially affecting the water quality and suitability for consumption.

3.6.3 Calcium

The average values of Calcium concentrations in the well water samples collected from S1 to S21 in District Bajaur ranged from 20.147 mg/L to 82.213 mg/L, as presented in Table 3. Notably, the highest average value of 82.213 mg/L was observed in the well water sample obtained from S3 (Sheikh Kaly), while the lowest average value of 20.147 mg/L was found in the well water sample collected from S18 (Malangy).

It is worth noting that the average values for Calcium (Ca+) concentration in the drinking water samples from areas S4, S5, S7, and S21 exceeded the permissible limits (75 mg/L) set by the WHO, the US-EPA, and the Pak-EPA. This indicates that the Calcium concentrations in these specific well water samples surpassed the recommended limits, potentially affecting the overall water quality and its suitability for consumption.

3.6.4 Magnesium

The average values for magnesium concentrations in the drinking water samples collected from various areas of District Bajaur ranged from 30.646 mg/L to 104.77 mg/L, as indicated in Table 3. Notably, the highest average value of 104.77 mg/L for magnesium concentration was observed in the water sample from S3 (Sheikh Kaly), while the lowest average value of 30.646 mg/L was found in the water sample from S19 (Kharkai).

Table 3: Chemical characteristics of the cations in the water samples evaluated for sodium, potassium, calcium and magnesium.

Samples code	Area name	Mg+2 (mg/L)	K+ (mg/L)	Na+ (mg/L)	Ca+2 (mg/L)
S1	Zubandar	34.82n	3.70klm	28.66hi	38.14j
S2	Tangi	39.51m	3.73kl	29.00h	38.68j
S3	Sheikh Kaly	104.77a	14.80a	94.00a	82.21a
S4	Loi Sum	92.79b	13.70b	87.00b	79.52b
S5	Inayat kaly	60.07de	5.50h	45.33f	46.18h
S6	Patak	59.28def	6.73fg	67.00d	55.61f
S7	Khar	82.43c	13.70b	85.66b	78.17b
S8	Taly	57.04hi	9.70c	85.33b	66.62d
S9	Raghagan	58.03fgh	8.56d	86.00b	65.01d
S10	Derakai	60.35d	5.50h	46.00f	52.11g
S11	Pashat	50.51k	3.93k	29.00h	42.17i
S12	Laradagai	33.71n	3.66klm	26.66hij	31.43k
S13	Ridawan	59.21def	5.73h	48.00f	54.26f
S14	Kotki	58.54fg	6.80f	77.00c	59.10e
S15	Umary	59.04ef	6.50g	53.33e	55.34f
S16	Sewai	56.003i	7.50e	85.33b	64.74d
S17	Dabar	57.30gh	4.80i	45.00f	45.40h
S18	Malangy	31.66o	3.43m	25.00j	20.14l
S19	Kharkai	30.64o	3.46lm	25.33ij	30.08k
S20	Amanatha	54.07j	4.33j	33.00g	43.25i
S21	Nakhtar	46.15l	9.70c	86.66b	75.49c
WHO standards (WHO, 2011)		150	12	200	75
US EPA limits (USEPA, 2018)		150	12	200	75
Pak EPA (Pak-EPA, 2008)		150	≤12	NA	75

Values that share the same letter(s) in each column are not significantly different from each other at a significance level of $p < 0.05$. The cations evaluated include sodium (Na+), potassium (K+), calcium (Ca+2), and magnesium (Mg+2), measured in milligrams per liter (mg/L).

It is important to highlight that the average concentration of magnesium in all the drinking water samples collected from S1 to S21 fell within the standard guideline of 150 mg/L set by established by the WHO, the US-EPA, and the Pak-EPA. This indicates that the magnesium concentration in all the samples was within the normal range and did not exceed the recommended limits.

3.7 The chemical properties of the anions present in the drinking water samples were assessed for bicarbonate (HCO3-), carbonate (CO3-2), chloride (Cl-), and fluoride (F-)

3.7.1 Carbonates

The average concentration of carbonates in the drinking water samples collected from different areas (S1 to S21) of District Bajaur ranged from 20.00 mg/L to 75.00 mg/L, as presented in Table 4. Notably, the drinking water samples from S4 (Loi Sum) and S3 (Sheikh Kaly) exhibited the highest average value of carbonates at 75.00 mg/L, while the water samples from S18 (Malangy) and S19 (Kharkai) had the lowest average value of 20.00 mg/L for carbonates.

It is important to note that there are no specific guideline values provided by the WHO, the US-EPA, and the Pak-EPA for carbonate concentration in drinking water. However, based on the research by Mohsin and Sahib(2013), it is recommended that the concentration of carbonates should not exceed 500 mg/L in drinking water.

In the present study, the average carbonate concentrations in the water samples collected from the areas S1 to S21 of District Bajaur were within the normal range, as they did not exceed the recommended limit of 500 mg/L. This indicates that the drinking water samples were not significantly affected by high carbonate concentrations that could potentially impact their quality or suitability for consumption.

3.7.2 Bicarbonates

The average concentration range of bicarbonate in the drinking water samples collected from different areas (S1 to S21) of District Bajaur was found to be between 68.333 mg/L and 235.00 mg/L, as indicated in Table 4. Notably, the drinking water samples from S3 (Sheikh Kaly) exhibited the highest average value of bicarbonate concentration at 235.00 mg/L, while the water samples from S18 (Malangy) had the lowest average value of 68.333 mg/L for bicarbonate.

It is important to note that there are no specific standard limits for bicarbonate concentration in drinking water provided by the World Health Organization (WHO, US-EPA, and Pak-EPA). However, according to the research conducted by Mohsin and Sahib (2013), it is recommended that the bicarbonate concentration should not exceed 500 mg/L in drinking water.

In the present study, the average bicarbonate concentrations in the water samples collected from the areas S1 to S21 of District Bajaur were within the safe range, as they did not exceed the recommended limit of 500 mg/L. This indicates that the drinking water samples were not significantly affected by high bicarbonate concentrations that could potentially impact their quality or suitability for consumption.

3.7.3 Chloride

The average chloride concentrations in the drinking water samples collected from S1 to S21 in District Bajaur were analyzed, and the results showed a range from 38.813 mg/L to 194.90 mg/L, as presented in Table 4. Among the samples, the highest average value of chloride concentration (194.90 mg/L) was observed in the water sample from S3 (Sheikh Kaly), while the lowest average value (38.813 mg/L) was found in the water sample from S18 (Malangy).

It is noteworthy that the average value of chloride concentration in all the drinking water samples collected from areas S1 to S21 fell within the permissible limits of 250 mg/L, as specified by the WHO, the US-EPA, and the Pak-EPA. This indicates that the chloride concentrations in all the samples were within the safe range for consumption, ensuring the quality and suitability of the drinking water.

3.7.4 Fluoride

The fluoride content in the collected water samples (S1 to S21) was analyzed, and the average values ranged from 0.0800 mg/L to 1.9667 mg/L, as indicated in Table 4. Among the samples, the highest average value of fluoride concentration (1.9667 mg/L) was observed in the water sample from S3 (Sheikh Kaly), while the lowest average value (0.800 mg/L) was recorded in the water sample from S18 (Malangy).

It is worth noting that the average values for fluoride concentration in the drinking water samples from areas S3, S4, S7, S8, and S21 exceeded the guideline values of 1.5 mg/L recommended by the WHO, the

US-EPA, and the Pak-EPA. However, the average values for fluoride concentration in the water samples from all the other treatments were found to be within the permissible limits.

Considering the analysis results, it can be concluded that the fluoride concentrations in some of the drinking water samples collected from District Bajaur, specifically areas S3, S4, S7, S8, and S21 exceeded the recommended guideline values.

Table 4: The chemical properties of the anions present in the drinking water samples were assessed for bicarbonate (HCO3-), carbonate (CO3-2), chloride (Cl-), and fluoride (F-).

Samples code	Area name	F (mg/L)	HCO3- (mg/L)	CO3-2 (mg/L)	Cl- (mg/L)
S1	Zubandar	0.650p	76.66j	26.66fg	46.15lm
S2	Tangi	0.670p	85.00ij	33.33ef	47.09l
S3	Sheikh Kaly	1.966a	235.00a	75.00a	194.90a
S4	Loi Sum	1.930b	176.67b	75.00a	185.55b
S5	Inayat kaly	1.070l	110.00gh	40.00e	59.55ij
S6	Patak	1.383h	130.00defg	45.00cde	67.05hi
S7	Khar	1.703c	171.67b	60.00b	113.55c
S8	Taly	1.583e	146.67cd	56.66bc	91.063e
S9	Raghagan	1.453f	141.67cde	55.00bcd	77.65f
S10	Derakai	1.150k	111.67gh	40.00e	63.02ij
S11	Pashat	0.733o	111.67gh	33.33ef	48.99l
S12	Laradagai	0.473q	75.00j	25.00fg	42.05mn
S13	Ridawan	1.226j	116.67fggh	40.00e	64.40i
S14	Kotki	1.406gh	105.00hi	45.00cde	70.29gh
S15	Umary	1.273i	123.33efgh	43.33de	65.08i
S16	Sewai	1.420g	111.67gh	53.33bcd	71.77g
S17	Dabar	0.860m	136.67def	35.00ef	58.45k
S18	Malangy	0.080s	68.33j	20.00g	38.81n
S19	Kharkai	0.133r	70.00j	20.00g	39.99n
S20	Amanatha	0.770n	105.00hi	35.00ef	57.02k
S21	Nakhtar	1.666d	158.33bc	33.33ef	103.85d
WHO standards (WHO, 2011)		1.5	NA	NA	250
US EPA limits(USEPA, 2018)		2	NA	NA	250
Pak EPA (Pak-EPA, 2008)		1.5	NA	133mg/L	≤250

Values that share the same letter(s) in each column are not significantly different from each other at a significance level of $p < 0.05$. The anions evaluated include bicarbonate (HCO3-), carbonate (CO3-2), chloride (Cl-), and fluoride (F-).

The objective of this investigation was to evaluate the parameters of well-drinking water collected from various places in District Bajaur, Pakistan. The average range of pH values (6.87 to 7.53) obtained in this study was comparable to the findings (6.9 to 7.8) of a study conducted on drinking water samples collected from the capital(Islamabad) of Pakistan. Mehmood et al. (2013). Jadoon et al. (2014) and Jain et al. (2016) conducted similar studies in District Dir Lower of Khyber Pakhtunkhwa, Pakistan, and District Jaipur from India, correspondingly. They reported pH values ranging from 7.1 to 7.5 and 6.7 to 8.60 in the water used for drinking purposes. The statistical analysis of this research work indicated that the study area of District Bajaur had a significant (P-value greater than 0.05) impact on the pH levels of the collected water samples.

The parameter of turbidity is commonly considered important for water intended for consumption (Hameed *et al*., 2010). Turbidity itself does not pose direct health hazards to humans, but it can create an environment suitable for the growth of microorganisms, including opportunistic pathogens, and can interfere with disinfection processes. As a result, turbidity can indirectly impact water quality and safety (Sehar *et al*., 2011). Indeed, turbidity can serve as a warning sign of the existence of harmful microbial loads such as bacteria, viruses, and parasites that can cause health problems like diarrhea, nausea, cramps, and headaches (USEPA, 2003). Hence, it is essential to keep a check on turbidity levels in drinking water and take measures to regulate it to ensure its safety for human consumption.

The average value range (3.4333 mg/L to 14.800 mg/L) for the concentration of potassium in drinking water obtained in this study exhibits comparability to the average value range (3.7 mg/L to 13.35 mg/L) reported in a study conducted by Khalid *et al*. (2018), which assessed the quality of drinking water in District Vehari, Punjab. Furthermore, a comprehensive investigation of groundwater quality in northwest Iran by Banitorab (2018) revealed an average value range for potassium concentration between 0.1 mg/L and 17.00 mg/L. According to the statistical analysis conducted, the results demonstrate that the area, specifically District Bajaur, significantly influences the concentration of potassium in the well water samples, as indicated by a P-value of less than 0.05.

The average value range of calcium concentration in drinking water from District Bajaur, ranging from 20.147 mg/L to 82.213 mg/L, shows similarities to the average value range observed in a study conducted by Hussain et al. (2014) in Islampur, District Swat, which ranges from 21.25 mg/L to 141.72 mg/L. Additionally, in a quality assessment of drinking water in the Piedmont of Beni-Mellah Atlas, Morocco, Barakat *et al*. (2018) discovered an average value range of calcium concentration between 42.72 mg/L to 79.26 mg/L. The statistical analysis conducted in this study highlights that the geographical location, specifically District Bajaur, significantly impacts the concentration of calcium in the well water samples, as denoted by P-values < 0.05.

The range of average values (20.00 mg/L to 75.00 mg/L) observed for carbonate concentration in drinking water samples collected from different locations of District Bajaur in this study shows similarities to the highest average value (66 mg/L) reported by Khalid *et al*. (2018) in their study on the drinking water quality of District Vehari, Punjab, Pakistan. Likewise, in a study conducted by Shaukat et al. (2016) to determine the concentration of carbonate in drinking water of Lahore, Pakistan, the range of carbonate concentration was found to be between 18 mg/L to 74 mg/L. According to the statistical analysis conducted, the results indicate that the area, specifically District Bajaur, has a significant impact on the concentration of carbonates in the water samples, with a P-value of less than 0.05.

Conclusions and Recommendations

The main objective of this study was to analyze the physical and chemical properties of water samples collected from wells in three tehsils (Khar, Mamund, and Salarzai) in District Bajaur and assess the presence of microbial contamination. By examining the physicochemical parameters, the study aimed to evaluate the suitability of the well water for drinking purposes. The findings revealed that several well water samples from Sheikh Kaly, Loi Sum, Nakhtar, Khar, Taly, Raghaghan, Sewai, Kotki, Patak, Umary, Ridawan, and Inayat Kali exceeded the permissible limits set by various regulatory bodies such as WHO (2011), US-EPA (2018), and Pak-EPA (2008). These samples exhibited high concentrations of heavy metals, anions, and cations, as well as elevated levels of turbidity, electrical conductivity, and total hardness. Consequently, it was determined that the well water from these areas was not suitable for drinking. The study emphasizes the inclusion of additional chemical parameters, such as sulphates, nitrates, nitrites, and phosphates, in the analysis of well water from the selected areas. This comprehensive analysis would provide a more comprehensive understanding of the water quality and potential risks associated with the consumption of the well water in these areas. Based on the findings, the study recommends conducting regular and thorough monitoring of the well water in the selected areas to ensure the safety and quality of drinking water. Research on the effect of drinking well water on the human health of District Bajaur should be conducted in the future.

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Novelty Statement

Hazrat Usman conceptualized, collect the data and wrote the manuscript. Shakeel Ahmad helped in formal analysis. Salah Uddin helped in methodology section. Humaira Wasila proof read the manuscript. Yasser Durrani supervised the whole research work.

Author's Contribution

This is a novel study. First ever study which explored well water quality of District Bajaur, Pakistan.

Conflict of interest

The authors have declared no conflict of interest.

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