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Assessment of Groundwater Quality in Kabul City: A Case Study of District 15

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ABSTRACT

In Kabul City, groundwater serves as the primary source of drinking water, but these resources are under immense pressure from both natural and human-induced activities. This study aims to assess the quality of drinking water in District 15 of Kabul city through the analysis of 14 groundwater samples, examining physical (electric conductivity, total dissolved solids, turbidity, and temperature), chemical (pH, chloride, fluoride, nitrate, nitrite, phosphate, boron, copper, cadmium, lead, manganese, and aluminum), and biological (total and fecal coliform) parameters using the standard method. Findings reveal that several sites exhibit exceedances in key parameters such as electric conductivity, total dissolved solids, chloride, fluoride, nitrate, boron, cadmium, and coliforms exceeding the WHO and ANSA permissible limits, posing significant health risks. To supply safe drinking water for Kabul city residents, it is recommended that future research should assess the groundwater quality across the 22 districts of Kabul city, factoring in seasonal variations over a year.

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INTRODUCTION

A substantial portion of the global population relies on groundwater as its primary source of drinking water. Groundwater is the world's largest reserve of freshwater (Opie et al.,2020). According to Jasechko et al. (2019), approximately two billion people worldwide depend on groundwater for a variety of purposes, such as irrigation, sanitation, and drinkable water. Haldorsen et al. (2016) reveal that groundwater is essential for the survival of nearly half of the global population. Based on Stevanović (2019), study around 678 million people, or 9.2% of the world's population, depend on karst aquifers for their water supply. Popa and Glevitzky's (2021) research offers valuable insights into the lower risk of microbial and chemical contamination in groundwater compared to surface water, particularly in developing countries. Even though estimates vary, the research emphasizes the critical role of groundwater in providing potable water to a significant portion of the global population. In order to guarantee the availability of groundwater resources, the text underscores the necessity of their efficient management and protection. Numerous studies carried out by experts in the field (Ahmed et al., 2020; Okoro et al., 2016; Rawat & Siddiqui, 2019) support this. The quantity and quality of groundwater are global concerns (Luczaj, 2015; Caravella & Martinez, 2020). Despite the widespread recognition of the right to safe, potable water, many poor nations struggle to ensure its availability (Okafor et al., 2024). In developed countries, clean water is easily accessible, whereas in underdeveloped nations, water sources are often polluted and subject to strict water quality standards. (Kroehler, 2014). The mortality rate is particularly high among children under the age of five as a result of safe water shortages (Gadgil et al., 2008). Aquifer decline is a well-known issue; however, groundwater pollution is equally significant (Babel et al., 2012; Currell, 2014).

In Afghanistan, the availability of safe, potable water is a significant issue, particularly in rural regions and Kabul City, where residents heavily rely on groundwater (Hayat & Baba, 2017). As per Hamidi et al. (2023), they estimate that the primary source of potable water for over 4.4 million residents of Kabul is groundwater. The quality and quantity of groundwater across the country, particularly in Kabul City, are declining as a result of urban development, population growth, climate change and overuse (Karim, 2018; Khalil et al., 2020; Mujeeb et al., 2024; Rashteen et al.,2024; Zahid, 2021). This decline has resulted in contamination of the groundwater with high levels of physicochemical parameters, rendering a substantial portion of it unfit for consumption without treatment (Jawadi et al., 2020). The quality of groundwater in many parts of Kabul city exceeds the WHO and National Drinking Water Quality Standards (Noori & Singh, 2021). Based on Wafa et al. (2020), they identified concerning levels of total and fecal coliform, while Zahid et al. (2019) found an elevated level of total dissolved solids (TDS) and electrical conductivity (EC) which make much of the groundwater unsuitable for consumption. According to Hamidi et al. (2023), it is reported that less than 35% of shallow groundwater is safe in Kabul city. Another research by Jawadi et al. (2020) discovered that around 40% of the groundwater in the Kabul city is drinkable.

In District 15, residents primarily depend on groundwater sources from boreholes and open wells to fulfill their drinking and domestic water needs. This study was conducted to analyze the concentrations of various physical, chemical, and biological parameters in groundwater and compare them with WHO and ANSA standards. Additionally, it aimed to identify potential causes of elevated parameter levels and explore associated health effects.

MATERIALS AND METHODS

Study Area

Kabul, the capital of Afghanistan, is located in the eastern part of the country at an elevation of 1,800 meters above sea level, with coordinates. It lies between 34°31′N latitude and

69°12'E longitude (Wafa et al., 2023; Afghan et al., 2022; Mushwani et al.,2024). Our research was carried out in the district 15, locally known as "Nahiya 15", situated in the northern part of Kabul City. Covering approximately 32 square kilometers. District 15 includes both planned and unplanned residential areas. It is bordered by significant landmarks such as Khwaja Bughra Mountain, Kabul International Airport, and Sultan Mahmood Ghaznavi Road. The district Key facilities include police, education, and national security offices, and have a population of over 620,000 (Municipality, 2022). However, the district faces challenges with limited groundwater for drinking, leading to reliance on private water suppliers in some areas.

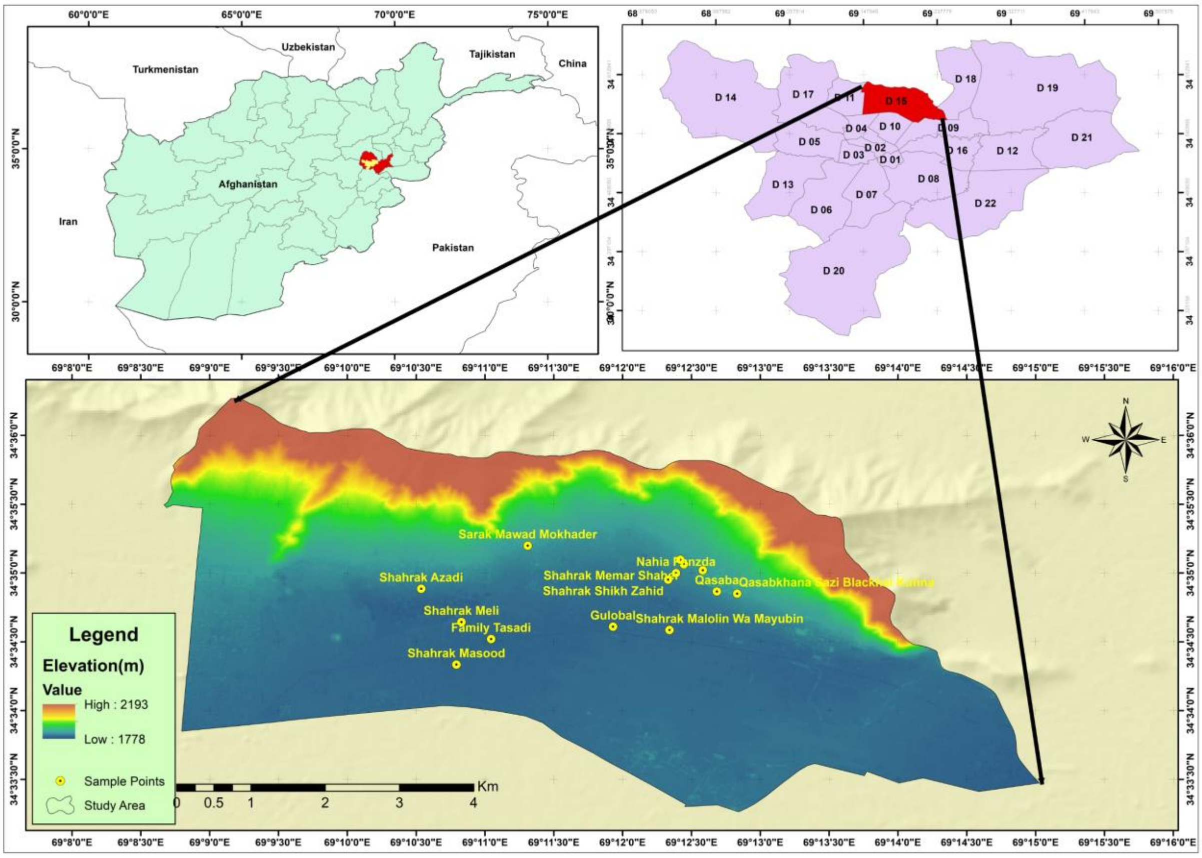

Figure 1: Geographical Location of Study Area

Sample Collection and Locations

In this study, we collected 14 samples from different areas of District 15 in March 2022. The method of sampling processes includes: Samples were collected in sterilized bottles of 1-liter capacity. The bottles were pre-cleaned with detergent and rinsed with distilled water before use. The samples were collected from the wells after purging the wells for at least 3 to 5 minutes to ensure that the stagnant water was removed. The first 500 ml of the sample was discarded to eliminate any possible contamination due to the well purging. The remaining 500 ml was collected and transported to the laboratory in a cool box containing ice.

Laboratory Analysis

The water samples were collected and the water laboratory of the National Environmental Protection Agency (NEPA) tested the physical, chemical and biological parameters. Physical parameters such as electrical conductivity (EC), total dissolved solids (TDS), turbidity, and temperature were measured at sample collection points with portable conductivity meter, TDS meter, turbidity meter, and thermometer. Chemical parameters include pH, chloride, Fluoride, Nitrate, Nitrite, Phosphate, Boron, Copper, Cadmium, Lead, Manganese, and Aluminum. The chemical parameters of water samples were conducted using standard methods. The chemical analysis method used for this research was the standard methods recommended by the American Public Health Association (APHA) (Rice and Bridgewater2012). Biological parameters consist of total coliform and fecal coliform. Membrane filtration method was utilized to determine the presence of total Coliforms and Fecal Coliforms bacteria in water samples.

FINDINGS AND DISCUSSION

Physical parameters

The Physical parameters analysis result is summarized in Table 1 below:

Table 1. Physical Parameters, concentration in water samples

NO	Village	EC (µS/cm)	TDS (mg/l)	Temp (^{O}C)	Turb (NTU)
1	Tank Tarakhel	1422	978	17.8	0.46
2	Qasabkhana Sazi	3460	2380	16.9	0.66
3	Qasaba	3130	2153	15.8	0.76
4	Family Qasaba	1609	1107	17.8	0.58
5	Nahia Panzda	1980	1362	17.6	0.71
6	Shahrak Mermar Shaher 1	1166	802	15.5	0.66
7	Shahrak Mermar Shaher 2	1159	797	15.4	0.57
8	Shahrak Shikh Zahid	10180	7004	16.9	0.17
9	Shahrak Malolin Wa Mayubin	1396	960	15.4	0.37
10	Sarak Mawad Mokhader	8310	5717	15.5	0.65
11	Shahrak Azadi	12480	8586	16.8	1.50
12	Shahrak Masood	1375	946	15.5	0.42
13	Shahrak Meli	1288	886	16.7	0.41
14	Family Tasadi	1293	890	18.6	0.33
	WHO standards	**-**	**-**	**25**	**5**
	ANSA Standards	**1500**	**1000**	**-**	**5**

The analysis of electrical conductivity (EC) level for 14 sites in district 15 reveals that most samples exceed the National standard limit for EC. ANSA limit is 1500 µS/cm. According to this limit only Tank Tarakhel (1422 µS/cm), Shahrak Mermar Shaher 1 (1166 µS/cm), Shahrak mermar shaher 2 (1159 µS/cm), Shahrak Malolin wa Myubin (1396 µS/cm), Shahrak Masood (1375 µS/cm), Shahrak Meli (1288 µS/cm) and Family Tasadi (1293 µS/cm) meet the national standard, while remaining sites exceed this threshold. Particularly high level is observed in Shahrak Shikh Zahid (10180 µS/cm), Sarak Mawad Mokhader (8310 µS/cm), and Shahrak Azadi (12480 µS/cm), indicating significant water quality concerns in these areas. Total dissolved solid (TDS) in 14 sites in district 15 show that only Shahrak Mermar Shaher 1 (802mg/l), Shahrak Mermar Shaher 2 (797 mg/l), Shahrak Malolin wa Mayubin (960 mg/l) and

Shahrak Meli (886 mg/l) meet ANSA standards of 1000 mg/l. The remaining sites exceed the limits, with Shahrak Shikh Zahid (7004 mg/l), Sarak Mawad Mokhader (5717 mg/l) and Shahrak Azadi (8586 mg/l) having the highest concentration. Temperature measurement across 14 sites in district 15 falls within the WHO guideline ranges from 12 – 25 °C for drinking water, indicating compliance with international standards. Value range from 15.4 °C in Shahrak Mermar Shaher 2 and Shahrak Malolin wa Mayubin to 18.6 °C in Family Tasadi. The turbidity levels across all 14 sites are within the WHO and ANSA recommended standards for drinking water, which are set at a maximum of 5 NTU. Turbidity level ranges from 0.17 NTU in Shahrak Shikh Zahid to a peak of 1.50 NTU in Shahrak Azadi, well below the permissible limit.

Overall, the results show that turbidity and temperature across tested sites generally meet both WHO and ANSA standards, indicating favorable conditions in these parameters for safe drinking water. This suggests stable physical water quality, despite an elevated level of TDS and EC in several locations. Previous research reveals that a high level of EC in groundwater is primarily caused by the presence of dissolved ions and salts. The concentration of these ions can increase due to natural processes such as water –rock interaction and dissolution of minerals (Alhumoud et al., 2010; Chakraborty et al., 2023). Research also highlighted that high TDS levels likely result from both natural and anthropogenic sources. Geological processes such as mineral weathering and dissolution, naturally elevate TDS (Rehman et al., 2023). While Anthropogenic activities, including untreated waste disposal, agriculture runoff, and urban effluent, also contribute significantly (Pushpalatha et al., 2022). Another research revealed that Elevated TDS and EC are often correlated and indicated high salinity level, which can lead to gastrointestinal issues (Rusydi, 2018). R search also reported that excessive TDS can also contribute to cardiovascular problems (Mumtaz et al., 2024).

Chemical parameters

The groundwater quality was checked for 12 key chemical parameters, pH, Chloride, fluoride, boron, nitrate, nitrite, phosphate, manganese, copper, aluminum, lead, and cadmium. Chemical parameter levels summarized in Table 2. The pH level observed in the 14 sampled sites generally align well with ANSA standards, which recommend a pH range of 6.5 – 8.5 for drinking water. Values range from 6.7 in Family Tasadi to 8.1 in Shahrak Azadi, all within acceptable range. The pH readings indicate that the water in the study area is suitable for consumption.

The chloride levels in the 14 sampled sites exhibit significant variability, with values ranging from 100 mg/l in Shahrak Shikh Zahid to 1040 mg/l in Shahrak Azadi. According to ASNA standard, which sets the permissible limit at 250 mg/l, only six sites (Tank Tarakhel, Shahrak mermar Shaher 1, Shahrak mermar Shaher 2, Shahrak Malolin Wa Mayubin, Shahrak Masood and Family Tasadi) fall within the acceptable range.

Table 2. Chemical parameters concentration in the water samples

No	Site name	pH	Chloride mg/l	Fluoride Mg/l	Boron (mg/l)	Nitrate (mg/l)	Nitrite (mg/l)
1	Tank Tarakhel	7.2	105	0.71	1.16	141.04	0.021
2	Qasabkhana Sazi	7.1	800	1.86	3.44	48.4	0.005
3	Qasaba	7.7	460	1.96	3.44	46.9	0.009
4	Family Qasaba	8	230	0.56	0.88	58.7	0.003
5	Nahia Panzda	6.8	245	0.71	0.76	70.3	0.004
6	Shahrak Mermar Shaher 1	7.2	225	0.83	0.43	26.5	0.003
7	Shahrak Mermar Shaher 2	6.9	110	1.01	0.88	26.58	0.009
8	Shahrak Shikh Zahid	7.5	1000	10.6	0.025	57.04	0.021
9	Shahrak Malolin Wa Mayubin	7.7	115	0.78	0.83	35.44	0.022
10	Sarak Mawad Mokhader	7.8	500	2.68	1.72	23.4	0.021
11	Shahrak Azadi	8.1	1040	9.9	0.027	71.24	0.076
12	Shahrak Masood	7.3	130	0.71	0.72	39.16	0.017
13	Shahrak Meli	7.5	185	0.56	0.99	38.44	0.014
14	Family Tasadi	6.7	125	0.36	0.82	96.04	0.014
	WHO (mg/l)	**-**	**-**	**1.5**	**2.4**	**50**	**3**
	ANSA (mg/l)	**6.5-8.5**	**250**	**1.5**	**-**	**50**	**3**

The remaining sites exceed these limits. Research indicates that the highest level likely influenced by anthropogenic activities or geological factors, posing potential risks to consumer health (Licciardello et al., 2011). The fluoride level measured in the 14 sites indicates noticeable differences. While most sites such as Tank Tarakhel (0.71 mg/l) and Family Tasadi (0.36 mg/l) fall within WHO and ANSA guideline of 1.5 mg/l, certain sites exceed this threshold. Notably Shahrak Shikh Zahid (10.6 mg/l) and Shahrak Azadi (9.9 mg/l) display fluoride levels far above permissible limits. Research reported that a high level of fluoride in water is due to fluoride-bearing aquifers, geological factors and weathering processes (Mukherjee & Singh, 2018). Research conducted by Panda et al. (2019), reveals that geochemical mechanisms of fluoride release into aquifers are influenced by soil properties, geological settings, climatic conditions, and water type. While anthropogenic causes are not fully explained, they contribute to the contamination (Nath, 2018). Research has shown that a high concentration of fluoride poses health risks such as dental, skeletal fluorosis, skin lesions and cardiovascular disorder (Dutta et al., 2018). Additionally, another study highlighted that high fluoride exposure can cause liver damage (Nizam et al., 2022).

The analysis of boron concentration shows variability in the sampling sites, in most sites, the boron level falls within the WHO recommended limit of 2.4 mg/l. Locations such as Tank Tarakhel (1.16 mg/l), Family Qasaba (0.88 mg/l) and Shahrak Mermar Shaher 2 (0.88 mg/l) fall well within the acceptable range, however, sites like Qasabkhana Sazi and Qasaba with (3.44 mg/l) exceed the recommended limit. Research highlights that boron is an essential trace nutrient, it can be toxic at high concentrations (Dotsika et al., 2006). However, research has also shown that high boron exposure may weaken bone health (Huang et al., 2024). The nitrate concentrations in the 14 sampled sites exhibit substantial differences, with values ranging from 23.4 mg/l at Sarak Mawad Mokhader to 141.04 mg/l at Tank Tarakhel. Several sites surpass the WHO guideline of 50 mg/l.

Research identifies the agriculture practices such as the use of nitrogen-based fertilizer and animal manure as a primary contributor to high nitrate levels (Jalali, 2010). Additional sources of contamination involve improper disposal of sewage, household waste and uncovered septic tanks (Omonona & Okogbue, 2021; Ramalingam et al., 2022). Research mentioned that elevated nitrate levels are associated with health risks like methemoglobinemia (blue baby syndrome) and increased birth defect (Fewtrell,2004; Sadler et al., 2016). conversely, the nitrite levels are consistently within WHO and ANSA threshold of 3 mg/l, ranging from 0.003mg/l to 0.076 mg/l.

The phosphate concentration measured at the 14 sampling locations ranges from 0.08 mg/l at Shahrak Azadi to 0.66 mg/l at Nahia Panzda, with most sites showing values under 1 mg/l. Although there are no specific WHO and ANSA standards for phosphate in drinking water. Research highlights that elevated phosphate level may pose an environmental risk such as eutrophication. Manganese concentration across the sampled location varies between 0 mg/l at Shahrak Mermar Shaher 2 to 0.005 mg/l at Sarak Mawad Mokhader, all remaining well below the WHO standard value of 0.4 mg/l. Copper levels recorded in water samples from the selected sites range from 0.05 mg/l at Shahrak Mermar Shaher 2 to a peak value 0.66 mg/l at Sarak Mawad Mokhader. All measured concentrations remain significantly below the WHO permissible limit of 2 mg/l. These findings indicate that copper content in the drinking water sources is within the safe threshold and does not pose a health concern. The Aluminum concentrations measured across the sampling sites ranged from 0 mg/l (Qasabkhana Sazi) to a peak of 0.12 mg/l (Family Tasadi). All recorded values align with the permissible limits of 0.2 mg/l as defined by WHO and ANSA standards. The result highlights that aluminum levels in these water sources are well within the safety threshold, ensuring no immediate health risks related to aluminum exposure.

Lead concentration in drinking water samples shows significant variation, with several locations exceeding the WHO and ANSA recommended limit of 0.01 mg/l. Concentration ranges from 0 mg/l in Qasabkhana Sazi to a concerning 0.097 mg/l in Shahrak Azadi. Sites such as Shahrak Shikh Zahid (0.06 mg/l) and Nahia Panzda (0.019) also report values above the permissible limit. Research reported that a high level of lead in groundwater can occur due to natural and human activities. Natural sources involve the geological composition of aquifers, while anthropogenic sources include mining, landfills and wastewater related activities (Akuo-Ko et al., 2023; Donohue et al., 2015; Kumari et al., 2017). Studies showed that high concentration of lead in water can result in both carcinogenic and non-carcinogenic health effects (Siame et al., 2023). Non-carcinogenic health risk of lead includes cardiovascular diseases, kidney and bladder disorders, reproductive failure and neurotoxicity (Sinha & Prasad, 2019). In this research, the cadmium concentration in sampling points highlights variability in compliance with WHO and ANSA standards, both of which set a permissible limit of 0.003 mg/l. Most of the sites, including Tank Tarakhel (0.001 mg/l), Qasabkhana Sazi (0.002 mg/l) and Nahia Panzda (0.002 mg/l), fall within an acceptable range. However, Shahrak Azadi (0.004 mg/l) exceeds this limit, indicating potential health risk due to cadmium contamination in this area. Research reveals that a high concentration of cadmium can lead to kidney dysfunction, cancer, and cardiovascular diseases. While long-term exposure can also cause chronic anemia and accumulation in the kidney (Burke et al., 2016).

Table 3. Chemical parameters concentration in the water samples

No	Site name	Phosphate (mg/l)	Manganese (mg/l)	Copper (mg/l)	Aluminum (mg/l)	Lead Mg/l	Cadmium (mg/l)
1	Tank Tarakhel	0.18	0.001	0.09	0.02	0.014	0.001
2	Qasabkhana Sazi	0.09	0.003	0.19	0	0	0.002
3	Qasaba	0.17	0.003	0.26	0.01	0.014	0.001
4	Family Qasaba	0.62	0.002	0.27	0.01	0.004	0.002
5	Nahia Panzda	0.66	0.002	0.31	0.02	0.019	0.002
6	Shahrak Mermar Shaher 1	0.59	0.001	0.23	0.01	0.006	0.001
7	Shahrak Mermar Shaher 2	0.21	0	0.05	0.04	0.005	0.001
8	Shahrak Shikh Zahid	0.09	0.004	0.31	0.01	0.067	0.003
9	Shahrak Malolin Wa Mayubin	0.31	0.002	0.28	0.04	0.007	0
10	Sarak Mawad Mokhader	0.29	0.005	0.66	0.03	0.001	0.002
11	Shahrak Azadi	0.08	0.001	0.39	0.02	0.097	0.004
12	Shahrak Masood	0.28	0.001	0.17	0.04	0.007	0.002
13	Shahrak Meli	0.24	0.001	0.09	0.04	0.006	0.001
14	Family Tasadi	0.26	0.001	0.09	0.12	0.006	0.002
	WHO (mg/l)	**-**	**0.4**	**2**	**0.2**	**0.01**	**0.003**
	ANSA(mg/l)	**-**	**-**	**2**	**0.2**	**0.01**	**0.003**

In this study, the concentration of 6 parameters including pH, Nitrite, Phosphate, Manganese, Copper, Aluminum, was within the acceptable limits of WHO standards. In contrast, the concentration of the remaining 6 parameters comprising chloride, fluoride, lead, cadmium, boron, and nitrate was beyond the WHO limits in some sampling sites of the study area. Our observations indicated that elevated concentrations of parameters in the district 15 are influenced by a combination of anthropogenic and environmental factors. These include improper waste disposal, the widespread use of nonstandard septic systems and agriculture activities, as well as the district-specific geological and climatic conditions, such as porous soil and semi-arid climate. These findings well align with existing research on contamination sources and underscore the need for proper management of interventions.

Biological Analyses

The result of the biological analysis reported the presence of total coliform and fecal coliform with low to high concentrations. The total coliform concentration in five sites in district 15 exceeds drinking water standards. The sites *Tank Tarakhel* (27 CFU/100ml), *Qasabkhana Sazi* (27 CFU/100ml), *Family Qasaba* (17 CFU/100ml), *Shahrak Shikh Zahid* (3 CFU/100ml), and *Shahrak Azadi* (29 CFU/100ml) exceed these limits. The fecal coliform concentrations in groundwater samples vary, with *Tank Tarakhel* having the highest level at 13 CFU/100ml, followed by *Family Qasaba* (3 CFU/100ml) and *Shahrak Azadi* (3 CFU/100ml). Other locations show no detectable fecal coliform presence, as clearly shown in Table 4. WHO and ANSA, both organizations recommended that the coliforms level should be 0 CFU/100ml in drinking water. In this study, total and fecal coliform bacteria were indicated in some areas, which can be attributed to the widespread presence of non-standard septic tanks in the study area. Additionally, previous research reveals that high levels of total and fecal coliforms in groundwater are often due to poor sanitation, sewage leaks, agriculture runoff, and failing septic systems, all of which introduce bacteria into water resources (Bain et al., 2014). Another study mentioned that agriculture practices, particularly manure use, lead to contamination when runoff infiltrates groundwater, especially in permeable soil (Graham & Polizzotto, 2013). Research demonstrated that bacterial contamination in water supplies can significantly impact human health, leading to diseases such as diarrhea, cholera and typhoid fever (Pal et al., 2018). Research has also shown that bacterial contamination can contribute to gastrointestinal illnesses and potential kidney damage (Pandey et al., 2014). Thus, research emphasizes that water must be properly treated and purified before consumption to minimize risk of waterborne diseases (Ahmadi et al.,2024)

Table 4. Biological Parameters Concentration in water samples

No	Location/site Name	Total Coliform	Fecal Coliform
1	Tank Tarakhel	27	13
2	Qasabkhana Sazi	27	0
3	Qasaba	0	0
4	Family Qasaba	17	3
5	Nahia Panzda	0	0
6	Shahrak Mermar Shaher 1	0	0
7	Shahrak Mermar Shaher 2	0	0
8	Shahrak Shikh Zahid	3	0
9	Shahrak Malolin Wa Mayubin	0	0
10	Sarak Mawad Mokhader	0	0
11	Shahrak Azadi	29	3
12	Shahrak Masood	0	0
13	Shahrak Meli	0	0
14	Family Tasadi	0	0
	ANSA(CFU/100ml)	**0**	**0**
	WHO (CFU/100ml)	**0**	**0**

CONCLUSION

This study provides critical insights into the groundwater quality in district 15 of Kabul city, offering a comprehensive analysis of the physical, chemical, and biological parameters across 14 sites. The findings revealed that several parameters, including TDS, EC, chloride, fluoride, boron, lead, cadmium, and total and fecal coliform, exceeded the acceptable limits of the WHO and ANSA in several sites of the study area. The physical, chemical, and bacteriological quality of drinking water in District 15 is significantly compromised due to inadequate waste management systems and the widespread use of non-standard septic tanks. These factors, combined with the natural activities, contribute to an elevated level of contaminants. The reliance of residents on these contaminated water sources exposes them to significant health risks, particularly diseases caused by high concentrations of heavy metals like lead and cadmium and microbial contamination such as total and fecal coliforms. Therefore, immediate actions are necessary to prevent and mitigate these risks. Groundwater exceeding the WHO and ANSA standards must undergo effective purification through accessible methods such as boiling, chlorination, and filtration, depending on the families' resources. Additionally, implementing water quality regulations, proper waste management, and improved sanitation systems are essential to mitigate the sources of contamination.

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