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Exploring the Current Status of Groundwater Resources in Herat City, Afghanistan: An In-depth Analysis

Abdul Wahed Ahmadi* and **Mehmet Emin Argun**

Konya Technical University, Faculty of Engineering and Natural Sciences, Environmental Engineering Department, Turkey

***Corresponding Author**
Abdul Wahed Ahmadi, Konya Technical University, Faculty of Engineering and Natural Sciences, Environmental Engineering Department, Turkey.

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Abstract

Groundwater depletion and pollution pose significant challenges to water security in Herat City, Afghanistan. Utilizing data collected from monitoring and research wells up to March 2023, this study assesses the static water levels and quality parameters across various regions. The analysis reveals a consistent decline in groundwater levels from 2015 to 2022, with reductions exceeding 10% in some areas. Additionally, water quality assessments based on WHO standards highlight elevated levels of electrical conductivity, salinity, and pH, indicating contamination and unsuitability for consumption and irrigation. Salinity levels in certain wells exceed recommended limits, reaching up to 1400 mg/L. Moreover, increased pH levels suggest pollutant infiltration from agricultural and wastewater sources. To address these challenges, sustainable management strategies are proposed, including centralized and decentralized wastewater treatment, standardized irrigation practices, and the promotion of responsible water usage. Collaboration among stakeholders and robust governance frameworks are essential for implementing these measures and ensuring long-term groundwater sustainability in Herat City. Continuous monitoring of water quantity alongside quality is emphasized to track progress and adjust strategies accordingly, safeguarding the availability and quality of groundwater resources. The outcome underscores the urgent need for comprehensive interventions to safeguard public health and secure access to safe drinking water in Herat City, Afghanistan.

Keywords: Groundwater, Contamination, Decentralization, Sewage Septic, Wells

1. Introduction

Water is the most valuable source of life for all living things and the most renewable source, essential for sustaining all forms of life such as food production, economic development, and general well-being [1]. Hence, It is impossible to substitute for major of its uses, difficult to de pollute, expensive to transport, and it is truly a unlimited gift to humanity from nature [2]. It is also one of the most manageable natural sources because it can be diverted, transported, stored, and recycled. All of these characteristics give water its great utility for humans [3]. The country's surface and groundwater sources play an important role in agriculture, hydroelectric power generation, livestock, industry, forestry, fishing, navigation, recreation, etc [4]. As we know that 3% of the earth is made and covered by water [5]. Therefore, freshwater at the ecosystems of the world comprise only about 0.5% of the earth's surface and have a volume of 2.84x105 Km3 [6]. Althought, the rivers and seas constitute an insignificant amount (0.1%) of the land surface. Only 0.01% of the waters of the earth occur in river channels. Inspire of these low quantities, running waters are of enormous significance [7]. In order to 100% of the exisiting water on the earth 91% of the mentioned waters are salty, 2% include refrigerators and only just 1% of these waters are sweet and drinkable [8].

However, water is the basic and main resources of energy production and economy in Afghanistan where agriculture accounts for more than 50% of the country's gross domestic product (GDP) [9]. On the other hand the groundwater as the basic and main source of drinking water in the most area and people of Afghanistan. Anyway, little of knowledge is available about the quantity and quality of groundwater within of the entire country, and its quality has not been investigated extensively yet as example of other countries in the world [10]. Although, based on the water resource and river basin Afghanistan has been divided into five general rivers basin including Amu River Basin, Northern River Basin, Harirod-Murghab, River Basin, Hilmand River Basin and Kabul River Basin also in each city has one sub-river basin Figure 1 [11]. The wide valley of lower Hari Rud basin which has the catchment area of about 10,000 sq. km. gets the average rainfall little more than 200 mm per year. The valley floor is about 2,500 sq. km. following the river course; one can see the river completely dry in many places and re-emerging downstream in the river basins [12]. Thus, there is loss in annual river discharge of 665 MCM in between Rabat-e-Akhond and Tirpul of Herat city. Indeed, recharge due to surface water loss and discharge to river due to aquifer saturation indicates good possibility of groundwater occurrence in lower Hari Rud wide valley [13].

However, the accumulation of Harirod-Murghab has been estimated (640Mm3/yr.) To the annual average rainfall in Herat city has been reported by Hydro metrological stations is about 210 mm and most highest rainfall has been recorded from near Tourghundi stations in Kohsan district-Chil Dokhtran village of Herat, the total rainfall of Herat city from 2008-2020 [14]. Groundwater pollution is a significant concern, primarily attributed to various anthropogenic activities including industrial discharges, urban practices, agricultural operations, groundwater extraction, and improper waste disposal. These activities have the potential to adversely impact the quality of groundwater. Instances of pollution can arise from human-induced factors, such as the leakage of fuel tanks or the occurrence of toxic chemical spills [15].

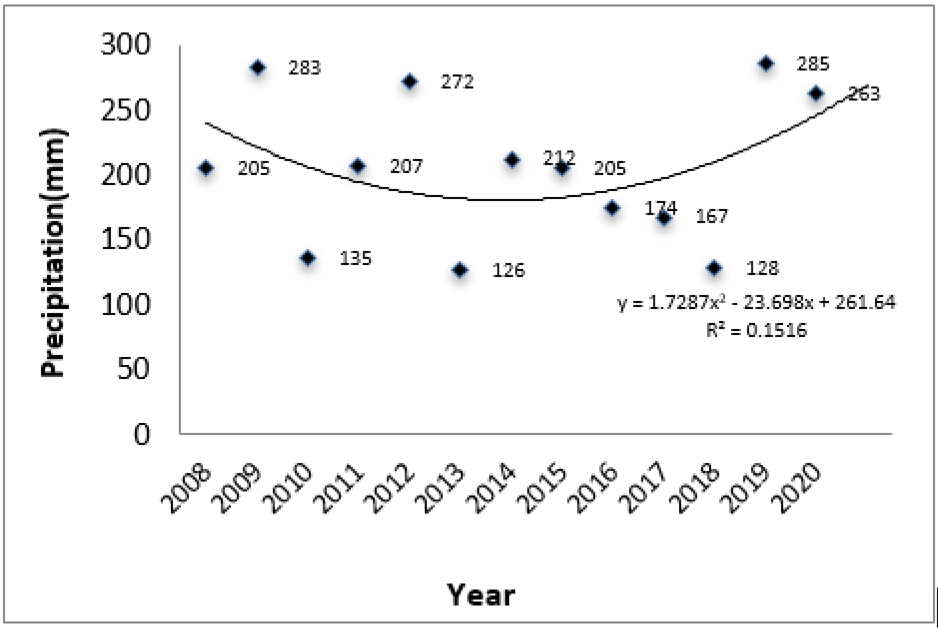

Figure 1: Annual Average Precipitation of Herat City

The unregulated utilization of groundwater for agricultural purposes, particularly through practices like excessive irrigation such as land flooding, and the nonpayment of taxes on groundwater usage, are among the primary factors that have detrimental effects on both the quality and quantity of groundwater in the city of Herat, Afghanistan, use of groundwater for car washes, Public pools and swimming pools, as they bear the main responsibility for surface water pollution in this process, and the use of chemical substances (soap, detergents, exhaust residues, gasoline, heavy metals from rust, and motor oils) can be washed off cars and flow directly into storm drains and the nearest stream or river, where they can affect water quality and wildlife [16,17]. In addition, many other reasons such as lack of standard septic tanks for domestic wastewater in public and private households, lack of water purification systems, and lack of government control over groundwater in most regions are the most important reasons for groundwater pollution and decrease of love for groundwater in Herat City [18]. The overall objective of this study is to assess the present condition of groundwater in various areas of Herat city and evaluate its quantity and quality in comparison to recent years. This will be accomplished by analyzing statistical data obtained from research and observation wells. Furthermore, specific objectives include conducting a comprehensive review of the existing groundwater quality and quantity trends in recent years, as well as proposing suitable and cost-effective methods to address the identified issues.

2. Methodology and Materials Used

In this study, primary data was obtained from 49 research and observation wells (monitoring wells) situated in different regions and districts of Herat city. These wells are subject to government control and supervision, as illustrated in Figure 2. The research wells are exclusively designated for groundwater research and are owned by the government, while the observation wells are privately owned but monitored by the government. The collected data encompasses key parameters including electrical conductivity (EC), water level (WL), pH, total dissolved solids (TDS), and water temperature (WT). Monthly measurements of these parameters are performed at both types of wells, enabling a comprehensive assessment of groundwater quality and quantity. Detailed information about the research and observation wells can be found in Table 1.

This study employed field testing as a method to analyze parameters, ensuring the reliability of sample analysis. Field testing offers the advantage of identifying challenges encountered during everyday work processes, providing valuable sample data that represents the target population and is not easily obtainable in laboratory settings. In addition, hydrometeorological data, including precipitation, was collected from 12 hydrological and meteorological stations in Herat province. The hydrological stations recorded various parameters such as precipitation, temperature, humidity, water levels, and meteorological conditions at 15-minute intervals. Additional parameters such as snowfall, wind speed, dew point, and solar radiation were recorded hourly. The collected hydro-meteorological data, including the aforementioned parameters, was recorded on a monthly basis. The data was then categorized, analyzed, and processed using the X-Connect software. The combination of field testing and hydrometeorological data collection provides a comprehensive understanding of groundwater parameters in Herat City, Afghanistan.

ID/No	Name of Well	Type of Well
H-1	Chaghara (shahid Najafi)	Monitoring
H-2	Pul malan	Monitoring
H-3	Simaye Herat	Monitoring
H-4	Kohsan	Research well
H-5	Madraca pir Herat	Monitoring
H-6	Zanda jan	Research well
H-7	Ghyzan Joycha	Monitoring
H-8	Zaman Abad	Monitoring
H-9	Shaidayi	Monitoring
H-10	Bagh Nazargah	Monitoring
H-11	Kamar kalagh	Monitoring
H-12	Shafakhana Hywanat	Monitoring
H-13	Payen Ab	Research well
H-14	Lessa khwaja Mohammad Taky	Monitoring
H-15	Sharwali	Monitoring
H-16	Shafakhana Hawzawi	Monitoring
H-17	Park taragi	Monitoring
H-18	Mahal Babaji	Monitoring
H-19	Roj	Research well
H-20	Awgha	Research well
H-21	Namber Yak Ghozara	Research well
H-22	Namber DO Ghozara	Research well
H-23	Namber Si Ghozara	Research well
H-24	Chah Reyasat	Research well
H-25	Ghoryan	Research well
H-26	Dasht House	Research well
H-27	Jabrayel	Monitoring
H-28	Jabrayel	Research well
H-29	Reyasat Mahdan	Monitoring
H-30	Reyasat Mahdan	Research well
H-31	Maktab shahid Afzali	Monitoring
H-32	Maktab shahid Afzali	Research well
H-33	Mawlana Jamee	Monitoring
H-34	Mawlana Jamee	Research well
H-35	Fath School	Monitoring
H-36	Fath School	Research well
H-37	Naween Sofla School	Monitoring
H-38	Naween Sofla School	Research well

H-39	Chowdengar School	Monitoring
H-40	Chowdengar School	Research well
H-41	Be be Aeisha Shool	Monitoring
H-42	Be be Aeisha Shool	Research well
H-43	Qawasnan School	Monitoring
H-44	Qawasnan School	Research well
H-45	Pohanton Herat	Monitoring
H-46	Pohanton Herat	Research well
H-47	Ryasat Zaraat	Monitoring
H-48	Tasisat Gomandani Amnaya	Monitoring
H-49	Ryasat Moad Naft	Monitoring

Table 1: Details of Research and Observation (Monitoring) Wells in Herat City of Afghanistan

Data collection from research and observation wells typically occurs on a monthly basis. During on-site observations, samples were analyzed for various parameters including electrical conductivity (EC), water level (WL), pH, total dissolved solids (TDS), and water temperature (WT). Well level sounders (WLS) were utilized to measure the water level in the wells. The WLS commonly utilizes a full depth stainless steel and a 16 mm diameter Teflon probe. This tool is widely used by groundwater hydrologists for measuring groundwater levels. The measurement process involves lowering a two-core cable with open ends into the well. This method is simple yet commonly employed for determining the depth of groundwater in wells. The WLS device typically consists of two wires with an electronic sensor that detects the presence of water and indicates the depth at which the tape encounters the water [19]. The GW-2000 Multi Parameter is an instrument used for water quality analysis. It combines a combination electrode and cuvette for analyzing multiple parameters simultaneously. The results of the analysis are conveniently displayed on the instrument's screen, facilitating the recording of observations in the data sheets or tables. To further analyze the collected data, statistical software programs such as SPSS and Excel were employed [20].

3. Result and Discussion

Based on the latest data (March 2023) obtained from monitoring and research wells, the static water level in various regions of Herat city demonstrates variations in depth, as illustrated in figure 2. The analysis of the data reveals a consistent decrease in the groundwater level between 2015 and 2022. Specifically, Figure 8 displays the water level (WL) of well ID/No. H-24, situated in the central area of Herat. In 2015, the water level was recorded at 22.42 meters, while by 2022, it had dropped to 26.86 meters. This indicates a decline of more than 4 meters in the water level over the course of the last 8 years.

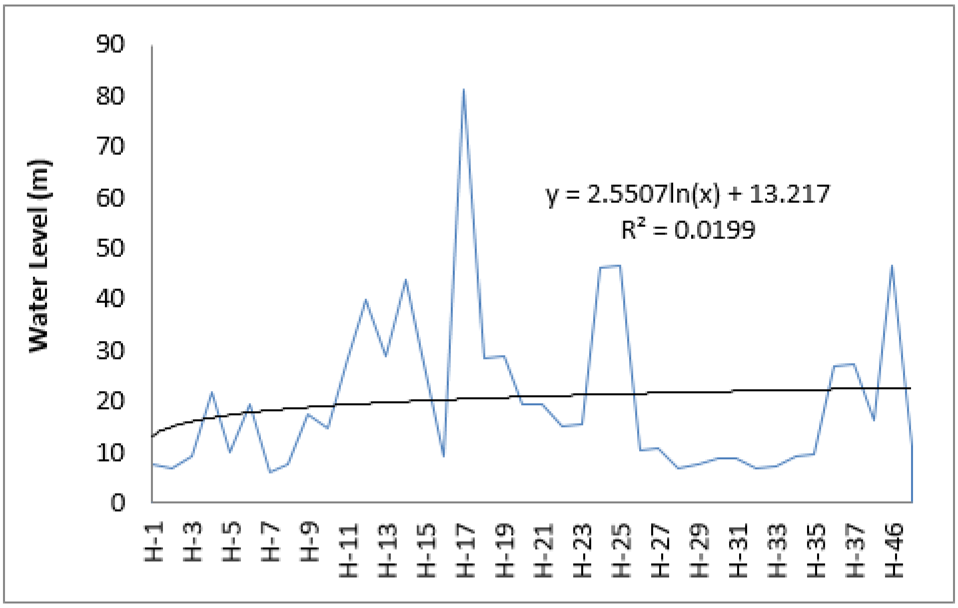

Figure 2: Static Water Level of Wells Based on Soil and Water Layers in Different Regions

Furthermore, focusing on well ID/No. H-5 in Madrasa Pier, located in Serwistan village within the Enjil district of Herat city, it was observed that the water level in this area decreased from 7.3 meters in 2021 to 9.2 meters in 2023. This indicates a decrease of 1.3 meters in the water level within the mentioned timeframe. Regarding water quality (WQ), it has been categorized and assessed based on a ranking system and its suitability for various applications, such as drinking water, in accordance with the standards set by the World Health Organization (WHO). Table 2 provides an overview of the water quality ranking system. The primary objective of this ranking system is to identify the regions and areas that are most susceptible to groundwater pollution, with a particular focus on urban areas. A comprehensive water quality assessment was conducted, considering four physiochemical parameters, which are detailed in Table 2.

ID/No	**Parameters**			
	EC (µS/cm)	**Salinity mg/L**	**PH**	**Temp (C)**
H-1	1320	800	8.3	20
H-3	1460	900	8.2	19.8
H-4	1460	800	8.6	21.8
H-5	970	600	8.4	20.1
H-6	780	500	8.5	20.1
H-8	1361	800	8.2	15.2
H-12	1872	1100	8	18.8
H-13	1270	800	8.3	17.5
H-14	1590	1000	8.5	20.1
H-16	1618	1000	7.7	18.2
H-17	1418	800	8.1	17.7
H-18	1520	900	8.6	18.2
H-19	2540	1400	8.4	20.4
H-20	1198	700	8.3	18.8
H-21	797	400	8.7	20.3
H-22	1136	600	8.4	21.3
H-23	2232	1300	8.4	18.8
H-24	710	400	8.6	18.9
H-25	1147	600	8.8	21.5
H-26	1363	800	8.7	19.1
H-28	1677	1000	8.3	18.7
H-30	1081	600	8.8	18.6
H-32	1230	700	8	18.8
H-34	1580	1000	8.4	17
H-36	1150	700	8.8	17.7
H-38	786	400	8.7	18.7
H-40	702	400	8.5	20
H-42	839	500	8.3	18
H-44	724	400	8.8	16.6
H-46	942	500	7.6	17.8
H-47	1120	600	8.4	19.2
H-48	1134	600	8.7	18.7
H-49	1021	600	8.5	15.4

Table 2: Water Quality Parameters of 49 Research and Observation Wells

Table 2 highlights that in numerous areas of Herat, certain parameters like electrical conductivity (EC) and salinity exceed the recommended range set by the World Health Organization (WHO), indicating elevated levels. For instance, in a specific test conducted on well number H-24, the results indicate a total dissolved solids (TDS) reading of 1820 mg/l, which is twice the limit prescribed by the WHO standard. This suggests a significant deviation from the acceptable water quality levels as defined by international guidelines.

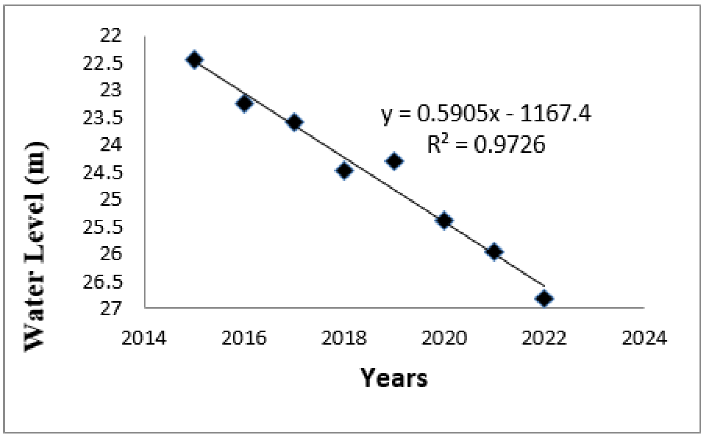

Figure 3: Comparison of the Static Groundwater Level with that of the Last Years

Elevated electrical conductivity (EC) in drinking water indicates the presence of a higher concentration of electrolytes. This parameter also serves as an indicator of total dissolved solids (TDS) since most salts can be ionized. However, a high EC value renders the water unsuitable for irrigation purposes. EC is of significance because it provides insights into the quantity of dissolved solids, chemicals, and minerals present in the water. A greater percentage of these impurities results in higher conductivity levels in drinking water. For instance, Diagram 4 illustrates that the EC range in well H-19 exceeds 2500, surpassing the WHO standard. In groundwater, elevated EC is primarily caused by the presence of inorganic dissolved solids such as chloride (Cl2), nitrate (NO3), sulfate, and phosphate anions, as well as positively charged ions such as sodium (Na), magnesium (Mg), calcium (Ca), iron (Fe), and aluminum (Al) cations.Salinity, measured in milligrams per liter (mg/L), serves as an indicator of water quality. Drinking water with salinity levels below 600 mg/L is considered of good quality, while levels between 600-900 mg/L and 900-1200 mg/L are classified as mediocre and poor quality, respectively. Salinity exceeding 1200 mg/L is deemed unacceptable. High groundwater salinity can pose risks to human health and agricultural productivity if not properly managed. Figure 9 indicates that salinity levels in certain wells, such as H-19 and H-23, exceed the WHO limit, ranging from 1300 to 1400, thus highlighting the presence of elevated salinity levels.

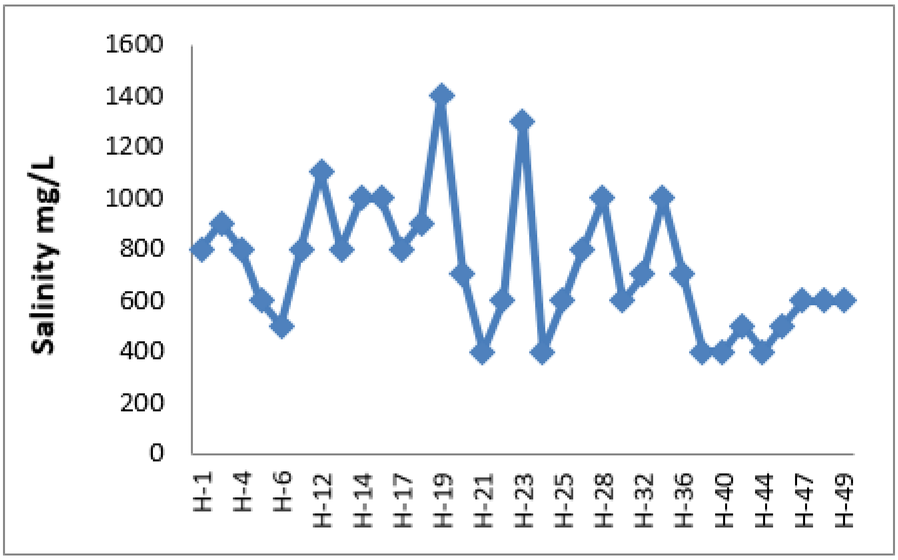

Figure 4: Average Range of Salinity mg/L in the Researches and Observation Wells

An increase in pH levels can result in a bitter taste in drinking water and the formation of sediment in water pipes and equipment. Moreover, high pH levels can reduce the effectiveness of chlorine as a disinfectant. Temperature also plays a role, as it can affect various physical properties of groundwater, including density, viscosity, conductivity, boiling and melting points, as well as the presence of dissolved compounds that contribute to taste and odor. Graph 6 illustrates the upward trend of pH levels and groundwater temperature in recent years. The rise in pH levels in groundwater is primarily attributed to the adsorption and accumulation of water pollutants, such as chemical fertilizers, insecticides, and other substances, by soil, as well as the infiltration of surface water into the groundwater system. Excessive consumption of salt in water can exert strain on the kidneys, potentially leading to kidney failure. Kidney dysfunction, in turn, can contribute to the development of heart disease and high blood pressure. Additionally, excessive salt content in irrigation water can cause soil damage [21].

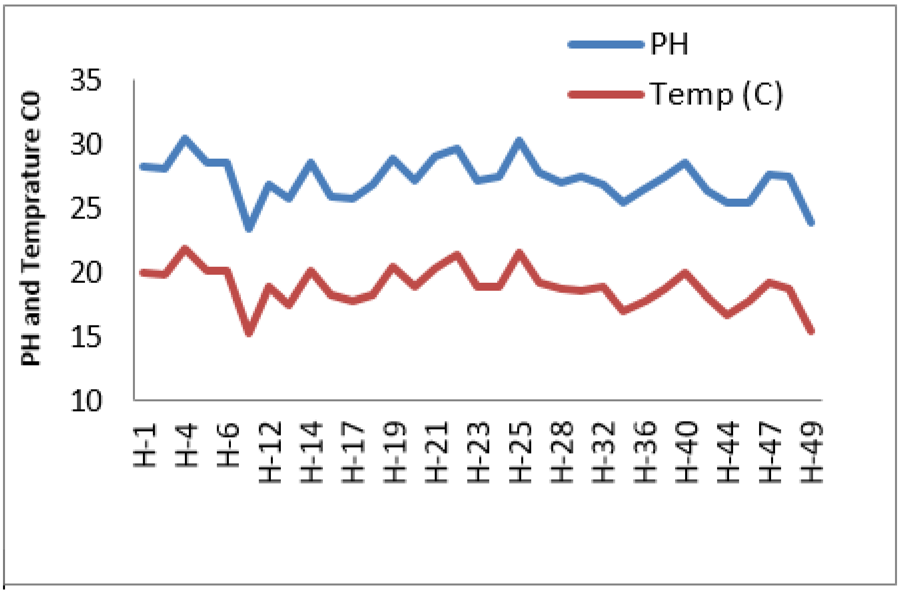

Figure 5: Average Range of pH and Temperature (°C) in the Wells

According to the World Health Organization, high pH levels in drinking water can result in a bitter taste, the accumulation of deposits in water pipes and consumption devices, and a reduction in the disinfecting effect of chlorine (Cl2), requiring additional chlorine when pH levels are high [22]. On the other hand, low pH levels in water can lead to the dissolution of elements and other materials. In Figure 5, it can be observed that the average pH and salinity range of groundwater in Herat province falls between 7.6 and 8.8. Although the WHO standard suggests a pH range of 6.5 to 8.5, some groundwater wells in the region exhibit lower pH levels, which can be attributed to factors such as acid rain or higher pH in limestone areas. The increase in pH levels is primarily attributed to the infiltration of nitrite from non-standard wastewater and septic wells, as well as the infiltration of chemical fertilizers used in agriculture through shallow waters in Afghanistan, particularly in the regions surrounding Herat. These findings highlight the need for appropriate management strategies to address the factors contributing to pH variations in groundwater, ensuring compliance with WHO standards and promoting the provision of safe drinking water to the population. Measures such as wastewater treatment and responsible agricultural practices can help mitigate the impact on groundwater quality and pH levels in affected areas.

4. Conclusion and Recommendation

In conclusion, the state of groundwater in Herat city, Afghanistan, is a matter of concern. Despite its importance as a primary source of drinking water, access to safe water remains low, particularly in rural areas. The overexploitation of groundwater, coupled with the lack of tax collection, has led to its depletion and compromised its quality. The data from surveys and monitoring wells indicate high levels of electrical conductivity, salinity, pH, temperature, and total dissolved solids, exceeding the recommended standards. To address these challenges, a multifaceted approach is required. Implementing sustainable water management practices is crucial, including the promotion of efficient irrigation techniques to reduce water consumption. Additionally, enforcing tax collection on groundwater usage can discourage excessive extraction and provide funds for conservation efforts. Investing in wastewater treatment infrastructure is essential to prevent pollution and maintain groundwater quality.

Public awareness campaigns on water conservation should be conducted to foster a culture of responsible water usage and promote alternative water sources. Community engagement and involvement in water resource management can help alleviate the pressure on groundwater resources. Continuous monitoring and regular assessments of groundwater quality and quantity are essential to track progress, identify emerging issues, and adjust strategies accordingly. By adopting these measures; it is possible to safeguard the availability and quality of groundwater in Herat city, ensuring sustainable access to safe drinking water for the population. However, these efforts should be accompanied by strong governance, policy support, and collaboration among stakeholders to achieve long-term success in managing groundwater resources. As short, the following suggestions are proposed for effective groundwater management in this research: The construction of a centralized wastewater treatment plant should be considered at the outlets of canals to mitigate groundwater pollution by treating contaminated water from the surface.

It is advisable to establish small and decentralized treatment plants for entities contributing to groundwater pollution, such as public baths, car washes, gyms, swimming pools, and similar sources. The standardization of groundwater usage in agriculture, particularly for irrigation purposes, should be prioritized. This can be achieved by meeting the water demands of farmers through surface water sources, such as the construction of dams and canals. There is a need to implement a plan for the installation of standardized septic tank systems instead of non-standard domestic wastewater wells. These wells are a significant source of groundwater contamination, and responsible agencies such as the Municipality and the Rural Development Department should take the lead in this initiative [23-34].

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