



Analysis of Groundwater Quality in Paghman Selected Regions, Kabul, Afghanistan

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Abstract

This study examines groundwater quality in the Paghman region of Kabul, Afghanistan, drawing on relevant groundwater data to support the analysis. The primary objective is to assess groundwater quality across different areas of the Kabul Paghman regions and evaluate its suitability for human health, as groundwater is the primary water source for most communities in the region. Where contamination is suspected, groundwater quality can be evaluated through a range of laboratory analyses, including physical, chemical, and biological tests. In this investigation, particular emphasis is placed on chemical and physical parameters. The scope of the study was constrained by limited access to analytical instruments, as a complete set of equipment required for a comprehensive groundwater assessment was unavailable.

Keywords

Groundwater quality, Physical properties, Chemical parameters, Paghman, Kabul

1. Introduction

Water is a critical natural resource for every country, and Afghanistan is no exception. The country has historically benefited from substantial water availability derived from glacierized and snow-covered regions. However, recent climate change impacts—particularly rising global temperatures—have led to significant reductions in both surface water and groundwater resources in Afghanistan.

Recent assessments indicate that the potential volume of surface water has declined from approximately 67 Mm³ to 49 Mm³, representing a reduction of about 8 Mm³, or roughly 13.3 percent of total water resources. This decline has been compounded by decreased precipitation and increased reliance on groundwater, especially in urban areas, making these regions increasingly vulnerable (Arian et al, 2015).

In recent years, rapid population growth and associated urban pressures have further exacerbated groundwater challenges in Kabul, particularly in the Paghman region, where issues of water quality, quantity, and overall water management have become increasingly severe. This study places particular emphasis on understanding these challenges to prevent further deterioration and mitigate the risk of more extensive, irreversible impacts. Addressing these problems requires coordinated action involving urban residents, government authorities, civil society (David, 2018), non-governmental organizations, and other relevant stakeholders.

Water is one of the most essential natural resources for all forms of life; without it, life cannot exist. Scientific theories on the origin of water have evolved. According to Laplace's nebular hypothesis, water was introduced during the early



stages of Earth's formation and played a fundamental role in planetary evolution. Historical perspectives also highlight the central importance of water. Ancient Indian philosophies regarded water as a primary constituent of the Earth, often symbolically described as an “egg” suspended upon water. Similarly, ancient Greek philosophers considered water one of the fundamental elements of nature, along with earth, air, and fire (Bohannon and Turner, 2007).

Increased reliance on groundwater for domestic use, drinking water supply, industry, agriculture, and other purposes has led to a significant decline in groundwater reserves, resulting in progressive drawdown of groundwater levels. In this study, a set of key parameters was analyzed to assess groundwater conditions. Multiple national and international standards were applied to identify groundwater quality issues, particularly from a human health perspective. This conceptual understanding persisted until the mid-18th century, when the French chemist Antoine Lavoisier demonstrated that water is not an element, but a compound composed of two atoms of hydrogen and one atom of oxygen (Bohannon, 2005), as expressed by the chemical formula H_2O .



In Equation 1, the relationship between hydrogen and oxygen in the water molecule is often represented in a simplified linear form. However, in reality, the water molecule has a bent (angular) geometry, as illustrated in Fig. 1.

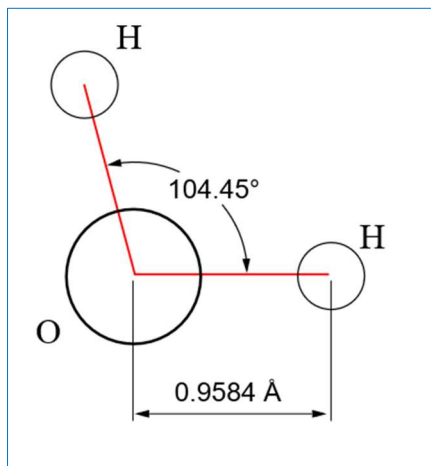


Fig. 1. Orbital hydrogen and oxygen in a water molecule (Molecular structure of water)

Water is the second most essential requirement for life, after air, and is one of the most critical components of Earth's system. Different organs and tissues of the human body contain varying proportions of water, underscoring its fundamental role in physiological functions. Water is also indispensable for food production, livestock, and agriculture (Vaseashta, 2021). Research indicates that the average daily water consumption per person is approximately 300 liters, while in industrialized countries this figure increases to about 450 liters per person per day; total per capita water demand, including indirect uses, may reach up to 600 liters per day

(Chenini et al., 2009). Ensuring access to safe and potable water is therefore vital for human health, particularly in developing economies, and requires sustained attention and effective management. Water security is closely linked to country-specific challenges and local environmental conditions. In developed countries, greater emphasis is placed on water quality, supported by the establishment and enforcement of comprehensive standards (Castany, 1967).

Global hydrological data indicates that approximately 70.8 % of the Earth's surface is covered by water in the form of oceans, seas, and lakes. The total volume of water on Earth is estimated at 1.38 million cubic kilometers. Of the Earth's total surface area of approximately 510 million square kilometers, about 361 million square kilometers are covered by water. Despite this vast quantity, only a very small fraction—approximately 0.003 %—is readily available for direct human use. Water resources are found as both surface water and groundwater, and humans rely on both sources for various needs (DACAAR Landell Mills, 2007–2017).

Each resource has distinct advantages and limitations, and its suitability depends largely on water quality. In some regions, surface water from rivers and streams is easily accessible and of relatively good quality. In many other areas, however, water resources are contaminated by sources such as solid waste disposal, petroleum activities, cemeteries, agricultural runoff, irrigation canals, and other anthropogenic influences (Dojlido and Best, 1993; Vaseashta, 2015).

Today, many countries face increasing water scarcity, even in regions with high overall water availability. For example, several Caribbean islands experience water shortages and rely on rooftop rainwater-harvesting systems to collect and store fresh rainwater for domestic and drinking purposes.

The main problems with water resources are as follows:

- Inadequate surface water reservoir,
- More usage of groundwater,
- The pollution of surface and groundwater,
- Potable water quality,
- Floods,
- Soil erosion and sedimentation, pollution, and to pout pollution,
- Dewatering turbid water moisture from soil.
- Downward of the lake and lateral waters.

Over the past century, approximately 80 % of human illnesses have been linked to water-related causes, a situation exacerbated by rapid population growth, rising living standards, economic development, agricultural expansion, and industrial pollution. These challenges highlight two interconnected and critical issues: water scarcity and water pollution (Vaseashta, 2021). Together, they underscore the need for more careful and responsible water use, as well as improved protection of water resources from diverse sources of contamination (Gray, 1994).

Global studies indicate that water demand increased nearly threefold between 1950 and 1995. During this period,

approximately 2.1 billion people worldwide lacked access to safe, potable water, forcing many to rely on contaminated sources. Water pollution arises from multiple factors, including the expansion of human activities and increasing consumption patterns. As early as 1977, chemists had identified approximately 4 million distinct water-quality parameters and contaminants. In 1993 alone, more than 11,000 pollution incidents in the United States resulted in the discharge of approximately 120 million liters of pollutants into water bodies. Similarly, in November 1986, the release of toxic substances—including mercury (Hg) and other hazardous compounds—into the Rhine River from industrial and urban sources across several European countries rendered large stretches of the river toxic (Landell Mills, 2017a), with transboundary impacts extending into the Netherlands. In recent decades, major oil and gas tanker accidents have also caused severe marine pollution, leading to widespread marine mortality and significant societal and environmental consequences (Landell Mills, 2017b).

Scientific research has demonstrated that elements such as iodine, boron, arsenic, potassium, nickel, lithium, copper, lead, and germanium occur naturally in surface and groundwater at varying concentrations. The presence of these elements contributes to the formation of different minerals and directly influences water chemistry (Landell Mills, 2017c). In water, these elements are typically present as dissolved salts, and the total concentration of dissolved salts is reflected in the water's electrical conductivity (EC) (Mania et al., 1985).

Electrical conductivity is a key indicator of water salinity and is commonly measured in micro-Siemens per centimeter ($\mu\text{S}/\text{cm}$). EC values may range from as low as $5 \mu\text{S}/\text{cm}$ to several thousand $\mu\text{S}/\text{cm}$. Generally, water with EC values between 0 and $250 \mu\text{S}/\text{cm}$ is considered low in salinity, while water with EC values above $750 \mu\text{S}/\text{cm}$ is considered saline. Highly saline water with EC values greater than $2,000 \mu\text{S}/\text{cm}$ is generally unsuitable for drinking.

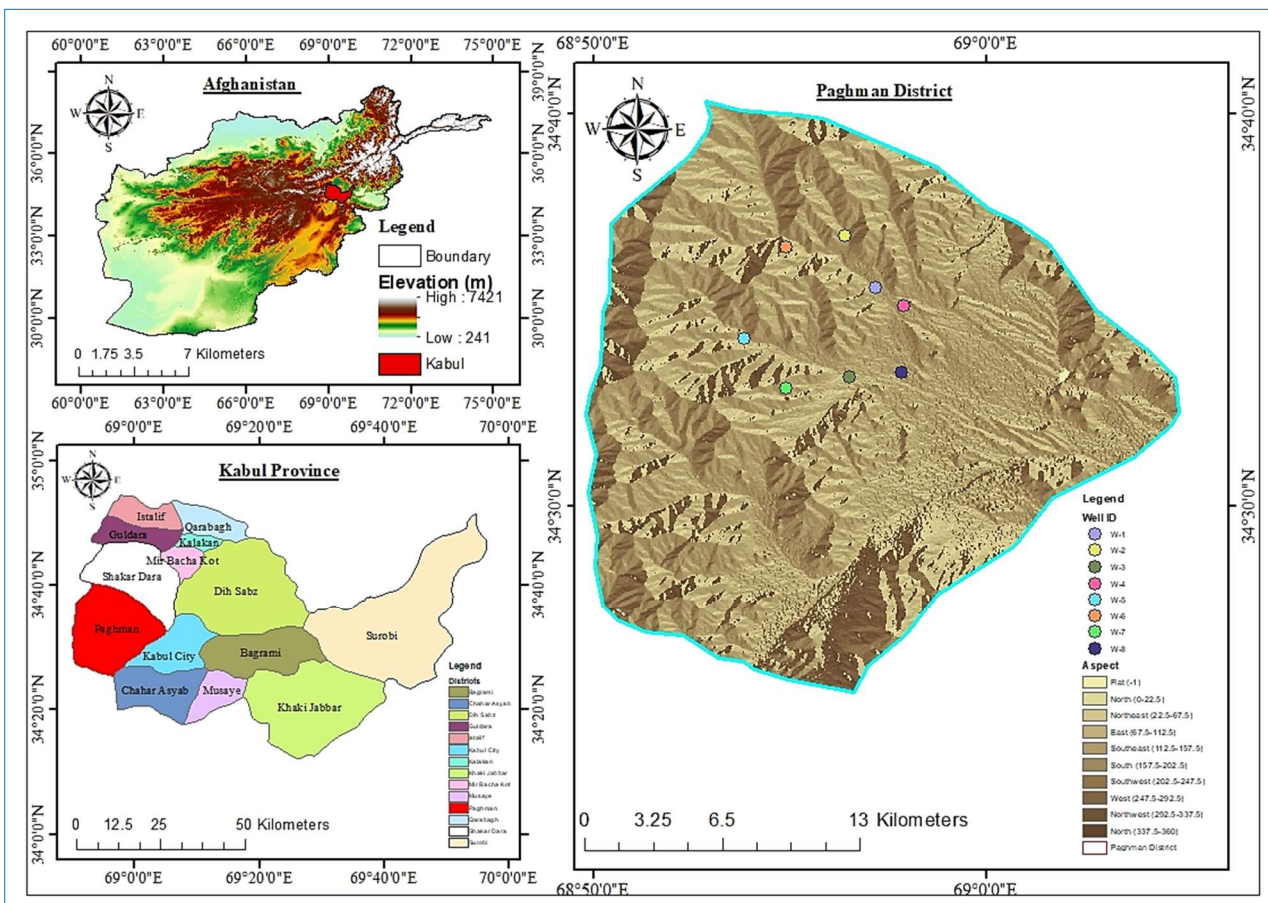


Fig. 2. The location map of the study area and the wells' locations

According to established standards, including those applied in the United States, the permissible concentration of iron in drinking water is $0.3 \text{ mg}/\text{L}$, nitrate (NO_3^-) levels must remain within acceptable limits, and pH values should fall between 6.5 and 8.5 under normal conditions.

Scientific studies indicate that fluoride concentrations in groundwater typically range from 0.3 to $3 \text{ mg}/\text{L}$; however, in

some regions, concentrations as high as $12 \text{ mg}/\text{L}$ or more have been reported (Landell, 2018). Global research conducted between 1984 and 1988 demonstrated that elevated nitrite concentrations in drinking water pose serious health risks, including toxicity for infants, neurological excitation in children, increased cancer risk among adults, and reproductive health effects. Elevated nitrite levels have also been associated with embryonic abnormalities and

developmental disorders (Mania et al., 1985). The World Health Organization (WHO) recommends that nitrite concentrations in drinking water remain below 10 mg/L. Salts transported by water interact with soil, affecting soil fertility and plant growth. Studies show that boron concentrations exceeding 4.7 mg/L in irrigation water can be toxic to plants, whereas insufficient boron can also limit plant growth and productivity. Therefore, chemical analysis of water quality is particularly important for determining its suitability for drinking and irrigation, thereby directly influencing agricultural productivity and food security. Afghanistan is relatively rich in both surface and groundwater resources, and the sustainable, well-managed use of these resources could provide substantial benefits for the country (Rasouli and Vaseashta, 2023a).

Experience further shows that elevated sulfate concentrations in water contribute to bitterness, increased hardness, and corrosion of water supply systems, particularly metal pipes. Under reducing conditions, sulfate may be reduced to sulfide,

producing an unpleasant odor similar to rotten eggs—an issue often observed in deep wells and sometimes mitigated by aeration. Sulfate has no essential nutritional role for humans, although magnesium sulfate ($MgSO_4$) can cause diarrhea at high concentrations. Fluoride is another important constituent, commonly found in groundwater at concentrations ranging from 0.1 to 3 mg/L, with levels as high as 12 mg/L in some locations (Dhal, 2006).

Numerous studies conducted by governmental, non-governmental, and international organizations have confirmed that Afghanistan's water resources contain a wide range of chemical elements and compounds (Rasouli, 2022). However, comprehensive and systematic nationwide assessments of groundwater quality remain limited. In this context, the present study focuses on groundwater quality in the 15th district of Kabul, where key physicochemical parameters were analyzed to better understand local groundwater conditions and associated health and environmental risks.

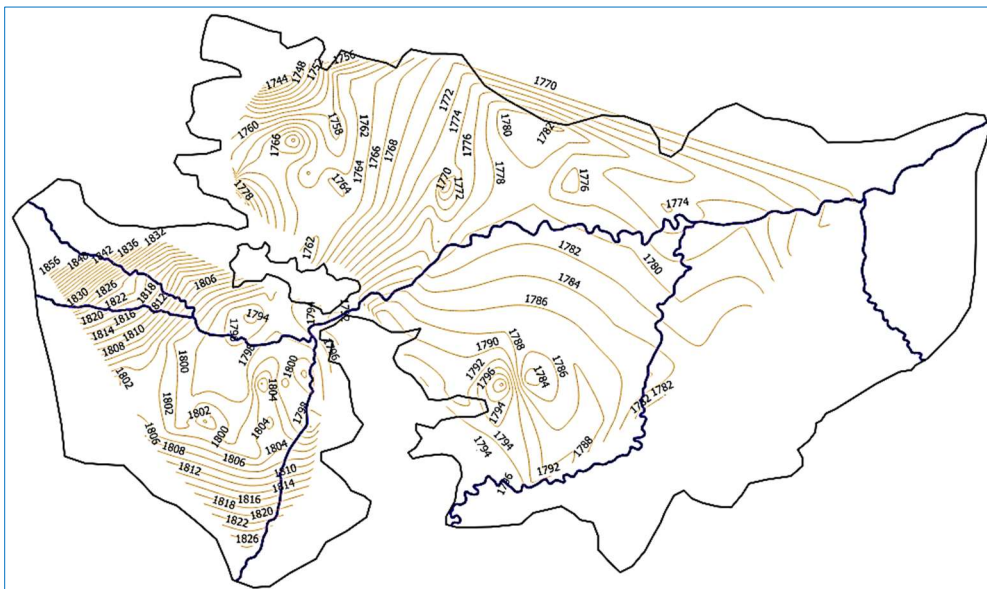


Fig. 3. Paghman River is one of the smaller parts of the hydrogeological map and groundwater contours

2. Area of Study

Plate tectonic processes primarily formed the structural framework of the Kabul Basin during the Late Pleistocene. The basin is underlain predominantly by metamorphic and igneous (granite) rocks and forms part of the Kabul tectonic block. Structurally, it is bounded to the west by the Herat–Bamyan fault system and to the southwest by the Chaman–Muqur fault zone. Numerous fractures and fault-controlled depressions within the basin are infilled with Tertiary sediments, predominantly Neogene, composed mainly of sand and gravel (Rasouli et al., 2023). Geophysical surveys indicate that the cumulative thickness of these sedimentary deposits reaches approximately 400 m in some parts of the basin (Rasouli, 2021b).

During the summer months (June–August), the influx of air masses enhances evapotranspiration within the basin. This process facilitates the precipitation of secondary minerals

such as carbonates and gypsum within the groundwater system (Rasouli and Vaseashta, 2023a). The basin fill also includes consolidated and unconsolidated sedimentary rocks, such as clay, sand, pebbles, gravel, and conglomerate, which play a critical role in groundwater storage and basin hydrodynamics.

This study was conducted in the Paghman region, which is located on the western side of Kabul. The Paghman region is one of the most important parts of Kabul because the main source of fresh water is from the Paghman Mountains and the surrounding areas (Saffi, 2011). Especially during snowmelt seasons, snowmelt streams and runoff recharge the groundwater, and this region is a lifeline for both surface and groundwater across different parts of Kabul. The Paghman mountains series is covered by snow throughout the spring season, and the peaks of the mountains and the snow line are good sightseeing for tourists, because in the valleys of these

regions, we can find different types of streams and fresh, clean water, and it is infiltrated into different types of sediments. However, these hydrological conditions also have adverse impacts, including soil erosion and increased sediment transport, which degrade agricultural land and reduce reservoir storage capacity and operational efficiency through sedimentation.

Seasonal variability in river discharge, particularly between spring snowmelt and summer low-flow periods, further constrains irrigation reliability, limiting farmers' ability to irrigate all agricultural lands (Tünnemeier and Houben, 2005). Nonetheless, the basin supports irrigation in neighboring provinces such as Wardak, Bamyan and Ghurband.

Table 1. Parameters sources, significant and potential impacts at high concentrations

Parameter	Typical Source	Significance for Water Quality	Potential Impacts at High Concentrations
Total Dissolved Solids (TDS)	Mineral dissolution, salts, wastewater	Indicator of overall mineralization and salinity	Unpleasant taste, scaling, reduced suitability for drinking and irrigation
Alkalinity (HCO ₃ ⁻ , CO ₃ ²⁻ , OH ⁻)	Carbonate and bicarbonate minerals	Buffering capacity against pH changes	Excessive alkalinity may affect taste and treatment efficiency
Hardness (Ca ²⁺ , Mg ²⁺)	Limestone, dolomite, gypsum	Influences soap consumption and scaling	Scale formation in pipes and appliances; economic losses
Calcium (Ca ²⁺)	Carbonate and silicate minerals	Essential mineral; contributes to hardness	Scaling and reduced soap efficiency
Magnesium (Mg ²⁺)	Dolomite, silicate rocks	Essential mineral; contributes to hardness	Laxative effects at very high levels
Fluoride (F ⁻)	Fluorite, apatite, groundwater-rock interaction	Beneficial for dental health at low levels	Dental and skeletal fluorosis at elevated concentrations
Sodium (Na ⁺)	Evaporite deposits, saline intrusion, wastewater	Affects taste and irrigation suitability	Health risks for cardiac/renal patients; soil degradation
Iron (Fe ²⁺ /Fe ³⁺)	Iron-bearing minerals	Aesthetic concern: staining	Taste, discoloration, and pipe clogging
Manganese (Mn ²⁺)	Manganese-bearing minerals	Aesthetic and operational concern	Staining and taste issues
Toxic Metals (As, Pb, Cd, Hg, Cr)	Natural geology, industrial and domestic effluents	Critical health indicators	Bioaccumulation, chronic toxicity, carcinogenic effects

In this investigation, we analyze physical and chemical parameters in the Paghman region, such as Total Dissolved Solids (TDS), Water hardness, Nitrite, Fluoride, Iron, Arsenic, AMMONIA, Sulphites, and Chlorine. For physical parameters, we used Turbidity, Hydrogen Ion Concentration, EC, Odor, Taste, and Color. For biological parameters, we used the POTATEST instrument (Wagtech Potatest Classic, PTW1005, Marketed by Palintest House, Gateshead, UK) in water and found fecal and total coliforms in the Paghman region (Fig. 2).

2.1. Paghman River Basin

The Paghman, part of the Kabul Basin, forms an integral part of the regional fluvial system and is drained by a complex network of mountain-fed rivers. The northern boundary of the basin is defined by the Hindu Kush mountain range, with elevations reaching approximately 3,900–4,000 m above sea level. The Paghman River, which originates in the Paghman Mountains (Hindu Kush range in Afghanistan). To the west, the basin receives surface runoff from the Paghman mountain ranges. The southern portion of the basin is drained primarily by the Logar, Kugyani, and Surkhāb (Springhare) rivers. To the east, the basin extends toward Central Kabul, where boundary drainage connects the Kabul River system to downstream regions.

2.2. Paghman River Regime

The Paghman River, like many major rivers in Kabul, exhibits distinct regional and topographical characteristics. The northern portion of the basin, draining the Paghman Mountains (Vaseashta et al., 2020), is characterized by significantly higher elevations, steeper slopes, and a larger

contributing catchment area than the southern portion—the average slope of the Paghman River catchments originating in the Paghman Mountains (Hindu Kush) (Vaseashta, 2021; Vaseashta, 2022). Climatological analyses indicate that precipitation, snowfall, and long-term snow accumulation in the Paghman mountain are considerably higher than in the Logar, Shakerdara, and Koh Asmayie basins—more seasonal flows, reflecting their limited snowpack and smaller contributing catchments.

2.3. Hydrogeology of Paghman Sub-Basin

From a groundwater-quality and vulnerability perspective, the Paghman Zone is structurally controlled by fracture systems developed along the southern flank of the Hindu Kush, which locally enhance groundwater recharge and subsurface flow connectivity. Within the Paghman sub-basin, Molasse-type and Neogene sediments occur mainly in this smaller sub-basin. In contrast, the principal river valleys are filled with thick Quaternary alluvial deposits that constitute the most productive aquifers (Vaseashta et al., 2022a; Vaseashta et al., 2022b).

Groundwater is primarily stored and transmitted through porous and permeable sedimentary units composed of sand, gravel, and locally occurring silt. These materials, which include both rounded and angular clasts, are concentrated within alluvial fans, floodplains, and river deltas, where hydraulic conductivity is generally high. Stratification and textural sorting within these deposits create multi-layered aquifer systems, with alternating high- and low-permeability horizons that influence groundwater flow paths, residence times, and contaminant transport (WHO, 2010).

Vulnerability analyses indicate strong spatial heterogeneity in aquifer characteristics across the basin, reflecting variations in sediment thickness, grain size distribution, and structural controls. The basin exhibits a complex stratigraphic architecture (WHO, 2009), with younger Quaternary sediments typically overlying older Neogene formations. This vertical arrangement governs recharge dynamics, aquifer confinement, and groundwater quality, making shallow aquifers particularly susceptible to anthropogenic pressures, including urban expansion, agriculture, and unmanaged wastewater discharge (Fig. 3).

Table 2. Physical properties investigated

No	Unite	Formula	Name
1	NTU	Turbidity	Turbidity
2		pH	Concentration of hydrogen ion
3	μS/cm	EC	EC
4		Odor	Oder
5		Test	Tats
6		Color	Color

Table 3. Chemical parameters investigated

No	Unite	Formula	Name
1	mg/l	Cl	Chlorides
2	mg/l	H	Hardness
3	mg/l	NO ₃	Nitrate
4	mg/l	F	Fluoride
5	mg/l	Fe	Iron
6	mg/l	Ar	Arsenic
7	mg/l	NH ₃	Ammonia
8	mg/l	SO ₄	Sulfite
9	mg/l	Cl ₂	Chlorine

3. Materials and methods

In this research, we used various physical, chemical, and biological parameters in the Paghman region, located on the western side of Kabul. In chemical parameters, we used Water hardness, Nitrite, Fluoride, Iron, Arsenic, AMMONIA, Sulphites, and Chlorine. For physical parameters, we used Turbidity, Hydrogen Ion Concentration, EC, Odor, Tats, and Color. For biological parameters, we used the Photatest instrument on water samples to detect fecal and total coliforms in the relevant regions of Paghman. For chemical parameters, we used instruments such as a Spectra-Photo Model DR3900, and for physical parameters, a Conductivity meter, a Potable groundwater temperature, and a pH meter.

In Afghanistan, we cannot perform additional laboratory tests, and some of the chemical work we have done has been with international organizations.

3.1. Properties of Groundwater

Groundwater is water that occurs beneath the Earth's surface within the pores, fractures, joints, and voids of rocks and unconsolidated sediments. In many cases, groundwater remains stored and largely undisturbed for long periods—ranging from years to centuries—before being extracted for use. However, groundwater quality can be adversely affected when pollutants infiltrate the subsurface through natural or anthropogenic pathways, leading to contamination (WHO, 2011).

3.1.1. Physical Properties of Water

Water occurs in its solid phase as a hexagonal crystalline structure and, in its pure liquid state, is colorless and transparent, with a faint bluish tint when present in large volumes. Water reaches its maximum density of approximately 1,000 kg m⁻³ at 4 °C. The melting point of water is 0 °C, and its boiling point at standard atmospheric pressure is 99.98 °C. Chemically, water is represented by the formula H₂O and has a molecular weight of 18.015 g mol⁻¹.

Sensory characteristics such as taste, odor, color, and temperature are often the first indicators used in the preliminary assessment of groundwater quality. These properties can be evaluated through human senses, including sight (to assess color and turbidity), taste (to detect abnormal or unpleasant flavors), smell (to identify odors), and touch (to perceive temperature). However, the presence of a pleasant taste or the absence of odor does not guarantee that water is safe or suitable for drinking or other uses, as many harmful constituents—such as dissolved salts, heavy metals, and inorganic contaminants—are colorless, odorless, and tasteless. Consequently, sensory evaluation alone is insufficient for determining water quality. Therefore, a comprehensive groundwater-quality assessment requires systematic analysis of key physical parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, and temperature. These parameters provide essential baseline information on the hydrochemical conditions of groundwater and serve as the foundation for subsequent chemical analyses and water suitability assessments discussed in the following sections.

3.1.2. Chemical Properties of Water

Its strong solvent capacity primarily governs water's chemical properties. As a result, water readily dissolves a wide range of substances, including dissolved solids, alkalinity- and hardness-forming constituents, fluoride, metals, organic matter, and nutrients. These components collectively define the chemical quality of water. Total dissolved solids (TDS) refer to the inorganic and organic substances that remain after the evaporation of water from a solution. The presence of dissolved constituents is a direct consequence of water's solvent nature, whereby substances dissolve upon contact with water.

Inorganic dissolved substances commonly found in water include minerals, metals, and gases derived from geological formations and atmospheric interactions. Organic dissolved substances typically originate from the decomposition of plant material and decaying organic matter, as well as from the entry of organic gases into the water system. While some dissolved constituents are essential and beneficial, excessive concentration can degrade water quality by imparting undesirable color, odor, or taste. It is important to note that not all dissolved substances are harmful; for example, the absence of calcium and magnesium can make water flat or tasteless, highlighting the importance of a balanced mineral content.

Alkalinity is defined as the capacity of water to neutralize acids. It is primarily controlled by the presence of alkaline substances such as bicarbonate (HCO₃⁻), carbonate (CO₃²⁻),

hydroxide (OH^-), and, to a lesser extent, ammonia (NH_3). These constituents typically originate from the dissolution of carbonate and silicate minerals. Among them, bicarbonates, carbonates, and hydroxides are the dominant contributors to alkalinity in natural waters.

Water hardness refers to the concentration of divalent and multivalent metal cations in water, primarily calcium (Ca^{2+}) and magnesium (Mg^{2+}). Hardness is generally classified into two types: carbonate hardness and non-carbonate hardness. Carbonate hardness corresponds to the portion of hardness

equivalent to the alkalinity of the water, while non-carbonate hardness represents the remaining hardness associated with sulfate, chloride, or nitrate salts.

In addition to calcium and magnesium, other metal ions, such as iron (Fe^{2+}), manganese (Mn^{2+}), strontium (Sr^{2+}), and aluminum (Al^{3+}), may contribute to hardness, although they typically occur at much lower concentrations. The practical impacts of hard water include reduced soap efficiency and scale formation in pipes, boilers, and household appliances, leading to operational inefficiencies and economic losses.

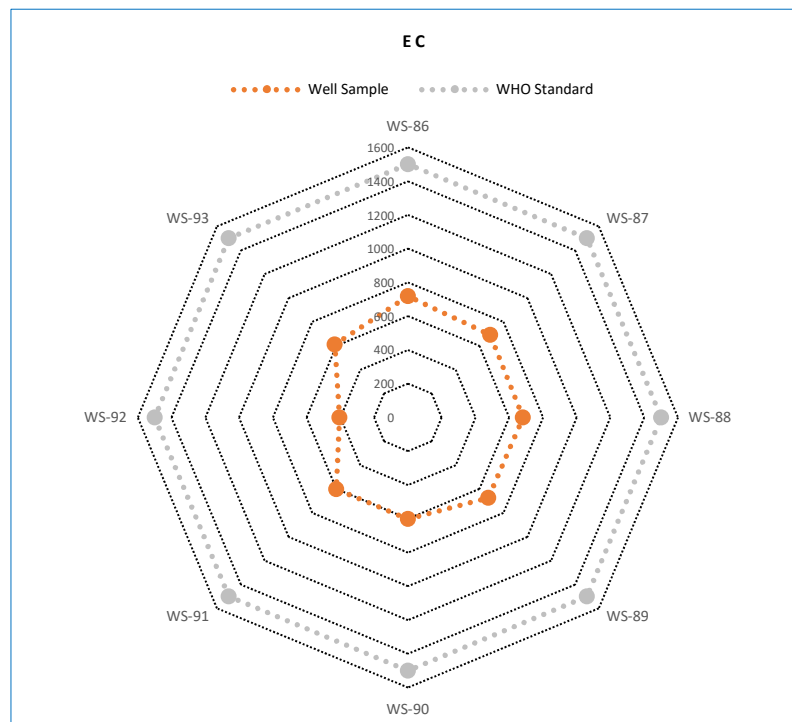


Fig. 4. EC of Paghman groundwater, Kabul, Afghanistan

Elevated sodium concentrations can impart a bitter taste to water and may pose health concerns for individuals with cardiovascular or renal conditions. In agricultural contexts, excessive sodium can degrade soil structure and adversely affect plant growth, making sodium-rich water unsuitable for irrigation. In contrast, toxic metals are those that can cause adverse health effects even at very low concentrations. Water-soluble toxic metals include arsenic, barium, cadmium, chromium, lead, and mercury. These elements are of particular concern due to their persistence, potential for bioaccumulation, and ability to enter the human and animal food chains. As noted by Pewey and colleagues, prolonged exposure to such metals poses serious risks to both human health and ecological systems. Listed below are the key chemical parameters of groundwater and their significance.

3.1.3. Biological Properties of Water

A wide range of biological organisms depend on water for either their entire life cycle or a significant portion of it. These organisms vary greatly in size and complexity, ranging from unicellular to multicellular forms. Because many aquatic organisms adversely affect human health, their presence in

water is widely recognized as an important indicator of water quality. From the perspective of human water use, pathogenic organisms are of particular concern. These microorganisms can survive for extended periods in water while retaining their ability to cause disease. The primary groups of waterborne pathogens include bacteria, viruses, protozoa, and helminthes (parasitic worms), all of which pose serious public health risks when present in drinking water.

Bacteria are microscopic, unicellular organisms that are typically colorless and can metabolize organic and inorganic substances in their environment. They occur in various morphological forms, including rod-shaped (bacilli), spherical (cocci), and spiral-shaped (spirilla). Several well-known waterborne bacteria cause gastrointestinal diseases when contaminated water is consumed. These include *Salmonella* spp., which cause inflammatory intestinal infections; *Shigella* spp., responsible for bacillary dysentery; and *Vibrio cholerae*, the causative agent of cholera.

Viruses are among the smallest known infectious agents that

can replicate only within living host cells. Due to their extremely small size, viruses can persist in water and are difficult to remove using conventional treatment methods. Waterborne viruses primarily affect the gastrointestinal tract but may also attack the nervous system and liver. Notable viral diseases transmitted through contaminated water include poliomyelitis and viral hepatitis.

Protozoa are unicellular eukaryotic organisms that may exist as free-living or parasitic forms and can be either pathogenic or non-pathogenic. Compared to bacterial infections, many protozoan diseases are relatively mild; however, some can be severe and life-threatening. For example, contamination of water with *Entamoeba histolytica* can result in amoebic dysentery with significant mortality. Giardiasis, caused by *Giardia lamblia*, is commonly transmitted through the consumption of untreated or inadequately treated water and primarily results in diarrhea. As noted by Pivi and colleagues, protozoan cysts are resistant to chlorination and can only be effectively removed through complete water purification processes, such as filtration. Helminths, or parasitic worms, complete part of their life cycle within the human body and are excreted into the environment through feces. Consequently, the use of untreated water contaminated with human waste exposes populations to a high risk of helminth infections. Such infections are particularly prevalent among

children, and their incidence has historically been high in regions with inadequate sanitation and water treatment infrastructure, including Afghanistan.

4. Results and Discussions

4.1. Sampling from the Area and the Analysis Method

Groundwater sampling was conducted at selected wells, with two samples collected per study area. The sampling procedure was implemented in two main stages:

Fieldwork, which involved the systematic collection of groundwater samples from eight representative wells across the study area, following standard sampling protocols to minimize contamination and ensure sample integrity.

Laboratory analysis, which was carried out at the Ministry of Public Health. This stage included the determination of six physical parameters—electrical conductivity (EC), pH (hydrogen ion concentration), suspended solids, color, odor, and taste—and nine chemical parameters—sulfite, nitrite, iron, chloride, total hardness, fluoride, arsenic, ammonia, and chlorine.

4.2. General Information about Wells

Complete information about the wells where the quality was evaluated is provided in the tables below (Tables 2 and 3).

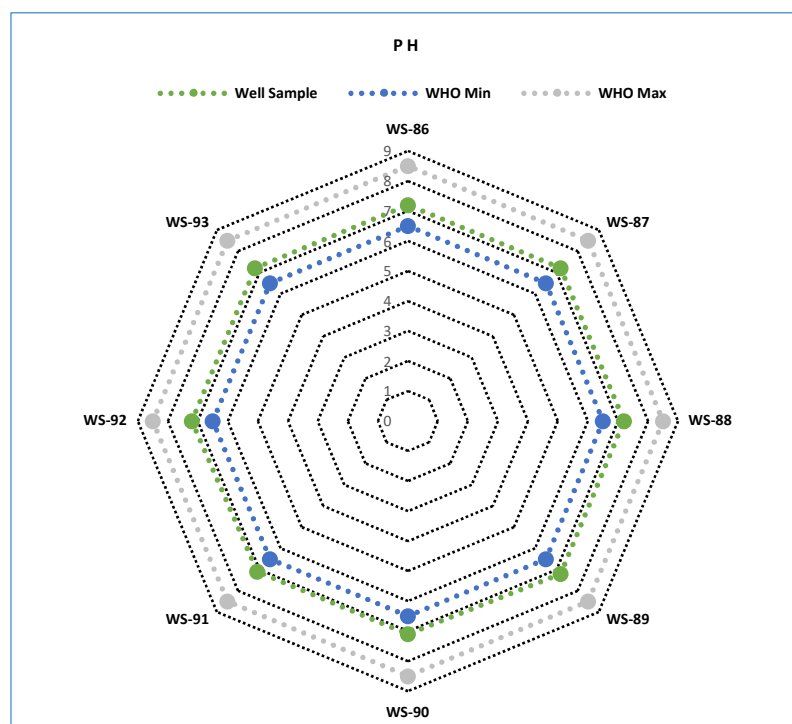


Fig. 5. pH of Paghman groundwater, Kabul, Afghanistan

4.3. Water Quality of the Area: Electrical Conductivity of Water

Electrical conductivity (EC) provides an integrated measure of the dissolved ionic content of groundwater and is closely related to total dissolved solids (TDS). In natural waters, TDS can be estimated from EC using an empirical relationship, typically: $TDS (mg L^{-1}) \approx 0.55-0.70 \times EC (\mu S cm^{-1})$, with the conversion factor depending on the dominant

ionic composition of the water. Consequently, elevated EC values generally indicate higher mineralization and salinity. Based on commonly used hydrochemical classifications, groundwater can be categorized according to EC as follows: low salinity ($<750 \mu S cm^{-1}$), medium salinity ($750-2,250 \mu S cm^{-1}$), and high salinity ($>2,250 \mu S cm^{-1}$), as shown in Fig. 5. Water with low to moderate EC is generally suitable for

drinking and irrigation. In contrast, high EC values may limit its usability due to taste issues, scaling potential, and adverse effects on soil and crops (Fig. 4). In the study area, variations in EC values reflect differences in groundwater–rock interactions, residence times, and anthropogenic influences, such as wastewater infiltration and excessive abstraction. Higher EC values are typically associated with elevated concentrations of dissolved salts, including chloride, sulfate, sodium, calcium, and magnesium, which may originate from geological formations or urban and domestic sources. From a water-quality perspective, EC values exceeding recommended limits indicate the need for further chemical analysis and, where necessary, treatment prior to domestic use. In urban environments such as the Kabul and Paghman regions, elevated EC may also signal the combined effects of declining recharge, increased evaporation, and contamination due to inadequate wastewater management. The value of electrical conductivity in the area is as follows.

4.4. Hydrogen Ion Concentration

pH is a fundamental parameter used to determine the acidity or alkalinity of water and is defined as the negative logarithm of the hydrogen ion concentration, expressed as $\text{pH} =$

$-\log_{10}[\text{H}^+]$. The concept of pH was introduced in 1909 by the Danish scientist Søren P. L. Sørensen, who defined it as a quantitative measure of the activity of hydrogen ions in aqueous solutions. The pH value provides important insight into the geochemical environment through which water has flowed, as it is influenced by water–rock interactions, dissolved gases, and biological processes. Pure water has a pH of 7, indicating neutral conditions. When pH is less than 7, the water is considered acidic; values greater than 7 indicate alkaline conditions.

Natural waters typically exhibit pH values between 6 and 8, although this range may vary depending on local geology and environmental factors. Elevated dissolved carbon dioxide (CO_2) concentrations can lower pH by forming carbonic acid, creating acidic conditions in water. pH plays a critical role in controlling most chemical and biological reactions in aquatic systems, including metal solubility, nutrient availability, microbial activity, and corrosion potential. Consequently, pH is a key parameter in assessing groundwater quality and its suitability for drinking and other uses. The measured hydrogen ion concentration (pH) values for the study area are shown in Fig. 5.

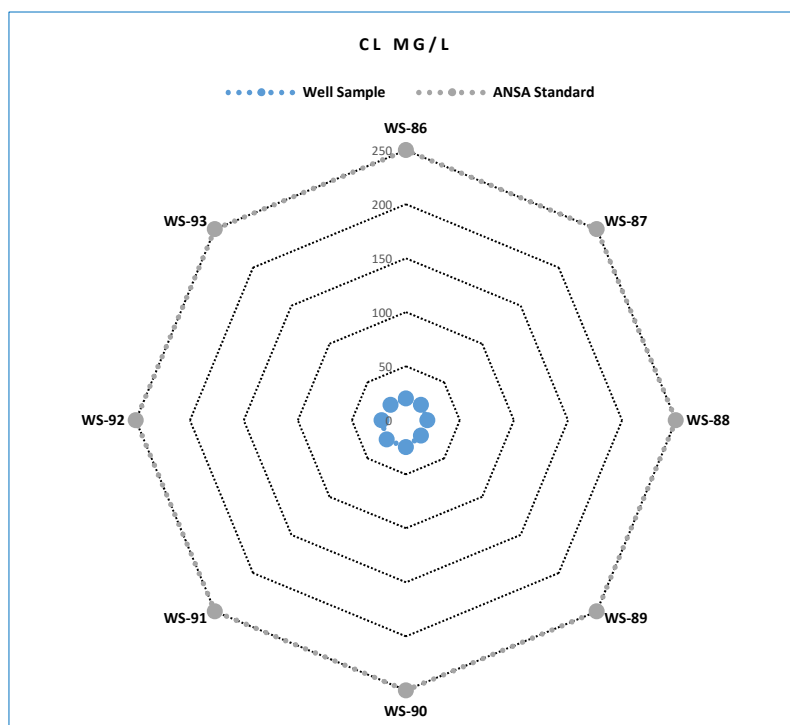


Fig. 6. Cl in Paghman groundwater, Kabul, Afghanistan

4.5. Turbidity

Turbidity refers to the reduction in water transparency caused by the presence of suspended and colloidal particles and should not be confused with watercolor. While water may appear dark or colored due to dissolved substances, it may still be clear and non-turbid. Turbidity specifically results from the scattering and absorption of light by fine, undissolved particles such as clay, silt, organic matter, and microorganisms suspended in the water column. Turbidity can range from very low levels to high concentrations,

rendering the water visibly cloudy or opaque. Turbidity is commonly expressed in nephelometric turbidity units (NTU), which are based on light-scattering measurements by suspended particles.

In drinking-water quality standards, turbidity values should generally be below 5 NTU to ensure acceptable clarity and effective disinfection. Turbidity is measured with a turbidimeter or turbidity meter, which provides a rapid, reliable assessment of water clarity.

4.6. Odor

Drinking water should be free from objectionable odors to ensure consumer acceptability. In certain water environments, odors may develop from contact with natural or anthropogenic substances; while such odors are not always harmful, they can adversely affect the taste and overall acceptability of the water. Surface waters, particularly small lakes and reservoirs, often exhibit unpleasant odors due to biological activity, including the growth and decay of algae and other microorganisms, and therefore require treatment prior to use. Odors associated with algal activity may be controlled through appropriate treatment measures, such as

applying algacides (e.g., copper sulfate, CuSO_4) or employing other advanced treatment processes. Additionally, some water treatment operations, particularly chlorination, may introduce temporary odors. In such cases, excess residual chlorine should be reduced or removed before consumption to improve palatability. Ultimately, the odor of drinking water should be at a level that does not cause discomfort or rejection by consumers. Although odor is primarily an aesthetic parameter, it plays an important role in public perception of water quality and may also indicate underlying chemical or biological processes requiring further investigation.

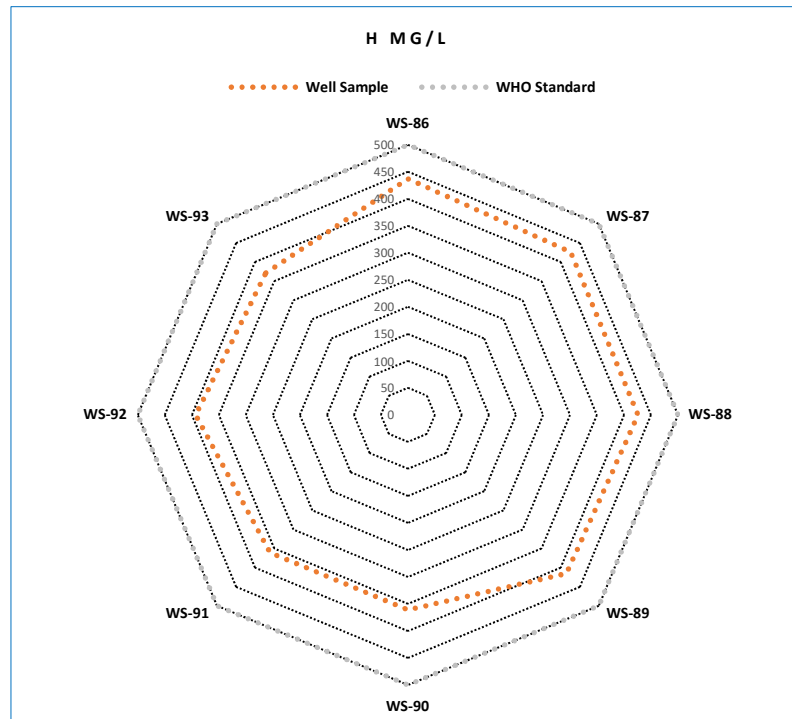


Fig. 7. H of Paghman groundwater, Kabul, Afghanistan

4.7. Taste of Water

Drinking water should have an acceptable and neutral taste; completely tasteless water is generally perceived as undesirable. Dissolved salts and other chemical constituents, including iron, manganese, sodium chloride, carbonates, and dissolved gases such as carbon dioxide, influence the taste of water. Depending on their type and concentration, these substances may impart either pleasant or unpleasant tastes. Organic compounds, which may also be present in groundwater, can contribute to distinctive taste characteristics, particularly when associated with the decomposition of natural organic matter.

In addition, naturally occurring chemicals derived from geological formations play a significant role in shaping water's taste profile. During water disinfection, reactions between chlorine and organic matter may form chlorinated compounds that impart an unpleasant taste to treated water if residual chlorine levels are not properly controlled. Water hardness also influences taste perception. Very soft water often tastes flat or insipid, whereas saline water indicates elevated sodium chloride concentrations. A bitter taste is

commonly associated with high concentrations of magnesium salts, while alkaline substances may impart a soapy taste. Conversely, acidic water typically has a sour taste. Although taste does not necessarily indicate water safety, it remains an important aesthetic parameter that affects consumer acceptance of drinking water.

4.8. Color

Watercolor is an important aesthetic parameter and is closely related to turbidity and the presence of certain dissolved metals. Pure water is essentially colorless; however, visible coloration typically results from dissolved organic matter or inorganic constituents. Organic compounds, particularly humic and fulvic acids formed from the decomposition of vegetation, commonly impart yellow to brown coloration. Inorganic substances such as iron and manganese can also influence watercolor, producing reddish-brown or dark brown to black hues, respectively.

Color and turbidity are distinct but interrelated parameters. Turbidity is caused by suspended particles that scatter light, whereas color is primarily due to dissolved substances.

Nevertheless, elevated concentrations of iron, manganese, or organic matter may contribute to both increased color and turbidity, especially when these constituents precipitate or oxidize upon exposure to air. Watercolor is typically measured in True Color Units (TCU) or Platinum–Cobalt (Pt–Co) units after the removal of suspended particles.

According to commonly applied drinking-water guidelines, color values exceeding approximately 15 TCU are considered aesthetically unacceptable. Although colored

water does not necessarily indicate acute toxicity, it is often associated with contamination, metal enrichment, or organic pollution and may reduce consumer confidence in water quality. Effective treatment methods for color removal include adsorption using activated carbon, oxidation followed by filtration, and removal of iron and manganese through aeration and filtration. The control of color in drinking water not only improves its aesthetic acceptability but also supports overall water-quality management by addressing underlying chemical and physical issues.

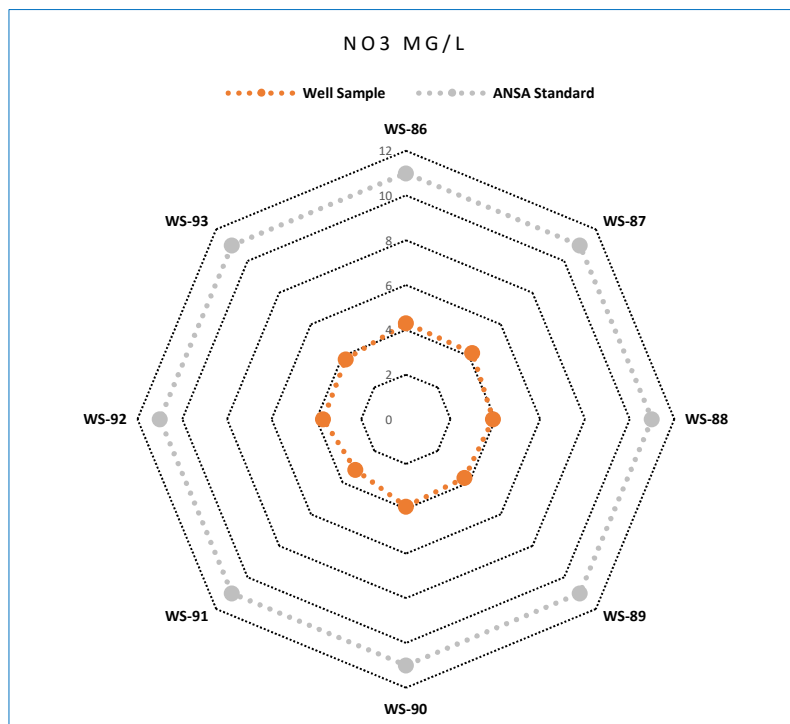


Fig. 8. NO₃ of Paghman groundwater, Kabul, Afghanistan

4.9. Chloride

Chloride (Cl⁻) is a negatively charged ion commonly associated with sodium as sodium chloride (table salt). In drinking water, elevated chloride concentrations impart a salty taste and can accelerate the corrosion of pipes, pumps, and other water-distribution infrastructure. Chloride is therefore an important indicator of both water palatability and potential operational issues.

In natural freshwater systems, chloride concentrations are typically low, often less than 10 mg L⁻¹, although background levels may vary depending on local geology. Elevated chloride concentrations are commonly observed in areas affected by saltwater intrusion, dissolution of evaporite deposits, road deicing salts, domestic sewage, or industrial effluents. In urban settings, increased chloride levels may also indicate contamination from wastewater infiltration. The measured chloride concentrations in the study area are presented in Fig. 6.

4.10. Water Hardness

The concentration of dissolved multivalent metal cations primarily determines water hardness. The most significant

contributors to hardness are calcium (Ca²⁺) and magnesium (Mg²⁺), although other cations, such as iron (Fe²⁺), manganese (Mn²⁺), strontium (Sr²⁺), and aluminum (Al³⁺), may contribute to a lesser extent. These cations occur in solution in association with various anions, including sulfate (SO₄²⁻), chloride (Cl⁻), carbonate (CO₃²⁻), bicarbonate (HCO₃⁻), silicate (SiO₃²⁻), and nitrate (NO₃⁻). Water hardness is commonly expressed in milligrams per liter (mg L⁻¹) as calcium carbonate (CaCO₃). Increased hardness can lead to several practical and economic problems, most notably the formation of scale in boilers, pipes, and water-heating systems, which reduces energy efficiency and shortens equipment lifespan. Extremely soft water may also be problematic. Water with hardness levels of 30–50 mg L⁻¹ (as CaCO₃) can be corrosive and may damage plumbing systems. According to European Union guidelines, the recommended minimum hardness concentration for drinking water is approximately 60 mg L⁻¹ as calcium, equivalent to about 150 mg L⁻¹ as calcium carbonate. Maintaining water hardness within an optimal range is therefore important for both infrastructure protection and consumer acceptability. The measured hardness values for the study area are presented in Fig. 7.

4.11. Nitrite

Nitrite (NO_2^-) and nitrate (NO_3^-) are inorganic forms of nitrogen commonly evaluated in water-quality assessments and are typically reported in milligrams per liter (mg L^{-1}) as nitrogen (N). Oxidized nitrogen in water refers to the combined concentration of nitrite and nitrate. Elevated concentrations of these nitrogen species, particularly when accompanied by high levels of ammonia, generally indicate contamination from domestic wastewater, agricultural runoff, or other organic waste sources. NO_3 of Paghman groundwater, Kabul, Afghanistan, is shown in Fig. 8.

In natural aquatic systems, nitrite is an intermediate compound formed during the oxidation of ammonia to nitrate. This process, known as nitrification, is carried out by specialized nitrifying bacteria and occurs under aerobic (oxygen-rich) conditions in soil and water. Ammonia derived from the decomposition of organic matter is first oxidized to nitrite and subsequently to nitrate, which is the more stable and commonly occurring form of nitrogen in groundwater. The presence of nitrite in groundwater is typically transient and may indicate recent pollution or incomplete nitrification, particularly in iron-rich or oxygen-limited environments where the conversion of nitrite to nitrate is inhibited. The widespread use of nitrogen-based chemical fertilizers has significantly increased nitrate and nitrite concentrations in both surface water and groundwater, especially in agricultural and peri-urban areas. Water containing elevated nitrite levels poses serious health risks, particularly to infants. Nitrite can interfere with oxygen transport in the blood, leading to methemoglobinemia, commonly known as “blue baby syndrome.” In addition, nitrite formed through the bacterial reduction of nitrate in the human digestive tract can react with secondary and tertiary amines to form nitrosamines, compounds known for their carcinogenic

potential. For these reasons, nitrite is considered a critical parameter in drinking-water quality monitoring.

4.12. Fluoride

Fluoride occurs naturally in water from the dissolution of fluoride-bearing minerals and may also be added in controlled amounts during water treatment to improve dental health. At appropriate concentrations, fluoride is beneficial, particularly for children, as it enhances tooth enamel's resistance to decay. A fluoride concentration of approximately 1 mg L^{-1} in drinking water is widely recognized as optimal for dental protection. However, excessive fluoride intake can have adverse health effects. Elevated fluoride concentrations in drinking water may lead to dental fluorosis, characterized by mottling and discoloration of teeth, and, at higher levels, to skeletal fluorosis, which causes pain, stiffness, and structural damage to bones in both children and adults. To balance the benefits of fluoride in preventing tooth decay with the risk of fluorosis, recommended fluoride concentrations in drinking water typically range from 0.6 to 1.7 mg L^{-1} , depending on climatic conditions and water consumption patterns. The F of Paghman groundwater, Kabul, Afghanistan, is shown in Fig. 9.

4.13. Iron

Iron is commonly present in natural waters and may also occur in drinking-water distribution systems due to corrosion of iron pipes and fittings. In water, iron exists in several forms, including dissolved ferrous iron (Fe^{2+}), ferric iron (Fe^{3+}), colloidal suspensions, and complexes with inorganic and organic substances. Iron is not generally considered harmful to human health at concentrations typically found in drinking water. However, elevated iron levels significantly affect the aesthetic and physical properties of water.

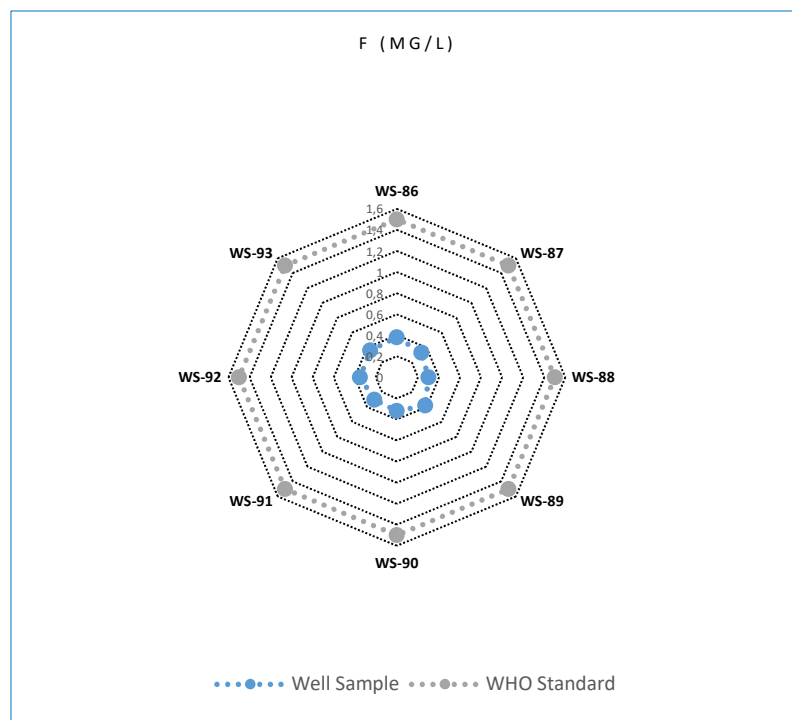


Fig. 9. F of Paghman groundwater, Kabul, Afghanistan

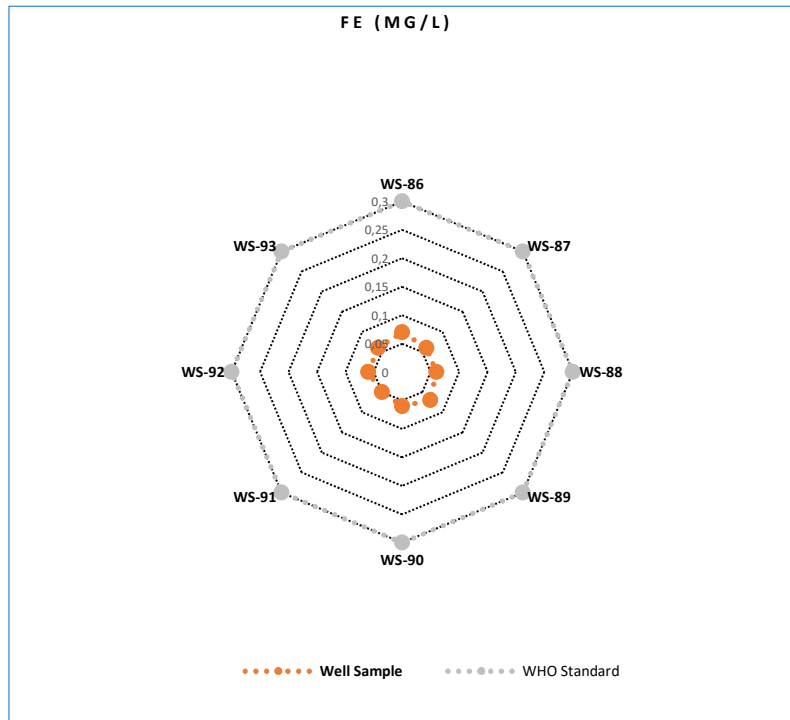


Fig. 10. Fe of Paghman groundwater, Kabul, Afghanistan

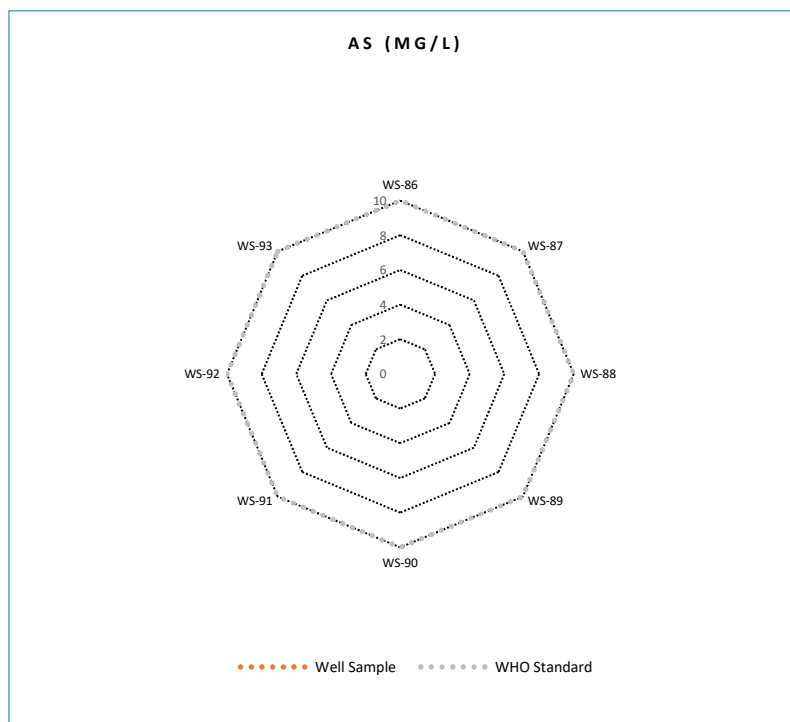


Fig. 11. As of Paghman groundwater, Kabul, Afghanistan

High iron concentrations can impart a metallic or bitter taste, discolor the water, and reduce its overall acceptability for domestic use. When iron-rich water is exposed to oxygen, ferrous iron oxidizes to ferric iron, forming insoluble iron oxides and hydroxides that produce reddish-brown turbidity and sediment. Excessive iron in water can also stain laundry, plumbing fixtures, and household appliances and clog pipes and filters. The measured iron concentrations in the study

area are presented below. The Fe of Paghman groundwater, Kabul, Afghanistan, is shown in Fig. 10.

4.14. Arsenic

Arsenic is a naturally occurring element found in both surface water and groundwater, particularly in regions associated with metal ore deposits and arsenic-bearing geological formations.

Arsenic can enter water systems through natural processes such as mineral dissolution, as well as through anthropogenic sources, including the use of arsenic-containing pesticides, industrial discharges, and mining activities. In aquatic environments, arsenic can accumulate in plants and animals and may enter the human food chain, for example, through the consumption of seafood such as shrimp. In humans, arsenic compounds are readily absorbed through the gastrointestinal tract and can also be absorbed through inhalation or dermal contact. Chronic exposure to arsenic-

contaminated water poses serious health risks. The health effects of arsenic exposure include gastrointestinal disturbances, loss of appetite, weight loss, diarrhea, and neurological disorders. Long-term exposure is strongly associated with skin lesions, hyperpigmentation, and an increased risk of skin cancer, as well as cancers of internal organs. Due to its high toxicity and carcinogenic potential, arsenic is considered one of the most critical parameters in drinking-water quality assessment. The As of Paghman groundwater in Kabul, Afghanistan, is shown in Fig. 11.

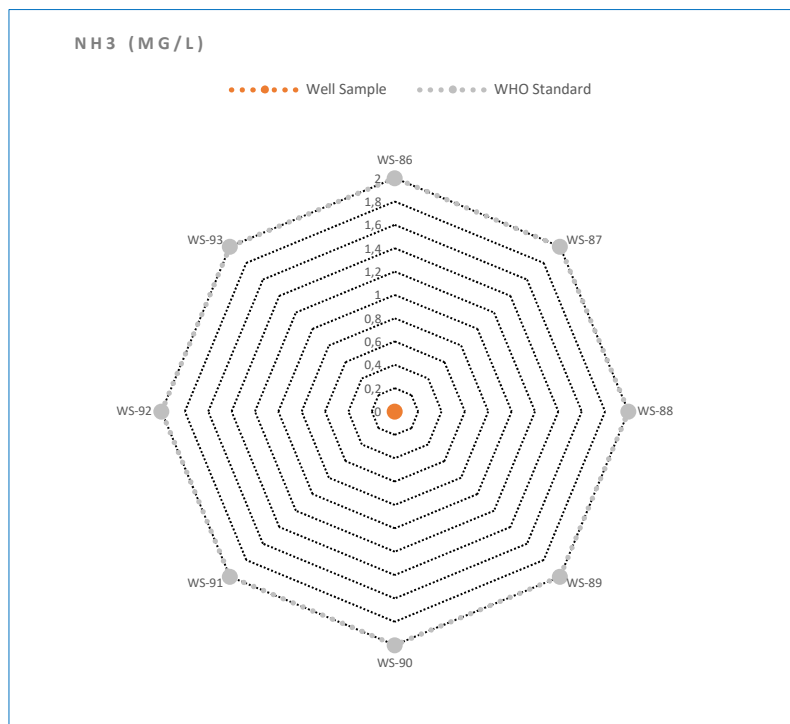


Fig. 12. NH₃ of Paghman groundwater, Kabul, Afghanistan

4.15. Ammonia

Ammonia is an inorganic nitrogen compound commonly detected in drinking water and is typically reported in milligrams per liter (mg L⁻¹) as nitrogen (N). In aqueous systems, ammonia may exist in its un-ionized form (NH₃) or as the ammonium ion (NH₄⁺), with the relative proportions depending on pH and temperature.

In groundwater, ammonia is often associated with anaerobic or reducing conditions, where nitrification is limited. Elevated ammonia concentrations may result from microbial decomposition of organic matter, reduction of nitrate and nitrite, or infiltration of domestic wastewater, agricultural runoff, and other waste materials. Deep or confined aquifers may naturally contain ammonia due to long residence times and low oxygen availability.

Although ammonia itself is not usually harmful to human health at concentrations commonly found in drinking water, high ammonia levels are undesirable because they indicate pollution, contribute to taste and odor problems, and interfere with disinfection processes by increasing chlorine demand. In treated water supplied through distribution

systems, ammonia concentrations are generally low, often remaining below approximately 0.4 mg L⁻¹. NH₃ of Paghman groundwater, Kabul, Afghanistan, is shown in Fig. 12.

4.16. Sulphites

Sulfate (SO₄²⁻) is a common inorganic anion in natural waters, with concentrations typically ranging from a few milligrams per liter to several hundred milligrams per liter, depending on geological and environmental conditions. Sulfate enters water primarily through the dissolution of sulfate-bearing minerals such as gypsum (CaSO₄·2H₂O) and anhydrite, as well as from sedimentary rock formations. In seawater, sulfate is a major constituent and is derived from the oxidation of reduced sulfur compounds, including sulfides and thiosulfates.

In surface waters and groundwater, elevated sulfate concentrations may also result from anthropogenic sources, particularly industrial effluents. Industries that use sulfuric acids, such as paper mills, textile processing plants, and leather tanneries, can contribute sulfate to nearby water bodies if wastewater is inadequately treated.

In addition, sulfur dioxide (SO_2) and hydrogen sulfide (H_2S) gases released into the atmosphere from industrial activities may dissolve in rainwater and, through oxidation, be converted to sulfate, contributing to sulfate enrichment in surface and groundwater. In drinking water, sulfate contributes to non-carbonate (permanent) hardness by forming salts with calcium and magnesium. High sulfate concentrations can impart a bitter or medicinal taste to water and, at very high levels, may cause laxative effects, particularly in individuals not accustomed to such water.

Populations exposed to sulfate-rich water over long periods may gradually adapt to its taste and physiological effects. Under anaerobic conditions, sulfate may be biologically

reduced to sulfide, producing hydrogen sulfide (H_2S) gas, which is characterized by a strong “rotten egg” odor. Hydrogen sulfide is commonly encountered in deep or stagnant groundwater and, although unpleasant, can be readily removed through aeration, which oxidizes sulfide to odorless forms. The measured sulfate concentrations in the study area are shown in Fig. 13.

17. Chlorine

Chlorine is widely used as a disinfectant in drinking water to eliminate pathogenic microorganisms and prevent the spread of waterborne diseases. After disinfection, a small amount of residual chlorine remains in the water, helping maintain microbiological safety throughout the distribution system.

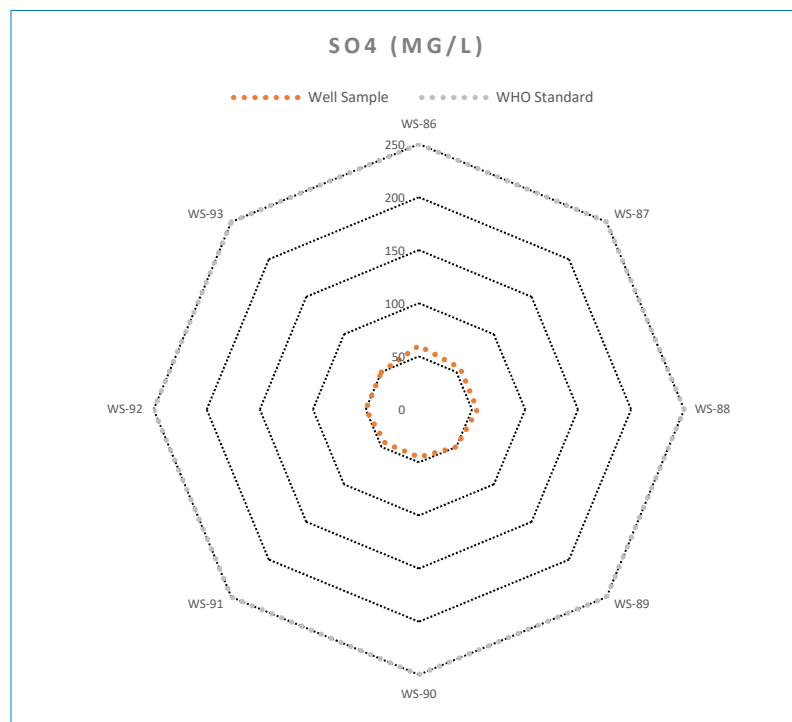


Fig. 13. SO_4 of Paghman groundwater, Kabul, Afghanistan

However, excessive residual chlorine is undesirable, as it can impart an unpleasant taste and odor to the water and may react with organic matter to form chlorinated by-products. The presence of natural organic and biological materials in water can further intensify taste and odor problems, often producing earthy or musty flavors following chlorination. For this reason, the concentration of residual chlorine must be carefully controlled to balance effective disinfection with acceptable sensory quality. In drinking water, the residual chlorine concentration should not exceed 0.2 mg/L in order to avoid adverse effects on taste and consumer acceptability while still ensuring adequate microbial protection. The Cl of Paghman groundwater, Kabul, Afghanistan, is shown in Fig. 14.

5. Analysis and Evaluation of the Research in Terms of the Water Quality of the Area

Under this section, the physical and chemical indicators of groundwater from eight wells were evaluated. Each

parameter was analyzed individually to assess its characteristics and variability. The average values obtained from the collected samples were then compared with the WHO guideline values and Afghanistan's national drinking-water standards. This comparative analysis enabled an assessment of the suitability of groundwater for drinking and other uses. The results indicate that, with respect to physical and chemical parameters, the groundwater in the studied area does not present any significant concerns and complies with the WHO guideline values. All measured parameters fall within the WHO's recommended limits. Therefore, from a physical and chemical perspective, residents of the study area can be considered safe to drink groundwater. As noted above, Kabul is predominantly underlain by Quaternary sediments, primarily unconsolidated clay and silt deposits. While the groundwater in the study area does not pose significant quality concerns for the local population, a critical challenge is its limited availability. According to investigations conducted by Dynamic Vision Company, the

groundwater resources in this area have a low supply capacity, which is inadequate to meet the growing water demands of the population. Pumping tests conducted on the

eight wells studied indicate groundwater yields ranging from 3 to 5 liters per second, confirming the aquifer's limited productivity.

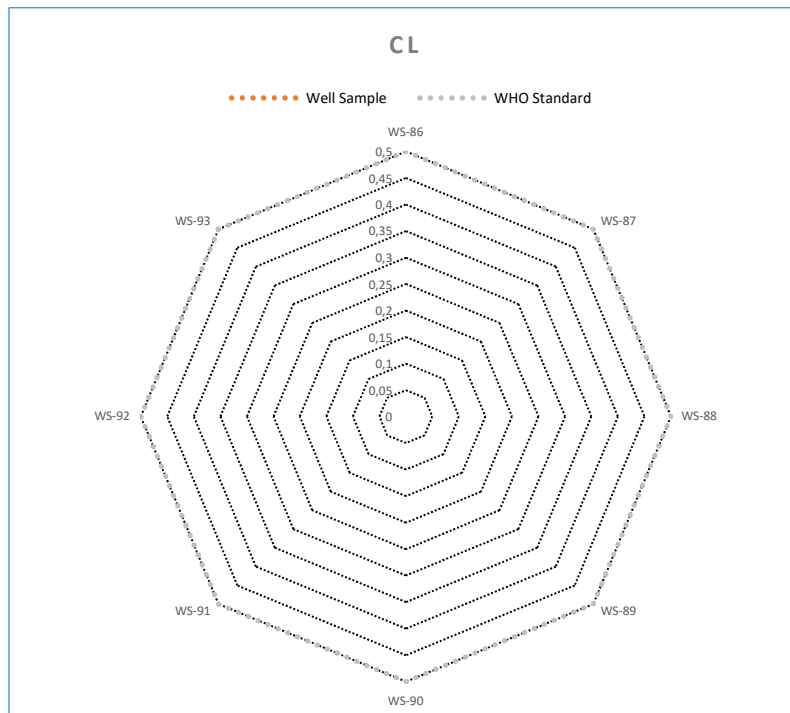


Fig. 14. Cl of Paghman groundwater, Kabul, Afghanistan

6. Conclusion

Groundwater is a finite, indispensable natural resource that plays a central role in meeting domestic, agricultural, and industrial water demands in the Kabul Basin. Given the strong hydraulic connection between surface water and groundwater, any deterioration in surface water quality poses a direct risk to groundwater systems. Therefore, the protection and sustainable management of both resources are essential. The findings of this study, based on comprehensive laboratory analyses, indicate that groundwater quality in the investigated areas of the Kabul Basin meets World Health Organization standards. The evaluated physical and chemical parameters fall within permissible limits, indicating that the groundwater is currently suitable for drinking and other domestic uses. Despite acceptable water quality, the study highlights a growing concern about groundwater quantity. Increasing population pressure, uncontrolled abstraction, reduced natural recharge, and inadequate water management practices threaten the long-term sustainability of groundwater resources. If current extraction trends continue without effective regulatory and recharge measures, groundwater depletion may intensify, compromising future water security. Accordingly, it is strongly recommended that integrated water resource management strategies be implemented, including controlled groundwater abstraction, enhanced artificial recharge, protection of recharge zones, expanded surface water use, and continuous monitoring of groundwater quality and levels. Such measures are necessary to ensure long-term availability, safety, and sustainability of groundwater resources in the Kabul Basin. The results presented above indicate that groundwater quality in the

Kabul area remains within WHO guidelines, however, despite satisfactory quality conditions, significant challenges remain regarding groundwater quantity. These quantitative constraints require serious attention from Kabul residents and the relevant authorities. Accordingly, groundwater must be used efficiently, responsibly, and sustainably to prevent further depletion and ensure long-term water availability.

Suggestions

1. To maintain water quality in Paghman, waste materials should be buried in arid and semi-arid areas outside the city. Since the Kabul Paghman region is small and densely populated, it should be maintained to ensure safe water.
2. Prohibiting the drilling of deep private wells in the area by the government.
3. Establishing an urban water supply system and promoting urban culture, which can increase the government's source of income and prevent water waste.
4. Informing and educating people not to throw solid and liquid waste into surface waters to prevent contamination from entering groundwater.
5. Informing people about the disaster they are in. This is one of the useful ways to maintain and control the quality and quantity of water in the regions.
6. A drip system should be used when watering gardens, ponds, and trees to prevent water waste.
7. Water waste should be prevented when washing or brushing teeth.
8. Establishing a sewerage and urban wastewater system in the area to prevent pollution of surface and groundwater.

9. Using insulation systems for septic wells and observing the distance of septic wells from drinking sources.
10. Establishing rainwater storage facilities to prevent water waste and, if necessary, use the water to recharge groundwater.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

Data Availability Statement

Data is contained within the article. Funding: This research received no external funding.

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