

Groundwater management challenges and Sustainability: The case of Kabul, Afghanistan

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Abstract

This paper focuses on the specific challenges and opportunities associated with groundwater management in Kabul City, Afghanistan. With increasing urbanization, industrial development, and agricultural activities, the groundwater resources in Kabul face threats of pollution and overexploitation. Despite these challenges, sustainable management of groundwater holds significant potential for enhancing Afghanistan's development. This paper reviews existing groundwater resource knowledge, management initiatives, and programs in the region. Key issues such as pollution, overexploitation, and climate change impacts are analyzed, highlighting the urgent need for effective management strategies. Establishing groundwater monitoring systems, analyzing the relationship between groundwater and aquatic ecosystems, regulating transboundary aquifers, and building capacity for groundwater management are among the recommendations. Addressing these challenges is crucial for ensuring the sustainable use of groundwater resources in Kabul City and beyond.

Introduction

Groundwater, comprising approximately 10,000 km³/year of the world's total water resources, plays a vital role in sustaining aquatic ecosystems and meeting human water needs globally [1]. In Afghanistan (Figure 1), a country marked by decades of conflict and instability, the management of groundwater resources presents significant challenges, particularly in urban centers like Kabul [2]. The aftermath of civil wars and military invasions has led to infrastructural damage, financial collapse, and a severe deficit in capacity building, hampering efforts to provide reliable drinking water to residents [2-5]. Kabul, along with the Helmand and Western River basins (Figure 1), has witnessed substantial declines in groundwater levels due to over-extraction, especially from unconsolidated aquifers supplying shallow wells, karezes, and springs [6]. This overexploitation has resulted in negative water balances in agricultural units, impacting agricultural activities and exacerbating water scarcity issues [7]. Furthermore, recent droughts have exacerbated groundwater depletion, leading to the drying up of essential water sources and further aggravating the situation [7,8]. Access to reliable drinking water remains a pressing issue throughout Afghanistan, particularly in urban areas like Kabul, where water supply shortages undermine stabilization efforts and pose significant health risks [9,10]. However, the lack of meteorological and hydrological stations, coupled with security concerns in

border regions, hinders the establishment of systematic data collection systems, impeding accurate assessment and management of groundwater resources [7,11]. Despite these challenges, efforts to address groundwater management issues are underway, with initiatives such as the Ground Water Monitoring Program led by the Danish Committee for Aid to Afghan Refugees (DACAAR) and the establishment of a national groundwater monitoring and management system supported by various international development agencies [12,13]. These initiatives aim to improve groundwater data collection, enhance technical capacity, and promote sustainable water use practices. Previous research efforts, including studies conducted by DACAAR and the US Geological Survey (USGS), have contributed valuable insights into groundwater quality assessment and management strategies in Afghanistan [14,15]. Additionally, province-scale assessments have provided valuable information on the spatial variability of groundwater resources and associated challenges [5,16].

In this context, this paper aims to review and analyze the main issues and challenges facing groundwater management in Kabul City, Afghanistan. By synthesizing existing literature and ongoing groundwater management programs, this study seeks to identify current and future opportunities for sustainable groundwater management in Kabul and contribute to the broader understanding of groundwater resources in the region.

Keywords

Pollution; overexploitation; climate change impacts; ecosystems; groundwater management; aquifers; sustainability

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Figure 1. Afghanistan River basins, Kabul River basin, produced by Authors. 2022

Purpose and methodology

The main objective of this paper is to examine the key challenges affecting groundwater management in Kabul city, including over-exploitation of groundwater, pollution, and limited access to data. It examines current practices, evaluates ongoing management efforts, and proposes practical strategies for improving groundwater management in detail. During this time of rapid urbanization and climate change, it is crucial to promote informed decision-making and sustainable water use.

The paper examines critical issues concerning groundwater management using Kabul City as the case study. Due to rapid urbanization, population growth, climate change, and decades of infrastructure degradation, groundwater has become both a valuable resource and a source of concern. The paper examines the hydrological, geological, and socio-political factors affecting groundwater availability, quality, and sustainability. To assess trends in overextraction, pollution, and recharge, it combines research findings, satellite data, field studies, and existing initiatives such as those by DACAAR and USGS. In addition to highlighting data gaps, technical capacities, and institutional coordination, the authors propose integrated methods, including monitoring networks, transboundary aquifer cooperation, and climate-resilient water policies. The study seeks to offer a comprehensive overview of the challenges in sustainable groundwater management in Kabul.

A multidisciplinary approach was adopted by the authors in the conduct of this study: hydrology, urban planning, environmental science, and policy studies. This approach reflects the complex nature of Kabul's groundwater crisis, which is more than a technical problem; it is also shaped by socioeconomic, political, and historical factors.

Initially, a literature review was conducted covering two decades of research and reports produced by various agencies such as DACAAR (Danish Committee for Aid to Afghan Refugees), Afghanistan Urban Water Supply and Sewerage Corporation (AUWSSC), and other stakeholders in the water sector. Then, the study incorporated satellite imagery and GIS analysis, allowing the authors to observe changes in land cover, vegetation loss, and impervious surface expansion across the Kabul Basin. Finally, the authors examined the structure of Afghanistan's water governance. The study assessed the responsibilities and limitations of key institutions, identifying where policy failures, lack of coordination, and weak enforcement have allowed over-extraction and pollution to persist.

The study constructed a multidimensional picture of Kabul's groundwater reality—one that captures not just what is happening beneath the surface, but how decisions, crises, and missed opportunities have shaped that reality over time.

Key Issues in Groundwater Management in Kabul City

Precipitation Patterns in Kabul City

Ground water and recharge rates in Kabul City, Afghanistan's capital and situated in the central part of the country, are significantly influenced by distinct precipitation patterns. With its climate, the city experiences seasonal variations in precipitation, with most rainfall in winter and spring [17]. Snowfall is predominant in winter, particularly in January and February, while moderate rainfall occurs in spring, mainly in March and April [18,19]. These precipitation patterns are influenced by westerly and monsoonal systems, with orographic effects from surrounding mountain ranges enhancing rainfall in certain areas of the city [18]. Long-term climate trends, compounded by potential impacts of climate change, underscore the importance of monitoring and analyzing precipitation data to understand groundwater recharge dynamics in Kabul City.

Geological Characteristics of Kabul City

The geological framework of Kabul City plays a pivotal role in determining groundwater availability and storage capacity. Located within the broader Kabul Basin, the city's geological composition comprises various formations, including sedimentary rocks, metamorphic rocks, and volcanic rocks [16]. These formations contribute to the development of aquifer systems crucial for groundwater storage and flow. Kabul City's aquifers include karstic and jointed aquifers formed by geological and tectonic forces, with specific characteristics influencing groundwater movement and distribution [7]. Understanding the geological context of Kabul City is essential for assessing groundwater potential and devising effective management strategies to ensure sustainable resource use. As demonstrated in Figures 1-3, Kabul has greatly complicated geology and tectonics.

The geological composition of Afghanistan comprises Proterozoic metamorphic and sedimentary rocks, volcanic rocks, basic igneous rocks, Paleocene sedimentary rocks, acidic igneous rocks, Triassic sedimentary rocks, Permian-Triassic Cretaceous-Paleocene sedimentary rocks, Cretaceous sedimentary rocks, Neogene sedimentary rocks, Jurassic sedimentary rocks, and Quaternary sediments [16]. According to Houben & Tunnermeier, [16] the Kabul Basin was formed due to plate movements during the Late Paleocene, surrounded by metamorphic rocks. Hydrogeologically, the Central Highland Regions are among the country's most significant intermountain stream basins. In fault-controlled basins, unconsolidated materials such as colluvial, alluvial, glacial, and lacustrine sediments are present. They hold substantial volumes of fresh groundwater in aquifers. Noteworthy intermontane basins include Ghazni, Jalalabad, Khust, and Kabul (Figures 2 and 3), which have been extensively studied by authors such as Houben G, et al. [4]; Lashkaripour & Hussaini [20]; Broshears [9]; Akbari et al. [21]; and Mack [5].

Current Groundwater Uses and Challenges in Kabul City

Groundwater serves as a vital resource for various sectors in Kabul City, including irrigation, domestic, and industrial purposes. However, the city faces significant challenges related to groundwater over-extraction, declining water levels, and quality issues. Studies indicate a substantial decline in groundwater levels, particularly in the Kabul Basin, attributed to over-exploitation and insufficient recharge rates [8]. Groundwater

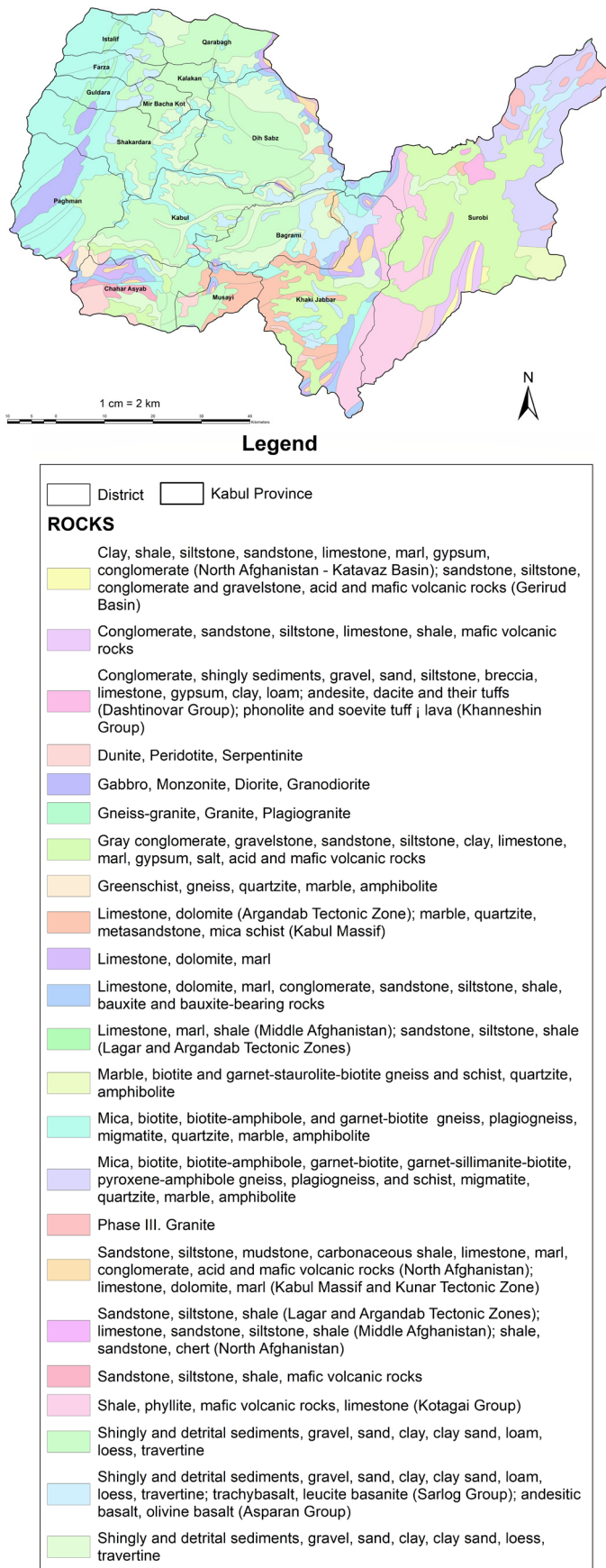


Figure 2. Geological map of Kabul, produced in GIS, by authors. 2023

quality concerns, including bacterial contamination, further exacerbate the challenges, posing risks to public health and environmental integrity [22]. Addressing these issues requires comprehensive data collection, monitoring, and management strategies tailored to Kabul City's unique hydrogeological conditions. Groundwater Monitoring Wells (GMWs) as shown in Figures 4 & 5 provide important qualitative and quantitative information on groundwater quality. The program's aim is to generate groundwater information and disseminate it to all stakeholders and collaborators to encourage their participation in the conservation and management of groundwater. The GMW Network will collect, interpret, visualize, map, manage, and present data collected by the GMW network in reports and presentations that summarize the findings. Groundwater resource managers and policymakers can use the information to develop regulations, strategies, and policies for efficient groundwater planning, development, use, protection, and conservation [14].

Role of Groundwater in Kabul City's Sustainable Development

Groundwater plays a critical role in Kabul City's sustainable development, serving as a primary water source for agriculture, domestic, and industrial activities. As a key component of the city's water supply, ensuring access to clean and sustainable groundwater is essential for poverty alleviation, economic growth, and environmental conservation. Sustainable groundwater management approaches must integrate scientific research, community engagement, and policy interventions to address the complex challenges facing groundwater resources in Kabul City. Effective solutions should prioritize water conservation, pollution prevention, and climate resilience to safeguard the city's water security and promote long-term sustainability.

Groundwater Pollution Challenges in Kabul City

Groundwater pollution poses a significant threat to public health and environmental integrity in Kabul City. Continuous degradation of groundwater quality, attributed to natural and anthropogenic factors, has led to water scarcity and contamination issues in both urban and rural areas [23]. Because of drying wells, communities deepen their wells to access dwindling water sources, resulting in water shortages [24]. Addressing groundwater pollution requires collaborative efforts to improve water sanitation practices, regulate industrial and agricultural activities, and implement sustainable groundwater management strategies tailored to Kabul City's specific needs and challenges.

Focusing on Kabul City, these key issues underscore the urgent need for comprehensive groundwater management approaches, integrating scientific research, community engagement, and policy interventions to ensure sustainable water use and environmental protection in the city.

Groundwater Management Challenges in Kabul City

Fluctuations in Groundwater Levels

Kabul City faces challenges related to fluctuations in groundwater levels, influenced by both anthropogenic and natural factors. These fluctuations include long-term, seasonal, and short-term variations, with overgrown urban areas particularly vulnerable to prolonged declines in groundwater levels [25]. Seasonal fluctuations are primarily driven by precipitation patterns and water use activities like irrigation, while short-term fluctuations may result from district water supply and pumping

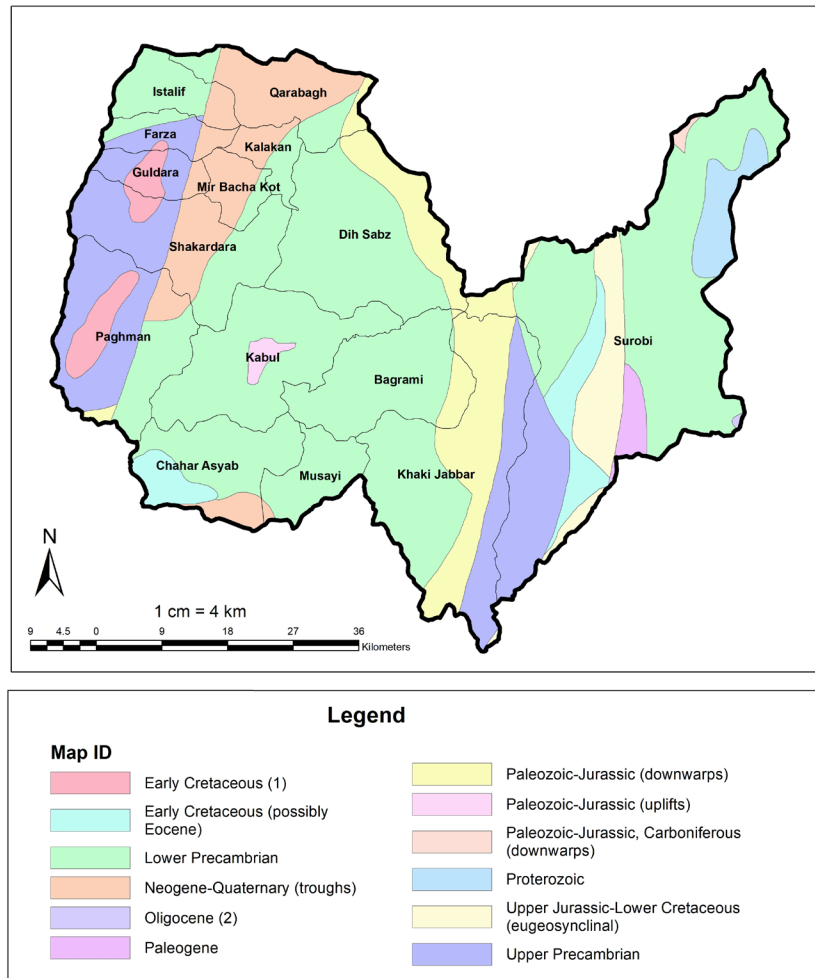


Figure 3. Kabul Tectonics Map, produced in GIS, by authors. 2023

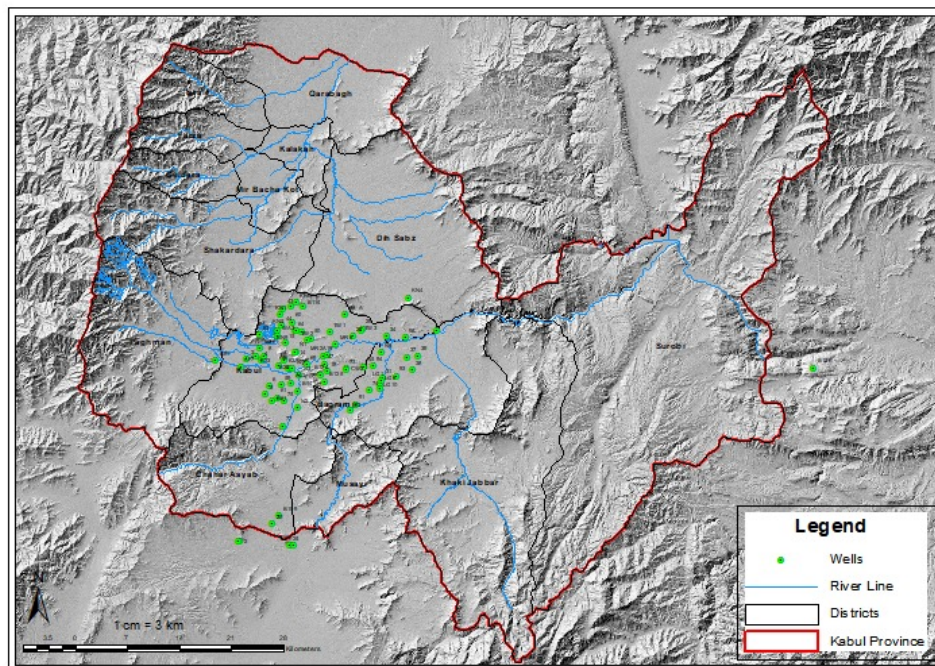


Figure 4. Geological Survey Wells network of Kabul, produced in GIS, by authors. 2023

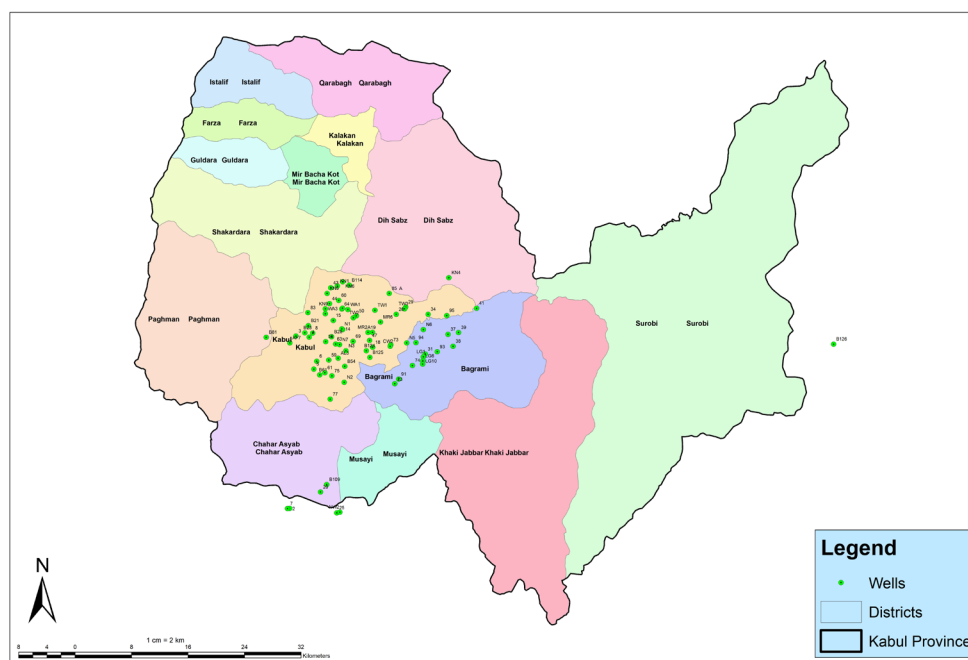


Figure 5. Groundwater Wells Network, produced in GIS, by authors. 2023

Limitations in Data Availability

Inadequate Technical Capacity

Climate Change Impacts

and population growth [8]. Developing adaptation strategies to mitigate the impacts of climate change on groundwater resources is imperative for ensuring long-term sustainability and resilience in Kabul City.

Management of Transboundary Groundwater Resources

Groundwater Management Information Program in Kabul City

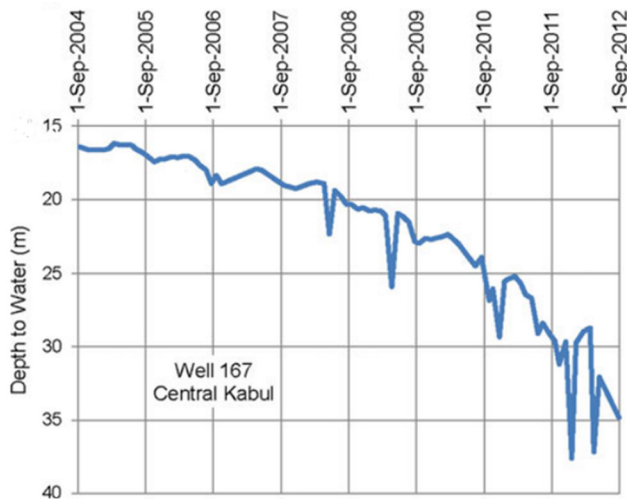


Figure 6. Monthly depth to water at Kabul Geological Survey wells, produced in GIS, by authors. 2023

Importance of Groundwater for Irrigation and Water Supply

Groundwater serves as a vital source of drinking water in Kabul City, especially in rural areas, where access to safe water remains a significant challenge [7]. Despite improvements in access to clean drinking water, concerns persist regarding water quality, leading to health risks for the population [7]. Shallow wells, often owned by families or communities, constitute the primary source of drinking water in Kabul City, supplemented by municipal supply wells in urban areas [8]. Moreover, groundwater is extensively used for irrigation, accounting for over 95% of total groundwater consumption [7]. Addressing water quality concerns and ensuring sustainable groundwater management are critical for safeguarding public health and supporting agricultural livelihoods in Kabul City.

Quantity Trends from Specific Observation Wells

Over exploitation of groundwater and droughts have resulted in a progressive decline in groundwater levels in Kabul City over the past few decades [2]. Studies report substantial decreases in groundwater levels with significant implications for water sustainability and resource management over several decades [4]. Despite efforts to monitor and manage groundwater resources, unsustainable discharge rates have posed challenges to maintaining water availability in Kabul city's Central Subbasin Area [8]. Trend analyses indicate a continuing decline in groundwater levels, emphasizing the urgent need for adaptive management strategies to mitigate further depletion and ensure water security in Kabul City.

The Kabul Basin, which supports over 10% of Afghanistan's population, relies almost entirely on groundwater for domestic use, raising serious concerns about long-term water sustainability amid rapid population growth and potential mining activities [7,10]. Historical and recent studies have documented significant groundwater-level declines, particularly during drought periods and due to increasing water demand [2,4]. While long-term data have been limited, monitoring efforts since 2004 by the Afghanistan Geological Survey (AGS) and DACAAR—using 167 wells across the basin—have revealed alarming trends. In the Central Kabul subbasin, groundwater levels declined by 3 meters from 2004 to 2007 and by an additional 15 meters from

2008 to 2012 (Figure 6), reflecting unsustainable extraction rates [8]. These findings underscore the urgent need for more sustainable groundwater management in Kabul.

Importance of Data Availability and Initiatives

The availability of comprehensive data is crucial for effective water resource management in Afghanistan. However, the lack of meteorological and hydrological stations, centralized databases, and information systems hinders the quantitative evaluation of water resources [14]. Limited hydrological data, scattered across various ministries and private sectors, underscores the need for organized data collection and analysis by skilled hydrologists [14]. Security concerns, particularly along the borders with neighboring countries, further impede systematic data collection efforts [25]. Addressing these challenges requires enhanced collaboration and transparency among stakeholders to establish joint technical committees and facilitate data sharing agreements [25]. Such initiatives can promote regional cooperation and resolve tensions over transboundary water resources [28].

National Groundwater Conference and Future Prospects

The National Groundwater Conference in Kabul (when?) brought together various stakeholders, including government ministries and non-governmental organizations, to address groundwater challenges and seek sustainable solutions [7]. The conference emphasized the importance of coordination among ministries, the establishment of information management systems, mapping groundwater resources, securing donor support, and developing action plans for groundwater management [7]. These collective efforts aim to improve data availability and enhance groundwater management practices in Afghanistan.

Conclusion

Groundwater plays a vital role in sustaining agriculture and supporting small-scale farming in Afghanistan. However, inadequate understanding and management of groundwater resources pose significant challenges. Climate change intensifies these challenges, affecting groundwater recharge, storage, and utilization. To address these issues, Afghanistan needs to enhance institutional capacity, stakeholder participation, and information management programs for groundwater management. Leveraging new technologies like artificial intelligence and machine learning can enhance monitoring and management efforts. Continuing initiatives, such as institutional coordination and capacity-building, are essential for ensuring sustainable groundwater management in Afghanistan.

Declarations

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All author(s) read and approved the final manuscript.

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