Water Resources in Afghanistan

A synthesis report on the understanding of surface- and groundwater in Afghanistan

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Image on the front page showing a farmer examining his solar powered deep well and reservoir in Helmand Province (source: Manfield, 2021)

Executive summary

This baseline study synthesizes the knowledge base on groundwater and surface water resources in Afghanistan and highlights key information, key issues and opportunities to initiate further development concerning improved water supply and effective groundwater monitoring. In addition, this study explores how the impacts of climate change and increasing water demand could be mitigated, and recommendations are given for future work and follow-up studies.

The inventory and review of all relevant documentation shows that key information on themes such as water scarcity, groundwater depletion, groundwater quality and irrigation water demand are abundant, but are often based on previous literature studies and not based on actual field measurements or quantitative data analysis. Some documentation (not digitized or in local language) is not available to the public. Relevant examples of key information are presented in this synthesis report, while limitations in the methodology or shortcomings in the derived conclusions are indicted where necessary. As such, this report forms the knowledge baseline and starting point for more in-depth research.

The first step in understanding the surface water and groundwater resources in Afghanistan is to understand the climatic and topographic setting of the country. Water resources are highly seasonal, and availability varies significantly across Afghanistan, due to the highly variable climate dictated by the country's topography influencing precipitation and runoff patterns. As a result, some parts of the country are naturally more prone to re-occurring drought and/or flood events.

So far, little research has been directed towards identifying how climate change is affecting runoff patterns, recharge mechanisms and water availability, which means current effects from climate change are based on general observations used to derive trends in precipitation and runoff patterns. One of these is that the once relatively constant supply of runoff water from snow melt is reducing, while rainfall is becoming more erratic, increasing the risk of both floods and droughts. Still, localized changes are hard to predict and how these potentially affect water allocation schemes.

Most groundwater in Afghanistan is abstracted from shallow aquifers that are found in the alluvial and colluvial water-bearing layers of the unconsolidated formations of the mountain valleys and stream beds. However, shallow aquifer systems are not sustainable in the long run, due to their high vulnerability to climate change, over-exploitation and anthropogenic contamination.

Hydrogeological field data collection has been limited and studies focus mainly on the unconsolidated sediments of Quaternary and Neogene age, while the groundwater potentiality of water-bearing layers in sedimentary deposits, carbonate rocks and bedrock formations have been studied to lesser extent. Literature on regional hydrogeology is available, but detailed and ground-truthed studies for local aquifer systems are limited to the Kabul Basin. This is in line with the regional understanding of recharge mechanisms in Afghanistan, without detailed knowledge of the water balance of local aquifers.

Similarly, patterns of groundwater contaminations have been established on national scale. There is a distinction between geogenic and anthropogenic contamination and as a rule of thumb, arsenic is often associated with Holocene sediments where redox and other conditions allow the concentration of arsenic and fluoride are associated with volcanic rock. Water quality sampling has been used to extrapolate sampling results showing groundwater contamination to provincial scale as general indication.

Several attempts have been made to capture how much groundwater and surface water is used for domestic drinking water as well as irrigation purposes in order to define regions with the highest demand and scarcity of water. Overexploitation of groundwater, mainly for irrigation and agricultural purposes, is observed in the Harirud-Murghab and Helmand Basins as well as the metropolitan areas of Kabul and Kandahar. Broadly speaking, overexploitation reflects that water resource development focused and focuses too much on water demand with insufficient consideration of water availability. One effect of this is that mismanagement leads to upstream use of water resources without sufficient consideration of downstream effects; nationally and transnationally.

Water balance estimations show that total groundwater recharge exceeds total groundwater abstraction for most of Afghan river basins, suggesting a potential for further groundwater development. However, these are estimations on a very large (regional) scale, where an overestimation of recharge at basin scale combined with an underestimated abstraction rate distort the hydrological understanding at local aquifer level. On a local scale groundwater can still be depleted even if estimates on a basin level show a large surplus. This observation is supported by the records from most groundwater monitoring points that indicate a trend of a declining groundwater tables.

The agricultural sector is identified as the main user of surface as much as groundwater withdrawal, however the exact abstraction rates have not been identified on neither local, provincial or national level. As the actual abstraction rates for irrigated areas are not being recorded, a linkage between the annual irrigation demand and availability of a local aquifer can not be established accurately. This poses a risk of uncontrolled groundwater abstraction and potential depletion of local aquifers.

Kabul and other main urban areas rely on groundwater for potable drinking water as well as for peri-urban agriculture (greenhouses) and beverage companies. Due to population increase and unregulated construction of deep tube wells, groundwater levels have dropped. The main reason is that the groundwater extraction occurs.

Declining groundwater tables are reported in many monitoring wells: the monitoring network covers 68% of all sub-catchments, however this does not mean that all aquifers are well-represented or that data is consistent with the monitoring points. Only 16% (243 monitoring points) are dedicated wells with the sole purpose of monitoring. These are mainly shallow wells with depths of less than 100m. With a better understanding of the hydrogeological system, the groundwater monitoring network can be improved and locations for groundwater monitoring that are of interest for sustainable groundwater resources development and protection can be determined. A better understanding of the aquifer systems of Afghanistan is required to determine why, where and how water resources should be monitored in the first place.

An integration of surface water and groundwater resources management is recommended, but requires a better understanding of water resources and follow-up research. Groundwater management should be incorporated in the local, regional and national governance level and capacity developed, for example through capacity trainings of hydrogeologists. Groundwater management can be improved by the regulation and control of existing groundwater abstractions and the permit release and construction of new wells. The development of groundwater models for key strategic aquifers is advised to allow management scenarios to be tested. Watershed protection, reforestation and measures to increase retention of water and improving groundwater recharge should be applied in ‘upstream’ watersheds to reduce surface water runoff and as such, reduce flood risk (attenuating the peak flow) while increasing groundwater baseflow (improving drought resilience) further downstream. This could be achieved with the development and implementation of river basin management plans. For a more equitable distribution of water, water allocation plans should be developed.

Prior to expanding the monitoring network, clear and realistic monitoring goals should be identified and embedded in the Afghanistan framework of water governance and compliance, water allocation and water management. By defining areas and aquifers that are of interest for further groundwater exploration or where an increasing demand for groundwater is expected, groundwater can be managed more effectively. Overall, more wells should be dedicated to the purpose of monitoring only. Further, standards and guidelines on record keeping of well reports can improve consistency of data that will allow for continuous data analysis. In turn, a hydro(geo)logical knowledge base can be created that enable groundwater abstraction limitations and permitting for groundwater protection zones or investigations of prospective productive aquifers.

Given the amount of runoff of surface water that is leaving Afghanistan to neighboring countries, an opportunity exists to manage water resources more equitably for Afghanistan and its neighboring countries, which needs further investigation, communication using evidence and diplomacy.

Preamble

Surface water and groundwater availability has been a concern in Afghanistan ever since civilization evolved and a question that determines the livelihood of its people. In order to develop water as a resource for agricultural activity, industrial development and domestic use, while maintaining environmental flows, the hydrological regimes that determine its presence and quality must be understood.

This need has gained recognition by the Afghan responsible institutions as well as the international donors involved in Afghanistan. Especially since the effects of climate change such as floods and droughts are increasingly exacerbating vulnerability and poverty in Afghanistan. In this light, UNICEF has recognized the need to integrate and update the available knowledge on the Afghan water resources and improve the hydrogeological understanding in order to improve water security for all.

This synthesis report is the result of a baseline study undertaken by Acacia Water and funded by the DRRS Programme of the Netherlands Enterprise Agency (RVO), on behalf of UNICEF. The DRRS Programme is implemented by RVO, on behalf of the Ministry of Foreign Affairs and the Ministry of Infrastructure and Water Management of the Netherlands. Parallel to this baseline study, an analysis of the existing monitoring data and monitoring network within the hydrogeological context established is funded by the Swiss Development Cooperation (SDC), also on behalf of UNICEF. That report will focus on strengthening the monitoring of groundwater and surface water in Afghanistan.

This baseline study is unique, as for the first time an integrated and up to date literature overview of available relevant studies, reports and maps on water resources in Afghanistan has been collected, reviewed and synthesized. The literature overview can be found in the attached Excel catalogue. All relevant hydrological and hydrogeological studies, reports and maps have been made available on the online database repository https://gw4a.acaciadata.com.

This report presents the current state of understanding of water resources in Afghanistan. It includes the newest studies and insights, providing a profound update from Danish Committee for Aid to Afghan Refugees (DACAAR) report of ten years ago (Saffi and Jawid, 2013) on water resources potential, quality problems, challenges and solutions in Afghanistan. As groundwater plays a leading role in improving water security and has a buffering capacity against climate hazards such as droughts and floods, the focus in this baseline study is on groundwater. This report presents key issues in terms of water scarcity, groundwater depletion and groundwater quality issues, and gives an indication of priority areas and priority topics for further research. Recommendations are given to improve access to safe water and address the impacts of water scarcity. As such, this baseline gives direction and rationale for a national water resources management and monitoring plan in Afghanistan.

This baseline report was reviewed by experts from the Ministry of Energy and Water (MEW), the Danish Committee for Aid to Afghan Refugees (DACAAR) and UNICEF, resulting in a version 1 of the report. In order to further engage local stakeholders and develop ownership, the main findings were presented and discussed during two webinars on July 27th and August 2nd 2023 with key stakeholders within the Afghanistan water sector. Among the participants were experts of the Ministry of Rural Rehabilitation and Development (MRRD) and the MEW, Kabul University and international research institutes, Afghanistan Urban Water Supply and Sewage State Owned Corporation (UWASS) and various NGO's of the WASH Cluster in Afghanistan. Based on their inputs and comments, additional adjustments and additions to the water resources assessment were made, resulting in this version 2 of the report.

This baseline study brings together the insights of many works done previously, but also shows that there are still many knowledge-gaps. It is recognized that this baseline study is neither exhaustive nor complete, if only because some studies have not been digitized or are not available in English. In addition, more information surfaces when a baseline study reaches a wider audience and over time new studies will be carried out and more advanced techniques and up to date data become available. Therefore, the assessment of water resources is an active and continuous process. The authors of this report highly encourage the continued development of the knowledge base on water resources in Afghanistan.

This assessment provides an overview of the currently available information on water resources in Afghanistan and serves as a first step towards a more sustainable and climate-resilient use and management of available water resources.

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This synthesis report on water resources in Afghanistan is the result of a baseline study undertaken by Acacia Water and funded by the DRRS Programme of the Netherlands Enterprise Agency (RVO), on behalf of UNICEF.

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Thanks are due to officials of the Ministry of Energy and Water, Ministry of Rehabilitation and Rural Development, the World Bank, local and international NGO's, especially DACAAR, and academia and key individuals who contributed in providing valuable inputs and comments to the draft versions of this report and during the online webinars that greatly enriched the outcome of this study.

Last but not least, the authors acknowledge and express gratitude to the colleagues of Acacia Water who contributed to this project in various capacities, providing assistance in developing the online dissemination tool, and feedback that enhanced the quality of this synthesis report.

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3R	Recharge, Retention and Reuse
ADB	Asian Development Bank
AIMS	Afghanistan Information Management Service
ANDS	Afghanistan National Development Strategy
AREU	Afghan Research and Evaluation Unit
ASR	Aquifer Storage and Recovery
BCM	Billion Cubic Meter
BGR	Bundesinstitut für Geowissenschaften und Rohstoffe (*German Federal Institute for Geosciences and Natural Resources*)
DRRS	Dutch Risk Reduction and Surge
DACAAR	Danish Committee for Aid to Afghan Refugees
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations
GLOF	Glacial Lake Outburst Flood
HAVA	Helmand and Arghandab Valley Authority
IA	Irrigation Association
ICIMOD	International Centre for Integrated Mountain Development
IIASA	International Institute for Applied Systems Analysis
IWRM	Integrated Water Resource Management
KMARP	Kabul Managed Aquifer Recharge Project
MAIL	Ministry of Agriculture, Irrigation and Livestock
MAR	Managed Aquifer Recharge
MCM	Million Cubic Meter
MEW	Ministry of Energy and Water
MOMP	Ministry of Mines and Petroleum
MOPH	Ministry of Public Health
MRRD	Ministry of Rural Rehabilitation and Development
MUDL	Ministry of Urban Development and Land
NAEZ	National Agro-Ecological Zoning
NBS	Nature Based Solutions
NWARA	National Water Affairs Regulation Authority
NWO	Non-Governmental Organization
RBA	River Basin Agency

RBC	River Basin Council
RVO	Rijksdienst voor Ondernemend Nederland (*Netherlands Enterprise Agency*)
SBA	Sub-Basin Agency
SBC	Sub-Basin Council
SDC	Swiss Development Cooperation
SLM	Sustainable Land Management
SWC	Soil Water Conservation
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
USGS	United States Geological Survey
UWASS	Urban Water Supply and Sewage State Owned Corporation
WUA	Water Users Association

1 Introduction

1.1 Background

Afghanistan, being a land-locked country, has experienced frequent periods of drought and unequal distribution of precipitation (snow and rain) and runoff, which has resulted in water scarcity for the Afghan people and water dependent ecosystems. Water scarcity it is particularly referred to as shortages of surface water resources – partially because small rivers are ephemeral only running for 3 – 4 months after glacial melt and snow melt water turns into run-off. As seasonal runoff would require adequate surface storage structures to utilize surplus runoff surface at seasons of low runoff and / or rainfall, and these are to a large extend non-existent, partially due to decades of internal conflicts, the country has not yet had the opportunity to invest in such infrastructure.

As a lack of information on groundwater resources, qualitatively and quantitatively exists and impedes the process to invest in any water management infrastructure, the Danish Committee for Aid to Afghan Refugees (DACAAR), with the financial support of UNICEF and other donors, has constructed, modified and monitored between 2005 – 2022 over 400 data collection points of the groundwater monitoring network within the Afghanistan River Basins. As most of the wells from MEW and DACAAR are pumping wells, these are deemed unsuitable for regional groundwater monitoring.

For these reasons, UNICEF initiated a ToR for in depth data collection and analysis on the surface and groundwater resources across Afghanistan's watersheds, in order to establish a baseline for further decision-making purposes in terms of future water resource development. The relationship between surface water and groundwater is important as most groundwater recharge of shallow aquifers is linked to infiltration along rivers.

1.2 Objectives

The aim of the study is to form a baseline understanding of water resources in Afghanistan, with a focus on groundwater, based on existing and available information, and to provide an overview of the key issues, priority areas and recommendations for future work and follow up studies.

1.3 Approach

The baseline study includes the following activities and deliverables:

1. Literature review: inventory of existing hard copies and online reports, papers, articles and other studies on the hydrogeology of Afghanistan
   Deliverable 1: Literature overview (catalogue) and database repository (open access, web-based) of existing hydrological and hydrogeological studies, reports and maps
2. Review and synthesis of all relevant documentation on (ground)water resources in Afghanistan and the identification of priority areas for follow up activities
   Deliverable 2: Concise synthesis report on the understanding of water resources in Afghanistan, with a focus on groundwater, and the indication of priority areas in terms of water scarcity and groundwater depletion

3. An online dissemination workshop with key stakeholders (to be selected after consultation with UNICEF) reporting on the main findings of the baseline study, and discussing the identified priority areas and possible follow-up research and actions
Deliverable 3: Minutes of the dissemination workshop

With the overall objective in mind, which is to establish a baseline understanding on surface- and groundwater resources from the existing literature and data available, this synthesis report is an addition to the online inventory of existing studies which highlights the main findings on the subject matter. The review of the existing literature has the purpose to highlight key information that serve as a starting point for water management and development in Afghanistan. To achieve this goal, this report points not only to the current challenges, but also gives recommendations and general direction for future work and follow up studies.

It is a distinctive issue with literature reviews in general, and with this study on water resources in Afghanistan in particular, that the limited amount of studies done in certain regions and on certain topics, creates a bias, as the reality seems represented by the availability of information rather than by the real situation ''on the ground''. For example, if research focus on the groundwater quality issues in a chosen area and emphasizes continuously on this area, this does not make the other areas less prone to groundwater quality issues but may simply reflect that there was either no data available, security restrictions by access of certain areas or remoteness of sparse population to ascertain the situation in a different area. This issues has been addressed as much as possible by considering what data is recorded (and what/where not) before drawing conclusions. Out of all available information, a total number of about 70 relevant studies were reviewed and included in this baseline, which were categorized according to their spatial focus (Figure 1) and main topic of interest (Figure 2).

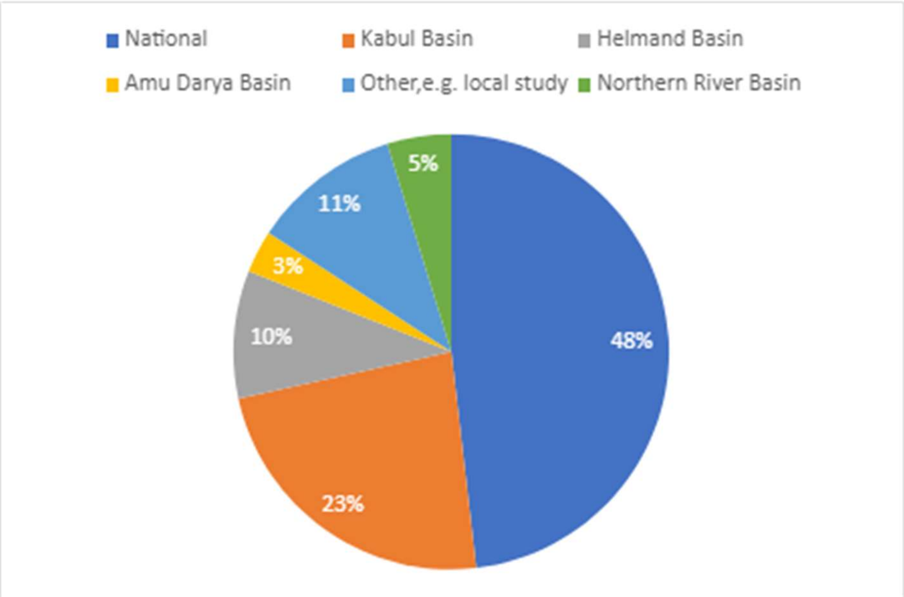


Figure 1. Percentage of studies conducted on national level and for specified basins only, based on 70 studies included in the literature review.

As shown, almost half of the studies cover content at a national level, whereas regional-specific studies are less common. As Afghanistan is divided into five major river basins, a further narrowed-down allocation has been made according to the basin, of which studies in the Kabul Basin are most frequent, followed by the Helmand Basin. This can be explained with Kabul and Kandahar being the major political centres located within these river basins.

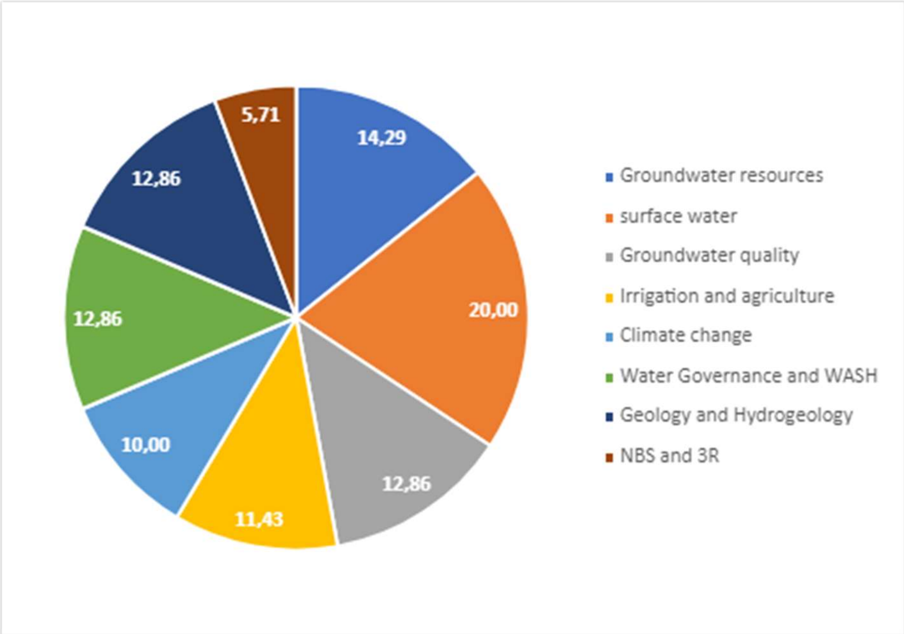


Figure 2. Percentage of studies conducted on topic based on 70 studies included in the literature review.

The main topics of the studies are related to groundwater (geology and hydrogeology, groundwater resources and groundwater quality, combined 34%) and surface water (19%). Other main topics include irrigation and agriculture (14,5%), nature based solutions (NBS) and recharge, retention and reuse (3R) measures (5%), water governance and WASH (5%) and climate change (6,5%).

2 Water resources in Afghanistan at a glance

Water resources are highly seasonal and availability varies significantly across Afghanistan. Although the water availability is deemed sufficient, the spatial and temporal distribution is uneven.
Groundwater is concentrated in broad alluvial fans following the courses of intermontane rivers and is accessible to most major urban areas, although in metropolitan areas groundwater levels are declining due to over-exploitation.
There are five main river basins, of which the Kabul Basin and Panj Amu Basin are the most hydrologically productive basins, containing 83% of surface water.
The agricultural sector is the largest consumer of surface- and groundwater resources, with nearly 98% of all freshwater abstractions for irrigation demand of which 85% covered by surface water.
Snow melt during the late spring and summer is key to replenish water resources particularly for major rivers in the east and northeast. Water is scarce in the deserts and steppes throughout the south and west.
Natural and anthropogenic contaminants increasingly threaten the viability of water sources, mainly from untreated wastewater and poor sanitation systems in urban areas and from naturally occuring heavy metals like arsenic.
Legal and institutional frameworks for transboundary basin management are limited and lead to international disputes over transboundary water allocation and river management.
There is a need to develop groundwater development plans. Deep groundwater exploration and abstraction is to most extent none-existant, mainly as essential hydrogeological data and field studies are missing.
Limited surface and groundwater level and quality monitoring impedes implementation of evidence-based policies and strategies for water management.

2.1 Water resources availability

2.1.1 Review of previous studies

Before moving to the content on what is available and known about water resources in Afghanistan, the main studies are highlighted in this section. Naturally, the majority of studies are imbedded in the context of humanitarian work and with the objective to provide water resources that can be developed for the Afghan people's livelihood. This concerns studies conducted by BGR, DACAAR, FAO, JICA, UNICEF, USAID and USGS and which largely attempted to capture the state of surface- and groundwater resources in a particular area. Research that included in-country data collection and are worthwhile pointing out are the *Streamflow characteristics of streams in the Helmand Basin studies* (Vining, 2010; USGS), the *Groundwater analysis report in eleven provinces of Afghanistan* (Kohistani and Mohammadi, 2023; DACAAR) and the *Water Resources Potential, Quality*

Problems, Challenges and Solutions in Afghanistan (Saffi and Jawid, 2013; DACAAR), and the *Hydrogeology of the Kabul Basin – part 1, 2 and 3* series by BGR.

In 2021, USAID published a concise overview of water resources in Afghanistan in their eight-page *Afghanistan Water Resources Profile*. One of the most critical reports on Groundwater in Afghanistan is still the *Afghanistan – an overview of groundwater resources and challenges* (Uhl, 2003). One of the most comprehensive works on surface water nation wide can be found in the *Watershed Atlas of Afghanistan* (Favre and Kamal, 2004), which was produced by the Ministry of Irrigation, the UN Food and Agriculture Organization (FAO), Afghanistan Information Management Service (AIMS), the Afghan Research and Evaluation Unit (AREU) and the Swiss Development and Cooperation (SDC). On a more regional level, the *Hydrogeological Atlas of Faryab Province Northern Afghanistan* was compiled by Norplan in 2014 and summarizes concise as much as complete information on hydrogeological at provincial level (Banks D., 2014).

Research conducted by universities and scientific institutions have a stronger focus on conceptualization, recharge dynamics, runoff patterns and the impact of climate change on precipitation, snowmelt and the water balance in the basins, catchments, and sub-catchments. Another field of interest is agriculture that also addresses traditional irrigation schemes. Research fields of disagreement are the water balances, recharge estimates and irrigation water abstraction, where different studies have come to different conclusions depending on the assumptions underpinning the calculations. A few studies have also been dedicated to relatively new topics such as managed aquifer recharge (MAR) potential and how glacial melt can be monitored to predicted future runoff scenarios.

2.1.2 Data gaps in hydrogeological understanding

The first step in understanding water resources in Afghanistan is to recognize the limitations of the methodology to arrive at the conclusions presented. A general concern is the lack of validated ground-truthed data, partially because field data campaigns were and still are impeded by violence and conflict and partially because data collection infrastructure has not been maintained. Since 1979, only minor field sampling by a few foreign and some Afghan hydrogeologists have taken place, which has produced several recent reinterpretations. Rare visits by different national groups of geologists embedded in the military missions (USA, UK, Germany, Lithuania, Japan, and others) for deployments by the International Security Assistance Forces (ISAF) have enabled short duration field work in Afghanistan in recent years (Shroder et al., 2021).

Geological and hydrological studies have been more frequent between 1960s and the 1980s through the collaboration between the Russian and Afghan governments, that have led to the first hydrogeological map. Fortunately, geology is not affected by short periods, so that these findings are still valid today with inaccuracies mostly caused by less sophisticated technology compared to current advancements (Shokory et al., 2023).

The discontinuities in long-term records of hydrometeorological data pose a key challenge for establishing scientifically-sound future projections based on models needed for water resources management and decision making. Meanwhile MEW has been working to somehow fill this gap of almost 30 years in precipitation data, with support of

NASA and calibrating data from the precipitation data of surrounding areas. The lack of ground-truthed data (hydrological, meteorological, geological and soil characteristics) hampers model calibration and eventually leads to assessment being underpinned by assumptions that are not validated (Shokory et al., 2023). Hence, this has resulted in little peer-reviewed literature and in-depth studies concerning climate trends and associated changes in water resources. Research that has moved beyond national borders of groundwater resources are unprecedented.

2.2 Water policy and governance

Key institutional and legal changes were implemented in 2020, including the formation of the National Water Affairs Regulation Authority (NWARA), based on presidential decree (Ministry of Justice, 2020) and the enactment of a new Water Affairs Management Law. Based on the law, NWARA was established by removing the previous MEW, but after the collapse of the Republic in August 2021, the new regime removed NWARA and brought MEW back, who is now responsible for implementing the provisions of this law. Key laws, policies, and plans are summarized in Table 1.

Table 1. Key laws, policies and plans in Afghanistan on water (USAID, 2021).

Name	Year	Purpose
Water Affairs Management Law	2020	Replaces the 2009 Water Law. The law clarifies sectoral responsibilities, affirms the authority of the Supreme Council of Water, Land and Environment (SCoWLE), and formalizes key structures to resolve water disputes and harmonize water sector policies and implementation. Focuses on equitable, efficient, and sustainable water use.
Water Sector Strategy (2007-2013)	2007	The Water Sector Strategy, which is within the 2007-2013 Afghanistan National Development Strategy (ANDS), defined a timeline and roadmap for establishing IWRM institutions and achieving basin development outcomes.

During the last 20 years, national budget and investments have prioritized hydraulic infrastructure, but the Integrated Water Resources Management (IWRM) concept was practiced in most of the projects. According to the Afghanistan Water Resources Profile Overview (USAID, 2021) governance mechanisms such as river basin councils (RBCs) and agencies have not been systematically established, but in recent years the MEW has established RBCs. As of now, RBCs are active in all five main river basins as well as in some sub-river basins. There are Water Users Associations (WUAs) active in most basins, mainly in the Panj Amu Basin, and more than 1500 irrigation associations (IAs) have been established.

Transboundary water governance has been ineffective, which has limited potential investments in key infrastructure. As an upstream country, Afghanistan has been reticent to establish water sharing treaties with riparian countries (see section 7.3). In some cases this has deterred donor support in new infrastructure investments. The 50 year old Helmand River Treaty between Iran and Afghanistan is Afghanistan's only transboundary water management treaty. However, instability and conflict have hindered its implementation and there have been key disagreements over water allocation requirements (see section 7.4).

Between 2007 and 2013, a portion of the national budget was allocated to establishing river basin organizations and capacity building initiatives. The Afghanistan National Peace and Development Framework (2017-2021) re-allocated resources to other sector priorities, which effectively reduced funding for new basin-management entities while ongoing security challenges have impeded the operations of existing IWRM entities. The 2020 Water Affairs Management Law established a Water Affairs Management Department to harmonize sectoral planning and implementation.

Limited funding and security challenges have impeded the development of key IWRM entities. Water resources management is generally characterized as a top-down process led by the Supreme Council of Water, Land and Environment and is more focused on hydraulic development than conservation, water quality monitoring, water allocation, and source protection. The enactment of the Water Affairs Management Law and establishment of the NWARA in 2020, followed by reinstalling the MEW in 2021, introduced sweeping changes to the legal and institutional framework for the water sector.

The current roles and responsibilities of transboundary, national, and sub-national water management entities are summarized in Table 2.

Table 2. Water resources management entities in Afghanistan.

Mandate	Institution	Roles and Responsibilities
National	Ministry of Energy and Water (MEW) (replaced by NWARA in 2020 but reinstalled in 2021)	The MEW holds the following Duties and Authorities: - Preparing and arranging the policy, strategy, and legal documents related to water. - Analyzing the capacity of available and accessible water and management of catchment areas. - Designing and drafting the appropriate water resources allocation and utilization plan and proposing it to the High Council of Water, Land, and Environment. - Designing and drafting rehabilitation, development, usage, safety, and operation and maintenance plans for water facilities and other water resources-related infrastructures, implementing and overseeing them. - Development of hydrological and hydrogeological networks in order to collect and analyze figures and data in cooperation with the stakeholder bodies. - Establishing a National Information Bank of Water Resources in order to plan and form the development and management of water resources with regard to the adverse effects of climate change, including reducing the effects of floods and droughts and sharing it with the public sector according to a separate procedure. - Facilitating private sector investment in the development of water resources, considering its economic and regional reasonableness. The Water Affairs Management Department, established within the Ministry of Water and Energy framework, establishes general directorates at the level of five river basins, sub-directorates at the level of provinces, and administrative units and drainage basins at the level of districts, in order to better manage the affairs of river basins
	Ministry of Rural Rehabilitation and Development (MRRD)	Through the Rural Water Sanitation and Irrigation Programme, the MRRD provides access to potable water and sanitation facilities to rural people, hygiene education and works on small scale irrigation infrastructure.
	Ministry of Agriculture, Irrigation and Livestock (MAIL)	Responsible for managing Afghanistan's agriculture policy, including irrigation. Among other matters, the Ministry oversees the work of the Helmand and Arghandab Valley Authority (HAVA), that manages one of the most important irrigation systems.
	Ministry of Urban Development and Land (MUDL)	Responsible supply for policy and planning of water supply including the development of water master plans for cities
	Ministry of Mines and Petroleum (MOMP)	Responsible for monitoring and managing groundwater quality, groundwater availability and balance studies, and permitting for deep wells.
	Ministry of Public Health (MOPH)	Responsible for setting water quality standards based on use, including drinking, domestic use, irrigation, and commercial use.
	Urban Water Supply and Sewage State Owned Corporation (UWASS)	Governmental joint corporation with the main objective to provide productive sustainable water and wastewater services for urban and semi-urban areas of the country. Formerly the Afghanistan Urban Water Supply and Sewerage Corporation (AUWSSC)
	National Environmental Protection Agency (NEPA)	Responsible for monitoring surface water quality along with MEW and River Basin Agencies.
Sub-national	River Basin Agencies (RBAs), Sub-basin Agencies (SBAs)	Established on all 5 main river basins and 35 sub-basins. RBAs and SBAs develop basin management and water use plans in accordance with national water policies and in consultation with the River Basin Councils (RBCs). Responsible for surface water quality monitoring.
	River Basin Councils (RBCs), Sub-Basin Council (SBCs)	RBCs and SBCs consist of water users and government representatives from in-line ministries. Provide advice on water management strategy an water dispute resolution, as well as advice and agreement on water allocation plans. Monitor water allocations and the protection of water rights.
	Water Users Associations (WUAs), Irrigation Associations (IAs)	WUAs are responsible for managing water use, distribution and operation and maintenance of main canals, and are registered with MEW. IAs responsibilities are similar to WUAs but these are registered with the Ministry of Agriculture, Irrigation and Livestock (MAIL). These entities are not consistently established in all river basins.

3 Climate and geographic context

Afghanistan consists of extensive desert plains, high mountain ranges and scattered fertile valleys in-between the mountains and along the major rivers. Only 10% of land is arable land while less than 2% is forested.

Elevation impacts precipitation distibution, with areas below 1000 m above sea level generally receiving less than 100 mm/yr and most areas above 4000 m a.s.l more than 1000 mm/yr. Erratic rainfall and snowfall during the winter months are imperative to feed rivers and contribute to groundwater recharge.

Afghanistan manages its surface water through five main river basins: Panj Amu Basin, Northern Basin, Helmand Basin, Harirud-Murghab Basin and Kabul Basin. Most major rivers originate in the Hindu Kush Mountains.There are 36 watersheds and 5 non-drainage areas.

Projections and historical data of stream flow show a decreasing trend of river discharge of all five major rivers, although some river basins may experience seasonal higher discharge due to increased snow melt.

Due to climate change, flood and drought risk are likely to increase in the future. Climate change is increasing evaporation rates, decreasing precipitation, and reducing the long-term water balance so that current drought conditions may be the new normal by the end of the century.

The impacts of climate change cause glacial retreat and less precipitation in form of snowfall at higher altitudes. This is expected to increase drought risk as snow melt is impacting natural water storage that safeguards river flow rates during seasonal and longer-term drought.

Located in central Asia, Afghanistan is a landlocked country bounded by Turkmenistan, Uzbekistan, Tajikistan, China, Pakistan and Iran (Figure 3). As of 2023, Afghanistan's population is 43.1 million of which 23% live in urban and 77% in rural areas (MEW population data, 2023). Afghanistan has an administrative division of 34 provinces and 401 districts. The population is spread and scattered over an estimated 40,000 to 50,000 villages, most of which are located close to water sources.

Figure 3. Location of Afghanistan in central Asia.

Afghanistan's society has evolved and grown along its water resources and will be discussed in context of its geographic and climate conditions throughout this chapter.

3.1 Topography

Afghanistan can be divided into three topographic zones; the lowlands with an altitude of 300 – 500 m a.s.l, the medium land with an altitude of 500 – 2000 m a.s.l and the high-lying lands with an altitude above 2000 m a.s.l. 25% of the country's area is lying above 2500 m (Favre R. and Kamal G., 2004).

The topography of Afghanistan is variable ranging from low-lying plains in the northern and southwestern parts and elevations rising from 258 m a.s.l. along the Amu Darya River at the northern Afghan border, to the highest peak, Mount Noshaq at 7492 m a.s.l. (Figure 3) into the north-eastern mountains (Gellasch C.A., 2014). The most prominent mountain features are the Elbourz mountains rising in the north of Iran and continuing through the Hindu Kush in Afghanistan up to the Pamir Mountains in Tajikistan and the Karakoram chain in Pakistan and India. No less important is the southern arc, starting in the Zarghos Mountains in the west of Iran and enter Afghanistan at the Suleiman mountain across Pakistan and Afghanistan that end with the northern arc in the Karakoram Mountains (Favre R. and Kamal G., 2004).

A visual overview of the country's topography is given in Figure 4. Detailed topographic maps have been prepared at 1:250,000 scale by the USGS and the Afghan cartography head office that used TNTmips to prepare a series of 32 maps (Bohannon R.G., 2010).

The elevation differences, angle and orientation of slopes determine the hydrological regime of surface runoff flow, recharge and lateral groundwater flow (Qureshi A. S., 2002). In addition, steep slopes in the mountains pose a challenge for development of water resource management infrastructure (Favre, A. and Kamal, G. M., 2004).

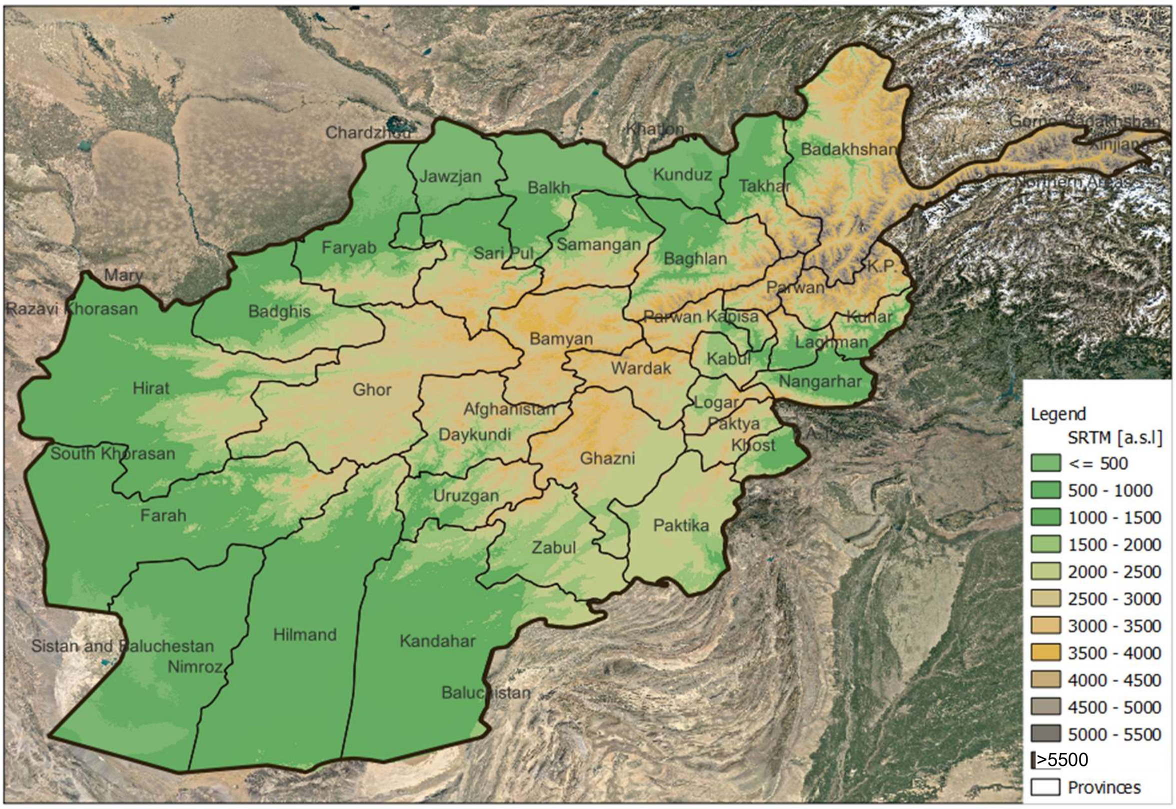


Figure 4. Topographic map of Afghanistan (source: SRTM).

3.2 Climate

According to the Koeppen climate classification system, the climate zones found in Afghanistan are hot desert climate, cold semi-arid climate, hot summer humid climate, subarctic climate and extreme cold climate (Climate change knowledge portal, 2021). Throughout the season, temperature and precipitation are subject to considerable variation (Figure 6). Precipitation and temperature are also influenced by the effect of topography and altitude: spatially, precipitation occurs at higher altitudes, which means the central and eastern parts of the country are affected by more precipitation, whereas the southwestern parts receive typically close to zero rainfall and are drier (Asian Development Bank, 2021). The national elevation profile and how this results in wetter and dryer areas due to the varying quantity in precipitation is given in Figure 4 and Figure 5 respectively.

Based on temperature regime classes, moisture regime classes and land cover classes, a total of 18 agro-ecological zones were recognized in Afghanistan by the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA) with support from the Ministry of Agriculture and Livestock (MAIL) (FAO and IIASA, 2019).

3.2.1 Precipitation

Being classified as an arid to semi-arid country receiving erratic rainfall and snowfall only for a couple of months during the winter season, these short periods are imperative to feed rivers and contribute to recharge. Besides the temporal distribution of precipitation (rainfall and snowfall), the spatial distribution of precipitation is a distinct factor in determining areas for water resource development. A general climatic classification is given in Table 3 and an illustration of the spatial distribution of annual mean precipitation is given in Figure 5.

Table 3. Overview of categorial characteristics used to divide Afghanistan into six climatic zones (Qureshi A.S., 2020).

Zone	Name	Precip. [mm]	Dry [months]	Frost [months]
1	Badakhshan (without Wakhan)	300 – 800	2 – 6	1 – 9
2	Central & Northern mountains	200 – 600	2 – 9	0 – 8
3	Eastern and Southern mountains	100 – 700	2 – 9	0 – 10
4	Wakhan corridor and Pamir	<100 – 500	2 – 5	5 – 12
5	Turkestan plains	<100 – 400	5 – 8	0 – 2
6	Western & South-western lowlands	<100 – 300	6 – 12	0 – 3

Precipitation data is recorded by the hydro meteorological office (Hydromet) of the MEW. Precipitation is directly related to altitude; meaning that mountain areas experience significantly more precipitation in form of either rain or snowfall compared to the low-lying areas, which experience less than 100 mm/yr once the altitude reaches less than 1000 m a.s.l. compared to more than 1000 mm/yr in most areas above 4000 m (Gellasch, 2014), except for Nangarhar and Laghman provinces.

Because most of Afghanistan – foremost the eastern mountain range – is characterized by high elevations, most precipitation falls in form of snow (Uhl, 2003). The Food & Agricultural Organization (FAO, 1996) indicated that, in an average year snow melt contributes 150,000 million m^3 and rainfall roughly 30,000 million m^3 to the total national precipitation of 180,000 million m^3/year (Uhl, 2003). Hence, exfiltrating snowmelt surplus does not only feed rivers, but is also the main source of recharge at the foothills (Raphy F. and Golam M.K., 2004).

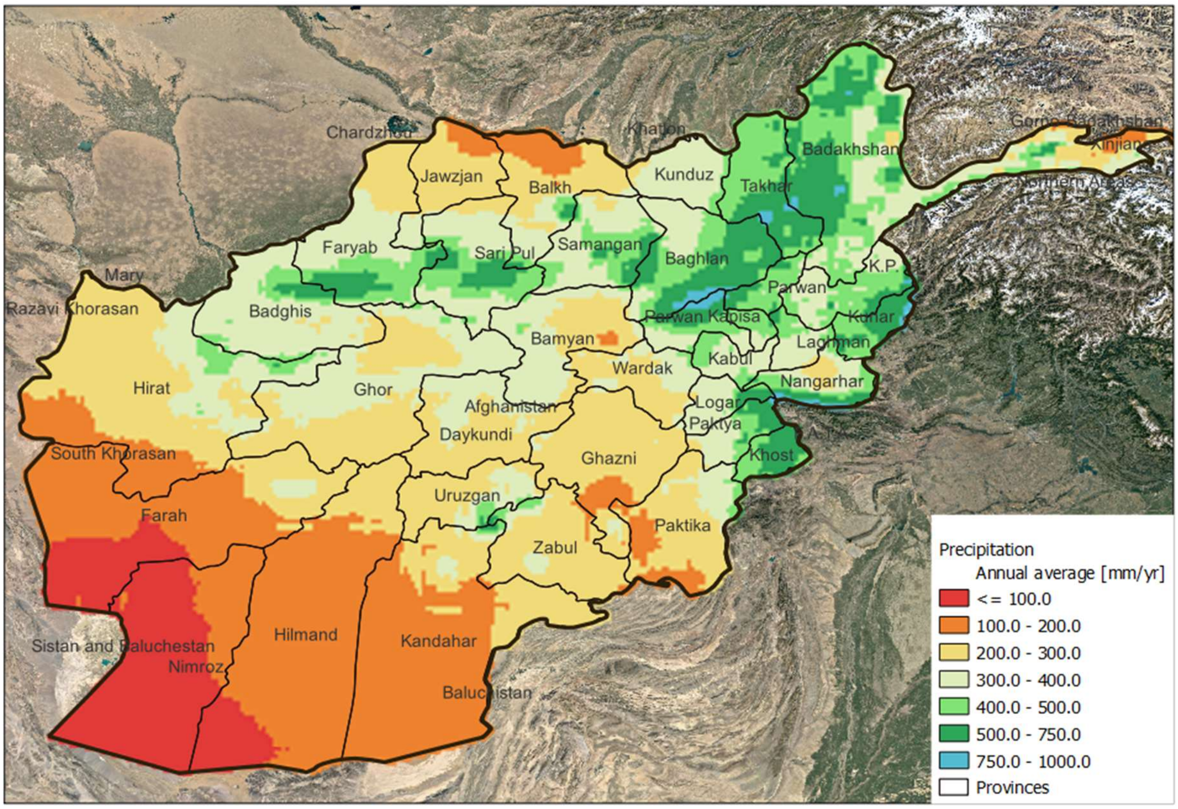


Figure 5. Spatial distribution of the annual mean precipitation in Afghanistan between 2002-2022 (source: CHIRPS)

In terms of temporal variation, no or almost no precipitation is recorded between the months June to October and a precipitation regime dictating wet months during the winter period from December till April (Figure 6). Note, that Figure 6 (Climate Information Platform, 2023) reflects the average climate of the country and not the regional precipitation patterns.

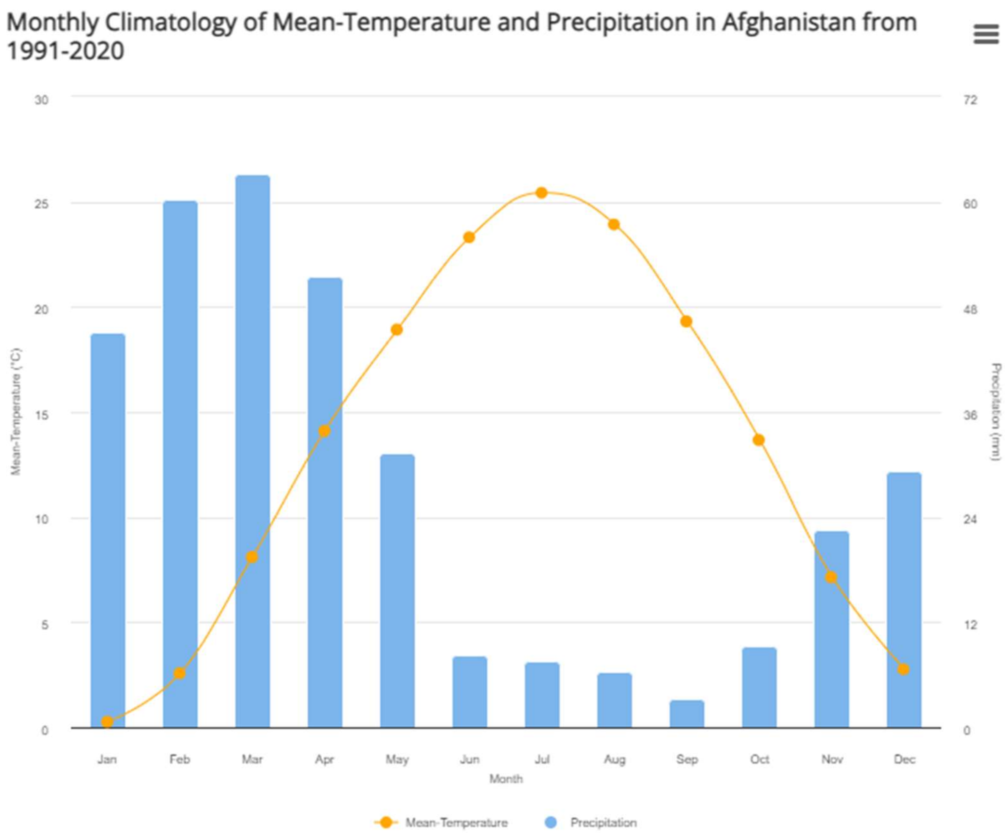


Figure 6. Graph of the average mean temperature and precipitation in Afghanistan (Climate Information Platform, 2023)

3.2.2 Evapotranspiration

The climate in Afghanistan is classified as continental and dry with dry air coming from the north and northeast. In the mountainous areas such as the Hindu Kush, the annual evapotranspiration rates are low and estimated at 900 – 1,200 mm/yr which is attributed to its winters and altitude. In the northern plains, the evapotranspiration rates vary between 1,200 – 1,400 mm and in the driest part of the county, the southern and southwestern plains values reach up to 1,800 mm. In summer, the evapotranspiration values are high everywhere with daily values of 5 – 8 mm between June and August. Areas where strong winds occur, such as the Herat that is located in the southwestern plains, the maximum daily evapotranspiration can be as high as 10 – 11 mm/d during summer (Saffi M.H. and Jawid A., 2013). As a rule of thumb, in all low-lying areas, evaporation exceeds precipitation as interpreted from remote sensing data.

3.3 Land cover and land use

The continental dry climate has made Afghanistan's landscape a harsh land that is almost exclusively covered by rangeland (43%) and bare land (39%). Only 12% is arable land and used for rainfed or irrigated crops, and less than 2% of land is forested. The major categories of dominant land cover types from the 2010 land cover database of Afghanistan are shown in Figure 7.

Coupled with annual seasonal climate trends, the geography of the country broadly distinguishes between the *lut*, arid steppes with no cultivation, and the *dash*, areas that turn green just after snowmelt and rainfall and that attract nomadic livestock (Favre, A.

and Kamal, G. M., 2004). This largely explains why Afghanistan's society has evolved in areas near water sources, while at the same time, a nomadic culture has evolved that reflects the search for alternative water sources.

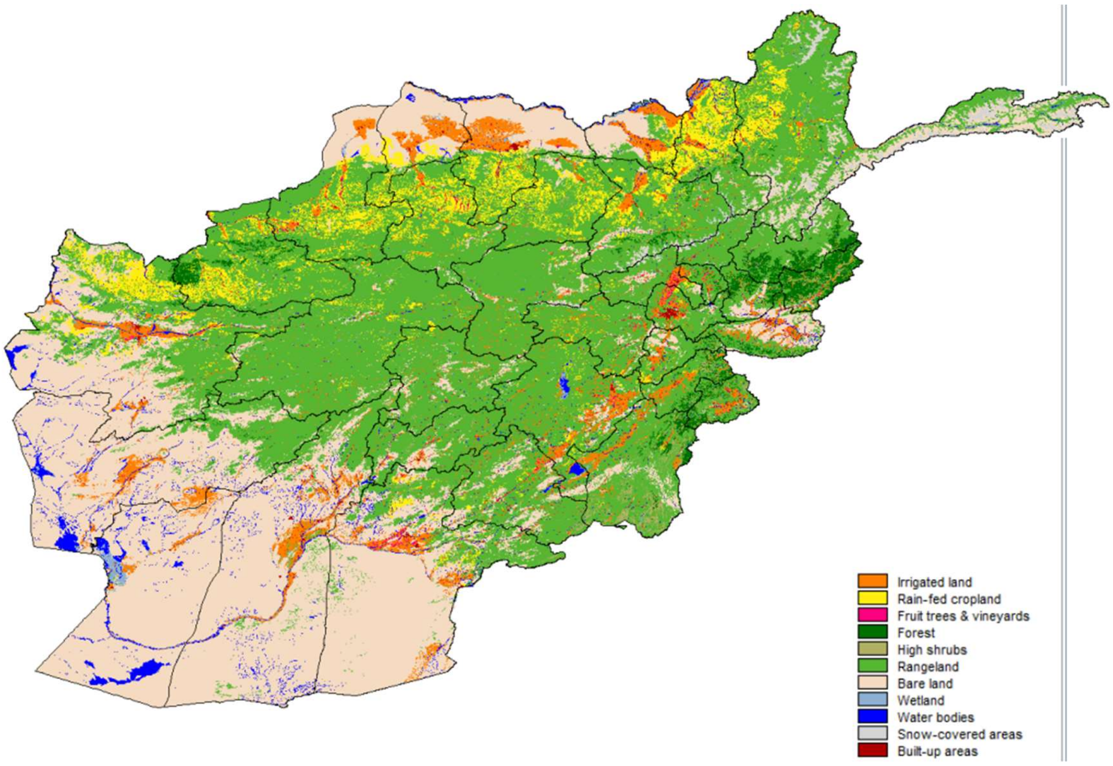


Figure 7. Dominant land cover in Afghanistan by 11 major categories, from the 2010 national land cover database (Source: FAO and IIASA, 2022).

3.3.1 Agro-ecological zones

The Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA) implemented a national agro-ecological zoning activity in Afghanistan (NAEZ) which assesses quality and availability of land resources and identifies crop cultivation potentials under given current or future agro-climatic conditions (FAO and IIASA, 2019).

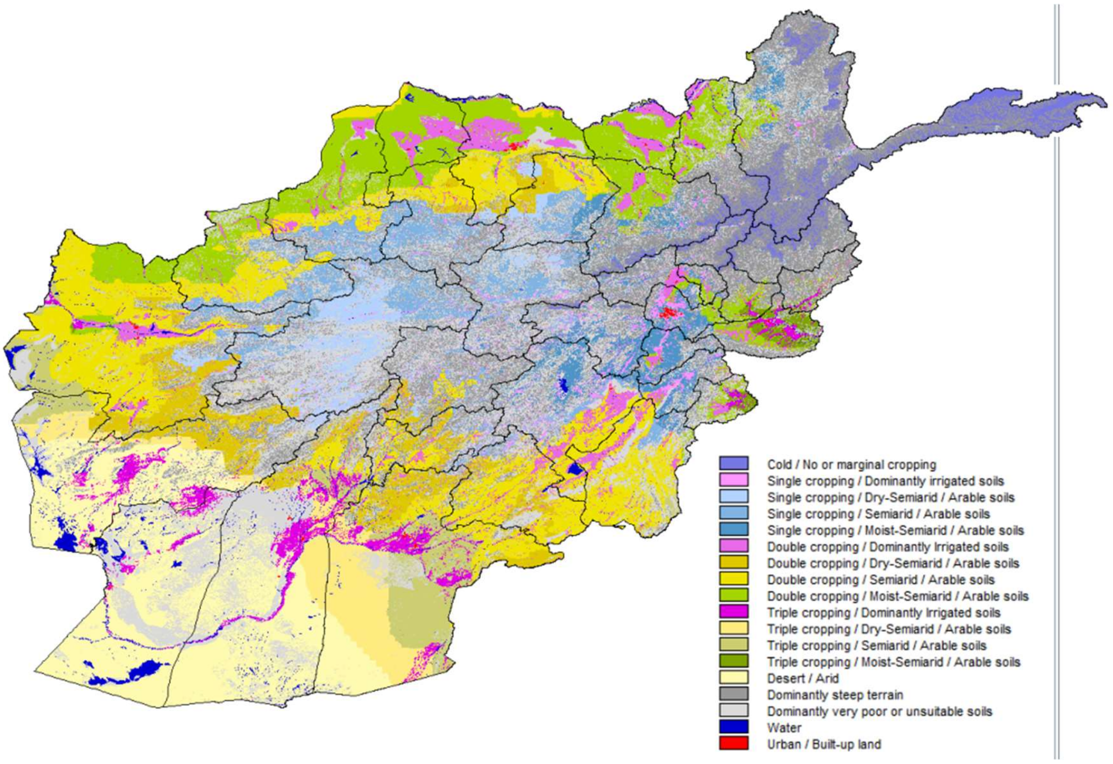


Figure 8. Agro-ecological zones classes for current and future climate, reference climate 1981–2010 (FAO and IIASA, 2022).

The spatial distribution of AEZ classes, using climate conditions of the historical reference period 1981–2010 is presented in Figure 8. Cold and cool zones are shown in blue colours, areas with severe soil/terrain limitations or dominantly steep slopes are mapped in grey colours, classes of dominantly irrigated land use purple colours, and arid areas are shown in a light-yellow colour.

3.4 River basins

Afghanistan can be divided into five major drainage basins as shown in Figure 9. Within the basins, the number of major rivers account to a total of 16, whereas the number of watersheds are 36 and an additional five non-drainage areas, which are administratively part of the main river basins. These have been originally mapped by Favre and Kamal (2004) as shown in Figure 10 and are listed in the subsequent subsections.

Most of the major rivers originate from the Hindu Kush located in the center of the country and from where river flow radiates towards the borders. Due to the climatic conditions described before, these rivers are all perennial which means their flow is not season-dependent. All other rivers in the country are dependent on seasonal flow. These include the Kabul River and its tributaries; the Kunar, Laghman, Logar, and Panjsher Rivers, the Helmand and the Arghandab, the Harirud, the Kunduz and the Kokcha, and the Amu Darya (Uhl, 2003).

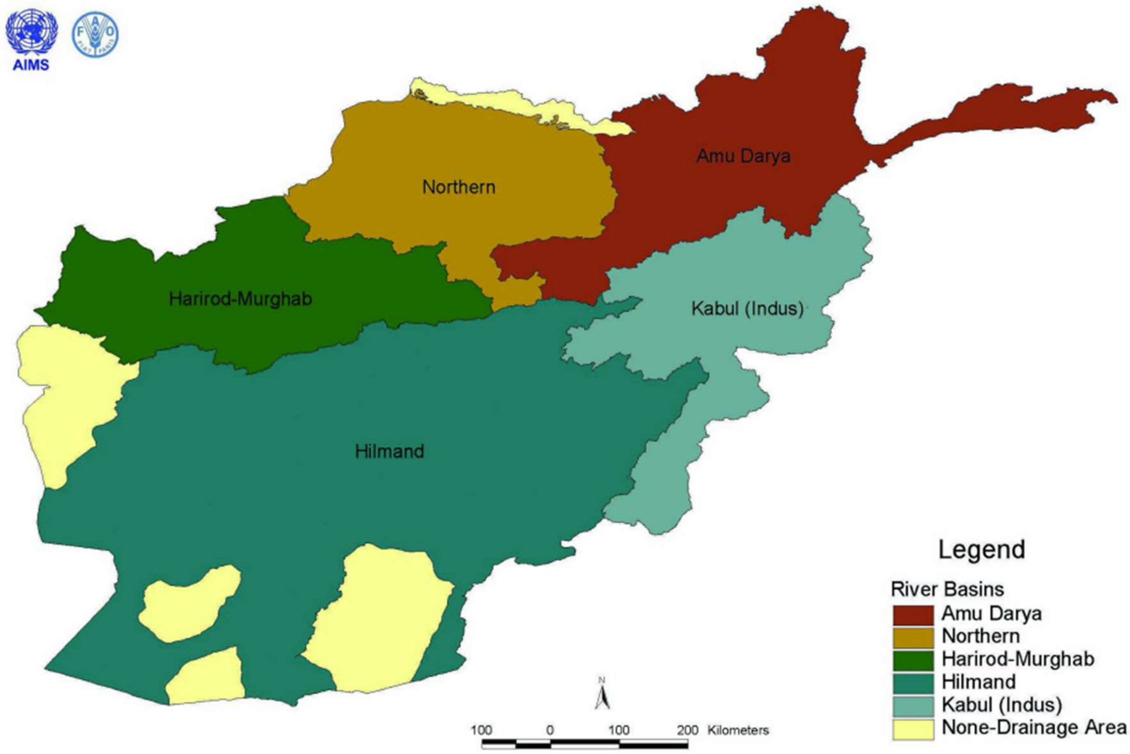


Figure 9. Delineation of major drainage systems in Afghanistan. Source: Watershed Atlas of Afghanistan (Favre and Kamal, 2004). Administratively, the five non-drainage areas are part of the corresponding main river basins.

A summary of the area of the five main river basins and population data from 2015 is provided in Table 4. A more extensive overview of the land cover type, population data and agricultural activities for each of the five major river basins can be found in Favre R. and Kamal G. (2004), but have been subject to significant changes over the past 20 years.

Table 4. River basins and population data.

River Basin	Area [km²]	%	Population (2015)	%
Panj Amu	90,692	14	4,449,000	16
Harirud-Murghab	77,604	12	3,694,000	13
Helmand	262,341	41	3,539,000	13
Kabul	76,908	12	12,110,000	44
Northern	70,901	11	3,927,000	14

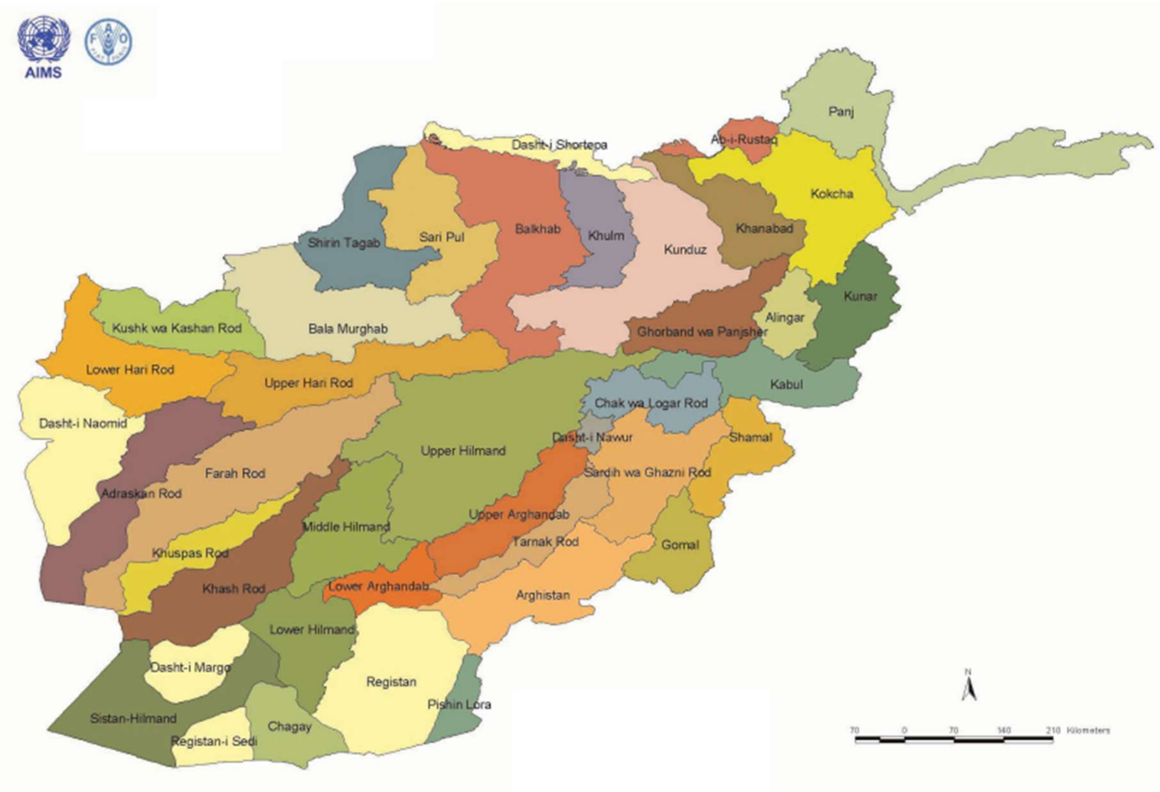


Figure 10. Delineation of Afghanistan's 36 watersheds and five non-drainage areas. Source: Watershed Atlas of Afghanistan (Favre and Kamal, 2004).

3.4.1 Kabul Basin

In the Kabul Basin, part of the Indus Basin, the rivers have their source in the high eastern mountains, which due to their altitude are covered in glaciers and can maintain surface water flow throughout the dry summer (Saffi M.H. and Jawid A., 2013). The largest river, the Kabul River, has a drainage area of 54,000km^2 and passes through Kabul and Jalalabad before joining the Indus River in Pakistan (Uhl, 2003). Besides the Kabul River, the Paghman River (draining 3 – 5% of the Kabul River Basin) and the Logar River (draining 78% of total river basin flowing into the Kabul River, are major rivers (Houben G. et al., 2009). Besides the stream flow regime, its worth pointing out that the eastern part of the Kabul Basin is influenced by the monsoon rains that reach the valley systems and which have resulted in coniferous forests to grow at an altitude between 1,500 – 3,000 m. The watersheds within Kabul Basin recognized in the Watershed Atlas of Afghanistan (Favre and Kamal, 2004) are:

1. Kabul watershed
2. Chak wa Logar Rud watershed
3. Ghorband wa Panjshir watershed
4. Alingar watershed
5. Kunar watershed
6. Shamal watershed
7. Gomal watershed
8. Pishin Lora watershed

The names used for watersheds have been subject to change since publication of the Watershed Atlas. The current names used for watersheds in Kabul Basin are: Upper

Panjsher, Lower Panjsher, Laghman, Logar, Ghorband, Upper Kabul, Lower Kabul, Shamal and Khuram, Kunar and Gomal.

3.4.2 Helmand Basin

Located at the southern part, the Helmand River Basin occupies almost half of the country's area, but only drains a small proportion of the total annual flow, accounting to at most 11% (Saffi M.H. and Jawid A., 2013). The rivers are drained from the upper catchment of the Sia Koh Mountains, where the Helmand River forms the longest river with a total length of 1,300 km – the upper catchment is known to receive snowfall in the winter months (Uhl, 2003). The major point of drainage is the Sistan Basin (or Godzareh depression), where a shallow wetland consisting of seasonally interconnected lakes and lagoons exists. From the five major river basins, the Helmand River Basin forms the most watersheds. The watersheds within Helmand Basin recognized in the Watershed Atlas of Afghanistan (Favre and Kamal, 2004) are:

1. Adraskan Rud watershed
2. Farah Rud watershed
3. Khuspas Rud watershed
4. Khash Rud watershed
5. Upper Helmand watershed (above the Kajaki dam)
6. Middle Helmand watershed
7. Lower Helmand watershed (intensively irrigated perimeters below the Kajaki dam)
8. Sistan-Helmand watershed (below the intensively irrigated perimeter in the Sistan zone)
9. Chagay watershed
10. Upper Arghandab watershed (above the Dahla dam)
11. Lower Arghandab watershed (intensively irrigated perimeter below the Argandab dam)
12. Tarnak Rud watershed
13. Arghistan Rud watershed
14. Sardih wa Ghazni Rud watershed
15. Dasht-i Nawur watershed
16. Alingar watershed
17. Dasht-i-Margo non-drainage area
18. Dasht-i-Naumed non-drainage area
19. Registan non-drainage area
20. Registan-I Sedi non-drainage area

The names used for watersheds have been subject to change since publication of the Watershed Atlas. The current names used for watersheds in Helmand Basin are: Farah, Upper Helmand, Tirin Kot, Upper Jelga, Ab-i-Estada, Tarnak, Arghandab, Lower Helmand, and Mid Helmand.

3.4.3 Harirud Murghab Basin

Because the Harirud Basin receives less precipitation compared to the other river basins, the existing rivers are marked by ephemeral (intermittent) flow and the total flow contribution is estimated at mere 4%. The Harirud River originates in the western slope of the mountains in the central highlands and is with a drainage area of 39,000 km^2 the major river. Because the river basin morphology is narrow, the Harirud barely has any tributaries. The Harirud-Murghab basin includes four main watersheds (Saffi M.H. and Jawid A., 2013):

1. Bala Murghab watershed
2. Kushk wa Kashan Rud watershed
3. Upper Harirud watershed
4. Lower Harirud watershed

3.4.4 Northern Rivers Basin

The Northern (or North-western) Rivers have the smallest annual flow contribution accounting for 2% of the total surface water flow in Afghanistan. All rivers have a small width as the rivers either dry up in irrigation canals that are 50 – 100km short or in desert sands, but most importantly, do not reach the Am Darya River. This partially explains how the non-drainage areas in the north developed. The exception is the Balkhab River, which takes up flood water in case of flood event that reaches the lowlands of Turkmenistan at the border. In addition to a non-drainage area, four watersheds are recognized:

1. Khulm watershed
2. Balkhab watershed
3. Sari Pul watershed
4. Shirin Tagab watershed
5. Dasht-i-Shortepa (non-drainage area)

3.4.5 Panj Amu Basin

With a length of 2,400 km, the Amu Darya is the major river draining the Panj Amu Basin (formerly known as Amu Darya Basin) with a contribution from a large number of tributaries (Saffi M.H. and Jawid A., 2013). The final outlet was the Aral Sea in the past, but due to intensive irrigation in the downstream countries, the river dries out before that, nonetheless draining 57% of the total annual flow in Afghanistan (Saffi M.H. and Jawid A., 2013). The other two main rivers are the Kunduz and the Kokcha River, which are both characterized by perennial flow originating in the Hindu Kush and to which substantial spring flow contributes from snowmelt. Further, the five watersheds are:

1. Panj watershed
2. Kokcha watershed
3. Ab-i-Rustaq watershed
4. Khanabad watershed
5. Kunduz watershed

3.5 Glaciers

Almost 4000 glaciers are covering 2,700 km^2 in the Amu Darya and upper Kabul Basins. These glaciers are of critical importance for the Afghans water supply for drinking and irrigation. Yet research shows Afghanistan's glaciers are melting. Almost 14 per cent of the total area of glaciers was lost between 1990 and 2015 as a direct result of climate change, and a reduction that can be expected to continue (Bjelica, 2021).

A recent study estimates that by 2100 at least half of the glacial mass in the Eastern Hindu Kush subregion, where most of Afghanistan's glaciers are found, will melt (Bolch et al, 2019). This forecast is supported by Mayar et al., (2020) study, that states that even 76% of glaciers in the eastern Hindu Kush will melt based on glacial analysis between 1976 and

2007. Glacial melt is impacting natural water storage that safeguards river flow rates during seasonal and longer-term drought. This has an impact on the availability of surface and groundwater as the melting snow provides a resource for more months through the year than rainfall only. In principle, the melting of glaciers provides more water resource than previously but this effect will be felt for a relatively short period, when all the ice will be melt, there will be no storage.

3.5.1 Cryptosphere

Although the understanding on the contribution and sensitivity to changes on the glacial-mass balance demonstrate a glacial retreat of 0.54% per annum, more in-depth studies are required to establish a linkage to water resource management (Shokory J.A.N., Scahefli B. and Lane S.N., 2023). The mountain ranges in eastern Afghanistan are part of the Himalayan Plateau where glaciers are retreating. The decrease in precipitation in the form of snow at high altitude triggers increased glacier melt combined with decreased ice formation. (Azizi A.H. and Asoka Y., 2020). During a period of 25 years (1990–2015), the total number and area of glacial lakes in Afghanistan increased by 8% and 10% (ICIMOD, 2018), likely due to increased glacial melt.

3.6 Water resources in a changing climate

Afghanistan is one of the lowest emitters of greenhouse gases, but among the top ten countries most vulnerable to climate change. Comprehensive and up-to-date analysis of climate change and its projections for the future for Afghanistan was carried out by the country's National Environment Protection Agency (NEPA) with the technical support of UN Environment (NEPA & UN Environment, 2016) and of UNEP and WFP (NEPA & WFP & UNEP, 2016). The effects of climate change on water resources in Afghanistan, highlighted by Mayar (2022), can be summarized as:

- Temperatures have been increasing significantly and dramatically across the country over the past thirty years. This shift has intensified glacier and snow melt and led to an increase in the number of flash floods, glacial lake outburst floods and river flooding.
- The number of droughts doubled compared to the previous decades, due to a decline in annual precipitation in most of the country's north and centre.
- Afghanistan's glaciers are melting. Glaciers and snow melt provide base flow to the rivers in the summer and their early melting or decline affect river flow in the summer.
- The shifts in precipitation pattern and temperature have also affected patterns of river flow, with an increase in the number of high flow days (floods) as well as low flow days.

3.6.1 Spatial shifts in agro-climatic characteristics of land

The NAEZ system for Afghanistan was used by FAO and IIASA (2022) to assess likely spatial shifts in agro-climatic characteristics of land due to projected climate change in the period 2041–2070 (the 2050s) and 2071–2100 (the 2080s). With climate change, the occurrence of agro-ecological zones will shift due to increasing heat provision, alterations in precipitation patterns, higher crop water requirements, and resulting changes in soil moisture conditions. Pastures at higher altitudes will become more accessible and for a longer period of time during the year, but may suffer from extended dry periods in summer.

FAO and IIASA conclude that climatic conditions in Afghanistan will become warmer and mostly dryer in the future. This can create new opportunities in the North-Eastern region, mainly due to longer temperature growing periods and sufficient precipitation, but will have negative impacts on water resources and rain-fed cropping in most other regions. For the 2050s under RCP 4.5 assumptions the average regional precipitation remains at approximately historical levels in the North-Eastern region but decreases by 5 to 15 percent in the other regions. Under RCP 8.5 assumptions, regional precipitation amounts decrease from about 5 percent (North-Eastern region) to as much as 18 percent (Central and West-Central regions). The study (FAO and IIASA, 2019) concluded that for projected future climate the average rain-fed Net Primary Production potential is found to decrease in all regions with the exception of the North-Eastern region. The irrigated Net Primary Production potential (assuming no water stress) increases in all regions due to warming, the least in the low-lying areas of the South-Western region and the most at higher altitudes of the Central and North-Eastern regions. However, these improvements can only materialize if irrigation water is available to meet the additional crop water requirements resulting in a future climate due to longer temperature growing periods and higher evaporative demand of crops per unit area. These benefits do also not account for possibly more frequent occurrence of extreme weather events, such as an overall decrease in number of frost days and increases of occurrences of hot and very hot days.

3.6.2 Flood and drought risks in river basins

According to Afghanistan Disaster Risk Profile (The World Bank, 2017) flooding is the most frequently occurring natural hazard historically in Afghanistan, causing average annual damages of US$54 million; large flood episodes can cause over US$500 million in damages. Droughts have affected millions of people since 2000, during seven major drought events in 2000, 2006, 2008, 2011, 2018, 2021 and 2022. On average, droughts cause US$280 million in economic damages to agriculture each year; extreme drought events could cost over US$3 billion (The World Bank, 2017). Figure 11 shows the drought risk (left) and riverine flood risk (right) in Afghanistan (USAID, 2021).

Due to climate change, flood and drought risk are likely to increase in the future. Climate change is increasing evaporation rates, decreasing precipitation, and reducing the long-term water balance so that current drought conditions may be the new normal by the end of the century.

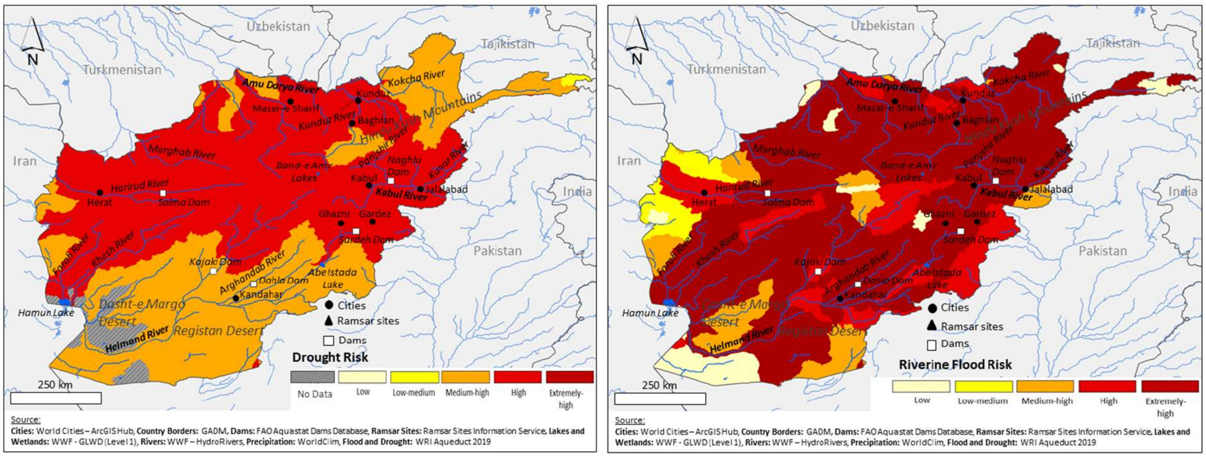


Figure 11. Drought risk (left) and riverine flood risk (right) in Afghanistan. Source: Afghanistan Water Resources Profile Overview (USAID, 2021)

Flood risks

Afghanistan is prone to river flooding because of steep slopes in headwaters. Still flood management has until recently been almost non-existent, partially because long-tern flood estimation has been impossible because the availability of discharge time-series are discontinuous (Mayar, Asady and Nelson, 2020). Flooding in rivers mainly occurs as a result of heavy rainfall coupled with rapid snowmelt; the sources of most of the rivers lie in the mountains and are fed by snow and glaciers. Lack of vegetation and denudation of the mountain areas also contribute to the occurrence of flooding. Urban flooding is a problem in major cities, and is often caused by intense local rainfall in combination with inadequate drainage systems. Flooding in May 2014 affected 90,000 people – displacing 20,000 – in 14 northern provinces, exceeding US$100 million in damages (The World Bank, 2017).

Most provinces in Afghanistan are susceptible to annual flooding, with areas closest to the river, which are the most densely populated and at most risk. According to the WASH Severity Classification (WSC) all three of the analyzed provinces are susceptible to flooding, Parwan Province has been affected most recently (August 2020), which destroyed agricultural land and contaminated water sources. In Helmand Province, flooding typically occurs between January and April, and has previously caused damage to water wells and drainage systems. Kunduz Province most recently saw a series of floods in May 2020 and experienced similar issues (WSC, 2020). Harirud and the Helmand basin have high levels of flood hazard, while Kabul Province is most affected population wise (The World Bank, 2017). According to the Afghanistan Water Resources Profile Overview (USAID, 2021), rapid snowmelt flooding has been an issue for communities on the lower reaches of the Helmand Basin near Kandahar and may worsen as temperatures rise.

Another flood risk to consider is a Glacial Lake Outburst Flood (GLOF), which is a sudden release of water from a lake fed by glacier melt that has formed at the side, in front, within, beneath, or on the surface of a glacier. The frequency of GLOFs and risk from potential GLOFs are expected to increase in Afghanistan as the climate continues to change. As temperatures rise, new lakes form, existing ones expand and sometimes merge, increasing the potential flood volumes in the high mountains.

Drought risks

Given the increasing severity, frequency and impacts of droughts in Afghanistan, the Government of Islamic Republic of Afghanistan decided to make a paradigm shift in its approach from the formerly management of drought as a disaster to proactively managing the risks of drought; resulting in the formulation of a long-term (2019-2030) strategy for drought risk management by the Food and Agriculture Organization of the United Nations (FAO, 2019).

Afghanistan suffers from recurring droughts with varying length and severity, affecting millions of people and causing large economic damages to agriculture, households and hydropower production. Droughts pose a threat to livelihoods, income and poverty reduction efforts as over 85% of the population rely on agriculture for livelihood (The World Bank, 2017).

In the last two decades, Afghanistan has experienced more severe and prolonged droughts than ever before. Half of Afghanistan's agricultural land depends on spring rainfall, which has become less reliable because of climate change. According to the Afghanistan drought risk management strategy (FAO, 2019), by 2030, annual droughts in many parts of the country will likely become the norm. On top of this, the country's population has more than tripled since the 1960s, while arable land has not expanded. The increased frequency of droughts has already made the country more dependent on imported food and pushed more Afghans into food-insecurity (Mayar, 2021a).

The primary element causing intra-annual variation are large-scale climate phenomena, namely the El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole that are associated with droughts in Afghanistan. The low-lying southeastern region is already chronically affected by the effects of drought (Asian Development Bank, 2021).

Trends in increasing temperature have been reported at all meteorological stations, however no specific trends could conclusively be derived. This implies, that the number of cold days is decreasing whereas the number of warm days is rising and that the temperature has already risen by approximately 0.6 – 1.8°C (Shokory J.A.N., Schaefli B. and Lane S.N., 2023).

Heat waves cause regular high maximum temperatures exceeding the maximum average temperature significantly in some extreme hot areas such as the cities Kandahar and Herat, where the summer maximum is up to 5 to 7 °C above the July average of 33 °C. Based on the current projections, heat waves could reoccur in 6 – 10 year intervals (Asian Development Bank, 2021). Drought risk is highest in the Helmand basin and lowest in the northeast of Afghanistan (The World Bank, 2017).

The 2018-drought directly affected more than two-thirds of Afghanistan (22 out of total 34 provinces) with around 10.5 million people (of the total 17 million in these 22 provinces) being most severely affected, according to the Food and Agriculture Organization (FAO) in the Afghanistan Drought Risk Management Strategy 2019-2030 (FAO, 2019).

In 2021, Afghanistan experienced one of the worst droughts of the last two decades. While drought is a frequent and devastating phenomenon in Afghanistan, climate change is making for more regular and more severe droughts, with the 2021-drought worse and more widespread than the last one in 2018. Conditions were particularly severe in the south, western and northwestern parts of the country. Water resources in these regions are severely reduced – a major factor behind 19 million people – nearly half the country's population – at crisis levels of food insecurity and poverty (Mayar, 2021b).

Several strands of scientific analyses and experiential evidence from Afghanistan indicate the increasing frequency, scale, duration, and impacts of drought in the country; a trend that is set to intensify in the future according to all climate change scenarios for Afghanistan (FAO, 2019).

During recent drought years, use of deeper groundwater via better pumps is rapidly decreasing water tables and depleting aquifers. Both state and non-state organizations drill many of these new wells and extract without restraint as much water as possible (Shroder et al, 2021).

With a decrease in annual precipitation combined with an increase in temperature in most sub-basins in Afghanistan, higher evaporation rates will cause more frequent and severe droughts that can affect streamflow and aquifer recharge. Projections indicate that evaporation rates will increase and that severe droughts will be 55 to 85 percent more frequent later this century (USAID, 2021).

3.6.3 Snowmelt, glacial retreat and surface runoff

In Afghanistan, the annual water supply relies largely on winter precipitation in the mountains that accumulates as glaciers, snow and ice and act as natural stores. Meltwater from glaciers, snow and ice in the mountains feeds irrigable land, rivers and reservoirs. Due to climate change, enhanced by the occurrence of the La Niña phenomenon in the Pacific Ocean in some years (like in 2021), drier and warmer than normal wet seasons do occur more often and lead to a considerable reduction in snow and rain. As a result, water shortages are devastating Afghanistan's agriculture and pastures and led to water scarcity for human consumption (Mayar, 2021b).

For the people of Afghanistan who rely on surface water runoff, glacial retreat means a more frequent uncertain agricultural growth season. This is because some rivers rely on water stored in glaciers and that feed rivers with meltwater during summer, when the climate is driest. Thus, glaciers improve the resilience of downstream populations during periods of droughts (Shokory J.A.N., Scahefli B. and Lane S.N., 2023). Cognizant of the observation that summer is the season where the irrigation water demand is highest, fluctuations in temporal and spatial availability of water resources can have detrimental affects on domestic food production and poverty alleviation as the reliability on surface water dwindles (Frotan M.S. et al., 2020).

As winter meteoric precipitation changes from snow pack that builds up during the winter months and melts slowly over the spring and summer, to rain that runs off immediately, relatively more rain instead of snow will lead to earlier peaks in river flow. This could also be considered as an opportunity to increase surface water storage, slow down the water and use at as recharge water for managed aquifer recharge structures. The median change in annual mean temperature projected for the period from 2011 to

2100 is 5.4 °C, but may differ depending on region, altitude and season (Climate Information Platform, 2023). The annual median change in precipitation is projected to be -3.7%, however changes in precipitation vary spatially where the higher, eastern parts of the country experience a positive change and the lower-lying, western region experience a negative trend. This will result in a relative decrease in water discharge of 50% in most of the country till 2100, which means, that during the dry summer less amounts of water becomes available or stream flow will cease earlier (Climate Information Platform, 2023).

With regards to the effects of climate change in the cryosphere and atmosphere, different conclusions have been drawn on how changes have and will cause new stream flow patterns. According to a national-wide study based on measured hydrological data by the Ministry of Energy and Water (MEW), the mean streamflow volume has decreased by 13%. This conclusion was drawn based on a measurement period between 1969 – 1980 and 2007 – 2016 as shown in Table 5. These effects are particularly observed in the Kabul Basin, where approximately 35% of Afghanistan's population lives (Houben and Tuennermeier, 2005).

Table 5. Surface water volume in five of Afghanistan's river basins between 1969 – 1980 and 2007 – 2016 (Shokory J.A.N., Schaefli B. and Lane S.N., 2023).

River basins (RB)	***Surface water [BCM] (1969 – 1980)***	***Surface water [BCM] (2007 – 2016)***	***Decrease in 2016 [%]***	***Projection by 2030 [BCM]***	***Decrease by 2030 [%]***
Kabul	19.3	17.1	-11	15.3	-21
Amu Darya	21.5	18.7	-13	16.2	-25
Helmand	10.4	8.4	-19	7.1	-32
Harirud Murghab	3.4	2.53	-26	1.7	-50
Northern Rivers	2.1	2.2	+5	2.0	-5
Total	**56.7**	**49**	**-13**	**42.3**	**-26**

While a decrease in river discharge may be the case for some basins, in other areas, notably the Northern River Basin experiences 12% higher discharge rates according to Frotan et al. (2020) and 5% higher discharge rates according to Shokory J.A.N., Schaefli B. and Lane S.N. (2023). This increase is likely attributed to glacial retreat and an increase in meltwater causing increased runoff patterns for some years. Hence, by 2100 at least half of the glacial mass in the Eastern Hindu Kush subregion is expected to melt and disappear, and where changes in the stream flow regime are expected (Bolch et al., 2019).

The state of the potential water resources of the five major river basins has most recently been assessed by the MEW, who analyzed the snow-water equivalent through observations in precipitation and snow patterns over the past 10 years for the months from October till March, and compared it with the 2022/2023 season (Taufiq, 2023). For their assessment, only 30 weather stations were available from which the readings were extrapolated to the whole river basin. A comparison was drawn from changes in a 10 year period, which is, in terms of long-term changes, too short and the resolution too coarse. It should be noted also that 2022/2023 was a drought year, which partly explains the overall negative percentual change.

The results of the analysis in Table 6 show a decreasing trend in precipitation and snow depth, however high variations were observed from a year-to-year basis, demonstrating the need for more data over a longer time span to predict future trends in precipitation and snow depth. Taufiq (2023) also pointed out, that the snow water equivalent estimated with satellite images was higher (20.99 BCM) compared to the calculated value of 14.60 BCM. It is further worth considering that the satellite imagery are not accurate in terms of absolute values and which would need calibration with ground-truthed data.

Table 6. Analysis by the MEW (Taufiq, 2023) of the precipitation and snow depth for the major river basins in 2022/2023 compared to the ten years before, based on extrapolation from 30 weather stations.

River basin	Precipitation [in mm]			Snow depth [in cm]		
	Av. 2012 – 2023	2022/2023	% change	Av. 2014 – 2023	2022/2023	% change
Harirud-Murghab	135.3	122.9	-9	104	92	-12
Helmand	49.4	34.3	-31	176	152	-14
Northern River	179.6	142.2	-21	245	176	-28
Kabul	122.9	97.9	-20	130	130	0
Amu Darya	210.8	216.7	3	234	111	-53
Total average	139.6	122.8	-12	178	132	-26

4 Groundwater systems

Groundwater availability and accessibility varies significantly across Afghanistan due to geologic and climate conditions. Groundwater is concentrated in broad alluvial deposits following the courses of intermontane rivers. Most groundwater recharge is linked to infiltration along those rivers.

The aquifer systems in the Central Highlands (the Hindu Kush Mountain Range) generally contain good quality and quantity water. This includes the three connected aquifer systems (Kabul, Paghman, and Logar) in the Kabul River Basin, which are highly permeable.

There are over 5,000 mountain springs mostly in the upper catchments of the Helmand River Basin

Groundwater in the Northern Plain (Northern River Basin around Mazar-e Sharif) is less accessible due to naturally higher salinity. The aquifer systems in the Great Southern Plain (Dasht-e Margo and Registan Deserts) are not well studied but shallow groundwater is readily available along major watercourses.

Shallow aquifers are commonly found in mountain valleys that are filled with Neogene and Quaternary sediments from erosion and river transport. Deeper aquifer systems are mainly unexplored, or were not readily available and digitalized, but especially semi-consolidated sediments and carbonate rocks could have high potential for groundwater development.

Aquifer systems in unconsolidated sediments are recharged mainly via focused infiltration from rivers and streams, while bedrock aquifers rely on diffuse infiltration of precipitation for recharge. The aquifer systems in the southern and northern desert parts of the country receive very little recharge due to low precipitation and high evapotranspiration.

High levels of salinity and naturally occuring contaminants, including arsenic and fluoride have been found in groundwater in most basins. Anthropogenic groundwater contamination is particularly severe in Kabul and as a direct result of the high number of households not being connected to the sewage network (86%).

Afghanistan can be characterized by three distinct hydrogeological areas: the Central Highlands, the Northern Plain, and the Great Southern Plain. Most groundwater is located in the Central Highlands, where water of sufficient quantity to meet the needs of the population is available primarily by digging wells into unconsolidated alluvial aquifers located in mountain valleys (Gellasch C.A., 2014).

4.1 Geology

The dominant feature of Afghanistan's geology is the Safed Koh/Koh-e-Baba/Hindu Kush range of mountains, which trend dominantly WSW–ENE. These are essentially a continuation of the Himalayan range. These consist mainly of lithified rocks of pre-Paleogene age (see Figure 12) and are dominated by metasediments (sandstones, slates, metaconglomerates, limestones, metabreccias, phyllites, schists, etc.), with some igneous rocks such as granites. The rocks are faulted, folded and deformed.

The plains surrounding the mountain ranges and the valleys between the mountain ridges are filled with Neogene and Quaternary sediments (see Figure 12), which are the products of erosion of the mountains and deposited at the foot of the mountain (proluvial), by a stream (alluvial) or by a lake (lacustrine) and have not been significantly deformed. Adjacent to the mountains, the sediments are dominated by coarse deposits such as gravels and pebbles, while further away from the mountains, the deposits are dominated by finer sediments such as fine sands/silts. The Neogene and Quaternary sediments also contain some volcanogenic deposits such as tuffs and lavas.

The Geologic and Mineral Resources Map of Afghanistan (Doebrich and Wahl, 2006) was developed by a joint collaboration between USGS and the Afghanistan Geodesy and Cartography Head Office. This map presents information about geological units, lithology, minerals, oil, gas, coal, water and earthquake hazard. However, the information shown on this map is derived from digitization of the original data from Abdullah and Chmyriov (1977) and Abdullah et al (1977). A simplified version of the Geologic and Mineral Resources Map of Afghanistan (Doebrich and Wahl, 2006) showing the geological epochs is shown in Figure 12. As more than two decades of war and a lack of security have prevented geological fieldwork (such as geophysics) that otherwise would have provided insight, updates on geological knowledge, has ceased since the late 1970s (Shroder et al., 2021).

The most extensive summary on what is available on the country's geology was provided by Schroder et al.'s (2020) study '*A review of Afghanistan and its water resources',* who, among other things points towards the complexity and variety in bedrock geology. What has been documented is the tectonic history of the region, that describes the faulting due to tectonic forces and which comprise the major tectonic features (Gellasch C.A., 2014). Information on faulting is primarily generic, meaning that there no studies have mapped the location and density of faults with quantitative methods other than describing the potentiality based on what is known on the geology. Only the USGS has attempted to map Quaternary faults in Afghanistan in the study *'Map and Database of Probable and Possible Quaternary Faults in Afghanistan*' (Ruleman C.A., 2007). A simplified geological sequence for Neogene and Quaternary deposits (light and dark yellow in Figure 12) in Afghanistan is described in Table 7.

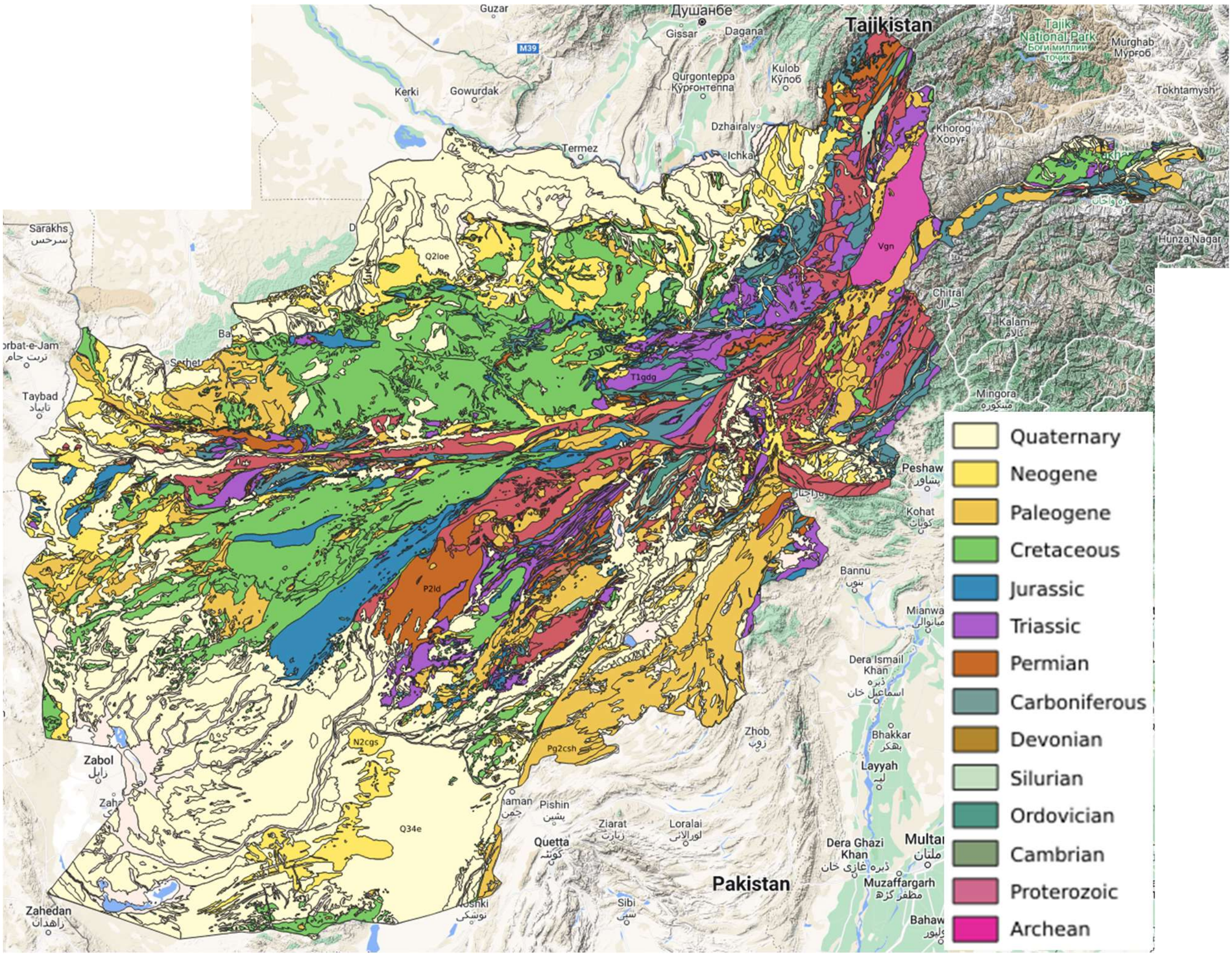


Figure 12. Geological Map of Afghanistan with a simplified legend showing the geological epochs, adjusted by Acacia Water from the original geological map of Doebrich and Wahl, 2006.

Table 7. Overview of a simplified geological sequence for Neogene (Miocene and Pliocene) and Quaternary deposits in Afghanistan (Banks and Soldar in 2002).

Period	Location	Description
Quaternary		Unconsolidated fluvial, lacustrine, glacial, and alluvial sediments, with travertine and volcanics
Pliocene	Northern part	Up to >5,000 m sandstone and conglomerate with interbedded clays and siltstone.
	Other parts	Up to 2000 m sandstone, conglomerate, clay, and siltstone. May also contain lacustrine deposits and volcanics. May be gypsum or brine bearing.
	Southwestern and western part	Up to 100 m of lacustrine clays.
Miocene	Northern part	200 – 300m siltstone, sandstone and clay
	Southern part	100 – 500m sandstone

No detailed assessments for groundwater development potential for different geological units, especially on the sedimentary and igneous rock have been conducted, or, where not readily available and digitalized. With respect to Table 7 its worth pointing out that the sandstone layer may be due to its thickness a huge potential source for groundwater resource development, however without more in-depth hydrogeological investigation no conclusions statement can be given on this presumption.

4.2 Hydrogeology

Based on scattered hydrogeological data in Afghanistan, particularly the work of Malyarov and Chmyriov in 1975 - 1976 and the 1986 UNDP report, the country can be divided into three hydrogeologic regions as shown in Figure 13 (Gellasch C.A., 2014). According to Shroder et al (2021) the three generalized major aquifer regions have been recognized but not mapped in any detail.

Figure 13. Depiction of the three hydrogeological units / regions in Afghanistan.

4.2.1 The Northern Plain

The Northern Region covers only 15% of Afghanistan geographically (Figure 13) and coincides with the Panj Amu Basin and the Northern River Basin. Generally, the northern artesian aquifers are medium to highly porous, consisting of consolidated and unconsolidated sediments and sedimentary rocks with low to medium permeability and transmissivity, limitations of GW storage, and no suitable GW quality observed or proved in most areas. Shallow unconfined aquifers here are commonly salty. Fresh-water aquifers occur closer to the mountain sources in the younger alluvium (Shroder et al, 2021).

Gellasch (2014) divides the Northern Plain into two hydrogeological sub-regions: sediments around stream valleys (alluvium) and sediments at the foot of slopes and/or deposited by wind (the eolian-prolluvial complex). The stream valleys are a narrow belt of fluvial and delta deposits saturated with fresh water, adequate yield and shallow depth to the water table. The eolian-prolluvial complex contain shallow and deep aquifers with brackish to saline water and are therefore deemed unsuitable for human and possibly also livestock consumption without significant investments for treatment (Gellasch C.A., 2014). Close to the northern border of Afghanistan, up to 6 km of thick Mesozoic- and Cenozoic-age strata (Triassic basalts, Jurassic evaporites, Cretaceous / Paleocene shallow-water marine limestones, Cenozoic continental deposits) overly the basement (Shroder et al., 2021).

4.2.2 The Central Highland Region

In the Central Highland Region the Hindu Kush mountain range is the most prominent feature defining the hydrogeology of the Central Highlands (Uhl, 2003). The Central Highlands comprise 50% of Afghanistan's aquifers (Figure 13) and is subdivided into the carbonate massif, the non-carbonate complex and the intermontane river basins. The larger area of the Central Highlands is made from non-carbonate complexes formed by a mix of sediments and crystalline rock that either yield no water or water sources are highly localized. The geology of the carbonate massif consists of limestone and dolomite, which yields no water at upper surfaces but springs yielding significant discharge are present along the contacts of geological units, e.g., at a topographic break when an underlying lower permeable layer is present. Areas that are of interest for groundwater abstraction for near-by residents are stream basins of alluvium that contain groundwater reserves (Gellasch C.A., 2014).

The central Afghanistan aquifer system is mostly hard metamorphic and igneous rocks in which groundwater is only in fractures or weathered zones with medium values of permeability and transmissivity. Thermal springs occur with good quality groundwater in a few localities. Unfortunately, no detailed investigation has been done on occurrence of groundwater resources in fractured aquifers of metamorphic and igneous rocks or the karst aquifers of carbonate rocks in Afghanistan. Fresh-water groundwater storage occurs in the river basins in the alluvium (Shroder et al, 2021).

4.2.3 The Great Southern Plain

The south and southwest of the country includes the Helmand and western flowing rivers basins. The Great Southern Plain is from a hydrogeological perspective subdivided into the Registan Desert, the Dasht-i-Margo Desert and the Piedmont area. In he Registan Desert aquifers exhibit low productivity with brackish to saline water quality due to high evaporation and low rainfall in the area. In the Piedmont area, different types of river sediments where deposited, making aquifers heterogeneous and the water quality ranges from fresh to slightly brackish. In Kandahar Province, reports have indicated free flowing or artesian wells which require no pumping, which means no power source is needed to pump the water (Gellasch C.A., 2014).

The southern and western artesian aquifer that extends north along the Iranian border contains consolidated sedimentary rocks and unconsolidated sediments with low to medium permeability values. Fresh-water GW storage occurs in river basins and plains areas with medium to high capacity of storage and potential for high yield (Shroder et al, 2021).

The hydrogeological map of Afghanistan (Figure 14) was digitized by DACAAR in 2017, and varies slightly from the original map made by the Russians in 1977.

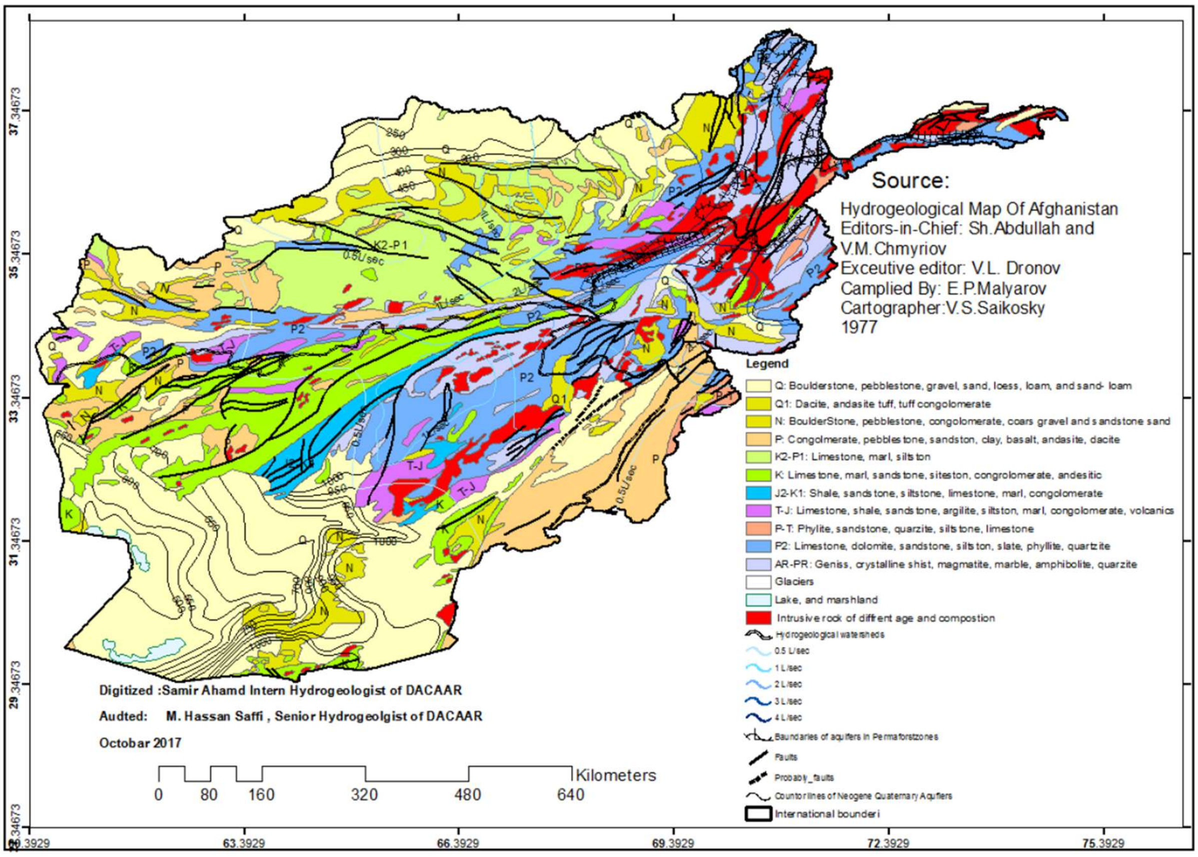


Figure 14. Hydrogeological map delineating the aquifers at national level (DACAAR, 2017).

4.2.4 Aquifer systems

Gellasch (2014) and Uhl (2003), describe three principle water-bearing formations in Afghanistan: unconsolidated and semi-consolidated sedimentary deposits, carbonate rocks and bedrock aquifer systems. Most of the available hydrogeologic data and information is for the aquifer systems within the unconsolidated and semi-consolidated Quaternary, Neogene and Paleogene sedimentary deposits. The primary water-bearing layer in the Kabul Basin, consisting of unconsolidated and semi consolidated sediments, is likely the best studied aquifer system in Afghanistan. The bedrock aquifer systems in the country are largely unexplored and some of these units may well represent valuable sources of irrigation and potable supply in the future (Gellasch, 2014).

Unconsolidated aquifer systems

The unconsolidated aquifer systems combine intermontane and stream valleys and generally all systems consisting of Quaternary deposits and Neogene sediments. Unconsolidated materials range from alluvial, colluvial lacustrine and glacial deposits. Alluvial and colluvial unconsolidated to semi-consolidated aquifers comprising 20% (in area) of the total mapped aquifers, while these aquifers contain an estimated 70% of the available shallow groundwater reserves. Aquifer systems that are classified as such are the major river valleys particularly in the Kabul River Basin, the river systems in the Helmand River Basin to the east (Ghazni, Tarnak, Arghistan and Arghandab), the Harirud River and certain river systems within the Northern Flowing Rivers and Panj Amu Basins. As emphasized, the intermontane stream basins in the central highland region are arguably the most hydrogeologically significant (in terms of productivity) in the entire country as a major proportion of freshwater storage is located in these basins. The most important of the intermontane basins include those near the cities of Ghazni, Khowst (Khost), Jalalabad, and Kabul.

Carbonate rock aquifer systems

The carbonate rock aquifer systems occur within the Hindu Kush mountain range and at its northern and southern flanks. The carbonate massif to the north is comprised of limestone and dolomite locally interbedded with sandstone and conglomerate. Limestone and dolomite aquifers make up only 15% of the total mapped aquifers and contain 20% of the available groundwater reserves (Gellasch C.A., 2014). There are occurrences of sink holes, caves and caverns. Due to the karstic nature of limestone, underground flow is hard to predict. Significant springs issue from the carbonate massif on the northern flank of the Hindu Kush and some of these springs form the headwaters of the rivers in north central and northwest Afghanistan (Northern Flowing Rivers Basin and the western part of the Panj Amu Basin) (Uhl, 2003).

Bedrock aquifer systems

The bedrock formations are composed of either crystalline rock such as granites, schist, gneiss, or sedimentary rock units. Crystalline rocks do not have significant yield potential, but the sedimentary rocks underly large parts of the country, may have been subject to significant fracturing, but no hydrological exploration of these systems is recorded (Uhl, 2003). A rough estimation indicated that these aquifers of low permeability comprise 65% of the country and store up to 10% of the available groundwater resources (Gellasch C.A., 2014).

Kabul Basin aquifer system

Kabul City almost entirely depends on groundwater and rely on (see Box 1 in chapter 5.1) four aquifers in the Logar-Upper Kabul river basin, with the majority of groundwater water coming from the shallow aquifer which reaches a depth of up to 150 - 200m. Water tables vary considerably beneath Kabul, typically from 30 to 70 meters, depending on distance from the main riverine recharge source and the local abstraction rate Mack et al (2014).

The Kabul aquifer system is composed of several superimposed aquifer layers. The upper one in the unconsolidated Quaternary sediments, is the most commonly exploited (Figure 15). The aquifers in the underlaying semi-consolidated are less used. Similarly, aquifers in the sedimentary and in the fractured metamorphic and crystalline bedrock of the surrounding mountains and interbasin ridges are the least used aquifers in the Kabul Basin. Alluvial fans have developed on the flanks of the mountains. Deposits in the central plains include alluvium and unconsolidated sediment, typically less than 80 m thick, that overlie semi consolidated conglomerate sediment up to 1,000 m thick, which could bear a significant resource. Studies that have investigated aquifers in the southern Kabul Basin include those by Japan International Corporation Agency (2007), Lashkaripour and Hussaini (2008) Houben et al (2009) and Mack et al (2014).

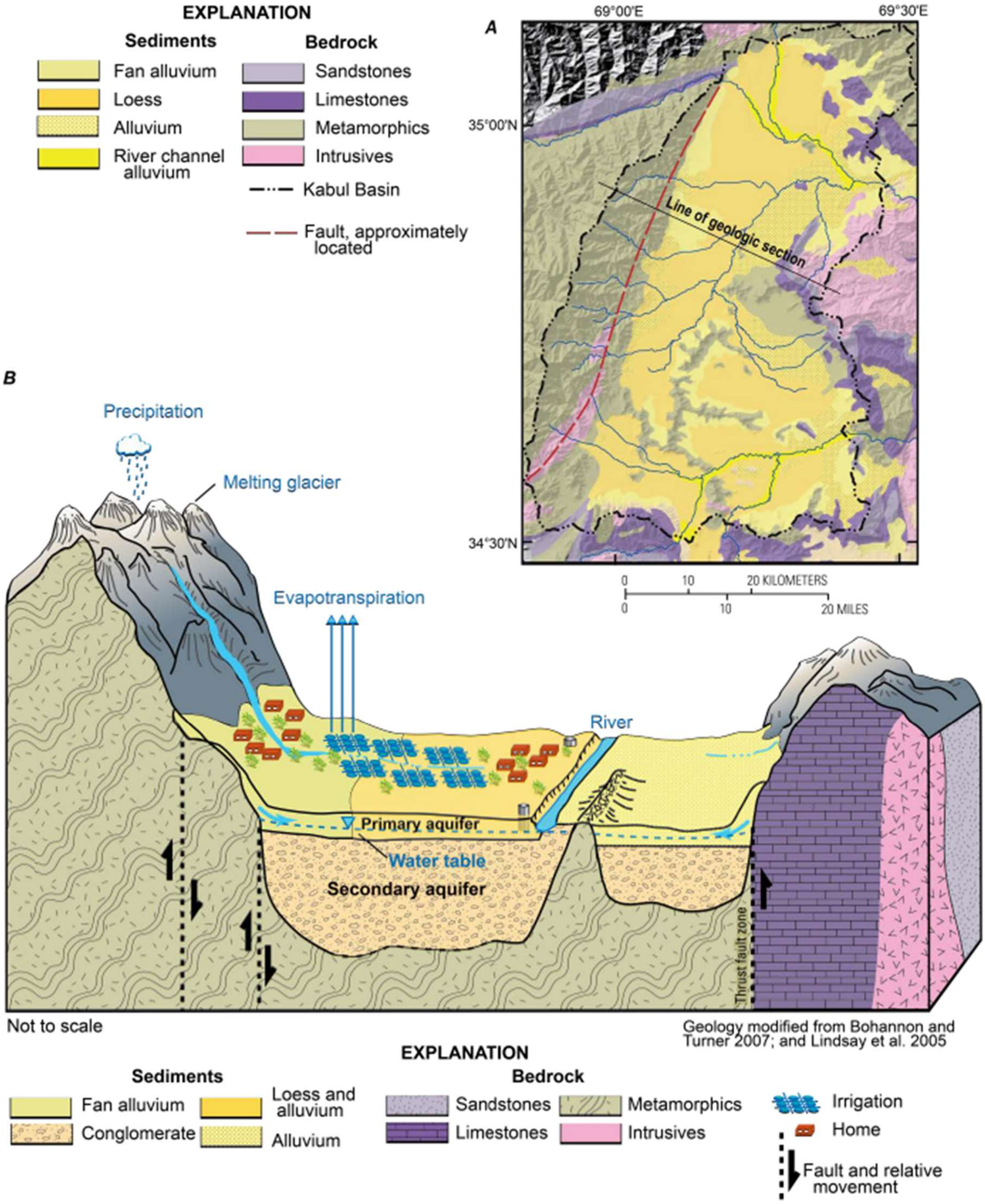


Figure 15. Generalized surficial geology and hydrogeological cross section and schematic diagram of the Kabul Basin aquifer system (Mack et al, 2014).

4.3 Groundwater recharge

Surface-groundwater interaction is poorly understood as there are no rigorous studies on groundwater recharge and aquifer development. While there has been no in-depth country wide evaluation of aquifer/groundwater recharge, several NGOs, consulting firms, and Afghanistan Governmental Departments have conducted studies to evaluate the magnitude of groundwater recharge in specific areas. A useful synthesis of the past studies of groundwater recharge is presented in the study of Uhl (2003).

An example of one of the exceptional groundwater balance studies on basin scale focused on the central Kabul sub-basin and viewed it as an integral part of the neighboring sub-basins. With the objective to quantify the potential contribution to groundwater regeneration as well as compensating the potential deficit with artificial recharge , the study focused on the surface water transmission loss of the Panjsher, Logar, Maidan, Paghman, Skakar-Dara and Istalef Rivers and how this varies spatially and temporally along the longitudinal channels. The results were used to calculate the proportion of infiltration water that actively recharges the groundwater in the central Kabul sub-basin. The study's outcome were intended for policy makers to understand the groundwater recharge potential to establish restrictions and options for sustainable groundwater management in Kabul (Najibullah, 2020)

Based on the overview given in Uhl (2003), the predominant groundwater recharge mechanisms include the following:

- Firstly, the Quaternary and Neogene aquifers are recharged mainly via focused (or indirect) infiltration from rivers and streams through runoff water originating from the high mountains that descends into the coarse, alluvial river beds and alluvial fans. In some river valleys, diffuse (or direct) recharge of precipitation in lowland areas occur from snowmelt in the winter and spring seasons. There is also a component of recharge from the bounding higher elevation bedrock systems to the unconsolidated and semi-consolidated sedimentary layers containing the Quaternary and Neogene aquifer systems from recharge at higher elevation traversing the fractured bedrock formation. Lateral inflow to lower lying areas occur through fractures and infiltrating streams, that are recharged by precipitation high-up in the mountains.
    - Naturally, recharge is highest during the snowmelt season, which is why these aquifers are sensitive to changes in precipitation and runoff quantities and patterns.
    - This dynamic has also been observed throughout the monitoring network from DACAAR, where areas that recently received precipitation that infiltrates causes a rise in water level.
    - Karezes (see section 5.2.2) have for centuries been installed in the same geological setting and the recharge mechanism explains their sensitivity to climate change and overexploitation of the most shallow unconfined aquifer by pumping.

- Secondly, the bedrock aquifers, which comprise a vast land area in Afghanistan, mostly rely on the diffuse infiltration of precipitation for recharge. This recharge will vary depending on the degree of fracturing, altitude, and relative amounts of precipitation and evapotranspiration. Some recharge originates from focused recharge were outcrops at hills and mountains occur

- Thirdly, the carbonate rock aquifer systems, from which large springs emerge, particularly on the northern flank of the Hindu Kush, are probably recharged from the diffuse infiltration of precipitation.

- Lastly, the aquifer systems in unconsolidated sedimentary deposits in the southern and northern desert parts of the country receive very little recharge due to very low annual precipitation and high rates of evapotranspiration. Therefore, most rain evaporates. Episodic recharge as a result of multiple and significantly large rain events in a row can saturate the soil and cause some water to infiltrate. This creates diffuse recharge but is very rare (only once in many years) in semi-arid and arid environments. Concentrated recharge through floodwater filling wadi-beds might occur more frequently (once a year) in some wadi or stream basins.

The possible recharge mechanisms of deep(er) aquifers have not been studied and described so far. In general, deep aquifer systems require much longer to be recharged due to their depth and travel time of the water after infiltration, or they are not connected anymore to the current area of recharge (fossil water).

4.4 Groundwater quality

Few studies have been carried out that involved assessment of groundwater quality. DACAAR undertook some of the most comprehensive research on a national scale (Hayat E. and Baba A., 2017). Basins and catchments were severe groundwater quality issues are known to occur are the Chak Karstic Sedimentary Basin, Wardak Province the Kabul Basin and Kabul and the Mazar-i-Sharif City in North Afghanistan (Rasouli et al., 2021; Mahaqi et al., 2018; Houben G., Tuennermeier T. and Himmelsbach T., 2005; Saffi and Kohistani, 2016). Still, the actual number of localized studies may be larger and groundwater contamination may deviate at local level.

The rural WASH website of the Ministry of Rural Rehabilitation and Development (MRRD) provides many maps on provincial level, based on the DACAAR Hydrogeology and data information system (October 2018) indicating the presence of various hydrochemical and physical parameters in groundwater such as nitrate, turbidity and fluoride. These maps are useful to get an indication where water quality issues are expected to occur. The maps do not show the location and number of data points are, nor information on the depth of the groundwater or the time of sampling. In addition, in areas with a limited amount of water quality analysis (for a certain chemical parameter), the maps can create a bias by suggesting information on groundwater quality while actually representing the availability of information. Without further information, care should be taken using and interpreting these maps. This would require a more detailed water quality analysis in specific areas.

For further distinction, pollutants leading to insufficient groundwater quality found in Afghanistan discern between natural (geogenic) groundwater contaminants, including boron, fluoride, arsenic selenium, and uranium, and anthropogenic contaminants (such as nitrate and coliform bacteria) that can be attributed to agricultural activity, septic tanks system as well as domestic and municipal wastes (Hayat E. and Baba A., 2017). A geographic overview of the dominant geogenic and anthropogenic contaminants is given in Figure 16 and Figure 17, where provinces with no indication were not part of the study. Safi and Kohistani (2013) have studied 764 drinking water points in roughly 50% of the country and 19 provinces – the other 50% of the country was deemed unsafe for ground research (Hayat E. and Baba A., 2017).

In places where concentrations exceed WHO guidelines for drinking water are found, groundwater is not suitable for human consumption, but might still be suitable for agriculture and livestock.

4.4.1 Geogenic (natural) contaminants

Geogenic contaminants encompass fluoride, boron, selenium, uranium and especially arsenic, which is the most extensive and significant health risk.

DACAAR has published that the provinces Ghazni, Farah, Panjshir, Laghman, Faryab, and Logar have arsenic contamination in groundwater that exceeds the WHO guideline of 10 µg/l. Arsenic is occurring as one of many geogenic contaminants in the country, meaning it occurs naturally and is mobilized from arsenic minerals occurring in clay matrices which precipitates into the groundwater (Amini M. et al., 2008). Similar conclusions have been made by studies to investigate groundwater contamination with arsenic in Ghazni and Maidan Wardak Provinces (Saffi and Kohistani, 2016).

Concerning fluoride concentration, 15.9% of the total number of 1758 water samples exceeded the WHO recommended drinking water limit. Provinces with the highest cases of fluoride concentration are Balkh, Faryab, Badghis and Herat in the north and north-west and Kabul, Nangarhar, Maydan Wardak and Kandahar in the south. The presence of high fluoride concentration is commonly associated with granite rocks, suggesting granite is present in the local geology (Amini M. et al., 2008).

Boron contaminations have been reported as well and which are predominately of interest in agriculture, as certain vegetable and fruit crops are sensitive to elevated boron concentrations. Boron sampling as been intensively conducted in the provinces Kabul (the Kabul Basin), Faryab, Nangarhar, Ghazni, and Herat (Hayat E. and Baba A., 2017). Sulfate is primarily observed in groundwater samples in the north, northeast and northwestern provinces of Afghanistan and the mean values are highest in Badghis, Balkh, Herat and Helmand. Sulfate in drinking water can have laxative properties and pose a risk to human health (Hayat E. and Baba A., 2017).

Figure 16 and Figure 17 show the groundwater contamination map of Afghanistan due to natural factors and due to anthropogenic causes respectively (Rural WASH Dashboard, MRRD). However, it is not known how many samples (% or number) exceed limits, if these are shallow hand dug wells or deep tube wells, the type of aquifer, etc. When assessing maps, where geogenic and anthropogenic contamination is extrapolated to district or provincial level, it should be realised that geogenic contamination is highly localized, one aquifer or even one well may be suitable while a near-by aquifer or well might not be.

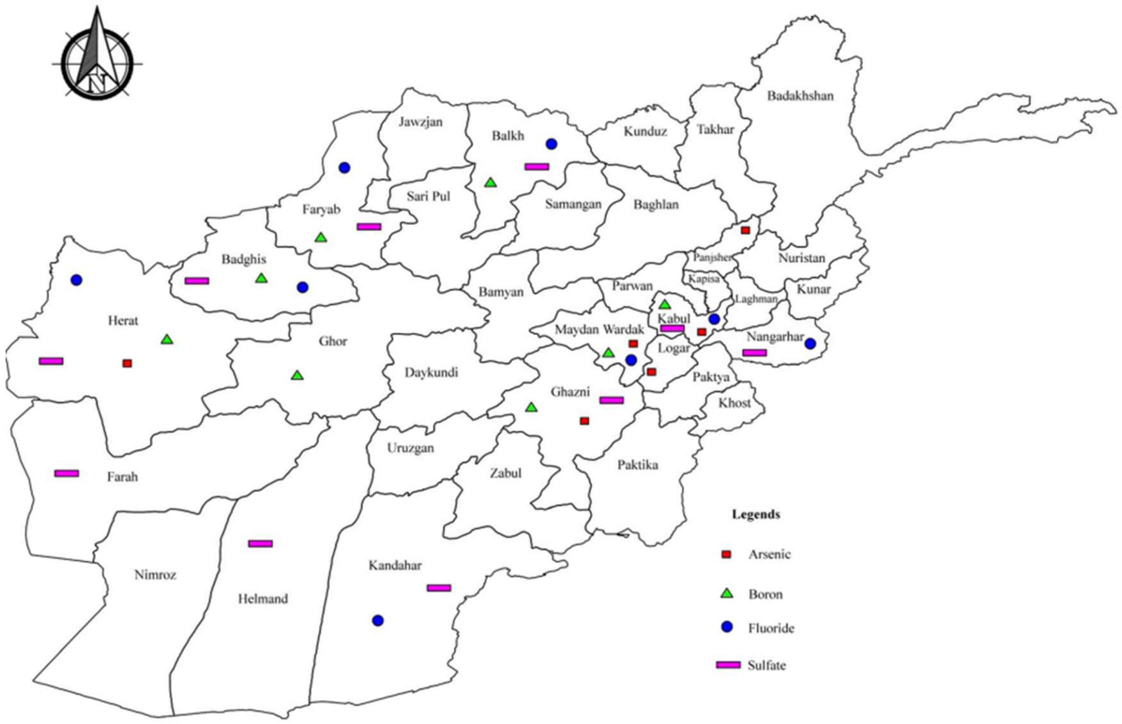


Figure 16. Groundwater map where the measured concentration of contaminants is exceeding the WHO limits due to natural factors (Hayat E. and Baba A., 2017).

4.4.2 Anthropogenic contamination

Anthropogenic contamination is particularly related to and of concern in urban areas, where poor sanitation prevails. Access to an improved water source does not mean that the water is safe to drink. For example, protected shallow wells in urban areas are often contaminated with E.Coli. Piped water supply can also be contaminated. Many households without access to an improved source take water from streams and rivers, open wells and unprotected springs, all of which are also often polluted. According to Himmelsbach T. (2005), 86% of households have a simple cesspit instead of being connected to a sewage network, but 20% only of Kabul's population have access to tap water and most likely rely on shallow wells. The numbers are likely to be equal or higher in other urban areas. The untreated and leaking wastewater poses great risk to the contamination of groundwater and potentially explains the high prevalence of water-borne diseases and contribute infant mortality in urban settings in Afghanistan. This relation becomes evident through the high presence of diseases and infant mortality. In Kabul City, approximately 1/3 of all sewage is assumed to leak and infiltrate into the ground and recharges the aquifer. Because the aquifers in Kabul City and the Kabul Basin are highly permeable, contamination plumes can spread fast (Houben G et al., 2009).

Similar patterns and problems have been observed for groundwater contamination from landfills and pesticide and fertilizer appliance in agriculture (Hayat E. and Baba A., 2017). In terms of agricultural activity, elevated nitrate and salinity levels can occur leading to groundwater quality that is even deemed unsafe for livestock and agriculture. It is assumed, that high salinity levels are multicausal due primary and secondary salinity. The causes for primary salinity can be water-rock interaction mainly occurring in the northern and central regions where the topography is mountainous. Combined with a low water table and high permeability, primary salinity can cause recharge of high saline water. The causes for secondary salinity are high evaporation rates and intensive agriculture (Himmelsbach T., 2005). In the Helmand River Basin, analysts also highlighted major concerns about the quality of the water being accessed for domestic use from various surface water sources, particularly in areas close to the Helmand River, where water salinity levels are reportedly high due to agricultural practices in general and poor irrigation drainage maintenance specifically (WSC, 2020).

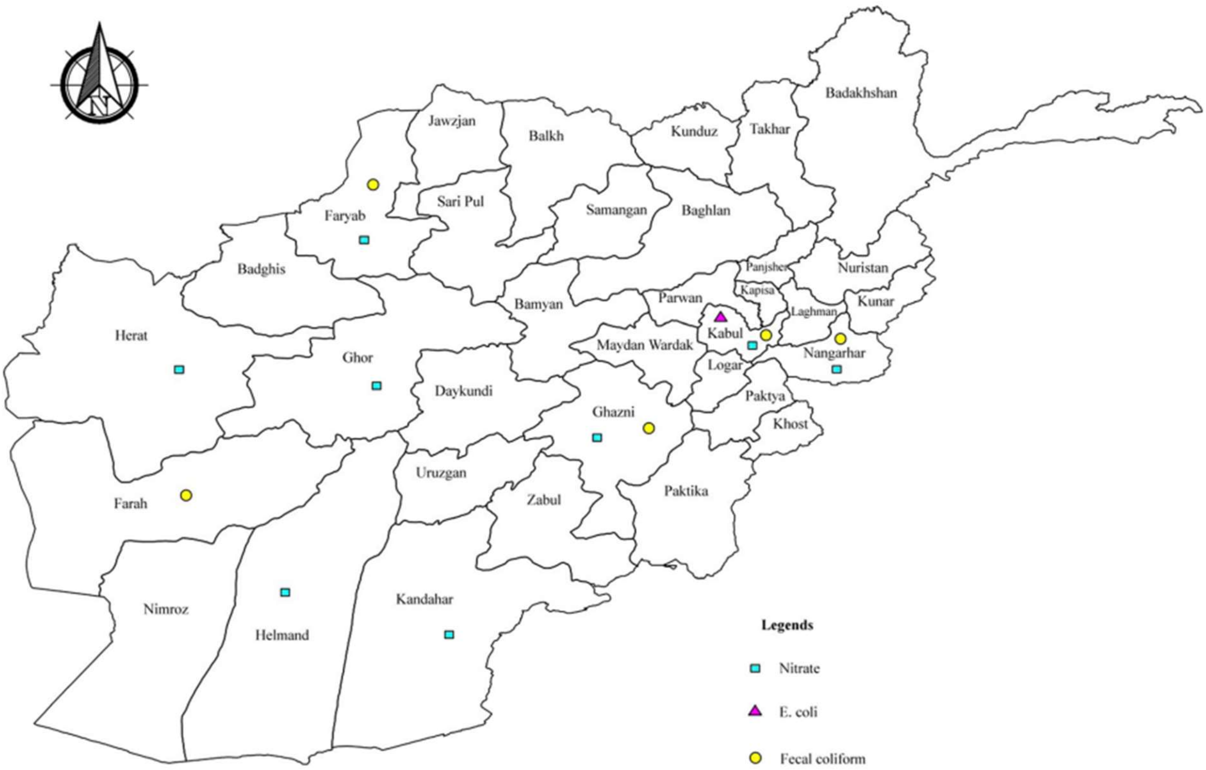


Figure 17. Groundwater map where the measured concentration of contaminants is exceeding the WHO limits due to anthropogenic factors (Hayat E. and Baba A., 2017).

5 Groundwater use

Irrigation abstractions are the largest use of groundwater in Afghanistan. Traditionally, groundwater has been developed and utilized for irrigation through the use of karezes (horizontal wells), springs and shallow hand dug open wells. However, over-abstraction has reduced their viability, and increasing water demand and climate change will further reduce their long-term viability.

Over the past decades, farmers in Afghanistan have turned to digging deep wells and using solar powered pumps for irrigation, which has improved their agricultural yields, but has also accelerated over-abstraction and groundwater decline.

Karezes vary in length from 2 to 10 km and are found in alluvial fans, exploiting unconfined groundwater sources, traditionally supplying people that live too far from rivers. Recent droughts and overexploitation have caused 60 to 70% of karezes to completely dry up.

Groundwater is the primary source of drinking and domestic water supply in most cities and rural areas. However, declining groundwater tables impact drinking water availability. Contaminated and depleted shallow aquifers are especially problematic for households as these rely on hand dug wells for their water needs.

Water balance estimations show that total groundwater recharge exceeds total groundwater abstraction for most of Afghan river basins, suggesting a potential for further groundwater development. However, these are estimations on a very large scale. On a local scale groundwater can still be depleted even if estimates on a basin level show a large surplus.

According to the most recent Afghanistan Multiple Indicator Cluster Survey 2022-23, 69% of Afghans have access to 'improved drinking water sources'. If properly constructed and well maintained, these improved drinking water sources are protected from outside contamination.

Kabul and other main urban areas rely on groundwater for potable drinking water as well as for peri-urban agriculture. Due to population increase and unregulated construction of deep tubewells, groundwater levels have declined. The main reason is that the groundwater abstraction rate exceeds the recharge rate.

Managed aquifer recharge, such as pilotted in the KMARP in Kabul, could help stabilize or raise groundwater levels, improve the supply and quality of potable water and make urban water supplies more drought resistant.

According to estimates of the FAO Aquastat, the total freshwater withdrawal in Afghanistan is 20.28 BCM/yr, of which 15 percent (3.04 BCM/yr) is from groundwater. The total municipal water withdrawal (0.20 BCM/yr) and industrial water withdrawal (0.17 BCM/yr) are assumed to be mainly from groundwater, but are only a fraction compared to agricultural groundwater withdrawal (2.7 BCM/yr). It should be noted that these figures have been estimated (carry forward, vertical imputation, linear interpolation) for the past two decades; the latest official data is from 1998.

In 2004, the estimated percentage of irrigation water originating from groundwater was 15% with 7.9% originating from springs, 7% from karezes and 0.5% from shallow- and deep wells combined. The remaining 85% comes from surface water and incidental rainfall (Favre R. and Kamal G., 2004). The proportion of irrigation water from deep wells has increased significantly over the past two decades, especially due to solarization (see Box 2). At the same time, the drying of karezes and springs has lowered the amount of irrigation water supplied by them.

The potential for further groundwater exploration, estimated in 2002, is evident from Table 8 and emphasized in several studies. However, concrete information on the spatial distribution, depth, thickness and other properties of aquifers is lacking, leading to the conclusion that groundwater potentials are estimated but there is little information on how such estimates haven been derived. In 2012, the water resources potential was estimated to be 80 BCM/yr, of which 22 BCM/yr from groundwater and 58 BCM/yr from surface water (The World Bank, 2012).

Table 8. The estimated water resources potential in Afghanistan (BCM/yr], according to Qureshi A.S., 2002 with in brackets an updated estimation from The World Bank (2012).

Water Resources	Potential	Present use	Balance	Future use	Balance
Surface water	57 (58)	17	40	30	27
Groundwater	18 (22)	3	15	5	13
Total	75 (80)	20	55	35	40

5.1 Domestic and industrial

According to the most recent Afghanistan Multiple Indicator Cluster Survey 2022-23 (UNICEF, 2023), 68.8% of Afghans have access clean drinking water through ‘improved drinking water sources’, a marked progress from a decade ago when drinking water reached only 20% of people. It should be noted that these improved drinking water sources are better protected from outside contamination compared to traditional water sources, but can still be prone to contamination, e.g. due to poor construction or lack of maintenance.

The Ministry of Urban Development and Land (MUDL), formerly the Ministry of Urban Development Affairs (MUDA), is responsible for policy and planning of water supply including the development of water master plans for cities. The Urban Water Supply and Sewage State Owned Corporation (UWASS) is responsible for the water services provision in urban areas, while the Ministry of Rural Rehabilitation and Development (MRRD) is responsible for the water supply in rural areas of Afghanistan.

Most urban centers and towns depend on groundwater from hand dug wells, commercial and municipal water supply for drinking and domestic usage (Uhl, 2006). Groundwater is utilized for domestic use for the approximately 5.6 million residents of Kabul (see Box 1) in addition to agricultural purposes (greenhouses) and industrial use (bottled water and beverage companies).

According to the Afghanistan Rural WASH dashboard of the MRRD, in rural areas, 63% of the beneficiaries are served by boreholes with hand pumps and 32% through piped water schemes (with solar pump, electrical pump or gravity fed). The remaining 5% is served through reservoirs or other water supply systems. The coverage of water supply in rural areas is shown in Figure 18. The MRRD dashboard does not specify the status of these water points (functional / dysfunctional), nor information on pumping rates or groundwater levels.

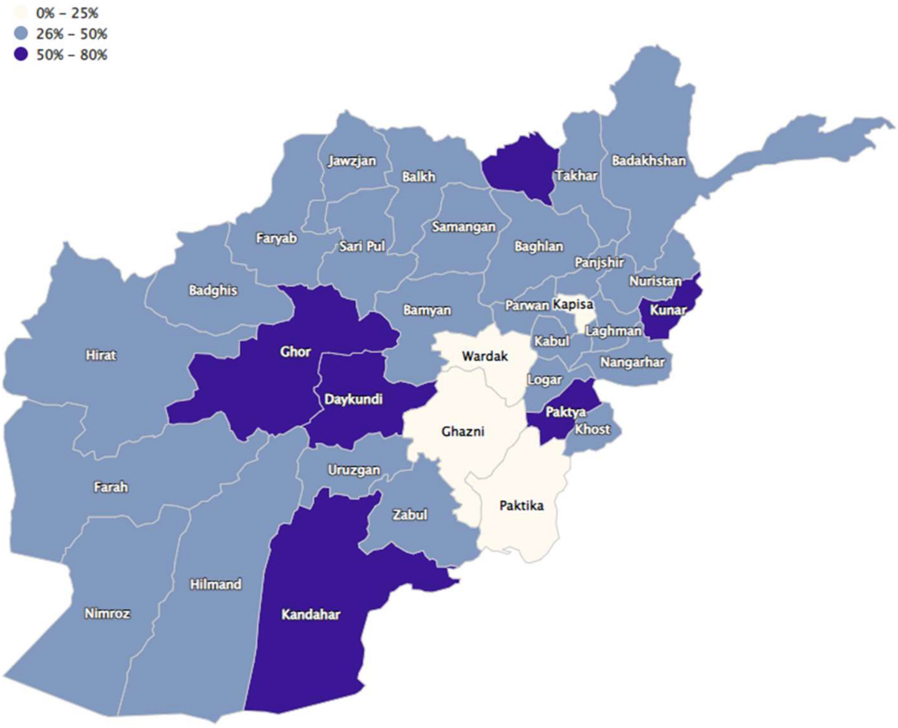


Figure 18. Coverage of water supply in rural areas, according to the Afghanistan Rural WASH Dashboard (MRRD).

A WASH Severity Classification (WSC) was undertaken in Afghanistan in October 2020 in three provinces: Helmand, Kunduz and Parwan (WSC, 2020). Results show that in Helmand Province, 17% of households accessed drinking water from unprotected wells or karezes, and 17% from surface water sources, with 66% using improved water sources (such as pumped wells, piped water, protected (covered) springs, wells, or karezes). In Kunduz Province 41% of households use unprotected sources, which is problematic in terms of water quality and also increases the risk of people contracting water-borne diseases. In addition, 8% of households reported having insufficient water for drinking purposes. In contrast, in Parwan Province, 98% of households use improved water sources (WSC, 2020).

In rural parts, smaller and larger settlements have evolved around the possibility of agricultural productivity to sustain a livelihood. With that, their existence depends on (shallow) groundwater, springs or surface water resources. According to Qureshi A. S. (2002). In order to obtain water, shallow wells are excavated and the depth increased as the water levels drop. The drop in groundwater level varies between 0.5 - 3.0 m/year based on the recordings from 2002 (Qureshi, 2002). Families that are unable to dig their wells deeper and whose wells dried up are forced to obtain water from communal wells.

Overexploitation of groundwater for domestic purposes is observed in the Harirud-Murghab and Helmand Basins as well as the metropolitan areas of Kabul and Kandahar (USAID, 2021).

Box 1: Domestic water supply and falling groundwater levels in Kabul city

Groundwater from four aquifers in the Logar-Upper Kabul river basin is utilized for domestic use, food production (greenhouses) and the beverages industry (mainly bottled water) for 5.6 million residents in Kabul. Kabul is the fifth fastest growing city in the world and among the world's most water-stressed cities. Its population is expected to increase to about 8 million by 2050. Majority of the residents in Kabul are undersupplied, averaging about 16 liters per capita per day (lpcd), compared to a desirable level of a minimum of 80 lpcd. Unmet water demand is multifold of the current supply (ADB, 2021a).

Kabul currently relies on groundwater for potable drinking water as well as for peri-urban agriculture. Due to population increase and unregulated construction of deep tubewells, groundwater levels have dropped. The main reason is that the groundwater abstraction rate exceeds the recharge rate. Overdraw in 2011 was estimated at 9.2% of supply. As water tables drop, the costs of pumping water and digging, drilling or deepening wells will rise. With per capita water demand expected to double over the next 15-20 years, combined with population increases, urban water supplies are under increasing pressure (ADB, 2021a). Managed aquifer recharge (MAR) could help stabilize or raise groundwater levels, improving the supply and quality of potable water and making Kabul urban water supplies more drought resistant (see section 5.3.2).

As of 2022, the urban water utility UWASS is providing 43,600 m^3/d (in 2005 this was 60,000 m^3/d) of drinking water to 65,907 household connections, covering a population of 659,000 or 12% of the population of Kabul through separate piped networks from different sources:

- The *Logar River aquifer* south-east of the city;
- The Afshar well field drawing from the *Paghman River aquifer* to the west;
- The Alaudin well field drawing from the *Upper Kabul Aquifer* to the south;
- A small part of the city used to be connected to a distribution system served by the Qargha Karez, but this traditional water supply system had fallen dry in 2002.

Most households meet domestic supplies from privately owned drilled wells within the urban and peri-urban area, with many households, particularly in the informal hill side settlement areas, relying on expensive tanker-delivered water. Nowadays, hand dug wells are rarely functional. Many Kabul residents get their water from up to 100,000 shallow private wells that are often polluted and vulnerable to drought. According to a USGS study carried out from 2005 to 2007, about a quarter of shallow wells have fallen dry. Roughly 40% of the remaining wells could fall seasonally or permanently dry because of increased withdrawals, if they are not deepened. Reduced water availability because of the impacts of climate change could further exacerbate the situation (Broshears et al, 2005 and Mack et al, 2010).

Water supply in Kabul city.

5.2 Irrigation and agriculture

Afghanistan relies on agricultural productivity to maintain social stability by ensuring food security and livelihood (Walters S. A. and Groninger J. W., 2014). The most common grown crops are cereals comprising of wheat, rice, maize, and barley, accounting for 77% of the agricultural gross domestic product in 2010-2011 (rain-fed and irrigation).

Irrigation for agriculture (crops and livestock) is important to the main economy of Afghanistan. More than 80% of irrigation water comes from diverting surface water and around 15 – 20% (depending on the individual studies outcome) comes from groundwater (Uhl, 2006; USAID, 2021).

With the absence of large-scale industry or large scale municipal water supply, water resources are predominantly allocated for agriculture comprising 98% to 99% of the share combined (FAO Aquastat, and Favre and Kamal, 2004). The total irrigation application was estimated in various studies and estimates vary. In Uhl (2003) estimated that 7,000 to 8,000 m^3/ha were used on an annual basis, and a total area of irrigated land of 2.6 million ha. Favre and Kamal (2004) estimated a larger rate of 10,000 m^3/ha and a total irrigated area of 2.4 million ha, of which only 15,4% or 367,260 ha are irrigated with (alluvial) groundwater. For comparison, the 1996 FAO study estimates that the country-wide groundwater recharge in a year of average precipitation is in the range of 18,000 million m^3 equivalent to 277 m^3/ha, equal to only 3-4% of the water usage of irrigated area. It should be noted that nowadays, the total area irrigated with groundwater is much higher, but accurate and up to date estimations are not available.

Groundwater has traditionally been developed and used for irrigation purposes through the use of karezes (chapter 5.2.1), springs and shallow hand-dug open wells (chapter 5.2.2). In recent decades, deep-drilled wells (tubewells) and solar-powered pumps have become more common throughout the country (chapter 5.2.3).

5.2.1 Traditional irrigation with karezes

A karez (also referred to as *qanat*) is essentially a horizontal well that collects water from a number of vertical wells. The horizontal well is a hand-dug tunnel conduit that allows surfacing of the upper aquifer's discharge. As of 2014, a study by Walters and Groninger concluded, that 6000 – 7000 karezes must exist in Afghanistan. These are found and concentrated almost exclusively on the eastern, southern and western flanks of the Hindu Kush mountains; from Parwan Province of Faryab, Herat and Farah Province. Karezes tap into alluvial aquifers at the mountain foot where they are fed and recharged by influent streams carrying snowmelt from the Hindu Kush. These systems can be described as subterranean channels with a gentle slope and to some degree run sub-parallel to terranean stream channels.

The extent of karezes varies between 2 to 10 km length. In areas with steep slopes, karezes are relatively short, that is to say, shorter than 4 km, and long in areas with a flat terrain. In some provinces, traditional irrigation ensured the largest proportion of irrigation water, largely because surface water and canals are not available, however many have either dried out and the remainder suffer from reduced flow by as much as 83%. This has led to 60 – 70% of karezes not being used any longer (Goes et al., 2016). For example, in Kandahar Province or Uruzgan Province springs and karezes supply 50% of irrigation water, which indicates the absence of near-by surface water resources (US Army Corps of Engineers, 2011).

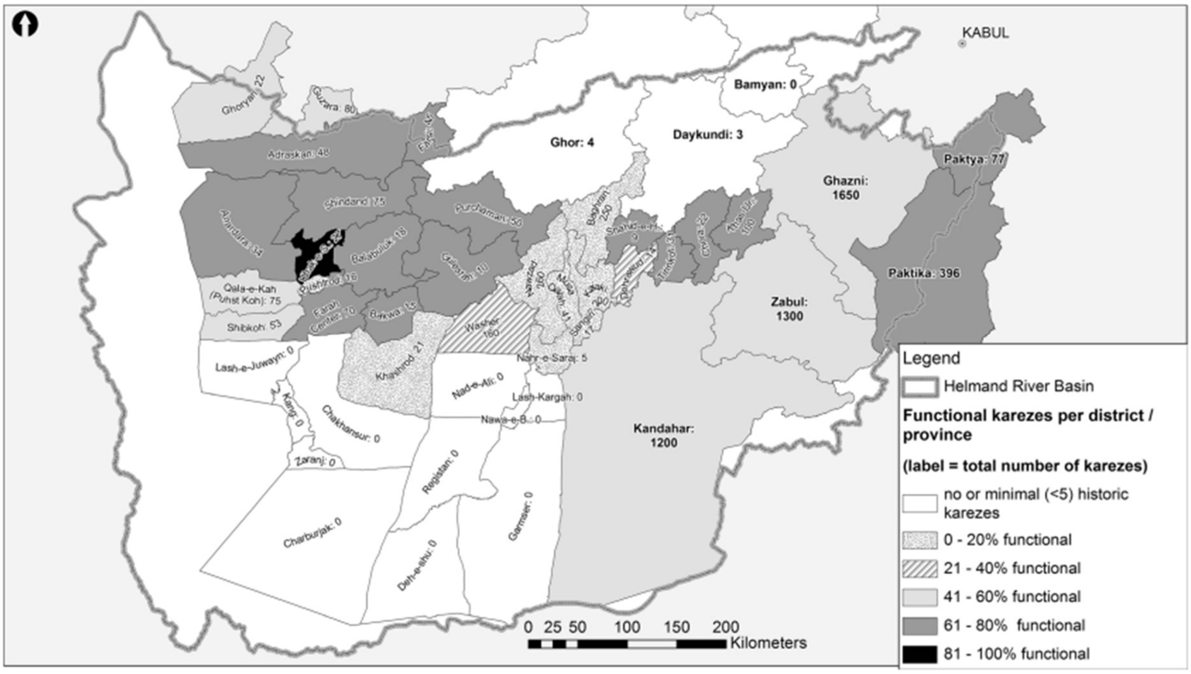


Figure 19. The number of karezes and relative percentage of functional karezes per province used in the Helmand River Basin bases on census data in 2016 (Goes et al., 2016)

However, as the water table steadily declines, the karezes cease flowing. The reasons for the karezes ceasing operation are multifold, of which one reason besides the reasons explained in section 3.6 are reduced recharge and impacts of boreholes designed for irrigation close by. This is because karezes and springs are sensitive to changes in the groundwater table which means these are the first to experience drought. At the same time, karezes become idle once the groundwater level drops and running dry, as altering the construction of a kareze is labour intensive. The reason for drilling near karezes is because these aquifers have historically been good sources for groundwater (Walters and Groninger, 2004).

Discharge rates from the karezes are observed to be higher in spring and early summer, supporting the origin of groundwater being linked to snowmelt (Macpherson G.L., Johnson W.C. and Liu H., 2014).

5.2.2 Irrigation with shallow wells and springs

In 2002, the area irrigated with shallow wells and springs was small compared to karezes, with an estimated 8,595 shallow wells irrigating 12,060 ha of land, mainly small-scale farms and irrigation schemes < 3 ha (Qureshi S.Q., 2002 and Favre R. and Kamal G., 2004). Shallow wells are more common in the west of the country, with most shallow wells located in Ghazni, Farah and Herat provinces, comprising 4,680 ha, 1,065 ha and 1,370 ha of irrigated land.

According to Qureshi (2002) and Favre and Kamal (2004), springs irrigate roughly 187,430 ha of land, and the number of active springs in 2002 was 5,558. However, springs are sensitive to any change in recharge rates, such as decreased precipitation or reduction of groundwater levels.

Provinces were spring outflow is used in significant quantities for irrigation are Ghor (1,599 ha), Ghazni (1,453 ha), Uruzgan (5,628 ha) Zabul (1,199 ha), Badghis (8660 ha), Takhar (8,150 ha) and Wardak (8,690 ha) (Favre R. and Kamal G., 2004). The spatial distribution indicates clustering of spring occurrence in the east, south-east and east which indicates potential for spring development for drinking water and the need for spring protection. Figure 20 shows the localization of springs in Afghanistan, as mapped by DACAAR in 2018 and published on the Rural WASH Dashboard (MRRD).

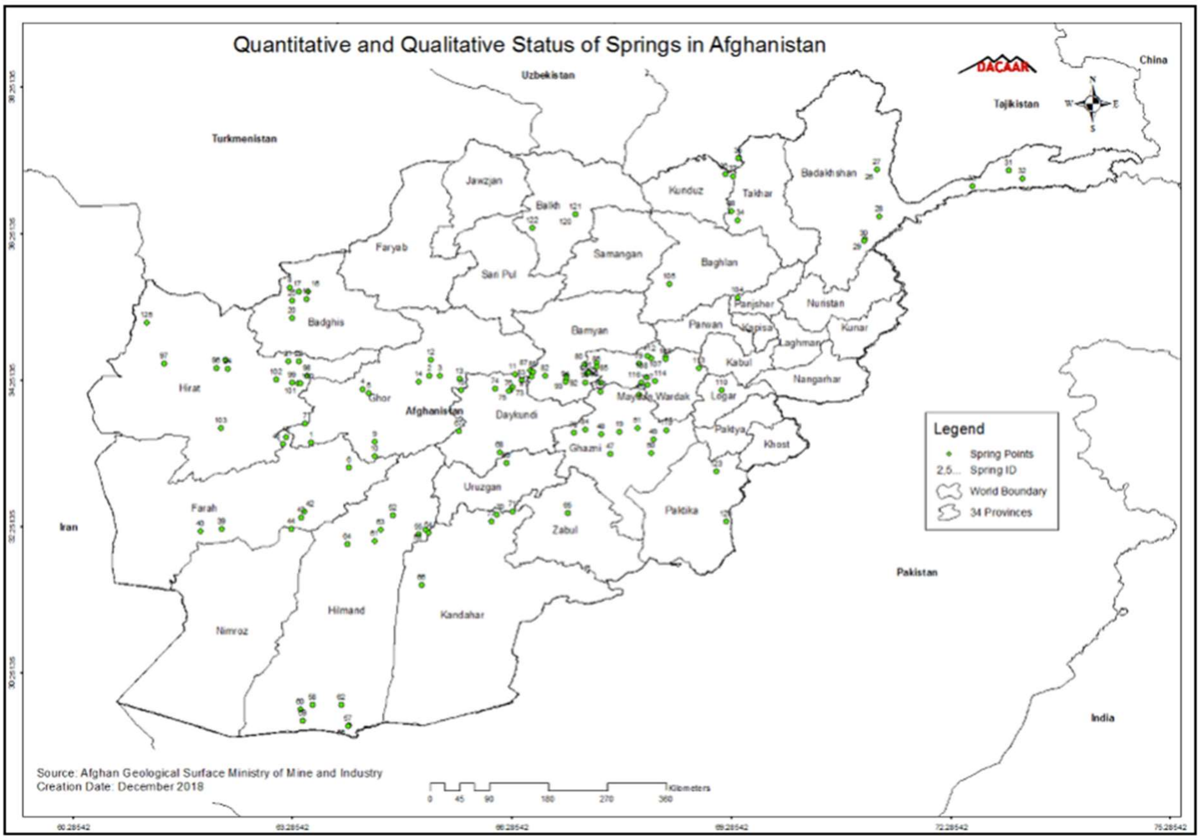


Figure 20. Geographic overview of springs in Afghanistan. Source: Afghan Geological Surface Ministry of Mine and Industry (December 2018), published on the Rural WASH Dashboard (MRRD).

5.2.3 Deep wells

Nowadays, a huge number of deep wells with solar pumps are irrigating large areas of agricultural land in Afghanistan, but there are no detailed nor nation-wide records of the number and scale of these deep well abstractions for irrigation. According to Mansfield (2020), in the in the barren deserts of southwest Afghanistan an increasing number of farmers installed solar power to pump water from their wells. Between 2014 and 2018, the number of solar powered deep wells in the south west doubled each year. By 2019 there were more than 67,000 solar powered deep wells in an area of only 900 km^2 of southwest Afghanistan (Helmand Province) - up from only 14,000 in 2016.

Monitoring, management and control is especially limited in the south-west of Afghanistan, which experienced an influx of people in two waves, in 2003 and 2007. The areas concerned by the new arrivals are the deserts of Helmand, Nimroz and Farah and host a population of approximately 1.5 million people who felt compelled to move beyond the control of the government. In order to sustain their livelihood in the arid terrain, the people in the desert plains practice agriculture. For this, they invested in shallow wells which after running dry are continuously deepened and reaching a depth of up to 130 m.

The transformation of the arid soils into productive agricultural land was partially realized through affordable imports of diesel generators and water pumps from Pakistan and China. Prompted by low yields, the rising costs of diesel and improved market access, some farmers began to experiment with solar technology. What started as a few isolated cases soon became a deluge, as an increasing number of farmers installed solar power to pump water from their wells (Mansfield, 2020). The environmental consequences of the uptake in relatively cheap solar powered technology is dramatic, resulting in steeply declining groundwater levels. According to unverified sources, the groundwater level in Kandahar and Helmand dropped to depths of 130 to 180 m.

Another example is Balkh province, where farmers have turned to digging deep wells and using solar power for irrigation, because of persistent droughts and lack of irrigation water. This has improved their agricultural yields, but might cause shortage of both irrigation and drinking water (Box 2).

In urban areas, groundwater use for irrigation can be high as well, for example by the large number of greenhouses in Kabul area (estimated around 400). In some provinces, like Kandahar, groundwater is being exploited for fishery services.

Box 2: Afghan farmers turn to digging deep wells and using solar energy for irrigation

Because of persistent droughts and lack of irrigation water, farmers in Afghanistan have turned to digging deep wells and using solar power for irrigation, which has improved their agricultural yields.

Recent droughts and overexploitation have caused 60 to 70 % of traditional irrigation systems in Afghanistan, such as karezes, to completely dry up (Macpherson et al, 2017). As a result, communities shift to groundwater for irrigation. Until recently, groundwater abstraction was powered by diesel, which is not affordable for everyone and leaves agricultural production subject to fluctuations in diesel markets. However, the use of solar-powered agricultural groundwater pumping has expanded in recent years, due to lower costs for solar panels in combination with soaring price and reduced availability of diesel.

For example in Balkh Province, where farmers have drilled hundreds of deep wells that pump water using solar power in Mazar-e-Sharif and other districts of Balkh to address their water shortages and irrigate their farms and orchards, said Shamsullah Khalid, director of the Balkh Department of Agriculture, Irrigation and Livestock (DAIL). While in the past farmers were able to cultivate only wheat and barley, this year farmers were also able to cultivate fruit, especially melons, said Abdul Wakil, 46, a farmer in Tana village of Chahar Bolak district, Balkh province. "I cultivated watermelons on two hectares of land, the fruits are ripe now and have good yields," he said. "From dawn to dusk, we irrigate lands using a four-inch pipe." His land had long been infertile from drought, he said. (Qasem, 2022).

Solar panels provide electricity to water pumps for irrigation in Chahar Bolak district, Balkh province

The expansion of solar power has brought many benefits, however, there are also concerns. Drilling wells and using groundwater without a strategic plan will cause a shortage of both irrigation and drinking water, said Mohammad Nazeem Samoon, an irrigation analyst in Balkh. "The groundwater level is dropping day by day," he said. "Lack of irrigation water should be addressed through logical means, and groundwater should be managed properly." (Qasem, 2022).

As solar power has the potential to extract more water than diesel-powered pumping as it comes with no ongoing fuel costs, there are fewer economic constraints on groundwater use. Those unintended consequences might happen in Afghanistan, similar to Yemen, where in a major new study (Nimmo, 2021), a potential link between steep declines in groundwater in Yemen and the expansion of solar power in agriculture was identified.

5.3 Groundwater availability

5.3.1 Water balance estimations on river basin level

There are few water balance studies conducted at country-wide, regional or (sub)basin-level in Afghanistan. The most significant water balance analysis is still the study conducted by Uhl in 2003, based on the approach applied by FAO in 1996. Considering the number of years that have lapsed since then, (with the changing climate), the estimations of precipitation and evapotranspiration are outdated. The methodology applied in this water balance also has its limitations, with the water balance components based on rough estimates (groundwater recharge) and inaccurate and incomplete data (groundwater abstraction). The assumptions make it apparent that the results are an oversimplification of a more complex reality. In addition, the study has applied the water balance on large-scale water basin level, which leads to local inaccuracies as aquifer properties and recharge mechanisms vary at a sub-basin level. An overview of the net water balances is given in Table 10 (Uhl, 2003).

The annual groundwater abstraction is not calculated based on metered recordings but based on estimations calculated from irrigation area, type of irrigation system and irrigation duration. These are proxies to estimate the withdrawal and use, applied on a country scale and do not provide details on the actual withdrawals and use at a sub-basin level, while differences might be important. Moreover, the derivation of recharge estimates are not always well described. Likely, the author has given more attention to recharge occurring within the unconsolidated formations, as these contain the aquifers that are the most exploited, but the information is generally lacking to support these assertions.

Recharge was calculated in terms of an estimated percentage of total precipitation that infiltrates, which ranges between 5 – 15% per geologic unit. No further explanation on the rational on how these ratios of infiltration to precipitation (infiltration coefficient) were determined and no recharge zones were defined. In addition, local precipitation data was extrapolated at a country scale. This is likely to result in a distorted estimate on recharge as the topography is mountainous, which means data on precipitation that is extrapolated on large scale resolution is flawed due to the varying precipitation patterns at different altitudes.

Other factors that have not been considered in the change in storage are slope, flow direction, lateral groundwater flow or water use for irrigation. Because hillslope recharge is crucial for water balances in Afghanistan, a significant proportion of the runoff does not return to baseflow in lower stream orders. In addition, a proportion of the recharge could infiltrate and recharge aquifers which eventually are part of a regional aquifer system, but hydrogeological data are not available in order to estimate the contribution to deep systems.

According to Tünnemeier (2005), in the Kabul Basin, riverbed infiltration is the predominant process of groundwater recharge, and this is also probably true for other comparable settings in Afghanistan. Areas concerned by consolidated units cover the major proportion of the area in the Kabul River Basin, Southeastern Basin, Eastern Helmand Basin and Panj Amu Basin, which explains why annual average recharge is estimated high compared to the unconsolidated aquifers, despite the lower infiltration coefficient. In terms of sustainable abstraction and recharge, most irrigation water originates from the unconsolidated aquifers which for at least the Kabul basin and the Eastern Helmand basin exceeds the estimated recharge of the unconsolidated aquifer. However, based on the water balance estimation, on a (large-scale) basin level, groundwater recharge exceeds groundwater abstraction for irrigation for all of the remaining basins and would indicate a potential for further groundwater development. However, these are very large scale calculations based on estimations. On a local scale groundwater can still be depleted while on a basin level there seems an excess. In addition, the estimations of groundwater recharge and of groundwater abstraction for irrigation are both hard to quantify.

Table 9. Overview on the parameters applied to derive annual recharge on basin level (Uhl, 2003)

Basin	Geological unit	Area [km²]	Precipitation [%, mm]	Annual recharge [Mm³/yr]
Kabul River Basin	Consolidated	45,600	5% of 500mm	1.140
	Unconsolidated	8,400	15% of 300mm	380
	Total	54,000	-	1,520
Southeastern Basin (Indus River)	Consolidated	15,000	5% of 350mm	260
	Unconsolidated	4,000	10% Of 350mm	140
	Total	19,000	-	400
Eastern Helmand Basin	Consolidated	51,000	5% of 250mm	640
	Unconsolidated	21,000	10% of 250mm	530
	Total	72,000	-	1,170
Western Helmand Basin	Consolidated	37,000	5% of 300mm	560
	Unconsolidated	25,000	10% of 300mm	750
	Total	62,000	-	1,310
Western River Basin	Consolidated	52,000	2% of 150mm	160
	Unconsolidated	56,000	2% of 150mm	340
	Total	108,000	-	500
Harirud River Basin	Consolidated	26,000	5% of 250mm	320
	Unconsolidated	13,000	10% of 250mm	320
	Total	19,000	-	640
Northern Flowing River Basin	Consolidated	10,000	5% of 250mm	130
	Unconsolidated	27,000	10% of 250mm	680
	Carbonate rock	53,000	10% of 250mm	1,330
	Total	115,000	-	2,140
Panj Amu River Basin	Consolidated	63,000	5% of 500mm	1,570
	Unconsolidated	28,000	10% of 500mm	1,400
	Total	91,000	-	2,970

Table 10. Water balance (in 2003) for each basin based on estimated abstraction and recharge rates (Uhl, 2003)

Basin	Groundwater recharge [Mm³/yr]	Groundwater abstraction [Mm³/yr]	Net balance [Mm³/yr]
Kabul River Basin	380	450	-130
Southeastern Basin (Indus River)	140	80	+60
Eastern Helmand Basin	530	750	-380
Western Helmand Basin	1,310	750	+560
Western River Basin	340	300	+40
Harirud River Basin	640	160	+480
Northern Flowing River Basin	2,140	210	+1,930
Panj Amu River Basin	2,970	100	+2,870

It should be noted that since these water balance estimations (Table 10), 20 years have passed during which the increasing use of deep wells and solar powered pumps for irrigation has increased the groundwater abstraction rate rapidly. For example, in 2020 the Western Helmand Basin was estimated to have a deficit (Mansfield, 2020) rather than a surplus of 560 MCM/yr. An update of the water balance estimation on basin and sub-basin level is recommended.

Besides an update, local validation with monitoring of groundwater levels over time would be required to actually measure and quantify variations in groundwater resources. As the recent groundwater analysis report by DACAAR (Kohistani and Mohammadi, 2023) shows, declining groundwater tables are reported for almost all of their monitoring wells. This means that locally, groundwater abstraction is higher than recharge, despite the groundwater balance on river-basin level showing a positive balance. The possible reasons for these seemingly contradicting findings are multifold and include:

- monitoring taking place in pumped wells mainly, in which observed groundwater level declines might be attributed to deteriorating well performance (e.g. due to well clogging) and more factors other than groundwater depletion in the aquifer,
- localized groundwater recharge and abstraction which indicates aquifer depletion but does not reflect in a change in storage on a basin level and studies on regional aquifers or sub-basins are not available
- changes in water level due to recharge in large basins will not be realized as a rise in water level at some distance away due to the long travel and residence times.
- unrecorded surface or groundwater abstraction.

5.3.2 Groundwater recharge enhancement

Groundwater recharge enhancement such as managed aquifer recharge (MAR) has been explored mainly in the Kabul Basin, because of the drop in the groundwater table due to excessive abstraction (Masoom M.F., 2018). Kabul relies on groundwater from four aquifers in the Logar-Upper Kabul river basin for potable drinking water as well as for peri-urban agriculture (see Box 1 in section 5.1).

As the water-tables drop, the costs of pumping water and digging, drilling or deepening wells rise. With as per capita water demand expected to double over the next 15-20 years, combined with population increases, urban water supplies are under increasing pressure. MAR could help to stabilize or raise groundwater levels, improving the supply and quality of potable water and making Kabul urban water supplies more drought resistant (ADB, 2021a).

In 2015, the Asian Development Bank (ADB) launched the *Preparing the Kabul Managed Aquifer Recharge Project* (US$ 7.60 million), intending to develop pilot recharge systems, and to test the feasibility of different recharge options including the use of recharge basins, injection wells, contour banking and trenches (ADB, 2015). A follow up project (US$ 1.00 million) was proposed in 2021, the *Kabul Managed Aquifer Recharge Project*, aiming to increase the availability of groundwater in Kabul (ADB, 2021a). The proposed project is an investment grant to finance the infrastructure and requisite soft component strengthening to facilitate accelerated aquifer recharge in the southern part of the Kabul river basin, increasing potable water supply essential to millions of Kabul residents. The project has four outputs (i) Kabul Basin MAR infrastructure operational, (ii) capacity of the communities and staff developed in water monitoring and management, (iii) aquifer protection zone/s performing, and (iv) legislative and regulatory reforms available. Through aquifer recharge protection zones, regulated groundwater abstraction rates and appropriate domestic water treatment, the project aims to produce potable quality water, while realizing that fully satisfying unmet demand will require further investment. The current status of this proposed project is not clear.

According to Landell Mills (2019), the first gravity fed MAR injection borehole was successfully constructed at Badam Bagh in Kabul in March 2019, as part of the Kabul Managed Aquifer Recharge Project (KMARP), administered by Asian Development Bank, funded by USAID, and implemented by Landell Mills. The MAR injection borehole takes water from a surface source via the Qarga Reservoir, flow through a canal and siphon system to supply water to the borehole injecting water into the aquifer to increase the water volume and level (Figure 21). KMARP is investigating the use of MAR techniques in order to improve groundwater levels and quality, as well as access to drinking water for Kabul. It includes testing pilot infrastructure as well as design of a follow-on loan investment project.

Figure 21. The first gravity fed MAR injection borehole at Badam Bagh in Kabul (Landell Mills, 2019).

In 2021, the Kabul Managed Aquifer Recharge Project was stopped.

Further, the application of MAR in the Kabul Basin has been theoretically researched through two studies (Mahdawi Q et al., 2022 and Hussaini M. et al., 2022), that both use computational modeling and remote sensing overlay analysis to assess the recharge potential, recharge quantity and the techniques that could potentially be used to recharge the aquifer. The source water is suggested to be supplied by the surface water flow of the Kabul River in the rainy season (March to June) that would otherwise drain into the Indus Basin across the border. Direct surface recharge through infiltration was suggested to naturally augment recharge in the sub basin. According to the Asian Development Bank, MAR takes advantage of water supplies available during the snowmelt and rainy seasons when river flows through Kabul are 15 times greater than in the dry season, and artificially augments recharge to increase underground water supplies for future use (ADB 2021a).

In his study, Masoom (2018) applied a groundwater model and estimated that 75,000 m^3/d could be diverted as recharge water under the precondition that surface water can be pretreated prior to infiltration to reduce clogging (Masoom M.F., 2018). However, the model developed and used was not calibrated and used historical data that was recorded more than 30 years ago and data obtained from USGS from 2004 – 2007. In addition, Mahdawi et al., (2022) pointed out data limitations due to the complexity in collecting data in Afghanistan which means proper research with sufficient data remains a challenge.

From the above it becomes clear that MAR can help stabilize or raise shallow groundwater levels, improving the availability of primary water supplies for potable use and making urban water supplies of Kabul (or other cities like Kandahar, Herat and Mazar) more secure. In addition, MAR has the potential to support the development of commercial well-fields to supply water to the piped water network. However, groundwater often suffers from microbial and chemical pollutants, and requires treatment to meet potable water quality standards. In addition, short-term and long-term impacts have to be considered, including effects for downstream stakeholders or environmental flow requirements, as well as risks to water quality and well clogging.

6 Groundwater monitoring

Surface and groundwater quality are not systematically monitored and monitoring mandates for several governmental entities overlap and collected data is not comprehensive, consolidated, or shared among water sector actors.

The Ministry of Energy and Water oversees the data collection for 1131 groundwater monitoring points, while the DACAAR manages the data collection for 426 monitoring points. The monitoring data includes the water level depth, electrical conductivity, pH and temperature.

The groundwater monitoring network covers 68% of all sub-catchments, however this does not mean that all aquifers are well-represented or that data is consistent with the monitoring points.

Only 243 groundwater monitoring points, 16% of the total number of monitoring points, are dedicated monitoring wells with the purpose of sole monitoring. The remaining 84% of monitoring points are used for abstraction, affecting the measured groundwater levels.

The distribution of the monitoring points in terms of different geological domains shows that the vast majority (83%) capture data within the Quaternary unconsolidated sediments.

Various studies suggest declining groundwater levels over the past few decades, mainly in urbanized areas in Kandahar and Kabul City. While groundwater table decline is observed in the southern part of Kabul Basin,the northern part receives more recharge and groundwater levels have generally been rising due to increased snowmelt producing more runoff.

Declining groundwater tables are observed in many monitoring wells, with over-abstraction and impacts of climate change cited as main causes. However, the collection and analysis of relevant time series of nearby groundwater abstractions, precipitation and streamflow is lacking, in order to substantiate those claims.

The information presented in this section and sub-section is based on data received from relevant authorities and sources in Afghanistan and is neither exhaustive nor conclusive as it stands.

6.1 Groundwater monitoring network coverage

The official groundwater monitoring network currently in place in Afghanistan is composed of 1,131 points that are monitored monthly by the Ministry of Energy and Water (MEW). In addition, the Danish Committee for Aid to Afghan Refugees (DACAAR) manages the collection of data for 426 monitoring points. Due to access and security issues, and due to donor driven programmes, monitoring wells are mainly concentrated around provincial capitals or close to them. Previously, MEW focused on groundwater monitoring of the major cities: Kabul, Nangarhar, Balkh, Herat, and Ghazni. In 2019, the groundwater monitoring system was expanded to cover more than 10 cities of Afghanistan.

The 1557 groundwater monitoring points are distributed among all five main river basins and show similarities in the proportion of monitoring points per River Basin (Figure 22). The only remarkable difference concerns the Helmand River Basin, more closely monitored by MEW, and the Harirud-Murghab River Basin, more closely monitored by DACAAR.

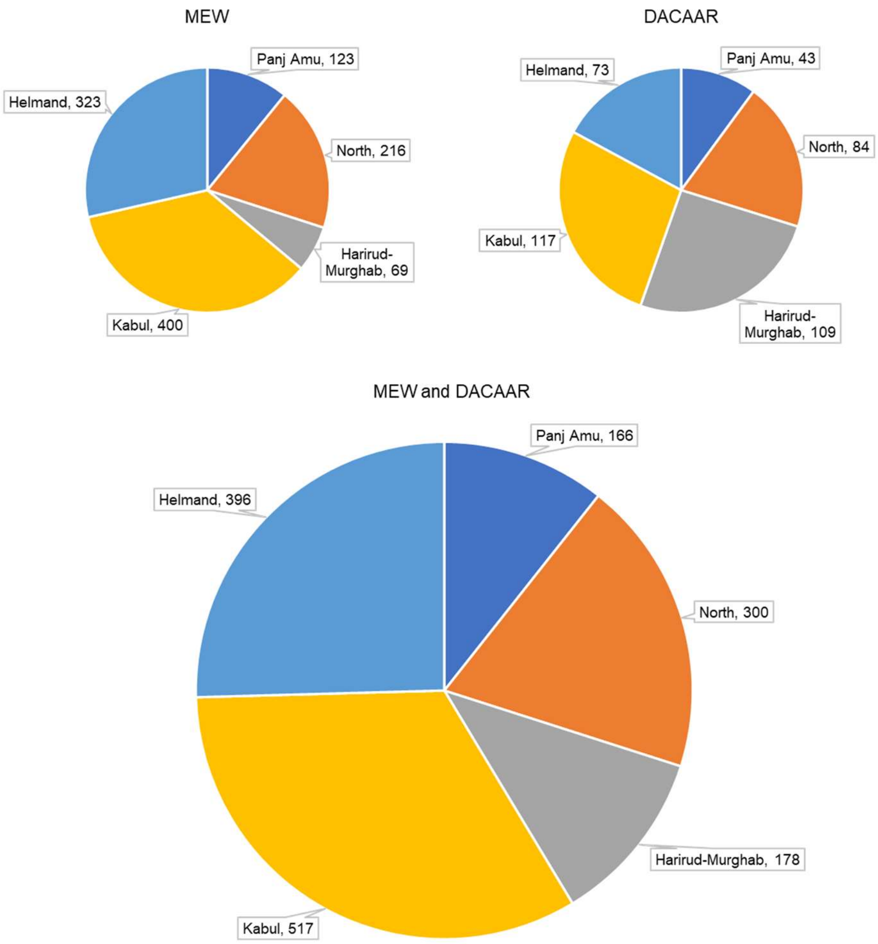


Figure 22. Distribution of the monitoring points from both MEW and DACAAR per river basin (Preview of the upcoming UNICEF report on groundwater monitoring).

At sub-catchment level, 68% of all the sub-basins have at least one monitoring point but that does not mean that these monitoring points are in the right place or representative of the main aquifer within the sub-basin The sub-basins without ongoing monitoring are Panj, Bala Murghab, Gomal, Khuspas Rud, Chagay, Upper Arghandab, Dasht-i Nawur, Pishin Lora and the 5 non-drainage areas (Dasht-i Shortepa, Dasht-i Margo, Dasht-i Naomid, Registan, Registan-i Sedi).

Currently, dug wells, tube wells or deepened wells are used as monitoring and no springs are monitored. For MEW, standard wells (171) and wells equipped with a telemetric system for the transmission of the data (38) correspond to points dedicated to the monitoring only, while public wells (922) correspond to points used by the population. For DACAAR, wells equipped with a diver (34) correspond to points dedicated to monitoring only, while the points used by the population are monitored manually (392).

The monitoring data includes the water level depth, electrical conductivity, pH and temperature. For MEW, water quality is not monitored systematically. For DACAAR, sampling for water quality analysis (physical, chemical and bacteriological) is performed every six months.

6.2 Monitoring different aquifer types

The groundwater monitoring points are unevenly distributed in terms of the representativeness of depths and aquifer types. This results from the fact that water points are mostly shallow and capture the unconfined aquifers within the Quaternary unconsolidated sediments. Being the most exploited, these are more closely monitored. Monitoring boreholes have not been installed in a systematic way following some predefined rationale or criteria for monitoring.

As part of the upcoming report 'Strengthening the monitoring of groundwater and surface water in Afghanistan' (UNICEF, to be published), the monitoring points have been grouped as aquifer types, according to the geological map from Doebrich and Wahl (2006), reclassified into the main rock types, namely «igneous», «volcanic», «limestone», «consolidated sedimentary» and «unconsolidated sedimentary» (representing the Quaternary deposits), and additional lithostratigraphic logs (937 points). It should be noted that the geological map presents surface geology, so in case monitoring points fully penetrate the surface geological formation into a deeper geological formation, the classified aquifer type could be different.

Total depths vary between 5 and 570 m. However, the majority (86%) of the monitoring points have depths <80 m (Figure 23). Some variabilities between river basins exist: maximum depths of boreholes reach 130 m for Amu Darya and Harirud-Murghab, 250 m for Helmand, 420 m for North and 570 m for Kabul. This shows that most wells are relatively shallow and likely capture predominantly the phreatic aquifer within the unconsolidated Quaternary sediments.

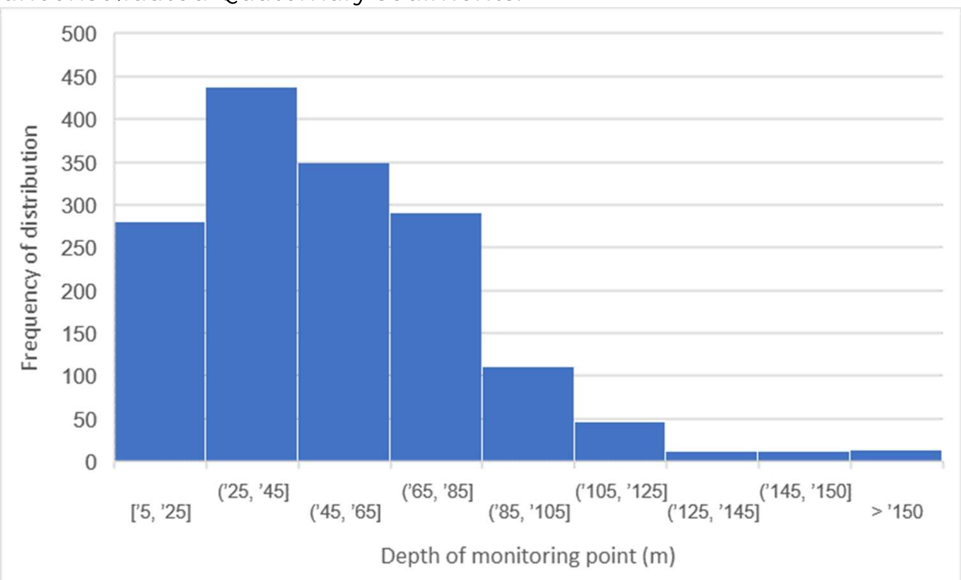


Figure 23. Frequency distribution of depths of the monitoring point.

The distribution of the monitoring points considering the different geological domains (Table 11) shows that the majority capture the aquifers within the Quaternary unconsolidated sediments (82.8%), the remaining being located within the consolidated sedimentary sequences (7.9%), igneous rocks (6.3%), limestone (2.3%) and volcanic rocks (0.7%). This also reflects in the relatively small number of lithostratigraphic logs having reached the underlying consolidated formations (1.3% sandstone, limestone and shale) or the crystalline basement (8%).

Table 11. Distribution of the monitoring points (MEW and DACAAR) by river basin, minimum and maximum depth and lithology.

Basin	Active	Dedicated to monitoring	Depth		Lithology									
			Min	Max	Igneous		Limestone		Consolidated sedimentary		Unconsolidated sedimentary		Volcanic	
					nb.	%	nb.	%	nb.	%	nb.	%	nb.	%
Panj Amu	166	8	5	130	9	5.4	2	1.2	38	22.9	112	67.5	5	3.0
North	300	42	10	420	0	0.0	20	6.7	2	0.7	278	92.7	0	0.0
Harirud-Murghab	178	20	6	130	1	0.6	1	0.6	46	25.8	129	72.5	1	0.6
Kabul	517	105	5	570	54	10.4	10	1.9	31	6.0	421	81.4	1	0.2
Helmand	396	68	6	250	34	8.6	3	0.8	6	1.5	349	88.1	4	1.0
Total	**1557**	**243**	**5**	**570**	**98**	**6.3**	**36**	**2.3**	**123**	**7.9**	**1289**	**82.8**	**11**	**0.7**

There are also spatial differences between river basins (Table 11), where North's and Helmand's monitoring points are mostly located within the unconsolidated Quaternary sediments (92.7 and 88.1%), Amu Darya and Harirud-Murghab having a relatively higher representation of monitoring points located within the consolidated sedimentary sequence (22.9 and 25.8%) and Kabul and Helmand having a relatively higher representation of monitoring points located within igneous rocks (10.4 and 8.5%). Monitoring points capturing the aquifers within limestones or volcanic rocks are represented in North (6.7%), and Amu Darya and Helmand (3% and 1%).

6.3 Observations from groundwater monitoring

As described, the existing groundwater monitoring network is continuously expanded, however historical data that has never been monitored and recorded cannot be used as input to expand the groundwater monitoring network. In addition, only 243 points, or 16%, are currently completely dedicated to the monitoring of groundwater (see Table 11) and these are concentrated in specific areas only, leaving the rest of the country with no or very few dedicated monitoring stations at all. Moreover, wells are generally concentrated along or close to rivers. The spatial distribution and types of monitoring points are shown in Figure 24. As most of these 'monitoring wells' are in fact pumping wells, the observed decline in groundwater level (DACAAR, 2023) could also be due to deteriorating well performance (e.g. due to well clogging) rather than a drop in groundwater table in the aquifer or a combination of both.

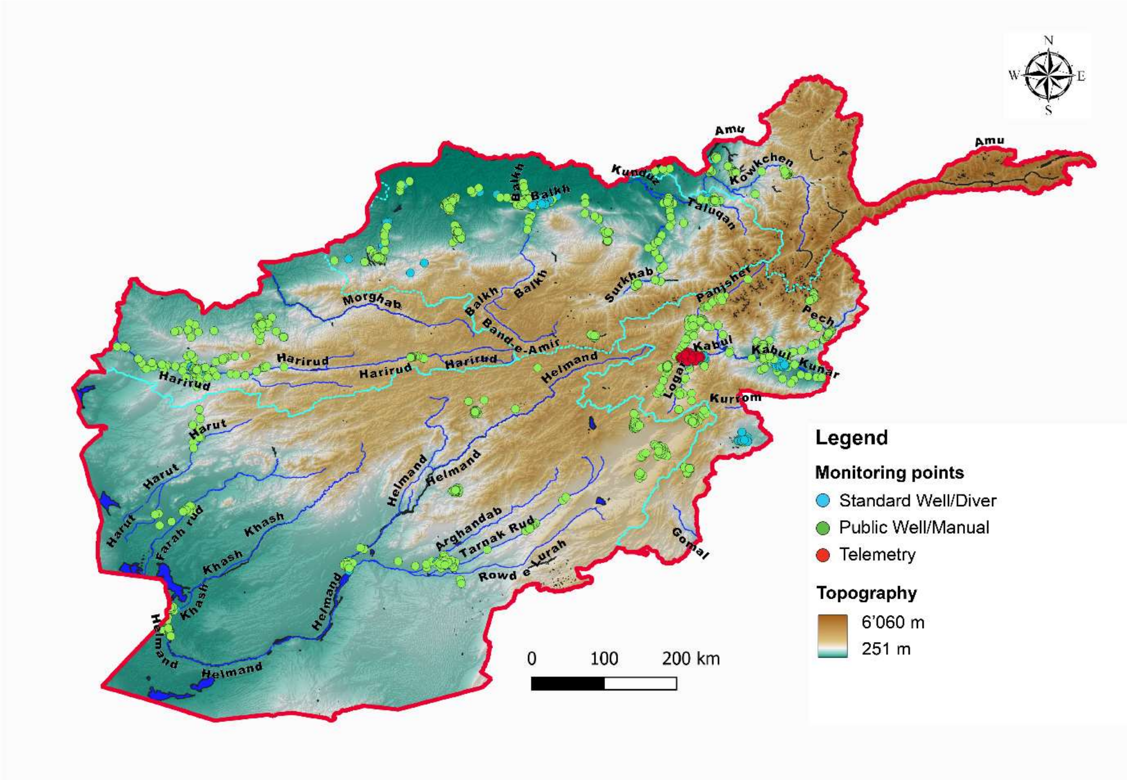


Figure 24. Spatial distribution and types of monitoring points (MEW and DACAAR).

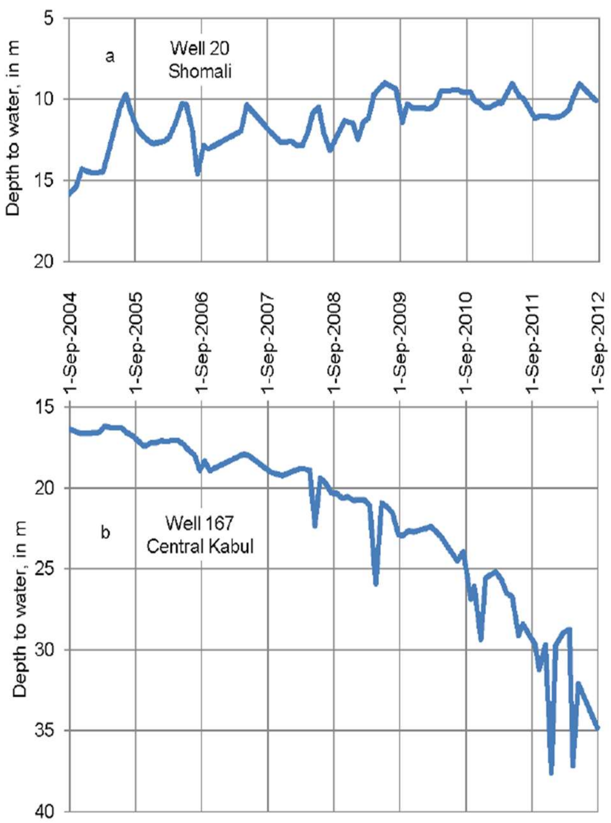
In Afghanistan, a lack of qualitative and quantitative information exists on groundwater resources. Nevertheless, over-abstraction is clearly a concern in Kabul (see Box 1), eastern Helmand and the western river basins. For the Kabul Basin, conclusions have been drawn because more detailed studies were conducted in the past.

In the groundwater analysis report by DACAAR (2023), declining groundwater tables are reported for almost all of their monitoring wells. The report refers to "*climate change, over-exploitation of groundwater (for agricultural purposes), high evapotranspiration, low recharge, unequal spatial and temporal distribution of rainfall, lack of water resources management, lack of water storage infrastructure, and other factors*" as reasons for the progressively declining groundwater levels. Even though all of these potential root causes are rational, there is no data presented that proves any of these conclusions, for any of the wells. Measurements of local precipitation, groundwater abstractions (nearby or in the 'monitoring well' itself), nearby streamflow, and detailed analysis of these time series are required to substantiate these claims and to determine which of these root causes are most important.

Groundwater monitoring and observations in the Kabul Basin was based on the JICA (2007) report on shallow Quaternary aquifer systems in the Kabul Basin, and reveals that some local aquifers receive less recharge than what is abstracted, leading to a negative ground water balance. This means that locally, the aquifer has been developed beyond the capacity of the aquifer potential and should be monitored carefully. To avoid depletion of shallow groundwater, abstraction should be controlled and permitting enforced.

Also the deeper, Neogene aquifer systems in the Kabul basin are inherently less productive due to their lower hydraulic conductivity and storability, which makes groundwater abstraction from these aquifers unsustainable. The unconfined Afshar aquifer in Kabul City, consisting of Quaternary sediments, is an example of this case, where currently out of nine deep wells only three are still functioning for 12 hours per day and with the remaining six wells being dry. The Afshar water supply project was functional from 1976 up 2017 and was only for drinking purposes (Schroder et al., 2022).

Groundwater levels in the southern part of Kabul Basin have declined considerably as a result of below-average precipitation in the early 2000s and increasing population and associated water use during the past decades. A study conducted by the US Geological Survey between 2004 and 2012 showed that groundwater levels in Kabul City had dropped by an average of 1.5 meters/year during 2008-2012 (Mack et al, 2014). However, within the entire Kabul Basin both groundwater level rises and declines have been observed, caused by various reasons. Groundwater level declines occur primarily in the urban areas, mainly the southern parts of the Kabul Basin. By contrast, the northern Kabul Basin is less populated, receives more recharge and groundwater levels have generally been rising between 2004 and 2012 due to increased snowmelt producing more runoff.



Groundwater levels in parts of the Kabul Basin have declined substantially as a result of periods of below-average precipitation and increased water use during the 2000s. By 2007, groundwater levels in rural areas in the Kabul Basin were rising in response to an increase in precipitation to more average rates relative to antecedent drought conditions, while groundwater levels were declining in the city of Kabul as a result of increased water use (Mack et al. 2010). Groundwater levels in some areas of the Kabul Basin have been rising since 2004, such as at well 20 near Shomali in the northern part of the basin (Figure 25a). By contrast, groundwater levels in the city of Kabul have been declining. For example, AGS monitoring well 167 in the Central Kabul sub-basin indicated a 3-m decline in groundwater level from 2004 to 2007; however, from 2007 to 2012, the decline was 15 m (Figure 25b).

Figure 25. Monthly groundwater levels (measured as depth to water) from September 2004 to September 2012 at (a) well 20 in Shomali in the northern part of the basin and (b) well 167 in the Central Kabul Subbasin in the southern part of the basin in the Kabul Basin (Mack et al, 2014).

7 Surface water use

The annual surface water withdrawal of 17 BCM/yr is primarily abstracted for irrigation and is not used extensively for urban or rural drinking water, with only a few percent of all surface water withdrawal for domestic water supply and industrial use.

Because Afghanistan shares some of its river basins with riparian countries, the total annual surface water volume is shared with its neighbors. Based on past water use estimations, 35% of the water that originates in Afghanistan is used nationally, while the remaining 65% (estimated at 42 BCM/yr) flow across the national borders.

The Amu Darya River is one of the longest and most important rivers in Central Asia, with Afghanistan contributing 25.5% of its total flow, being vital to regional agriculture. The new constructed Qosh Tepa Canal with a capacity of up to 650 m^3/s, will support irrigation of 550,000 ha for the nearby provinces Balkh, Jowzjan and Faryab.

According to FAO, the environmental flow requirements of Afghanistan are 28 BCM/yr. High abstractions on the Helmand River limit environmental flows needed to protect biodiversity in the transboundary Sistan-Helmand (or Hamun) wetlands.

Runoff from surface water is intermittent and dictated by seasonal and inter-annual variations in precipitation which leads to downstream drought and flood events, which is why dams and reservoirs have been built to secure water management.

Surface water has been monitored in Afghanistan since 1946, with the installation of the first stations in the Helmand River Basin. Surface water quality has not been studied nor monitored extensively.

Compared to groundwater, surface water has been more extensively studied in terms of stream gauging stations, stream flow characteristics and seasonal stream flow patterns. In that respect, extensive studies have been conducted by the USGS on the Helmand Basin and South-Eastern River Basin and on the Northern River Basin and Panj Amu Basin. For the south-eastern River Basin, stream gauging stations are deployed for the Provinces Ghazni, Khost, Logar, Paktya, Wardak and partially Kabul, where mean and annual discharges, peak discharge, gauge height and other properties were studied (Vining K.C., 2010). For the purpose of water resource development, the effects of climate change have been assessed for the northern river basin specifically and for which stream gauging stations have been installed for the Sare Pul River, the Shirintagab River, the Khulm River and the Blakh River with the remainder of sub-basin regions having no data available as rehabilitation of data collection activities only commenced in recent years (Frotan et al., 2020).

Part of the total annual surface water volume that originates in Afghanistan is shared with neighboring countries through transboundary rivers. Based on past water use estimations, 35% of water originates in Afghanistan is used nationally, while the remaining 65% flow across the national borders (The World Bank, 2004). The FAO estimates that 42.2 BCM/yr of surface water is leaving the country to other countries, of which the majority of outflow (35.5 BCM/yr) is not submitted to treaties (FAO Aquastat).

7.1 Domestic and industrial

Surface water is not used extensively for urban or rural drinking water. Run-of-the-river hydropower plants are the primary source of local power and notably include the 151 MW capacity Kajaki Dam on the Helmand River and the 100 MW capacity Naghlu Dam on the Kabul River. According to the Afghanistan Water Resources Profile Overview (USAID, 2021), surface water is primarily abstracted for irrigation (section 7.2), with only 2% of all surface water withdrawal for domestic water supply and industrial use combined.

7.2 Irrigation and agriculture

According to the FAO, surface water withdrawals for irrigation are high relative to water supply, as nearly 98% of all freshwater abstractions are for irrigation and 85% of these withdrawals (17.24 BCM/yr) are from surface water (FAO Aquastat). However, these FAO figures have been imputed for over two decades and the latest official data is from 1998.

Surface water abstraction for irrigation is largest in Balkh, Jowzjan, Kunduz, Herat, Helmand and Feryab provinces, along the Kunduz, Kabul, Harirud, and central reaches of the Helmand River and their tributaries. The total amount of areas irrigated with surface water were estimated at 2,018,250 ha by Favre and Kamal in 2004. What is worth pointing out is that current irrigation practices and land management practices tend to be inefficient, meaning that the total surface water abstractions are high relative to the supplied areas – an issue criticized by the international community (Klemm W., 2010).

According to The World Bank (2004), the Kabul River Basin has the highest annual flows (about 24 BCM/yr) but the least area (79,000 km^2), followed by the Panj Amu Basin (about 17 BCM/yr) with an area of about (242,000 km^2), and the Helmand River Basin (about 14 BCM/yr) but with the greatest area (320,000 km^2). The Panj Amu Basin, however, has the most irrigated lands (about 1.16 million ha in 2004) and the highest area under rainfed agriculture, and is therefore, the most important for Afghanistan as indicated above. Although quantity of irrigated land in the Helmand River Basin (1.1 million ha in 2004) is comparable to that of the Panj Amu Basin, the Helmand Basin has very little area with rainfed agriculture. The Kabul Basin has the least irrigated area (less than 0.5 million ha in 2004) primarily because of topographic limitations (The World Bank, 2004).

Intensive irrigation, particularly of wheat, occurs along the Kunduz, Kabul, Harirud, and central reaches of the Helmand Rivers and could also contributing to any salinity. The irrigated wheat production per region is shown in Figure 26 (USDA, 2018).

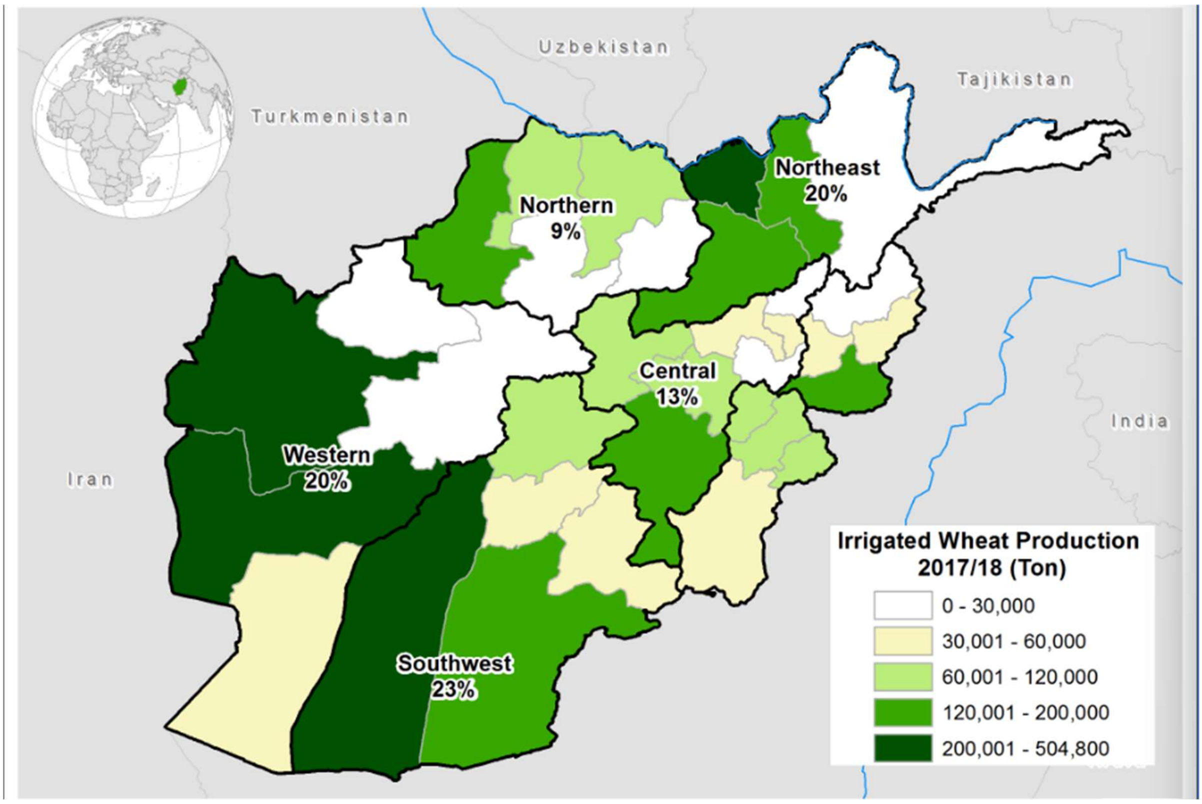


Figure 26. Distribution of wheat production that is under irrigation schemes according to the US Foreign Agricultural Service (2018).

7.3 Transboundary impacts of surface water use

Afghanistan has three major transboundary river basins, the Helmand River in the Sistan Basin draining towards Iran, the Kabul River in the Indus Basin draining towards Pakistan, and the Amu Darya River in the Panj Amu Basin draining towards Central Asian States. The Balkhab River in the Northern Rivers Basin only reaches the lowlands of Turkmenistan at the border in case of flood event, while the rivers within Harirud Murghab Basin end in Afghanistan.

The subject of transboundary impacts of large scale surface water abstraction mainly concerns the Amu Darya River and its tributaries, for which till recently little dialogue on the matter of sharing its resources has been initiated between riparian nations. The Amu Darya River, that has its origins from the Pamir and Wakhan River, crosses the northern border into Turkmenistan, where it flows from there north-westwards into the southern remnants of the Aral Sea. In Turkmenistan, an estimated flow of 13 BCM/yr is diverted via the 1375 km Karakum Canal, making it one of the largest irrigation and water supply canals in the world. The canal, started in 1954 and completed in 1988, is a major factor leading to the Aral Sea environmental disaster. Further downstream there are more canals diverting an equivalent amount of water from Amu Darya for irrigation.

As the Afghan Government is currently "underexploiting" the Amu Darya River's water resources from their point of view, a new canal is currently underway. Since March 2022, the building of the 285 km Qosh Tepa Canal, has been underway in northern Afghanistan to divert water from the Amu Darya. Uzbekistan has expressed concern that the canal will have an adverse effect on its agriculture, and expected to make the Aral Sea disaster worse. As over-abstraction is already high, more tributaries in the neighboring countries are expected to disappear through increased abstraction upstream (News Central Asia, 2023) which could potentially result in tension between upstream and downstream nations. According to the Afghan Government, the initiative is expected to convert 550,000 hectares of desert into farmland in the nearby provinces Balkh, Jawzjan and Faryab. With a capacity of 650 m^3/s (News Central Asia, 2023), the Qosh Tepa Canal would be able to divert more than 20 BCM/yr of water. This would be higher than the average annual flow of the Panj Amu Basin (about 17 BCM/yr) out of Afghanistan according to The World Bank (2004).

As sharing of transboundary water resources is a subject of interest by several nations, the average annual flow rates of the Amu Darya River have been estimated with little consensus. The mean flow generation per riparian country together with the last reported flow diversion has been estimated by The Food and Agriculture Organization (FAO) in the study 'The Afghan part of Amu Darya basin. Impact of irrigation in Northern Afghanistan on water use in the Amu Darya basin' (Klemm, 2010) and is shown in Table 12. The reported 80 BCM/yr of generated average annual flow is a bit higher than the 70 BCM/yr average annual flow reported elsewhere, such as by Glantz (2005).

Table 12. Comparison between the generated average annual flow and the average annual use listed for each riparian nation of the Amu Darya River (Klemm, 2010).

Riparian country	Generated average annual flow [MCM/yr]	Share of total average annual flow [%]	Average annual water use [MCM/yr]	Share of total average annual use [%]
Tajikistan	50,000	62.5	7,500	11
Afghanistan	22.000	27.5	5,000	7
Uzbekistan	5,000	6.3	33,000	47
Kyrgystan	1,500	1.9	1,500	2
Turkmenistan	1,500	1.9	23,000	33
Total	**80,000**	**1000**	**70,000**	**100**

Present water allocation are in theory dictated by the Tashkent Agreement issued in 1987 to regulate the water shares of the Aral Sea Basin (so considering flow of the Syr Darya River as well), however Afghanistan has never been considered in any formal water allocation scheme. As can be derived from Table 12, Afghanistan contributes 27.5% of the rivers average annual flow, however only abstracts an average of 7%, while in Uzbekistan and Turkmenistan only small quantities are generated, but have a combined 80% share of total average annual use. Hence, a discrepancy exists between generated flow and use of surface water. Further, the missing 10 BCM/yr are explained with natural losses due to evaporation and drainage into the Aral Sea Depression (Klemm W., 2010).

7.4 Environmental flow requirements

Environmental flow requirement for allocation of surface water resources means that a certain amount of surface water is required into an aquatic ecosystem to maintain it in a condition that will support its direct and indirect use values. According to FAO, the environmental flow requirements of Afghanistan are 28.29 BCM/yr (FAO Aquastat), hence much higher than the annual surface water withdrawal (mainly for irrigation) of 17.24 BCM/yr.

The conservation of headwaters is crucial to sustain ecological life-supporting functions along the perennial or seasonal rivers. In Afghanistan, there are a few lakes and wetlands, which are valuable from an ecological perspective and provide ecosystem services. The largest wetland in Afghanistan is the transboundary Sistan-Helmand wetlands (or Hamun wetlands), which includes the Helmand's inland delta, as well as hamouns (lakes) and wetlands on the border of Afghanistan and Iran. As wetlands beds are formed by transported sediments, they are productive ecosystems and are viable habitats, particularly for migrating birds. Reeds are grown and used by communities both as local material and for income generation In terms of ornithology, the Ab-I Istada and the Dasht-i-Nawur are the most important habitats for migrating birds (Favre R. and Kamal G., 2004). While the Ab-I Istada still has water, the Dasht-i-Nawur has dried.

The existence of the marshes and wetlands is threatened due to slow disappearance of these areas. Drought, high surface water abstractions, and poor reservoir management have reduced environmental flows and impacted downstream wetlands. The transboundary Hamun Wetlands, which are the largest in Afghanistan, have been degraded by drought and mismanagement of the Helmand River. Afghanistan is not a member of the Ramsar Convention, but the Iranian portion of the wetlands have been designated as a Ramsar Site. The Hamun Wetlands almost dried up in the early 2000s after years of drought, over-abstraction, and reduced outflows from the Kajaki Dam, likely because of several drought years (Klemm W., 2010).

Increased evaporation caused by hotter temperatures and stronger winds combined with less precipitation has further reduced water availability in the watershed. This continuing trend makes ecological recovery unlikely. Indeed, the Sistan-Helmand wetland ecosystem may already be at the tipping point, creating a looming loss of ecological security. As the basin's lakes dry and wetlands vanish and its biodiversity decreases, the livelihoods of those who depend on it for activities including fishing, bird hunting, and reed harvesting are threatened (Palmer-Moloney, 2022).

7.5 Surface water storage, dams and reservoirs

Runoff from surface water is intermittent and dedicated by seasonal and inter-annual variations in precipitation which leads to downstream drought and flood events, which is why dams and reservoirs have been built to second water management.

As surface water irrigation and rainfed agriculture is widespread, reservoirs provide prolific storage, especially during the second rainfall season in spring when precipitation is heavier and more erratic. Where such dams have been built, runoff is retained for irrigation of summer crops (Klemm W., 2010).
The Kajaki (1,200 MCM, Helmand River), Salma (633 MCM, Harirud River), Naghlu (550 MCM, Kabul River), Dahla (288 MCM, Arghandab River), and Sardeh Dams (259 MCM, Gardez/Sardeh Rivers) are the largest in Afghanistan but overall per capita storage capacity is 2 to 50 times less than neighboring countries (USAID, 2021). The areas under

irrigation by dams are listed in Table 13. Irrigation schemes that were built by the Afghan Government are maintained by NGOs.

Table 13. Overview on formal irrigation schemes built but the government (Klemm W., 2010)

Name of scheme	Province	Irrigated area	Main structure
Helmand & Arghandab	Helmand & Kandahar	103,000 Ha	Kajaki & Dhala Dams
Sardeh	Ghazni	15,000 ha	Reservoir
Parwan	Parwan & Kabul	24,000 ha	Main canal and side canals
Nangarhar irrigation	Nangarhar	39,000 ha	Darunta dam
Sang-i-Mehr	Badakhshan	3,000 ha	Main canal
Kunduz- Khanabad	Kunduz	30,000 ha	Diversion dam and canals
Shahrawan	Takhar	8,000 ha	Intake, main canal
Gawargan	Baghlan	20,000 ha	Intake, main canal
Kilagay	Baghlan	20,000 ha	Intake, main canal
Nahr-i-Shahi	Balkh	50,000 ha	Diversion dam and main canal

7.6 Surface water quality

Surface water quality has not been studied nor monitored extensively. As with most water quality studies this is restricted to the Kabul River Basin (BGR, 2006). What can be derived from chemical and microbiological testing throughout the Kabul Basin is that fecal contamination is widespread, likely due to limited sanitation services and wastewater treatment as well as damaged cesspits and contamination by livestock. This leads to the assumption that a similar situation could be found in other densely populated areas.

In addition, more than 1,400 informal mining sites are located around Kabul. The effects of these informal mines on the surface water and groundwater quality has not been studied in detail in Afghanistan, but open pit mines are expected to increase erosion as well as sedimentation. More severe though, is the increased risk of groundwater contamination as depending on the geology, recharge increases as well. In addition, tailings with chemicals from ore processing and heavy metals cause risks to human health (Tuennermeier and Houben, 2006).

Although surface water may not be directly used for human consumption, due to its interaction with groundwater through percolation and recharge of the shallow groundwater table, insufficient surface water quality data and monitoring is still a concern because of shallow groundwater abstraction along the stream beds.

7.7 River basin management

The economy in Afghanistan relies on agricultural production, and so access to irrigated water is essential. However, lack of efficient water management within river basins means that water is not being distributed equitable between users and much of the water is being wasted. In addition, factors such as climate change, a rapidly growing population and demand from hydropower all jeopardize the availability of water in the country. Therefore, river basin management is an important step to ensure that water resources in the country are more economically and equitably managed and sustainably protected.

In the past, nation wide water master plans have been developed, including:

- National Water Master Plan project (GIZ-funded)
- Afghanistan Water Resources Sector Development project (ADB)
- National Water Master Plan Volume 1 Water balances, water demand scenarios and long-term investment framework (2014, Ministry of Energy & Water)

For some of the major river basins, specific master plans or management plans have been developed in the past, such as:

- Hari Rud River Basin Master Plan (Asian Development Bank, 2014)
- Helmand River Basin Master Plan (Mott MacDonald, 2013)
- Panj-Amu River Basin Programme 2009-2017 (Landell Mills, EU-funded, in cooperation with MEW and MAIL)
- Scoping Strategic Options for Development of the Kabul River Basin (The World Bank, 2010).

It is not clear if these river basin master plans, management plans and investment plans have been successfully implemented and if programmes have been continued river basin management plans been updated.

7.8 Hydro-meteorological network

Surface water has been monitored in Afghanistan since 1946, with the installation of the first stations in the Helmand River Basin. Discharge data and sediment sampling have been analyzed between 1960 and 1980. This was followed by a 25 year data gap in the recording of hydro-meteorological data. In 2004, the network was rehabilitated and three cableway stations (CBW) in the Kabul River Basin were installed. Automatic hydrological stations (AHS) capturing discharge and meteorological data (air temperature, relative humidity and precipitation) every 15 minutes were installed between 2008 and 2017. Automatic weather stations (AWS) capturing a range of parameters (11) every hour and were installed between 2012 and 2017. Snow measuring stations were also installed in this same timeframe, capturing snow depth data every hour in addition to the other meteorological parameters. Table 15 illustrates the types and number of hydro-meteorological stations currently in Afghanistan, distributed by River Basin, according to the MEW.

Table 14. Number and type of hydro-meteorological stations in Afghanistan, according to MEW.

River Basin	AHS	SSS	CBW	AWS	Total
Kabul	50	9	18	7	84
Helmand	42	4	14	3	63
Harirud-Murghab	21	2	6	3	32
North River Basin	18	2	8	6	34
Amu Darya	41	13	27	7	88
Total	172	30	73	26	301

8 Key issues

Declining groundwater tables are observed in wells and many karezes have dried up. The flow of springs has reduced, impacting water availability for domestic use and irrigation and downstream recharge.

Unregulated drilling of deep wells and adoption of modern borehole technologies, such as solar powered wells, may be accelerating groundwater declines.

There is little hydrogeological understanding of available groundwater resources and limited monitoring of the groundwater system.

Due to the nature of the aquifers, mainly shallow and unconfined, groundwater supplies are very vulnerable with regards to both quantity and quality (salinity, geogenic and micro-bacterial).

The once relatively constant supply of runoff water from snow melt is reducing, with rainfall becoming more erratic, increasing the risk of both floods and droughts.

The groundwater development potential of deeper (fractured) bedrock aquifers and (fractured or karstified) sedimentary rock aquifers is mainly unstudied and unexplored.

Water resource development is focused too much on water demand with insufficient consideration of water availability.

Upstream use of water resources is insufficiently considering downstream effects.

8.1 Contributing factors – context and vulnerabilities

Afghanistan has experienced decades of protracted crisis, political, and economic instability, which has led to widespread underinvestment in public services, such as providing and accessing safe and sufficient water supply, but also presented persistent challenges with regard to continued monitoring of water resources and lack of groundwater management. Acute shocks, such as conflict escalation, seasonal droughts, flooding, and most recently, COVID-19, have compounded the impact of stressed hydrogeological resources and limited economic opportunities, leaving groundwater potential undeveloped, groundwater abstraction unregulated, water resources unmonitored and leaving a large segment of the population mostly unable to sustainably meet their water supply needs.

When it comes to the challenges of groundwater and surface water in Afghanistan, a distinction can be made between root causes and the actual issues. Root causes are the basic reasons behind the key issues observed. The major issues are introduced in this chapter as well. This differentiation between issues and root causes is important for the realization that problems alone cannot materialize any change without turning to the root causes as well. For example, humanitarian aid will not address the underlying issues that leave Afghanistan vulnerable to climate change-related shocks, as pointed out by Mhd Assem Mayar (2021b).

Some of these root causes are direct causes of human activity, such as deforestation and poor land-use practices, resulting in increased risks and impacts of both floods and droughts. Other root causes are related to human inactivity such as the lack of systematic groundwater monitoring or unregulated well drilling and abstraction permitting, resulting in over-abstraction of groundwater. Other root causes include national and international migration, urbanization and rapid population growth leading to further demand for limited resources. The increased use of water in combination with increased variability in temporal and spatial distribution of rainfall, runoff and recharge, disturbs hydrological regimes and increases the imbalance of availability of water of sufficient quality at the right moment and at the right place.

8.2 Groundwater and surface water challenges

Groundwater level decline

Recent droughts and over-abstraction of groundwater by an increasing number of wells drilled into the shallow aquifers have caused falling groundwater levels, many karezes to completely dry up and have reduced the flow of springs. This has made traditional agriculture and irrigation less viable for many farmers. Increasing water demand and climate change will further reduce their long-term viability. As most groundwater recharge is linked to infiltration along rivers, groundwater level decline could be due to less recharge from surface water. Groundwater decline is not observed in all parts of Afghanistan, partially due to the limited coverage of the monitoring network in the country. Over-abstraction is clearly a concern in the Kabul River Basin, eastern Helmand River Basin and Western River Basin and in urban centres, where drawdown resulted from increased deeper drilling and abstraction. Exploitation of the Kabul Aquifer is considered unsustainable, with almost half of shallow wells are expected to be seasonally dry within the next few decades.

Groundwater quality issues

Due to the nature of the aquifers, shallow and unconfined in most places, groundwater supplies are very vulnerable with regards to both quantity and quality (salinity, geogenic and micro-bacterial). While groundwater quality issues (section 4.4) are primarily attributed to anthropogenic causes, high levels of salinity and natural groundwater contaminants (such as arsenic) are often neglected but widespread in Afghanistan. In addition, pathogenic contamination of groundwater is widespread, in particular in urban areas like Kabul. Faecal contamination from poor sanitation and well infrastructure and untreated wastewater pollutes aquifers with faecal coliforms, E. Coli, nitrates and can cause waterborne diseases. Contamination due to mining activities is less researched but at local level poses large risks for human and environmental health.

Insufficient hydrogeological understanding

Improved hydrogeological understanding is required for a more sustainable use of groundwater resources. Declining groundwater tables are reported in many monitoring wells, but there is a lack of data, analysis and hydrogeological understanding to identify what the actual root causes of the observed groundwater fluctuations are. With a better understanding of the hydrogeological system, the groundwater monitoring network can be improved and locations for groundwater monitoring that are of interest for sustainable groundwater resources development and protection can be determined. A better understanding of the aquifer systems of Afghanistan is required to determine why, where and how water resources should be monitored in the first place.

Unknown groundwater development potential

According to the current available information, most wells and groundwater monitoring wells focus on shallow, Quaternary aquifers in alluvial deposits along the main streams (see Figure 22). At the same time, little documentation exists on the groundwater development potential of (karstified) carbonate rocks and (fractured) bedrock aquifer systems in Afghanistan. The semi-consolidated and sedimentary rock units, which underlie the unconsolidated (mainly alluvial) aquifer systems in parts of the country may have development potential, but have not yet been explored in any detail (or information is not available). Hence, the groundwater potential of other than unconsolidated formations remain mainly unexplored due to the lack of knowledge generation.

Poor water supply access and service quality

Groundwater is the primary source of drinking and domestic water supply in most cities and rural areas (section 5.1). In rural areas, water supply infrastructure is limited, while in urban areas the piped water supply is facing a lack of maintenance and poor service quality, including service interruptions that are partly caused by unreliable electricity supply. Challenges include also a high level of non-revenue water (NRW) estimated at 40% including water use from illegal connections. In addition, access to an improved water source does not mean that the water is safe to drink, due to contamination (section 4.4.2).

Local water availability is unknown

Based on the available studies, water resource development in Afghanistan is mainly a water demand driven approach, with insufficient evidence-based consideration of water availability. This crystallizes through WASH data that monitors the national wide distribution of water supply, however does not provide vital information on the current status (dysfunction, functional, dry wells), the average abstraction rates and depth to groundwater (Rural WASH Dashboard, MRRD), nor considering long term sustainability. Existing water balance studies (e.g. Uhl, 2003) cover large-scale river basins rather than localized aquifers. The required level of detail and frequency of measurements is unsuitable for a local assessment of water availability. Aquifer-specific characteristics such as hillslope hydrology and the dynamics of local recharge and discharge mechanisms are not taken into consideration. The estimation of groundwater recharge is probably an over-estimation as a percentage of recharge is used for the entire catchment instead of determining groundwater recharge areas first. Meanwhile, groundwater abstractions are averaged for the entire catchment, therefore underestimating the concentrated impacts (groundwater depletion) in areas with high groundwater abstractions, which are often very localized. This leads to the conclusion that the current water balance estimates might be overestimating the groundwater recharge, while underestimating the groundwater withdrawals, resulting in a (regional) positive water balance while locally the aquifer can be over-abstracted and unsustainable for further groundwater development.

Changes in meltwater and erratic rainfall

While there is little information on the effects of climate change on hydrological regimes in Afghanistan, a shift from precipitation in form of snowfall to rainfall is expected and already taking place. Snowpack and glaciers are a natural inter-annual and inter-seasonal water storage mechanism that sustain perennial watercourses and recharges aquifers. Meltwater provides a relatively constant and stable supply of runoff water (long-term release) while erratic rainfall events provoke the concentration of water as runoff along the river network, eventually posing risks of flooding and consequential temporary water supply cession or reduction. This issue concerns the whole country as most headwaters are meltwater fed and most aquifers are located in alluvial sediments, where groundwater recharge is linked to infiltration along rivers. Flood damages to irrigated land are common, particularly in the large schemes supplied by rivers changing their course frequently due to their high sediment load and unfavourable geo-morphological conditions. Given the possible climate trends and the consequent alteration of the snow-runoff-recharge mechanisms, close observation should be implemented and integrated into catchment planning and management (IWRM).

Rising competition over shared water resources

The equitable allocation in terms of quantity, quality or timing of water resources between and within different sectors and for different uses, is one of the biggest challenges in the management of water resources in Afghanistan. With increasing demands on water from different sectors, growing water scarcity and climate variability, the competition over shared water resources is rising. These water allocation issues take place both within Afghanistan and transboundary.

Within Afghanistan - the withdrawal of surface water for irrigation is very high (see section 7.2). Most irrigation systems are community-managed canals where upstream areas benefit from vast supplies of water, whereas downstream areas receive the remaining amounts. With increasing water demand and climate variability, downstream water availability is increasingly under pressure. Meanwhile, the actual irrigation water use and irrigation water demand is not exactly known, as estimates are inaccurate due to unaccounted abstraction (illegal, irrigation losses and unmetered) and lack of data. Hence, in order to design well-functioning water allocation schemes for upstream and downstream users, irrigation volumes should be estimated more accurately. Remote sensing coupled to ground-truthed data, could provide a tool for monitoring the evolution of irrigated areas over time.

Transboundary - While the above applies mainly to the national level, the water allocation (and compliance) of transboundary rivers are important on a regional level. High abstractions on the Helmand River in Afghanistan limit environmental flows needed to protect biodiversity in the transboundary Sistan-Helmand wetlands (see section 7.4). Failure to determine the water balance and factor in the high demand of irrigation water use is partly to blame for the ecological destruction and disruption of the Sistan-Helmand wetlands. The large runoff quantities and constant summer flow of the transboundary Amu Darya River are of major interest to Afghanistan and its riparian, downstream nations (see section 7.4). With the new irrigation canal under the upper Amu Darya and lower Panj underway, up to 650 m^3/s could be diverted for irrigation purposes in northern Afghanistan. It may be true that the full capacity of the river will not be exploited, but being the upstream nation, Afghanistan has the responsibility to protect their resources because this has an impact on the riparian countries.

Insufficient capacity at institutional level

While the monitoring network has been growing over the past decades, the capacity at the different institutional level has not kept up. The number and level of qualified personal (e.g., remote sensing specialists or hydrogeologists) is not sufficient to collect and analyse data for high-level decision making on the assessment, management and development of water resources in Afghanistan. Hence, water management is not adequately incorporated at local, regional and national governance level and monitoring of both surface- and groundwater resources is flawed which leads to data gaps or the risk of equipment not being updated and through that impeding data collection.

9 Recommendations and way forward

The assessment of water resources in Afghanistan is a first step towards a more sustainable and climate-resilient use and management of the available water resources. This baseline report brings together the insights of many studies done previously, providing a hydrogeological and hydrological framework. It shows that there are still many knowledge-gaps (sub-section 2.1.2) and provides an overview of key issues (chapter 7). However, there are also many options to improve water security and potential to further develop and manage water resources in Afghanistan. This chapter starts with a general direction for future work, followed by recommendations for follow up activities, follow up research and priority areas.

9.1 General direction for future work

- Most groundwater in Afghanistan is abstracted from shallow alluvial aquifers. However, shallow aquifers are not sustainable in the long run, due to both high vulnerability from climate change and contamination. Strategic reserves and alternatives one could think of are:
    - Deep groundwater potential mapping and development of renewable deep groundwater resources
    - Reduce water consumption and non-revenue water (NRW, estimated at 40%) and increase irrigation efficiency (estimated at 25-30%) in traditional and irrigation schemes
    - Reduce surface water outflow into neighboring countries,
        - by increasing the retention and recharge of water through NBS, MAR and 3R measures
        - by expanding water infrastructure such as dams, irrigation canals and reservoirs which can store water for eventual use

- Before further expanding the groundwater monitoring network, a better understanding of the aquifer systems of Afghanistan is first required to determine why, where and how water resources should be monitored.
    - Prior to expanding the monitoring network, clear and realistic monitoring goals should be identified and embedded in the Afghan framework of water governance and compliance, water allocation and water management.
    - Isolated, project based monitoring networks are relatively expensive, have a short lifespan and may not contribute to achieve regional or country wide monitoring goals.
    - Monitoring becomes more useful if data is not only being measured but also continuously analyzed and interpreted within the hydrogeological context. Monitoring data should be linked to a decision making framework with clear context specific threshold and targets together with roles and responsibilities of various institutions.

- This report is based on more than 60 documents and reports and is not exhaustive.

- Additional sources to prioritize are available hardcopy and softcopy studies, databases and reports, from various Ministries, including Ministry of Agriculture, Irrigation and Livestock (MAIL), Ministry of Energy and Water (MEW), Ministry of Mines and Petroleum (MOMP), Ministry of Rural Rehabilitation and Development (MRRD).
- Additional research and collation of data should be directed to areas that may have strategic significance. It is recommended that donors, through funding programs, invest on small research programs which collect specific results to fill these gaps.

9.2 Recommendations

The following recommendations are given:

Groundwater management

- Regulate and control existing groundwater abstractions and the permitting and construction of new wells
- Develop groundwater models for key strategic aquifers to allow management scenarios to be tested
- Incorporate groundwater management in the local, regional and national governance level and develop capacity, e.g. by training more hydrogeologists
- Estimations of the future water demand to ensure national food security considering the expected population growth
- Ensure capacitated personnel are available to manage and monitor both surface and groundwater resources through capacity building of hydrogeologists
- Investments in improved waste disposal, rural sanitation systems and urban sewage infrastructure are required in combination with awareness campaigns
- Test and record well performance and aquifer properties (such as transmissivity and storativity) by means of pumping tests
- Improve the recording of well completion reports (e.g. depth of well and screened interval, lithology and water strikes encountered) '
- Improve the availability of groundwater data, e.g. Develop a GIS-based online system for adding the well completion information including location, depth, water table, water quality and monitoring data

Groundwater monitoring

- The monitoring of existing pumping wells should be improved by systematic monitoring of groundwater abstractions and water quality, besides water levels
- Allocate more wells dedicated to monitoring alone (so not being pumped) at strategic locations to allow for measurement of long-term trends in groundwater levels and regional effects in relevant aquifers
- Combine the monitoring of groundwater levels with monitoring of abstraction rates, nearby stream flow, precipitation and other hydrological aspects, in order to relate the observed trends in groundwater level and groundwater quality with possible root causes, such as over-abstraction or climate change and determine which of them are most important in different regions, aquifers and specific wells
- Determine why, where and how water resources should be monitored and develop a framework for a national water resources monitoring program

Groundwater development

- Map groundwater needs and groundwater vulnerability and develop groundwater development plans
- Based on the above, map strategic and renewable (ground)water resources in Afghanistan, to investigate where and what the possibilities are for more secure and sustainable (ground)water development. This includes:
    - Groundwater potential mapping
    - Geophysical surveys
    - Exploration drilling and test pumping
- Assess the capacity of drilling contractors in Afghanistan
- Development of renewable deep groundwater resources, that are hardly explored and mostly undeveloped; investigate other-then-shallow-alluvial-aquifers such as deep sedimentary aquifers in the North and South region, deep conglomerate aquifer in Kabul Basin, limestone and dolomite aquifers (that potentially contain 20% of the available groundwater reserves) or regional fault systems in basement areas
    - Confined aquifers are less responsive to potential effects of changes in climate and shallow withdrawals, therefore a more secure water supply might be developed; if sustainable. Limestone and bedrock aquifer systems in the country are largely unexplored and some of these units may well represent valuable sources of irrigation and potable supply in the future.
    - Careful evaluation and management of new withdrawals, along with monitoring climate trends and effects of other withdrawals, will be needed to protect existing community water supplies.

Improve water availability

- Groundwater recharge could be locally enhanced through the implementation of small scale technologies, using nature based solutions (NBS), recharge - retention – reuse (3R) practices and managed aquifer recharge (MAR). Enhanced groundwater recharge measures can provide a low-cost solution to improve urban, rural, and agricultural water supplies by increasing annual recharge to groundwater storage.
    - detailed information on aquifer properties and water quality of the source recharge water is required prior to designing, piloting and implementation
    - short-term and long-term impacts have to be considered, including effects for downstream stakeholders or environmental flow requirements to sustain ecosystems or changes in the groundwater quality of connected aquifers
    - potable water quality can be achieved through aquifer recharge protection zones, regulated groundwater abstraction rates and appropriate domestic water treatment, combined with education, water quality monitoring and appropriate technologies.
- The construction of artificial glaciers in elevated areas could also be a low cost and low tech solution to freeze and store unused winter meltwater for gradual release and infiltration into the soil during spring and summer time for the benefit of villagers and farmers downstream. As such this could be an option to (partly) compensate for glacial retreat and reduced snowfall due to climate change.

- within Afghanistan, no examples of artificial glaciers are known to the authors, but for example in Ladakh, North India, conical ice stupas have been constructed successfully since 2019, serving as water towers, storing winter meltwater for spring planting (Kumar-Rao, 2020).
- Introduce water harvesting techniques on household level
- Improve irrigation water efficiency,
    - by introducing more efficient forms of irrigation, such as drip irrigation (mechanized and monitored)
    - by using less water intensive crops
    - reducing (open water) evaporation
- Awareness raising of farmers and rural / urban communities on integrated water resources management (IWRM) and the importance of water saving

River basin management

- IWRM should be applied at river basin level to improve water security and to reduce soil erosion and soil degradation.
- Develop catchment management plans; and improve water allocation while consider upstream and downstream effects.
- Equitable distribution of water between users needs to be promoted
- Given the amount of runoff of surface water that is leaving Afghanistan to neighbouring countries, an opportunity exists to manage water resources more equitably for Afghanistan and its neighbouring countries, which needs further investigation, communication using evidence and diplomacy.

Drought and flood risk reduction

- There is a need to build and – and re-build – Afghanistan's national disaster mitigation and management infrastructure, with particular effort to create effective watershed management mechanisms. Harvesting rainwater during the wet season and directing it to the groundwater aquifers would go a long way in moderating water shortages during future droughts. Afghans should take local action to build small water conservation ponds or groundwater recharge schemes. Employing new techniques such as drip irrigation and cultivating different varieties of crops can increase revenues per unit of irrigation water.
- Watershed protection, reforestation and sustainable land management (SLM) and soil and water conservation (SWC) practices should be applied in 'upstream' watersheds to reduce surface water runoff and as such reduce flood risk (flattening the peak flow) while increasing groundwater baseflow (improving drought resilience) further downstream.
- The 3R concept is an approach to promote the use of groundwater as a buffering solution between periods of surplus and shortage, in a way that reduces the risks of both floods and droughts. These are measures to retain water on the land (Retention), so that water can infiltrate into the soil (Recharge), so that water is stored in the ground and is available to be used in an efficient way during dry periods (Re-use). These include a combination of multiple small scall measures including:
    - In-stream surface water storage (large reservoirs and valley dams)
    - Off-stream surface water storage (valley tanks, water pans or ponds)
    - In-stream groundwater storage (sand dams, subsurface dams, permeable dams)

    - Surface water runoff interception (stone bunds, trenches, half moons)
    - Groundwater storage in aquifers (managed aquifer recharge, riverbank infiltration)
    - Overland water spreading (floodwater spreading or spate irrigation)
    - Hard surface water storage (road water harvesting, rooftop water harvesting)
- Crop diversification and implementation of water saving technologies are also options to reduce water shortages during droughts while maintaining agricultural productivity.

9.3 Follow up studies

Improved understanding of aquifer systems, updated water balance analysis and evaluations, and the engagement of local key experts are precursors to the development of evidence-based management plans for water resources in Afghanistan. Hence, we foresee this baseline study as a starting point for follow up studies such as, but not limited to:

- the establishment of localized groundwater monitoring, improved understanding of aquifer properties and conceptual hydrogeological models to produce water balances on aquifer scale in areas of population centres where abstraction is concentrated, in order to determine a sustainable water supply rate;
- the mapping of Afghanistan's landcover and analyse the main trends in landcover changes over the past decades, using remote sensed data, in order to better understand the implications of landcover changes on water resources;
- the development of a hydrogeological map showing groundwater potential and vulnerability;
- the collation and combined analysis of all available meteorological, surface water and groundwater monitoring data, including
    - stream flow + surface water level (rating curve estimations),
    - groundwater abstraction rates + groundwater level variation,
    - relation between precipitation + stream flow + groundwater recharge,
    - surface water (quality) – groundwater (quality) interaction;
- the assessment of capacity of stakeholders followed by capacity building of stakeholders and partners in IWRM, hydrogeology, hydrology, monitoring and analysis, including
    - on the ground discussions and engagement with all stakeholders who have a vested interest in water resources at all levels in Afghanistan, such as the MAIL, MEW, MOMP, MRRD,
    - inclusion of expert knowledge and involvement of local hydrogeologists and water resources experts;
- the improvement of (ground)water balance analysis (section 5.3.1) on basin and sub-basin level, including more accurate estimations of groundwater recharge and groundwater abstraction, to refine the safe sustainable yield estimates in all major river basins and sub basins in Afghanistan.
    - estimation of irrigation groundwater use could be updated with more accurately permitting and recording groundwater abstractions and by estimating total irrigation water use with satellite data.
    - estimation of groundwater recharge could be updated with the newest data on precipitation and evapotranspiration, and by redefining recharge

according to an infiltration coefficient assigned to different surface geology types.

- Scenario analysis and impact assessment of climate variability and changing demographics on the availability and quality of water resources and the temporal and spatial mismatch between water supply and water demand, for specific priority areas.

9.4 Priority areas

The identification of (ground)water availability priority areas is a first step to determine where detailed assessments on (sub)basin level of water demand and water availability, mapping of water uses for each sector, water balance analysis and ultimately strategies towards a more sustainable water management are most required and most effective.

The key issues presented in chapter 8 are among the topics to be prioritized for follow up studies and more detailed assessments. The geographical areas to be selected for a more focused analysis and improved monitoring of water resources depends on criteria including:

- water demand vs water supply,
- security and accessibility,
- (ground)water availability,
- (ground)water quality.

Kabul and Kandahar are the main urban centers and are considered priority areas to monitor and maintain domestic water supply of safe quantity and quality. In terms of irrigation abstraction and potential groundwater level decline, the Farah, Ghanzi, Helmand, Kandahar, Uruzghan and Kabul provinces are potential priority areas. The alluvial aquifers along the main rivers are priority areas for the recommended river basin management measures, with a focus on (mitigating the impact of) erratic rainfall and longer dry spells in the southern and western part of the country and melting glaciers in the more elevated central and north-eastern part of Afghanistan.

The improvement of water governance and its enforcement and advocacy and awareness of water issues are also considered important priority topics.

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10.1 Relevant websites on water resources in Afghanistan

Afghanistan Analysts Network
https://www.afghanistan-analysts.org/en/about-aan/
The Afghanistan Analysts Network (AAN) is an independent non-profit policy research organisation. It aims to bring together the knowledge, experience and drive of a researchers, analysts and experts to better inform policy and to increase the understanding of Afghan realities. Multiple analysis on Afghanistan and its region, of high quality and research-based, can be found on its website, including articles related to water supply, climate change, droughts, glaciers and water shortages.

Afghanistan Groundwater Information
https://sureshuprety56.wixsite.com/af-gwinfo
and
https://sureshuprety56.wixsite.com/afgw
By: Groundwater Resources Department, National Water Affairs Regulation Authority, Islamic Republic of Afghanistan

Afghanistan Rural WASH Data
http://ruralwash.gov.af/
Online dashboard of the Ministry of Rural Rehabilitation and Development (MRRD).
Ru-WatSIP Management Information System
Re-structured by: MRRD/ Ru-WatSIP/ MIS-GIS Department.

Climate Change Overview – country summary Afghanistan
https://climateknowledgeportal.worldbank.org/country/afghanistan
By: The World Bank Group (2021)

FAO Aquastat Main Database
http://www.fao.org/nr/water/aquastat/data/query/results.html
Database assessed on 23-06-2023.
It should be noted that most figures presented in FAO Aquastat have been estimated (carry forward, vertical imputation, linear interpolation) for the past two decades; the latest official data is from 1998.

Glacial Lakes in Afghanistan
http://geoapps.icimod.org/AfGlacialLake/

Groundwater Resources Department
https://sureshuprety56.wixsite.com/afgw
Website of the Groundwater Resource Department of the former National Water Affairs Regulation Authority (NWARA), now the Ministry of Energy and Water (MEW) containing some interesting links and reports on groundwater resources in Afghanistan.

Climate Information Platform
https://ssr.climateinformation.org/
Database assessed on 08-06-2023.

The Climate Information Platform is developed by the Swedish Meteorological and Hydrological Institute (SMHI), on behalf of the World Meteorological Organization (WMO), World Climate Research Programme (WCRP) and the Green Climate Fund (GCF).

Watershed Atlas of Afghanistan
http://aizon.org/watershed_atlas.htm
The Watershed Atlas of Afghanistan provides geo-referenced watershed maps, information on watershed development initiatives, natural resources, climate, agriculture and a set of statistical data presented by watershed and river basins. The Atlas has been produced by the Ministry of Irrigation, the Food and Agriculture Organization (FAO), Afghanistan Information Management Service (AIMS), the Afghan Research and Evaluation Unit (AREU) and the Swiss Development and Cooperation (SDC).

Literature overview and database repository

All available relevant studies, reports and maps on water resources in Afghanistan have been collected, reviewed are categorized in a literature overview can be found in the attached Excel catalogue. *Literature overview water resources Afghanistan.xlsx*

All relevant hydrological and hydrogeological studies, reports in the online database repository https://gw4a.acaciadata.com. This database also contains a map viewer.

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