Central Asian Journal of Water Research (2017) 3(2): 3-11
Special Issue on Water Use Management Challenges in Central Asia and Afghanistan

Assessment of water quality and quantity trends in Kabul aquifers with an outline for future drinking water supplies

Abdulhalim Zaryab[1*], Ali Reza Noori[1], Kai Wegerich[2], Bjørn Kløve[3]

[1]Kabul Polytechnic University, Kabul, Afghanistan
[2]Martin-Luther-University Halle-Wittenberg, Institute for Geosciences and Geography, Germany
[3]University of Oulu, Faculty of Technology, Water Resources and Environmental Engineering Research Unit, Finland
[*]Corresponding author.
Email address: abdulhalim.zaryab@yahoo.com

Abstract
The water supply to Kabul city is at serious risk due to groundwater over abstraction and severe contamination by sewage. The water overuse is partly due to poor management and a long period of war, and instability in Afghanistan. In recent years shallow wells have been installed and financed by aid programmes, but this, along with high population increase has also lead to over-use of groundwater resources. The current water supply of about 85% inhabitants depends exclusively on local, individual groundwater sources, obtained predominantly from shallow aquifers, mainly, by hand-pumps. The paper analyses the status and trends of the Kabul groundwater system and assesses new solutions to meet the future water supply demand. The status of groundwater shows that groundwater levels are declining quickly (1 m/year) and several wells are already dry. Moreover, water quality analyses of the Kabul aquifers show a negative trend in groundwater quality in respect to concentration of nitrates, borates and faecal microbes (indicated by the coliform bacteria). This pollution exceeds the maximum permissible values determined by the WHO. To provide new solutions for Kabul city, a master plan for future water resources has been developed and this is further discussed.

Keywords: water supply, aid programmes, aquifer, overuse, nitrate, pathogens.

1. Introduction

Kabul has experienced quick and uncontrolled population growth in consequence of due high population growth in Afghanistan [1]. A feasibility study for the extension of the Kabul water supply system, conducted in 2004, shows an estimated population in 2015 of 4,089,000, with water demand about 123.4 million m^3/year [2]. However, the estimated groundwater availability in Kabul city, being approximately 44 million m^3/year, can only supply around 2 million inhabitants at a modest per capita consumption of 50 lit/day [8]. Besides the insufficient water resource, Kabul is one of the least developed cities of the world regarding access to clean water supplies and effective sanitation [3].

Kabul Basin consists of sand, gravel conglomerate and loess loam, which have a particularly good filtration capacity. The main sources of pollution are drainage pit latrines, road site ditches, sewerage, leaking septic tanks, Kabul River and irrigation channels. Kabul city has no general waste water treatment. The other pollution sources, which contaminate the groundwater within Kabul Basin, are sewage absorption wells, existing solid disposal, uncontrolled spreading of waste material, lack of a central sewerage system, overexploitation of groundwater, lack of water distribution pipelines, low public awareness of water related quality problems. Use of fertilizer for agriculture and existence of landfill sites in high permeability areas cause to pollute groundwater. In addition, low annual precipitation and low groundwater recharge coupled with groundwater extraction result in a negative balance between extractions and recharge. This means that current groundwater extraction is unsustainable, and the reduced groundwater volumes are unable to dilute increasing groundwater pollution.

The objective of the present analysis is to assess current status and trends of groundwater and explore other sources of drinking water outside the Kabul city. The study uses various reports and data sets from different sources to assess the current status and provide future recommendations. Understanding the current situation will help to develop the resource in a sustainable way and also provide an example on groundwater resource management from a quickly developing region with major conflicts and few similar reported studies.

2. Study area

2.1. Climate and hydrology

In Kabul, the air temperature ranges from a mean monthly low in January of -7 ˚C to a mean monthly high in July of 32 ˚C. The mean annual precipitation in Kabul is 300 mm. The annual evaporation rates in Kabul Basin are approximately 1,600 mm.

Three rivers enter the Kabul city region: Kabul River, Paghman River and Logar River. The Kabul River enters the Kabul Basin from the south, and flows to the north about 21 km to the city of Kabul, and then flows to east. The Paghman River flows eastwardly from the Paghman Mountains and enters the Kabul River in the city of Kabul near the point where the Kabul River begins to flow east. The Logar River, a large tributary to the Kabul River, enters the Kabul City from south through a steeply cut valley and flows northward for about 28 km. The Logar River enters the Kabul River at the eastern edge of the city of Kabul, about 17 km downstream of the mouth of the Paghman River.

2.2. Geology and Hydrogeology of Kabul Basin

Kabul city is located mainly in the flat Kabul Basin and it is surrounded and underlain by mountain ranges composed mainly of a variety of metamorphic rocks. The Kabul Basin is a basin structure that arose as a result of plate movements during the Late Palaeocene (early Tertiary) time. These rocks are part of the Kabul block and are intersected by the faults of the Herat-Bamyan-Panjsher main fault in the west and north-west, the Sorobi fault in the east, and the Chaman fault system in the south-east. The surrounded mountain ranges and bedrock are composed generally of a variety of metamorphic rocks, including gneiss, amphibolite, quartzite, slates, schist, marble, sandstone, mica of Precambrian age and consolidated rocks (limestone, dolomite) of Perm-Triassic age. The filling of the Kabul Basin itself consists of an accumulation of terrestrial and lacustrine sediments, mainly of Quaternary and Neogene ages unconsolidated and semi-consolidated lacustrine, fluvial and aeolian sedimentary rocks such as sand, gravel and silt [4,5,6].

The region outlining the Kabul aquifer is generally described as having four main Quaternary interconnected aquifers. The upper Kabul Basin (Darulaman-Paghman sub basin) has two aquifers lying along the course of the Paghman River and the upper course of the Kabul River. The lower Kabul Basin (Kabul-Logar sub-basin) has two aquifers lying along the course of the Logar River and the lower course of the Kabul River. For the water supply are mostly used the aquifers of Quaternary and the upper aquifer of Tertiary.

The recharge condition of the groundwater system is characterized by following sources being 1) recharges from rivers bed, 2) direct recharge from precipitation excess, 3) foot hill recharge from snow melt, 4) recharge from irrigation channels. Also, recharge from water supply networks, percolation of sewage, leakage septic tank and pit latrines might occur. The highest river discharge period, when almost all of water flow occurs is in April-May when snow melt occurs, and this is also the most likely period for aquifer recharge. The recharge sources and rates are not well documented for the aquifer.

2.3. Present Quantity and Quality Status of the Kabul Basin aquifer

The physical, chemical and microbiological parameters of Kabul groundwater were analysed in the last 16 years by different organizations (Danish Committee for Aid to Afghan Refugees (DACAAR), Afghan Geological Survey, United States Geological Survey (USGS), Bundesanstalt für Geowissenschaften Und Rohstoffe (BGR), Japan International Cooperation Agency (JICA), etc.). The conducted tests show that nitrate and boron concentration are progressively increasing in the urban area. The tests also indicated that other harmful elements such as sulphate, chloride, boron, sodium and others are also progressively increasing [5, 6].

3. Results and discussion

3.1. Groundwater Quantity Changes

In recent years, a severe decline in a groundwater level has been observed (Table 1). A comparison of data of water levels from the Mack et al. [5] study with the water levels reported by Myslil et al. 1982 [6] indicates that water levels have declined by more than 10 m in foothill areas and 5 to 6 m in the area of the city of Kabul. Water levels have declined by more than 15 m in the upper the Kabul Basin areas from 2003 to 2016 [7]. The reason for a lowered groundwater level is the increase in the number of inhabitants which has doubled since 1990s.

The rate of groundwater-level decline in the city increased (1.7 m/year on average) from 2008 to 2016. Many supply wells were installed only a few meters below the water table and are vulnerable to seasonal drying and now 33% of them are not in operation. Groundwater resources in the city of Kabul clearly face long-term sustainability concerns, such as increasing numbers of shallow water-supply wells going dry, whereas fewer issues with long-term water sustainability may have occurred in the northern Kabul Basin [8].

Table 1. Decrease of water level in last 34 years [6,7,9]

Year	Water level change (m)	Decline (m/year)
1982 – 2003	6	0.28
2003 – 2016	15	1.15

3.2. Groundwater quality changes

The water quality investigations show a negative trend indicating that groundwater pollution has gradually increased. The water quality analyses show a great variation of groundwater quality especially in urban areas [4]. The primary groundwater quality concerns in Kabul city are salinity, nitrate, hardness, boron and coliform bacteria. Microbiological analyses show high and increasing levels of faecal (coliform) bacteria in approximately 58 – 70 % of the wells in the urban area of Kabul city [8]. Since shallow groundwater and surface water are the main sources of potable water supply, contamination-related diseases frequently affect the population. The measured concentration exceeds the WHO guidelines for drinking water.

For nitrates, the analysis by Bundesanstalt für Geowissenschaften Und Rohstoffe (BGR) in 2004 shows that 42% of the analysed samples exceed the WHO limit of 50 mg/l. 32% of all hand pumped wells in Kabul Basin indicated that the nitrate concentrations level exceeded the HWO limit of 50 mg/l [7]. Analyses by DACAAR in 2011 show that the nitrate concentration of 47% of analysed samples exceeded the WHO limit of 50 mg/l [7]. This shows that nitrate concentrations are progressively increasing; the tests also indicated that other harmful elements such as sulphate, chloride, boron, sodium and others are also progressively increasing [6]. The WHO guideline for the electrical conductivity (EC) of drinking water is 1500 micro mhos [11]. But due to water shortage in Afghanistan, EC values of up to 3000 micro mhos are tolerated for human consumption. The distribution of EC in the Kabul Basin groundwater ranges between 306 – 13899 micro mhos [2]. The tests conducted by DACAAR in 2010 show that boron concentration in the urban areas of the Kabul Basin is higher than in most rural areas. In the urban area, 76% of water samples from the drinking water points indicated that boron concentration exceeded the WHO limit of 0.5 mg/l [8, 10]. About 52% of all hand pumped wells in urban area of Kabul city indicated that the nitrate concentrations level exceeded the WHO limit of 0.5 mg/l [7].

4. A case study for future water supply

4.1. Groundwater extraction and protection

A feasibility study for the extension of the Kabul water supply system was carried out in 2004 and funded by KfW. The current extraction is estimated to be more than 120,000 m^3/day and only 27.5% of Kabul population is provided with a piped water supply [5]. The population was estimated to be 4,089,000, in 2015 with a water demand of about 123.4 million m^3/year. Then the groundwater resources in Kabul city was estimated to be approximately 44 million m^3/year in 2015, and could only supply around 2 million inhabitants at a modest per capita consumption of 50 lit/day. This study recommended supplying the remaining inhabitants by developing remote surface water, to be conveyed from the upper flow of the Logar River and/or the Panjshir River. This study showed that the groundwater basin cannot supply sufficient drinking water for the Kabul city residents and it recommended developing and searching for sources of remote surface water. However, it is desirable that the local groundwater resources be utilized as much as possible, rather than transferring water from other basins at much higher costs with other related risks of safety, such as high evaporation.

The Estimated Availability of Kabul groundwater is approximately 44 million cubic meters (MCM) per year, according to the KfW water study. The estimated local available groundwater potential is shown in Table 2. In the upper Logar aquifer, the groundwater potential is estimated at around 63 MCM/year, but without detailed information about the upper Logar aquifer condition. It should be noted that the groundwater potential of the middle Logar aquifer was estimated as 63 MCM/year. Nevertheless, this aquifer is contaminated by arsenic and is not acceptable for drinking water, and it can only be used for future development of the Einak (Aynak) copper mine. The groundwater is only water sources for residents of Kabul city and for 5 million inhabitants at only modest per capita consumption of 24 lit/day. The locations of available water resources are shown below (Figure 1).

For the Kabul Basin aquifer, the water well water quality can perhaps be improved by drilling deeper wells to provide a solution to the acute well anthropogenic contamination. The direction of the groundwater flow and the location of the town can be considered to avoid water intakes from contaminated areas of the aquifer. The contamination is restricted to the town and the area east of the town and up to 90 m depth.

Table 2. Regional and local groundwater availability [3,10]

Aquifer	Water resources availability	
	10^6 MCM	m^3/day
Logar	24.64	67,500
Allaudin and upper Kabul	12.48	34,200
Afshar	3.65	10,000
Lower Kabul	3.65	10,000
Total	44.42	121,700

4.2. Surface Water as Future Sources (Remote Sources) for Kabul Inhabitants

Potential surface water resources are situated in the upper Kabul River Basin, the Shatoot dam on the Maidan River, and the Gat dam on the Logar River. Water resources are also situated in the Panjshir river basin, the Panjshir fan aquifer, the Gulbahar dam, and the Salang dam, and were the subject of a feasibility study by JICA in 2011. Of these, the development of the Gat dam and local groundwater in Kabul faces difficulties due to their large impacts on the social environment.

The Shatoot dam feasibility study was completed in February 2010. This analysis expects and suggests 94.6 MCM/year as a daily maximum and 87.2 MCM/year as a daily average could be obtained for the water supply to Kabul city. Thus, by completion of the Shatoot dam the amount of available water will increase to 87.2 MCM/year. Until completion of the Shatoot dam, the available drinking water resource for the Kabul inhabitants is limited to Kabul groundwater with 44.4 MCM/year after enhancement works plan by KfW. When the Shatoot dam, will start its operation, the average flow of the Maidan River will decrease dramatically. By 2025, the local groundwater availability will be reduced to an average level of 33 MCM/year [2]. Therefore, the sources of drinking water for the city will be 120.4 MCM/year by 2025 (Table 3). This means that some 6.6 million of the population may be the maximum capacity in the area of the upper Kabul Basin, by the applying the most conservative target of 50 lit/day by the Ministry of Urban Development Affairs as the unit per capita water consumption.

Table 3. Availability of drinking water resources [4, 6]

Resource	Available supply MCM/year
Local available water resource (local groundwater)	33.2
Shatoot Dam and WTP	87.2
Total	120.4

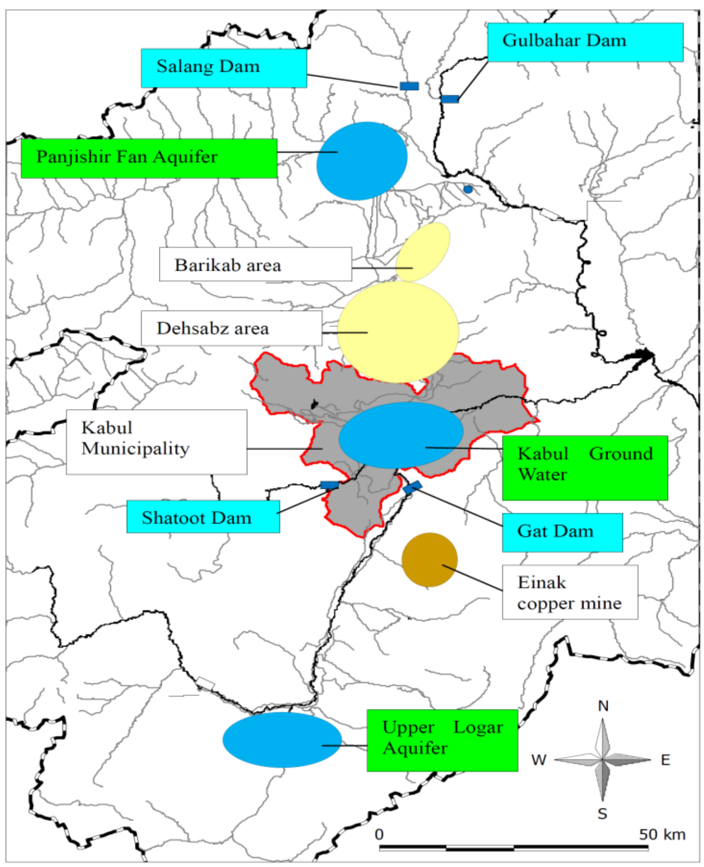

Figure 1. Location of potential water resources [5]

The Ministry of Energy and Water and other water related organizations expect the Gulbahar dam to be key solution for the chronic water shortage in the Kabul area. The feasibility study was conducted by the JICA and completed in December 2012. The Gulbahar dam is located on the Panjshir River to the north of Kabul city. The Gulbahar dam is designed as a concrete-arch type dam. The proposed dam height is 140 m with a storage volume of 240 MCM. The dam would be capable of supplying water for domestic and industrial use in the new city, and for existing and new agricultural use, while ensuring water for environmental flows, including supplementary hydroelectric power. Since the capacity of the dam is expected to be 240 MCM/year it has the potential to become the main water resource of the region including Kabul city and Dehsabz.

The Salang dam feasibility study was conducted by JICA and was completed in December 2012. The Salang dam is designed as a rock-fill type dam. The proposed dam height is 110 m with a storage volume of 40 MCM, which could supply water for domestic and industrial use in the new city and ensure water for environmental flows and existing agricultural use.

The Panjshir fan aquifer is located at the eastern part of Chahrikar city. It was proposed that drinking water to be supplied for Dehsabz new city from this fan aquifer. Therefore, the feasibility study was funded and conducted by JICA and the potential of the Panjshir fan aquifer was estimated to be 210 MCM/year. This fact allows that a part of water from the Panjshir fan aquifer would be pumped through a pipeline to Dehsabz city. Deducting the expected demand of 52.3 MCM/year by the residents and 44.6 MCM by the new city, there would be nearly 100 MCM/year of water available for use in Kabul City.

Although development of the Panjshir fan aquifer project take less time than constructing the Gulbahar dam. It is estimated that the operational cost for bringing water to the city of Kabul will be 10 times higher than in the case of the Shatoot dam.

As yet not considered in all studies, another possibility exists in supplying the town with water. This is artificial recharge of the Kabul aquifers by surplus surface water (rivers and snow melt water), which could also be a good option for increasing the natural reserves of groundwater in Kabul city. Artificial recharge is a process by which excess surface water is directed into the ground either by infiltration by surface canals/notches, by using recharge wells, or by altering natural conditions to increase infiltration to replenish an aquifer by underground dams. It refers to the movement of water through man-made systems from the surface of the earth to the underground water-bearing strata where it may be stored for the future use. But a comprehensive study regarding artificial recharge in the Kabul Basin has not been conducted yet. For safe use of the aquifer the pollution by sewage should also be eliminated. Then the existing pollutant plume from sewage sources will eventually be decayed and replaced with cleaner water sources.

5. Conclusion

The water-supply in Kabul is at risk due to groundwater depletion caused by unsustainable and uncontrolled groundwater abstractions, and contamination of groundwater resources by various sources such as untreated sewage. The Kabul Basin aquifers groundwater contamination and water quality analyses show that the groundwater quality within the urban area of Kabul city is progressively deteriorating. About 85% of the inhabitants mainly use uncertified sources of drinking water hand-pumps and shallow wells [6].

It was estimated that the groundwater potential in Kabul city is approximately 44 million m^3/year, which can only provide drinking water for 2 million inhabitants at modest per capita consumption of 50 lit/day. However, more than 4 million people live in Kabul city so a study was recommended into developing remote water supplies. For this reason, feasibility studies of the Shatoot and Gulbahar dams, the Panjshir fan aquifer and the Salang dam were conducted by the government of Afghanistan with the financial cooperation of Japan International Cooperation Agency (JICA). The studies estimated the supply capability by these dams and the Panjshir fan aquifer, but the projects are not developed yet.

For future water supply, we recommend that attention is to put at proper sewage treatment and safe disposal to the Kabul River or the underlying aquifer after a proper treatment. The over abstraction of the aquifer needs immediate attention to avoid problems related to lowered groundwater levels. The role of the aquifer recharge during spring snowmelt should be analysed as a way to increase the aquifer capacity and renewal rate. On the other hand, the population of Kabul city gradually increases so recommended that the surface waters, which have been investigated by the government of Afghanistan and JICA in 2006 to 2011, should be developed and supplied for the Kabul city residents.

6. Acknowledgement

This journal paper was prepared during the Central Asia education initiative funded by the Organization of Security and Stability in Europe (OSCE).

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