

# Chapter 2

## Groundwater Availability in the Kabul Basin, Afghanistan

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**Abstract** The Kabul Basin in eastern Afghanistan contains a sedimentary and semi-consolidated rock aquifer that is as much as 1,000 m thick. The city of Kabul is in the southern part of the basin where the population has doubled in the past 15 years to about 4.8 million in 2015, which represents about 15% of the total population of Afghanistan. This rapid population growth, together with potential impacts of climate change, has raised concern for groundwater availability, which is the primary source of drinking water in the basin. Rising groundwater levels indicate that the basin has emerged from the severe drought of the late 1990s and early 2000s that affected much of Afghanistan. However, groundwater level declines of up to 1.5 m/yr in the city of Kabul illustrate the concern for the sustainability of groundwater resources in the face of growing demands for water. Groundwater flow modeling has been used to estimate water resources in the basin, the potential effects of increased groundwater withdrawals, and potential climate-induced changes to recharge in the basin. Simulated increases in groundwater withdrawals will affect areas of the basin with the greatest population growth, while a climate-induced reduction in recharge may have a more widespread impact and may particularly affect areas near the mountain front. In addressing the sustainability of groundwater in the Kabul Basin, there are various options for water resource managers to explore while continued development of groundwater and surface water monitoring networks is needed.

### 2.1 Introduction

The Kabul Basin (Chap. 1, Fig. 1.3) is a fault block valley in eastern Afghanistan, approximately 80 km long and 10–35 km wide, which contains Afghanistan's capital city of Kabul in the southern part of the basin (Fig. 2.1). Groundwater is the primary source of drinking water supply in the basin and is increasingly being used

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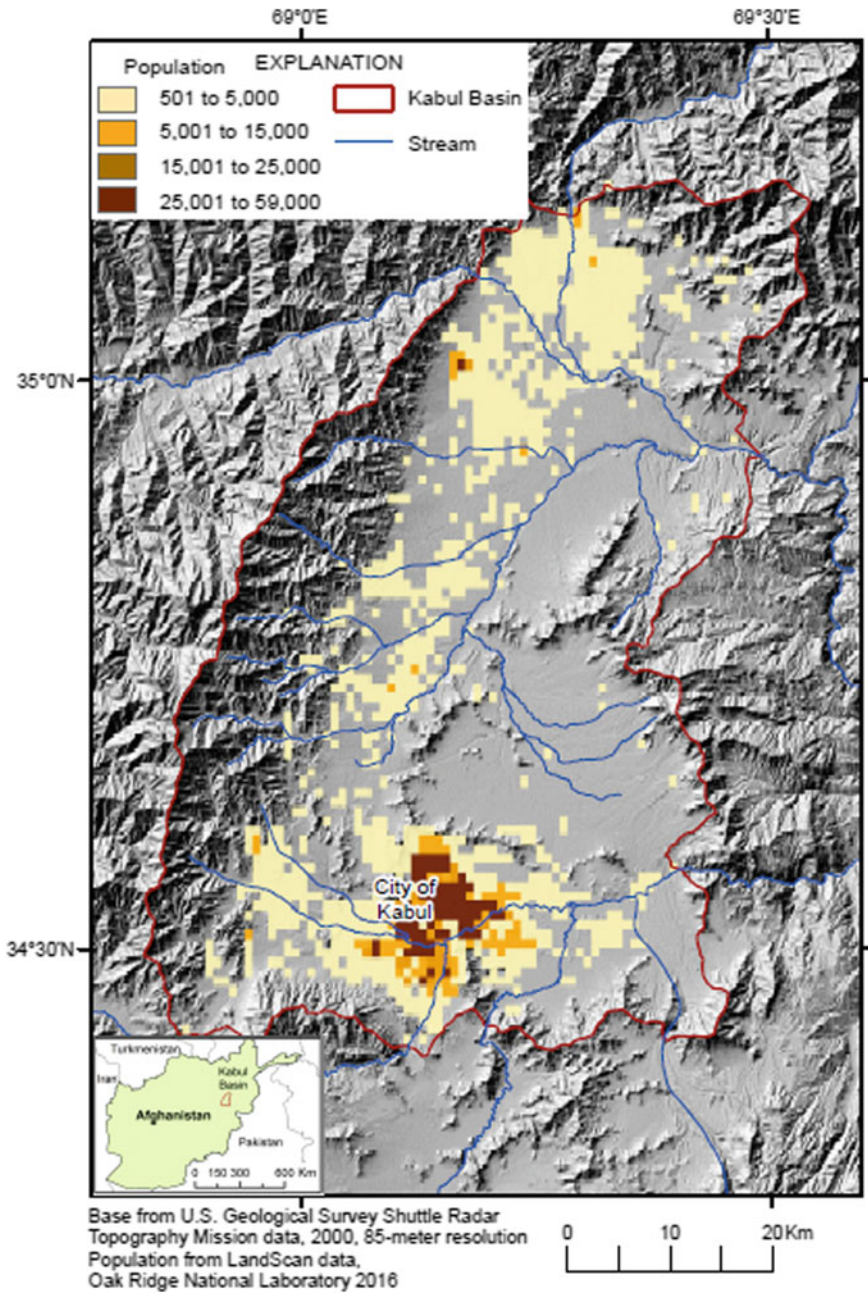


Fig. 2.1 Kabul Basin and estimated 2015 population, Afghanistan

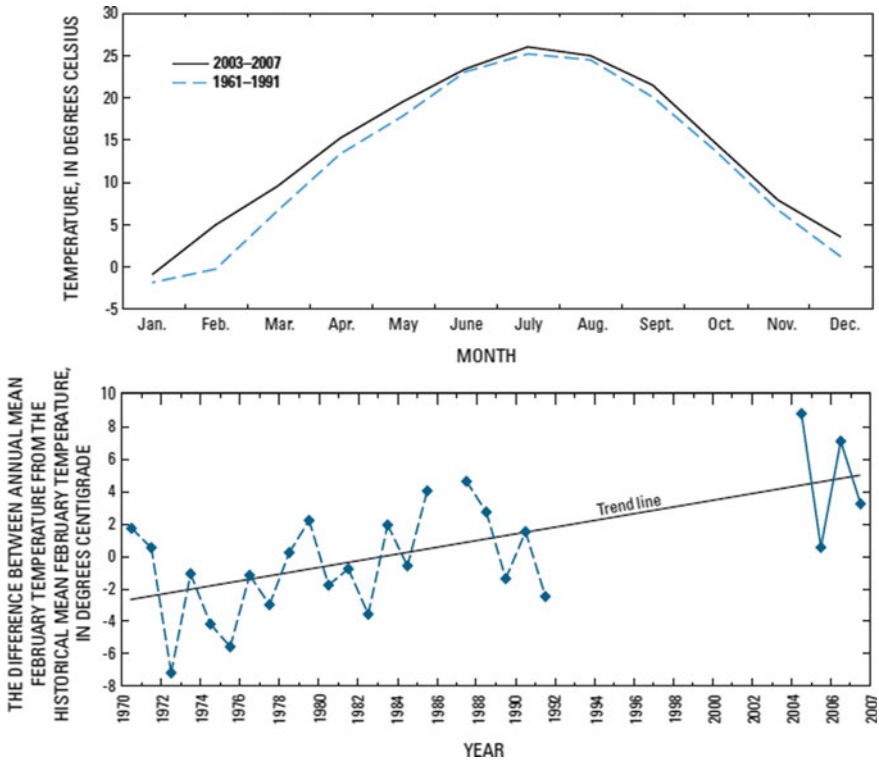
for agricultural irrigation. Between 2000 and 2015, the population of Kabul grew from 2.4 to 4.8 million (United Nations 2016) as a result of numerous factors including returning refugees, nationwide conflict, and relative security in Kabul, and population migration due to a drought that affected much of Afghanistan in the late 1990s. As of 2015, about 15% of the population of Afghanistan resides in the city of Kabul (Fig 2.1) (Oak Ridge National Laboratory 2016). This is the highest percentage of any one city in South or Central Asia (United Nations 2016). This rapid population growth, and the potential effects of climate change, has raised concern for the groundwater availability for a considerable proportion of Afghanistan's population and particularly those in the Kabul Basin.

Comprehensive investigations of the groundwater resources of the southern sub-basins of the Kabul Basin, immediately surrounding the city of Kabul, include those of Böckh (1971), Houben et al. (2009), Myslii et al. (1982), and Niard (2007). The investigations of Broshears et al. (2005) and Mack et al. (2010) covered the entire Kabul Basin. Niard's (2007) investigation, in the sub-basins of the southern Kabul Basin, includes a numerical groundwater flow model that was valuable for the conceptual understanding of the groundwater flow system. Mack et al. (2010) developed a groundwater flow model of the entire Kabul Basin, also to assess the conceptual understanding of the flow system and to estimate the effects of increasing groundwater withdrawals with population growth and the potential effects of climate change on groundwater availability in the basin. More related information regarding groundwater of South Asia are available in Mukherjee (2018).

## 2.2 Climate

The Kabul Basin is a semiarid region that receives approximately 330 mm of precipitation annually with the highest precipitation historically occurring during winter months as snow (Mack et al. 2010). Much of Afghanistan was in a drought from about 1998 to 2004, with reports that Kabul received no precipitation during this period (International Water Management Institute 2002). The rate of evapotranspiration in the basin, 1600 mm/yr, is much greater than total precipitation resulting in little if any groundwater recharge by direct precipitation on the land surface. Therefore, the winter snowpack in the mountains adjacent to the Kabul Basin is an important source of recharge in the Kabul Basin (Mack et al. 2010). The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) found that Central Asia, including Afghanistan, was particularly at risk for increasing warming temperatures (Cruz et al. 2007). This assessment has not changed in more recent IPCC analyses (IPCC 2014).

Although a gap of more than 20 years exists in Afghanistan's climate record, preliminary analysis of limited temperature data noted increasing monthly mean temperatures in the city of Kabul (Fig. 2.2). The greatest change in monthly mean temperatures was observed in February (Mack et al. 2010). Warming winter

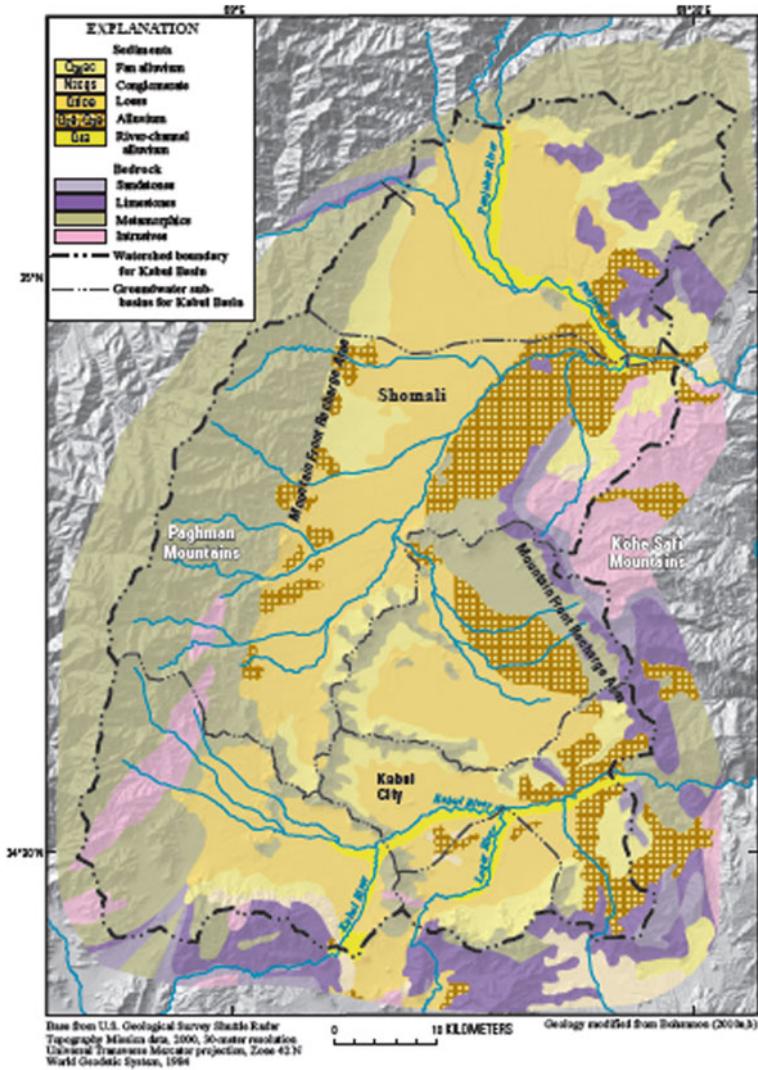


**Fig. 2.2** Graphs of monthly mean temperatures for 1961–1991 and 2003–2007, and difference in mean February temperature from historical mean February temperature for 1970–2006, at Kabul, Afghanistan

temperatures may decrease spring recharge and snowmelt may occur earlier in the year, further from the summer growing period when it is most needed. Along this line, the IPCC Working Group 2 ranked the water resources of central and west Asia as “highly vulnerable” to impacts of climate change at a “very high” level of confidence (Cruz et al. 2007).

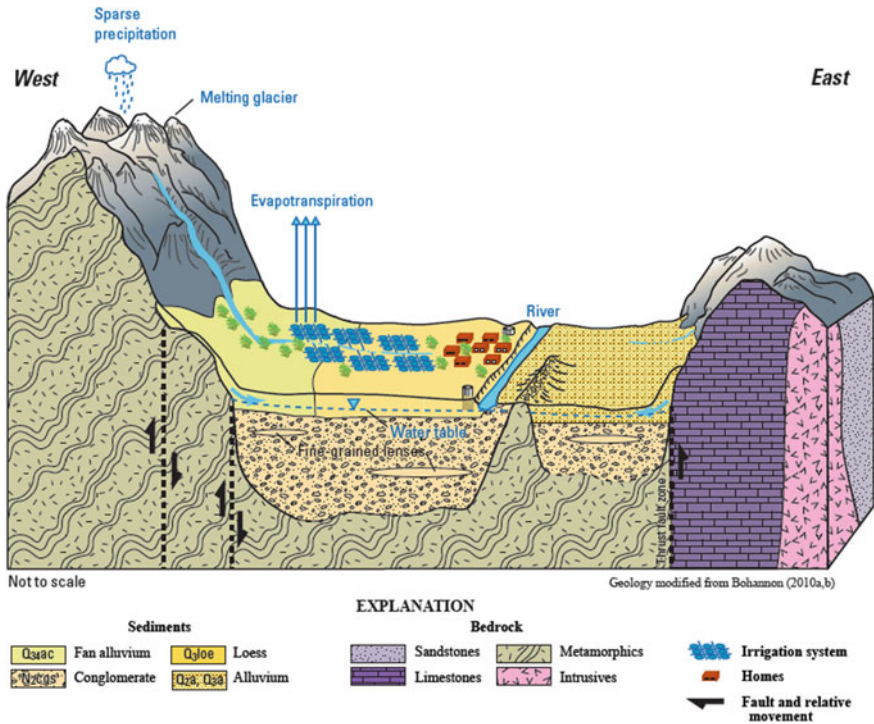
### 2.3 Geohydrology

The surficial geology of Afghanistan had been mapped by Soviet and Afghanistan Geological Survey (AGS) efforts prior to 1980. The Soviet-AGS maps were refined by the USGS, and surficial geologic maps of the Kabul Basin are provided by Bohannon (2010a, b). The primary aquifer in the Kabul Basin is a surficial sedimentary aquifer, consisting of alluvium and loess, in the base of a valley formed by eastern and western flanking mountain ranges of various rock types (Fig. 2.3).



**Fig. 2.3** Generalized surficial geology of the Kabul Basin, Afghanistan. Modified from (Mack et al. 2010)

Figure 2.4 presents a generalized schematic diagram of the Kabul Basin (Mack et al. 2010). This conceptualization was used to develop a groundwater flow model for estimation of the effects of increasing groundwater withdrawals and climate change on the basin’s groundwater availability. The thickness of the surficial aquifer is generally less than 80 m but may be 200 m or greater in the center of the valley, particularly in the northern Kabul Basin (Böckh 1971). Reworked river channel alluvium along the main river channels in the basin (Fig. 2.3)



**Fig. 2.4** Generalized schematic diagram of the Kabul Basin, Afghanistan. Modified from (Mack et al. 2010)

has been estimated to be highly transmissive (more than 100 m/d, Böckh 1971) which allows for considerable infiltration from the Kabul River and its tributaries. The underlying semi-consolidated Neogene conglomerates are up to 1,000 m thick and represent a lower yielding secondary aquifer system (Homilius 1969; Japan International Cooperation Agency 2007). Sub-basins in the Kabul Basin are formed by interbasin bedrock ridges. The southern part of the Kabul Basin is separated into several sub-basins where the southernmost contain the city of Kabul (Figs. 2.3 and 2.4). The interbasin ridges restrict, or prevent, groundwater flow between sub-basins of the Kabul Basin.

## 2.4 Recharge

Recharge to the Kabul Basin aquifer system occurs primarily from infiltration leakage from streams and irrigated areas in the basin, and from mountain front recharge at the valley walls adjacent to the basin (Figs. 2.3 and 2.4) (Mack et al. 2010). Very little recharge occurs from precipitation directly on the aquifer.

Direct precipitation recharge is primarily from larger precipitation events, or snowmelt, during the non-growing periods. Chemical and isotopic analysis of groundwater in the basin found that groundwater in the surficial primary aquifer was generally less than 30 years old, becoming older further from recharge areas (Mack et al. 2010). Carbon-14 analysis of groundwater at the top of the lower secondary aquifer was several thousand years old and may be much greater at depth (Mack et al. 2010). Based on analysis of historical streamflows (Olson and Williams-Sether 2010), and chemical and isotopic data, mean annual recharge on the 780 km<sup>2</sup> basin floor area was estimated to be approximately 8.2 Mm<sup>3</sup> from river leakage and 2.8 Mm<sup>3</sup> from irrigation leakage and recharge directly on the land surface (Mack et al. 2010). Streamflow into the northern Kabul Basin was about five times that of the southern basin. The northern Kabul Basin is fed by the Panjsher River and its tributaries (Fig. 2.3) which, as of 2007, contained approximately 66 km<sup>2</sup> of glacier-covered area (Mack et al. 2010). The Kabul River and its tributaries drain lower elevation upland areas with no glaciers. Analysis of historical streamflow data for rivers and tributary streams flowing into the Kabul Basin found an average annual runoff per square kilometer of 0.020 m<sup>3</sup>/s for the northern drainages compared to 0.004 m<sup>3</sup>/s for the southern drainages (Mack et al. 2010). Additionally, the Panjsher River streamflow, and the other northern drainages, typically peaks in June or July about 2 months later than streamflow in the Kabul River (April) and the southern drainages. The timing of the streamflows in the northern Kabul Basin, particularly the higher flows later in the summer months in the northern part of the basin, is critical for agriculture needs and recharging groundwater during the seasonal high demand.

## 2.5 Groundwater Availability and Future Needs

Historically, drinking water for many areas of the Kabul Basin was supplied by shallow hand dug wells or karezes, a hand dug water conveyance system that skims water from an upgradient water table. The amount of agricultural water use in the basin is unknown but is likely to be an order of magnitude greater than that of domestic use. Historically, this use was supplied by kareze flows and channel diversions from streamflow. However, agricultural use is increasingly being supplied by pumped groundwater, which is leading to kareze failures throughout Afghanistan (Goes et al. 2017). The decline in functional karezes has been documented in the Kabul Basin and in the Chakari Basin, about 20 km southeast of the city of Kabul (Mack et al. 2014a, b). Municipal water use in the Kabul Basin is not metered but was estimated to be about 46,765 mL/yr (128,000 m<sup>3</sup>/d) based on a 2002 population of 3.5 million and a per capita use estimate of 25 L/d (Mack et al. 2010). The per capita water use rate and agricultural demands are expected to increase in the future with the rising living standards and population growth. United Nations projections estimate the population in the Kabul Basin to grow to about 9 million by the year 2057 (United Nations 2015). With an expected per capita use

rate of 78 L/d, closer to other surrounding countries, the projected drinking water use rate in the basin would increase to about 725,000 m<sup>3</sup>/d, a sixfold increase (Mack et al. 2010).

Between 1997 and 2005, non-governmental organizations had installed more than 1500 shallow drinking water supply wells, with a median depth of 22 m, in the Kabul Basin (Safi and Vijijselaar 2007). About 25% of those wells in the city of Kabul, and about 20% of those in the larger Kabul Basin, were reported to be dry (Safi and Vijijselaar 2007). There also are anecdotal reports of groundwater level declines of up to 10 m in the city in the early 2000s (Uhl 2006). A simulated sixfold increase in groundwater withdrawals was projected to result in groundwater level declines of 0.5 m, at 54% of the basin's wells, and more than 1.0 m at 36% of the wells (Mack et al. 2010). Given that most of the wells in the basin are screened at the water table such groundwater level declines may cause many wells to be seasonally inoperative or dry in the future.

An analysis of groundwater level trends between 2004 and 2012 in the Kabul Basin (Fig. 2.5) was conducted on 70 wells monitored by the AGS and 10 wells monitored by the Danish Committee for Aid to Afghan Refugees (DACAAR). The study found that although groundwater levels in the basin were recovering from the drought of the late 1990s and early 2000s, at rates of up to 0.6 m/yr, there were declines of more than 1.5 m/yr in the city of Kabul (Mack et al. 2013). Monthly groundwater levels between 2004 and 2012, for two AGS network wells in the Kabul Basin, are shown in Fig. 2.6. Well 20 (Fig. 2.6a) located in the Shomali sub-basin (Figs. 2.3 and 2.5) shows a groundwater level rise of about 5 m since the early 2000s while at well 167 (Fig. 2.6b) in the city of Kabul in the Central Kabul sub-basin (Figs. 2.3 and 2.5), groundwater levels have declined more than 15 m in this same period. The areal extent of measured groundwater declines in the city of Kabul, for the September 2008–2012 period with the greatest measured declines (Mack et al. 2013), was in line with groundwater model simulated declines due to projected population growth (Mack et al. 2010) (Fig. 2.7). The sub-basin containing a large part of the city of Kabul is isolated by interbasin ridges from the major sources of recharge in the region such as mountain front recharge and irrigation leakage. The primary source of groundwater recharge to the city of Kabul is leakage from the Kabul River while flow from the river to this area is restricted by ridges with low permeability (Fig. 2.7).

The potential effects of climate change on the water resources of Southeast Asia and Afghanistan's have been examined by numerous investigations including Milly et al. (2005), Vining and Vecchia (2007), and the IPCC (2014). Potential changes identified by these studies include warming temperatures, which could result in earlier spring-melt peak recharge events, and increased rates of evapotranspiration. Groundwater flow simulations of a 10% reduction in recharge, as suggested by Vining and Vecchia (2007), result in even greater, and more widespread, groundwater level declines in the Kabul Basin than were simulated by increasing groundwater withdrawals (Mack et al. 2010). An earlier annual recharge peak, from snow and glacier melt, would greatly reduce the available water in the Kabul Basin and particularly in the northern areas of the basin where this peak typically occurs during the summer growing period.



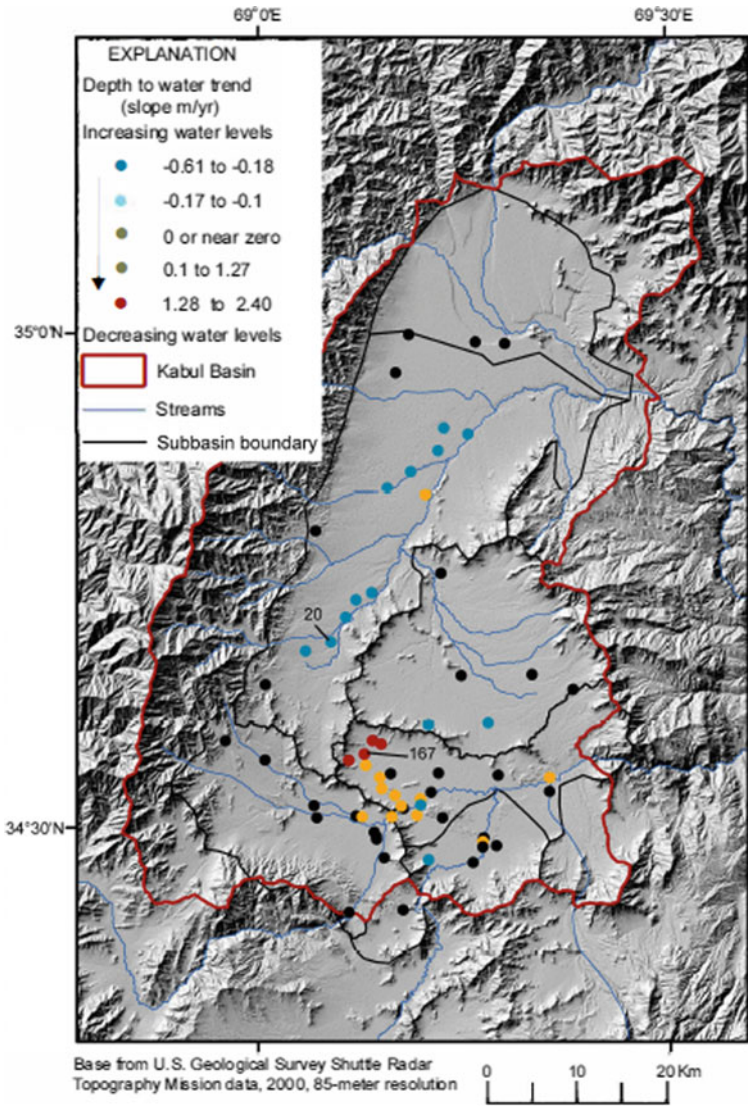
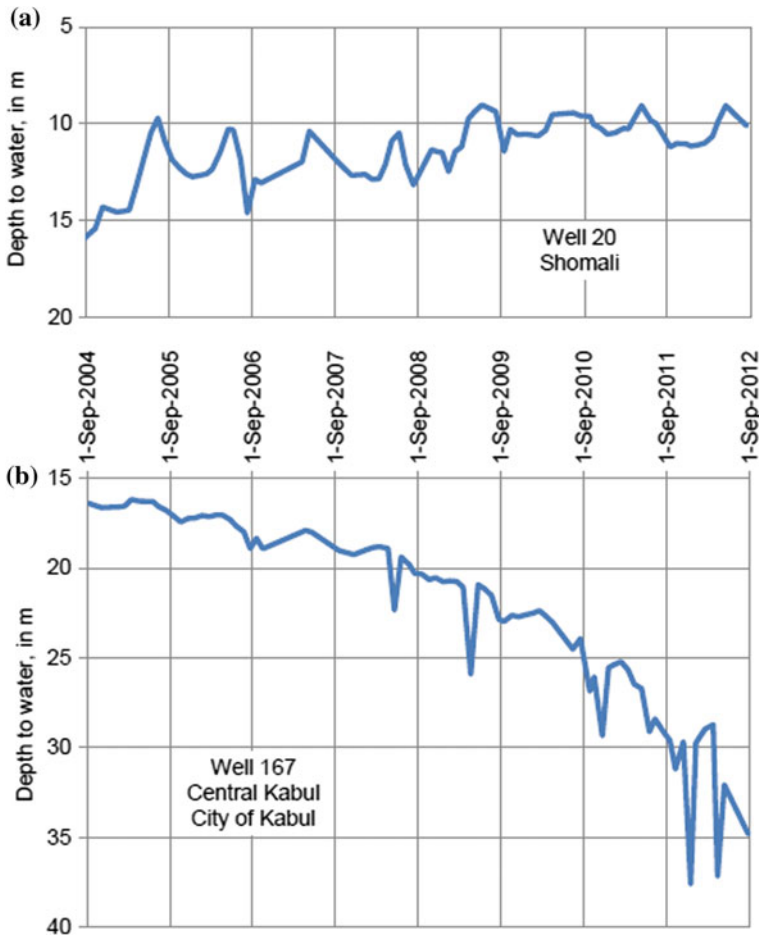


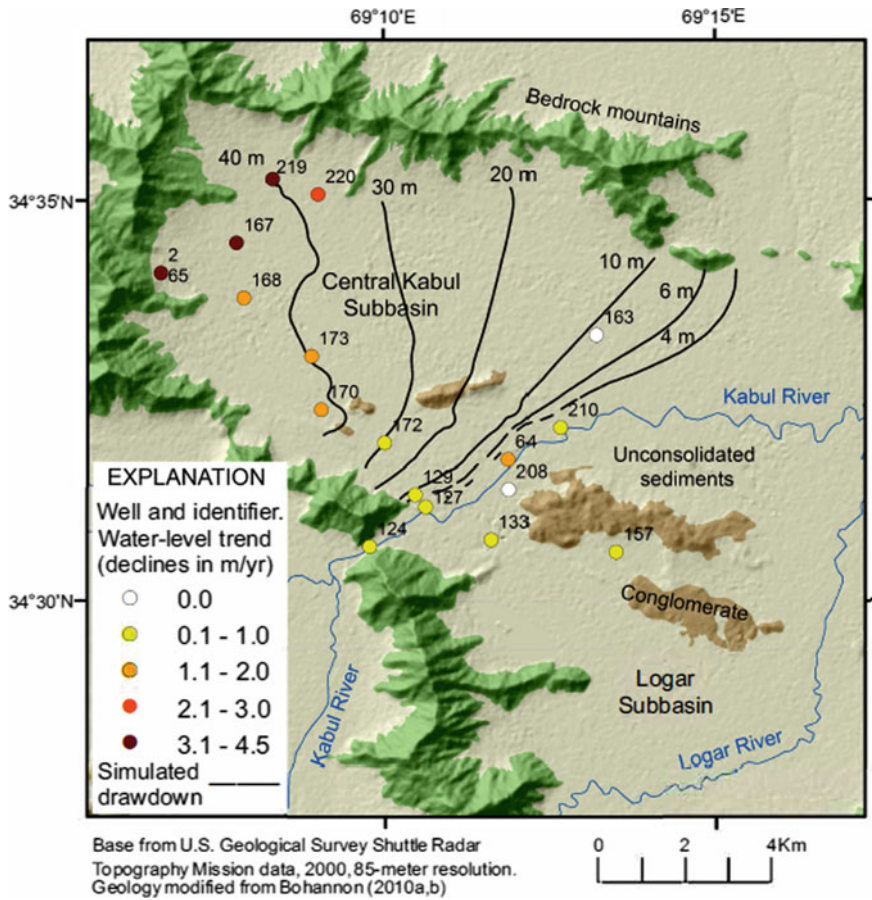
Fig. 2.5 Groundwater level trends from 2004 to 2012 in the Kabul Basin, Afghanistan. From (Mack et al. 2013)



**Fig. 2.6** Depth to water at Afghanistan Geological Survey groundwater network wells in Shomali (a) and Kabul city (b). From (Mack et al. 2013)

## 2.6 Discussion

The availability of groundwater in the Kabul Basin is challenged by droughts, the growing population's increasing needs for water, and potential changes to the timing or quantity of recharge due to climate change. To help address future water needs water managers may explore several options. The deep, or secondary, semi-consolidated aquifer, underlying the primary surficial aquifer, may represent a relatively unused source of water with considerable storage. However, the deep aquifer has a relatively low permeability and coarse-grained lenses within this aquifer would need to be identified in order to support large groundwater withdrawal rates. Additionally, the age of the groundwater in the deep aquifer is likely



**Fig. 2.7** Groundwater level trends between 2008 and 2012, and simulated drawdown with a projected sixfold population increase, in the city of Kabul, Afghanistan. From (Mack et al. 2013)

to be two or more orders of magnitude greater than that of the surficial aquifer and therefore may have an undesirably high dissolved solids content. Another potential source of water includes capturing more of the spring high flows and designing means to increase the infiltration of that water. Thirdly, the northern Kabul Basin has much greater recharge and groundwater in storage than the southern basin and water systems may be designed to make wider use of water in the northern basin. However, water availability in the northern basin is dependent on snow and glacier melt and the timing of such water may be impacted by climate change. These factors highlight the importance of continued groundwater level and surface water flow monitoring and exploration of comprehensive water management strategies.

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