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REPORT

Karez (qanat) irrigation in the Helmand River Basin, Afghanistan: a vanishing indigenous legacy

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Abstract A karez is a gently sloping tunnel into a hillside with a series of vertical shafts. At the upstream end, the karez depresses the water table such that groundwater enters the tunnel. Farmers all over Afghanistan have built and managed karezes for centuries using indigenous knowledge. This report focuses on karezes in the Helmand River Basin in southern Afghanistan, and describes the location of karezes in relation to geology, technological and managerial aspects of karez irrigation, and their current status. Karez irrigation has declined in recent decades due to the following: a prolonged reduction in precipitation, increase in number of boreholes that lower the water table below the karez tunnel, breakdown in community-based management, and reduced maintenance. Systematic field measurements are a challenge in the Helmand Basin due to security constraints. The current condition and management of the karezes have been assessed through short field visits and structured focus-group discussions with karez farmers and staff from provincial departments. The surveys indicate that over half of the karezes in the Helmand Basin have gone dry. Furthermore, the flow in karezes that are still operational has also declined significantly. The report demonstrates the value of using data from the US National Centres for Environmental Prediction (NCEP) Reanalysis 1 project, to estimate historic precipitation for various karez zones in this data-poor basin. Strategies for rehabilitating karezes are discussed. Rehabilitation is financially expensive in comparison to drilling new boreholes, but karezes are part of the national heritage of Afghanistan and can facilitate social cohesion.

Keywords Afghanistan · Arid regions · Karez · Qanat · Over-abstraction

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Introduction

A karez, also known by the name of 'qanat', is an ancient groundwater collection system that draws water from an aquifer, at the base of an alluvial fan in mountainous areas or from a floodplain. Technologically, it is a gently sloping (less than the land surface and water table) tunnel with a series of well-like vertical shafts. The shafts supply air and light, and are used for sediment removal during construction and for maintenance. At the upstream end, the karez depresses the water table (Macpherson et al. 2015) such that groundwater enters the tunnel. The first air shaft is also called 'mother well'. A karez is actually an ancient version of a horizontal well. The most complex form of a karez involves a fan of underground tunnels tapping the aquifer at different points (Anderson 1993). The karez then transports the water by gravity to an open land surface. Figure 1 presents a schematic view of a karez irrigation system.

Three types of karezes can be distinguished. Long karezes, which in southern Afghanistan usually have a length of 2–4 km but can be over 10 km, start at the foothills of mountains and tap the regional water table. Short karezes (<1.5 km), sometimes called 'mountain karezes' (Hussain et al. 2008), are mostly found at higher elevations where a stony subsurface makes the maintenance relatively hard. The flow in short karezes often fluctuates more than in long karezes because it

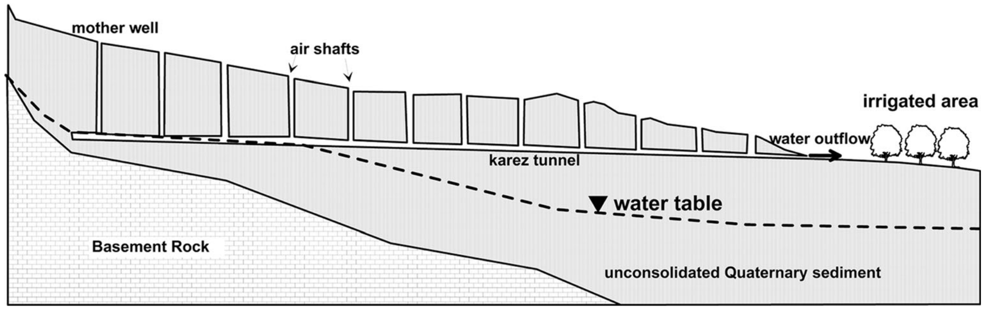

Fig. 1 Schematic diagram of a typical karez irrigation system at the base of a mountainous area

responds directly to seasonal snowmelt and/or rain (Anderson 1993). Long karezes were usually created because of a regional scarcity of annual rainfall and gentle slopes, while shorter karezes have benefited regions with more rainfall and steep gradients (Motiee et al. 2006). A third type of karez is the so-called 'tile' or 'plain' karez that starts in or on the banks of seasonally flash-flooded floodplains. In this type of karez, the tunnel has been excavated as an open channel and then closed using stone slabs supported on stone walls. Access shafts are not constructed as they would allow the direct entry of water and sediment from the floodplain. Tile karezes are much more costly and difficult to maintain as they are subject to damage during flash floods that can lead to excessive entry of water and collapse (Anderson 1993).

The construction of a karez is extremely labour intensive and can take up to several decades. The karez system is intrinsically sustainable as it uses the force of gravity to surface up water (Nasiri and Mafakheri 2015) and when the groundwater level drops because of reduced recharge, then the amount of water flowing through the karez also reduces (Taghavi-Jeloudar et al. 2013). However, the self-limiting factor of a karez is, for farmers who use the water, also a disadvantage compared to boreholes. Another disadvantage is that karezes need regular maintenance because they are vulnerable to sedimentation and collapse.

The geographical extent of karezes has been documented from Western China to as far west as North Africa and Spain (Mustafa and Usman 2007; Hussain et al. 2008; Wilkinson et al. 2012; Taghavi-Jeloudar et al. 2013). Different views exist with regard to the exact invention period of the karez, which is possibly as long ago as 2000–3000 BC (Lightfoot 1996 and Fattahi 2015). Most authors believe that the karez was first invented in or around Iran (Rahman 1981; Mostafaeipour 2010; Fouache et al. 2010 and Wilkinson et al. 2012).

Many papers report a decline in the number of active karezes. In Syria, 30 out of 91 karezes surveyed were still in active use in 2001 (Wessels 2005). In northern Tafilalt (Morocco) the number of active karezes declined from originally 80 irrigating 3,000 ha to 27 irrigating 1,750 ha (1970) and 19 irrigating less than 900 ha in mid-1990s (Lightfoot 1996). More than 38,000 qanats were reported to be active in Iran until 1966, but that number had fallen to 20,000 by 1998 and for 2009 the estimate was approximately 18,000 (Ahmadi et al. 2010). These papers all state that an increasing extraction of groundwater through deep tube wells and a related water-table decline is the key cause for a reduced water production, drying and abandonment of karezes. Still, other causes have been reported as well. In Mashhad (Iran) urban expansion has resulted in the destruction of 88 qanat fields (Hosseini et al. 2010). Groundwater contamination has led to a decrease in water demand from qanats in Tehran (Motiee et al. 2006). A changed pattern of ownership from private to quasi-public negatively affected personal initiative in the maintenance of qanat systems in Iran (Jomehpour 2009). Ahmadi et al. (2010) also mention additional socioeconomic causes in Iran such as changes in cropping patterns designed to obtain higher returns required more water than qanats could provide, and difficulties in ensuring community-based maintenance resulted in silt build up in many karezes.

It has been widely accepted that many karezes around the world are drying up. Though suggestions have been made on restoring (e.g. Motiee et al. 2006; Hussain et al. 2008; Taghavi-Jeloudar et al. 2013) or even constructing new (Endreny 2008) karezes, there are actually few documented field examples of rehabilitating karezes through external interventions. Wessels (2005) and Rahman (1981) have described a couple of cases of externally supported interventions in revitalizing karezes in Syria and Pakistan, respectively. The activities focussed on cleaning and strengthening karez tunnels through concrete lining and placing concrete pipes. It was noted that the impact of the karez cleaning was significant in Syria with up to a doubling in flow (Wessels 2005). There are some documented case studies concerning 'delay action dams' built across small rivers in the Baluchistan Province (Pakistan) with the aim of enhancing groundwater recharge for karezes. The dams delay the passage of floodwaters and allow percolation through the reservoir beds upstream of the dams, initially helping to increase groundwater recharge in the area. As a result, the groundwater level rose by 3 m and discharges through nearby karezes increased 'substantially' (Mandokhail 2003; Ahmad et al. 2004). However, these studies further concluded that a high content of fine clay brought by runoff gets deposited and eventually seals the reservoir beds. Consequently, the benefit is not sustained and eventually the dams act as mere evaporation ponds with little to no recharge through the beds (Ahmad et al. 2004; IUCN 2005; Qureshi 2007). This suggests that artificial recharge of groundwater through a pond or reservoir in watersheds with a high silt fraction in the runoff only lead to a temporary improvement; however, studies are continuing in Baluchistan with specific attention to sediment management through experimenting with ‘leaky’ delay-action dams (Qureshi 2007).

The first objective of this report is to quantify the drying of karezes through comparing historic with current flow and developing a map showing the current functionality of the karezes for the administrative units in the data poor Helmand Basin. The second objective is to examine the causes for the drying of karezes in Helmand Basin and their relative importance for certain districts. The report demonstrates the value of using data from the US National Centres for Environmental Prediction (NCEP) Reanalysis 1 project, to estimate the historic precipitation for various karez zones in this data poor basin. The third objective is to reflect upon the effectiveness of past and examine strategies for possible future karez rehabilitation efforts given realities on the ground of poor security and competition from relatively cheap boreholes. The final objective is to examine the relation between the geology and karez locations in the basin. The objectives are addressed through the analyses of field studies from 1960s and 1970s, recent focus group discussions and historic precipitation data. The remainder of the report discusses the information on karezes in the basin, the objectives and conclusions.

Information on the Helmand Basin

There is, especially compared to neighbouring Iran, very limited current information on the number of active karezes in Afghanistan. Many authors (e.g. Anderson 1993; Qureshi 2002; Banks and Soldal 2002; Rout 2008; Hussain et al. 2008) re-use the same historic estimate of the number of karezes per province in Afghanistan for 1967/1968 (Table 1, column 2) which is based on GoA (1980). It is not clear how GoA (1980) arrived at their estimate. As far as is known, only one good documented field study on the status of karezes took place in the Helmand Basin. The field study (McClymonds 1972) covered 80 karezes in a part of Kajaki District (Helmand Province) and took place in 1971. Sammel (1971) also provides some field information on karezes near the city of Kandahar. Khan et al. (2015) studied the water distribution of three karezes fed irrigation systems in Ghazni Province (north-eastern part of Helmand Basin). Non-governmental organisations (NGOs) have been involved in the rehabilitation of karezes in Afghanistan especially during the period 2002–2012. Still, this was mostly (for security reasons) done outside the Helmand Basin. With the exception of Rout (2008, discussed in the following), there is little accessible information available on karez rehabilitation in the Helmand Basin.

Field surveys have been very difficult in the Helmand Basin since 1980 due to insecurity (Macpherson et al. 2015; Goes et al. 2016); hence, new information had to rely on indirect information from focus group discussions (FGD) with karez farmers, interviews with staff from the ministries of water and agriculture in relevant provinces, a few short field visits by national staff and remote sensing. The FGD were conducted between 2011 and 2013 and were within the framework of the Helmand River Basin Master Plan (HRBMP) study (Mott MacDonald 2013d). The most elaborate FGD with the karez farmers were concentrated in districts in Helmand Province—Mott MacDonald 2013b, summarised in Tables 3 and 4 (in the Appendix). The other FGD with farmers and ministries in Uruzgan (Mott MacDonald 2012b), Farah, Nimroz and Kandahar (Mott MacDonald 2013a) focused on irrigation practises with some questions on karezes. During the preparation for this report, supplementary information on the number of karezes per administrative unit and their functionality was collected from the provincial ministries (Table 1, column 3).

The surveyed farmers in Helmand Province use a local term to define rate of water flow called *polah*. The farmers reported that ‘one polah of water is the flow which is required to irrigate a strip of land of approximately 2 × 50 m (0.01 ha) within one irrigation turn of roughly 20 min at farm level’. Based on reported historic mean karez flows of 10–20 L/s (Sammel 1971; McClymonds 1972) and ~8 polah (discussed in section ‘Recent water yield fluctuations of karezes in Helmand Basin’), it is estimated that one polah is equivalent to a flow between 1.3 and 2.3 L/s. Still, uncertainty remains on how to exactly convert polah into L/s. Hence for this report ‘polah’ has only been used as a relative value to compare past with present flows.

Precipitation is a key-factor influencing recharge of karezes. In the absence of a long-term precipitation-gauge network in the basin (e.g. Mott MacDonald 2012a; Macpherson et al. 2015), recourse was made to the US National Centres for Environmental Prediction (NCEP) and National Centre for Atmospheric Research (NCAR) ‘NCEP Reanalysis 1’ data (provided by the National Oceanic and Atmospheric Administration (NOAA), Oceanic and Atmospheric Research (OAR), Earth System Research Laboratory (ESRL) and Physical Sciences Division (PSD) in Boulder, Colorado, USA; see NOAA 2015). Almost 67 years of gridded climate data are available at time scales down to 6 h. A climate reanalysis produces historic climate data on the basis of models and observations. The data are produced by a 3D global weather-forecasting model that has been tuned to historic weather observations. A state of the art analysis/forecasting system is used that makes use of a wide range of

Table 1 Overview of karezes per province and district in Helmand River Basin

Province	Historic (1967/1968) karezes estimate[b]	Recent FGD (2012, 2013) and consultations (2015) for current estimate	Current karezes estimate - total	Functional karezes No.	Functional karezes % of total	Districts in Helmand River Basin with karezes (total, % of total functional)	Rainfall zone (Table 2)
Bamyan[a]	0	–	–	–	–	–	–
Daikundi	84[b]	Information from Uruzgan survey (below)	3	3	100%	Gizab (3, 100%)	–
Uruzgan		FGD with province (MEW and DAIL), FGD with farmers from Chora District and consultation of a local expert	176	115	65%	Tirinkot (31, 61%), Chora (22, 77%), Dehrawud (14, 36%), Khas Uruzgan (100, 68%), Shahid-e-Hassas (9, 67%)	2
Farah	352	FGD with province (MEW and DAIL), FGD with farmers from Farah Centre and Pushtrod districts and consultation of, district community elders from Gulestan and Purchaman districts.	368	232	63%	Anardara (34, 74%), Bakwa (15, 73%), Balabuluk (18, 67%), Farah Centre (70, 63%), Khak-e-Safed (27, 100%), Qala-e-Kah/Pusht Koh (75, 43%), Pushtrod (16, 6%), Shibkoh (53, 60%), Gulestan (10, 80%), Purchaman (50, 80%)	5
Ghazni	1,516	Consultation with province (MEW)	1,650	700	42%	Only data at province level	4
Ghor[a]	4	–	–	–	–	–	–
Helmand	276	FGD with province (MEW and DAIL), FGD with farmers from Kajaki, Musa Qala, Baghran, Washer, Nawzad and Sangin districts.	933	144	15%	Kajaki (200, 7%), Musa Qala (41, 17%), Baghran (250, 10%), Washer (160, 38%), Nawzad (260, 13%), Sangin (17, 18%), Nahr-e-Saraj (5, 20%)	1
Herat[a]	228	Consultation with province (MEW) and a local expert	270	173	64%	Ghoryan (22, 55%), Guzara (80, 44%), Adraskan (48, 65%), Shindand (75, 80%), Farsi (45, 78%)	5
Kandahar	631	FGD with province (MEW and DAIL)	1,200	600	50%	Only data at province level	2 and 3
Nimroz	18	FGD with province (MEW and DAIL)	21	–	0%	Khash Rod (including Delaram) (21, 0%)	6
Paktika[a,b]	(528)[bc]	Consultation with province (MEW)	396	250	63%	Only data at province level	4
Paktya[a]		Consultation with province (MEW)	77	61	79%	Only data at province level	4
Zabul	743	Consultation with province (MEW)	1,300	600	46%	Only data at province level	4
Total	4,380		6,394	2,878	45%		

FGD focus group discussion, *MEW* Provincial Ministry of Energy and Water or Sub Basin Agency, *DAIL* Provincial Ministry of Agriculture, Irrigation and Livestock

[a] Part of province is outside Helmand Basin

[b] GoA (1980), following the former provincial boundaries hence some of the historic estimates (e.g. Daikundi and Uruzgan) are aggregated over several current provincial boundaries

[c] Khost (outside Helmand River Basin), Paktya, Pakitika and parts of Ghazni provinces

global weather observations including land surface, ship, rawinsonde, pibal, aircraft, satellite, and other data, which are quality controlled and assimilated within the analysis/forecasting system. Users of the data are cautioned that variables such as precipitation are completely determined by the model, forced by the data assimilation. Nevertheless, a comparison of these variables with different types of observations and climatologies show generally useful information on time scales from a few days to inter-annual variability (Kalnay et al. 1996). The grid spacing is 2.58° (~250 km in Afghanistan) and for Afghanistan, the data were downscaled to a 10-km grid. Ten kilometer grid points within an NCAR grid were simply assigned the NCAR grid value. Daily averages were then made of grid point precipitation falling within each of the six zones in Helmand River Basin that have been identified as having relatively many historic karez-irrigated areas (Fig. 2). The generated annual precipitation data for the 'water years' 1948–1949 to 2014–2015 (e.g. '1948–1949 water year' represents October 1948 to September 1949) are presented and discussed in the following in relation to the water yield of karezes in the specified zones.

As discussed already, the precipitation observations for the Helmand Basin are very limited. The often very steep and inhospitable terrain leaves much of the basin inaccessible for routine meteorological measurements. There are more streamflow observation stations in the Helmand Basin than precipitation gauges, but the streamflow data collection ceased in the late 1970s. For surface-water resources assessments in the basin, a means was required for extending these streamflow data beyond 1979, and in the absence of a network

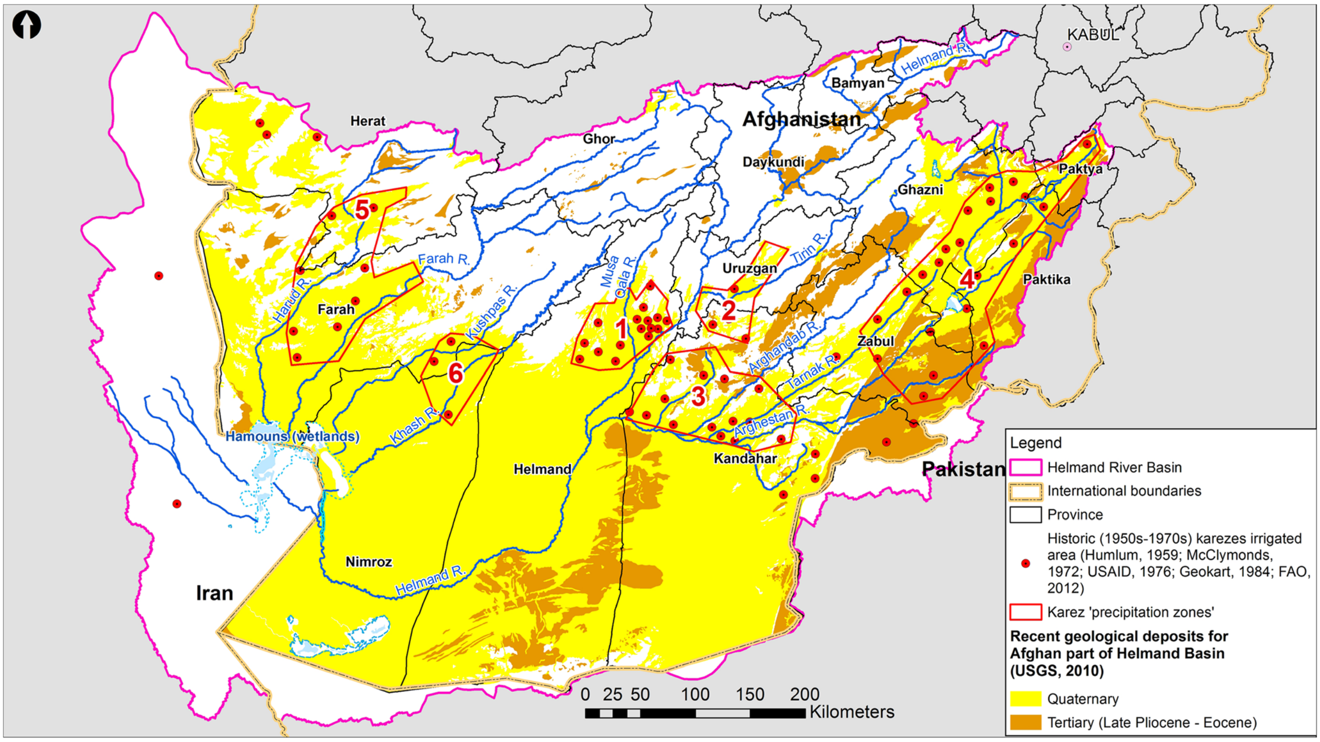

Fig. 2 Helmand River Basin showing historic (1950 to early 1970s) karez-irrigated areas, Quaternary and Tertiary deposits and zones for which annual precipitation records have been generated

of precipitation gauges, recent investigations made recourse to reanalysis data, and the NCEP Reanalysis 1 data in particular. There are other similar re-analysis products (e.g. ECMWF re-analysis products, ECMWF 2015). Still, the US Geological Survey (USGS 2007) had demonstrated good success using the NCEP Reanalysis 1 data as input to a rainfall-runoff model to simulate Helmand River flows. Later Mott MacDonald (Mott MacDonald 2013c; Goes et al. 2016) adopted a similar approach in simulating river flows throughout the entire Helmand Basin, achieving good calibrations at most locations. There can therefore be reasonable confidence in the NCEP Reanalysis 1 data for the Helmand Basin, especially on a seasonal basis, and the objectivity that it has brought to this analysis.

Karezes in the Helmand River Basin, Afghanistan

Overview

The Helmand basin, meaning ‘abundant water’ in Old Persian, is the largest river basin in Afghanistan. It covers an area of approximately 400,000 km^2 across southern Afghanistan (81.4% of the basin), Iran (15%) and Pakistan (3.6%). The elevations in the basin range from over 4,400 m above sea level (masl) in the edges of the Hindu Kush Mountains in the north-east, where most of the rivers originate, to 490 masl in the Sistan depression in the south-west (Shroder 2014). The mean simulated river flow in the Helmand Basin for recent years (1999–2012) has been almost 40% below the long-term (1952–2012) mean. The recent mean river flows are almost the same as the current (2010–2012) net surface water needs which is mainly irrigation (Goes et al. 2016); hence, surface water is no longer ‘abundant’ in the basin.

Afghanistan has never had a dedicated and comprehensive groundwater survey of a modern kind (Shroder 2014). There is very little location-specific hydrogeological information available on the Helmand Basin. The unconsolidated and semi-consolidated Quaternary and Neocene deposits along major river valleys comprise the most prolific aquifers in this basin (Uhl and Tahir 2003). The main sources of recharge are precipitation in the upstream part of the basin, unlined irrigation canals and (over)irrigated farms within large formal irrigation projects (e.g. the groundwater ‘high’ near Kandahar; Sammel 1971), and infiltration through riverbeds. Groundwater is the main source of water for drinking and it is also gaining importance for irrigation. In many parts of the basin (e.g. northern part of Helmand Province, Farah and Ghazni provinces) the number of boreholes for irrigation has increased rapidly during the past 10 years.

Agricultural civilizations using simple surface-water irrigation systems have occupied the deltaic plains in Sistan intermittently since at least 3200 BC (Whitney 2006). Another ancient water collection and distribution technique in the basin is by karezes, with most karezes being hundreds if not over a thousand years old. McClymonds (1972) stated that all the karezes they surveyed in part of Kajaki District (Helmand Province) were constructed much more than hundreds of years ago. No new karez has been constructed in the living memory of interviewed staff working for the water ministries in the Helmand basin. All karez farmers interviewed for this study indicated that it is a 'riddle' how or when the karezes were built and that it was much longer ago than the time of their grandfathers (Table 3). Karez diggers in the region, who are known by the names of Karez-Kesh (Rahman 1981) and Karez-Kan (Anderson 1993; Rout 2008), have had the profession for generations. Karez-Kans still exist but now work only on repairs and cleaning and are, especially since the 1980s, becoming increasing rare.

For Afghanistan it has been estimated (GoA 1980), based on data from the late 1960s, that about 167,750 ha was irrigated by approximately 6,741 karezes (~7% of the irrigated area). Approximately 90,000 ha of the karez-irrigated land was located in Helmand Basin (GoA 1980, cited in: Anderson 1993; Rout 2008 and Favre 2004). Analysis from Landsat Imagery (Mott MacDonald 2013b; Goes et al. 2016) showed that agricultural land in the Helmand Basin covered approximately 520,000 ha in 2010–2011. Approximately 100,000 ha of the agricultural land is not along the main rivers or their irrigation systems and is not irrigable from spate flows. As rain-fed agriculture is practically non-existent in the Helmand Basin it can be assumed that this area is almost completely irrigated with groundwater from boreholes, wells and karezes. The majority of the currently groundwater-irrigated area is, given the status of the karezes (discussed in the following), at the moment irrigated by boreholes.

Extent of karezes in Helmand Basin

The extent of karezes is determined by hydrogeology, precipitation and topography. The main areas historically (1950 to early 1970s) irrigated by karezes in the Helmand Basin are shown in Fig. 2. The location of karez-irrigated areas is based on maps from various different sources (Humlum 1959; McClymonds 1972; USAID 1976; Geokart 1984; FAO 2012). When the areas are overlain with the geological map (USGS 2010) it becomes clear that most karezes are located within the gently sloping unconsolidated Quaternary, mainly fluvial, alluvial, glacial and lacustrine deposits (conglomerates, gravels, sand and clay) in the middle part of the basin. There are also some karezes areas within more consolidated Tertiary sediments (i.e. conglomerate, silt stone, sand stone, and limestone) in the eastern part of the basin. The annual precipitation ranges between 150 mm in the middle part of the basin to over 400 mm in the mountains upstream of the karez zones (Daly et al. 2010).

There are no karezes in the high (>2,300 masl) mountainous north-eastern part of the basin where the geology is very complex, much older (lower Tertiary to Cambrian), and dominated by hard rock. The terrain here is steep and has no or only a thin weathered layer on top.

The lower (or south-western) parts of the basin (500–1,000 masl) are mostly comprised of undulating flood plains and desert. Aquifers are present here but karezes are rare because of the relatively flat landscape (hence a low groundwater gradient) and low annual precipitation (50–150 mm, Daly et al. 2010).

Attributes of karezes in Helmand Basin

Figure 3 shows an aerial view of a karez irrigation system in Kandahar Province. Figure 4 shows some pictures of karezes that were taken during field visits in Farah and Herat provinces. Based on 80 karezes in Helmand Province, surveyed in 1971, it was concluded that the 'mother well' was usually dug from 2 to 5 m below the regional water table and that the length of the tunnel section at their upstream ends that collected groundwater was on average 200 m (McClymonds 1972). The distance between the air shafts varies between 10 and 50 m but its median value is approximately 25–35 m (McClymonds 1972; Anderson 1993; Banks and Soldal 2002; Rout 2008 and Table 3). Traditionally air shafts were covered with large stones to ensure that sediment did not enter (Anderson 1993). However, the air shafts of the few karezes seen in the field (Helmand, Farah and Herat provinces) during the FGD were not covered (Fig. 4). The range in the reported depths of the air shafts is quite wide from 4 to 60 m (Anderson 1993; Table 3). The steeper the terrain the greater is the depth of the mother well. The average mother well depth for the relatively mountainous Zamin Dawar area in Kajaki district is 23 m (McClymonds 1972). Deep air shafts required a closer spacing than shallow shafts in order for karez workers to have sufficient oxygen. Anderson (1993) provided the following rule of thumb for this: 'the sum of the depth of the shaft and half the distance between two consecutive shafts will never exceed 60 m'. The approximate tunnel height and width are 1.25 and 0.70 m, respectively (Anderson 1993). The length of the karez tunnel is usually in the range of 1–8 km with a median value of ~3 km (McClymonds 1972; Anderson 1993; Rout 2008 and Table 3). Karezes are relatively short (0.5–4 km) in areas where the topographic surface is steep (e.g. on average 2.8 km for surveyed districts in Helmand Province, Table 3) and longer in flatter areas (e.g. on average 5.5 km for surveyed districts in Farah and Nimroz provinces).

Water use from karezes

The outflow from karezes was mostly used for irrigation. Irrigation water need varies per season and crop but roughly a gross karez flow of about 0.7 L/s is required to irrigate 1 ha (Anderson 1993). McClymonds (1972) measured an average

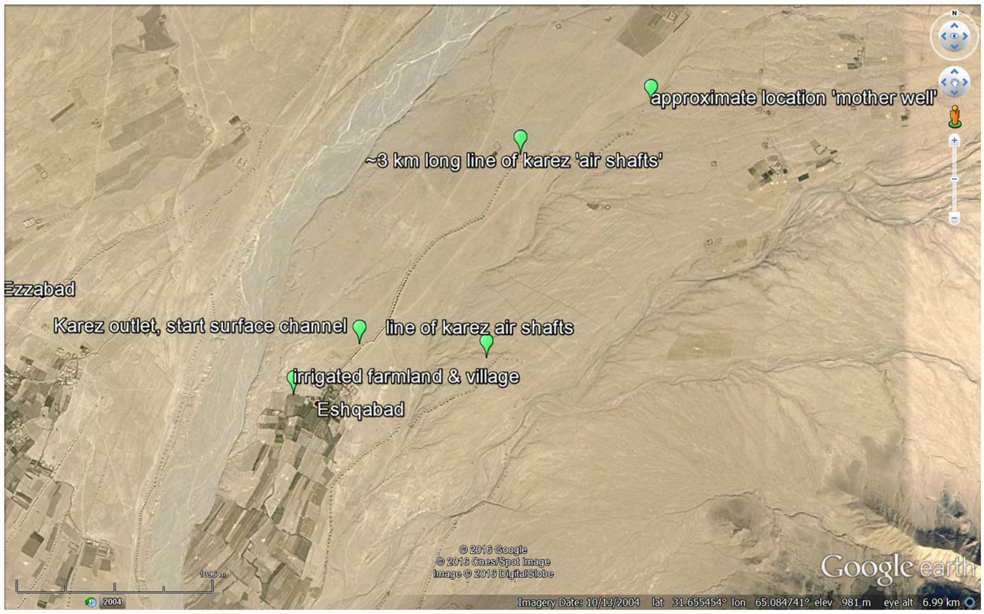

Fig. 3 Aerial view of a karez emerging into an open channel in Maiwand District, Kandahar Province, Afghanistan (Cnes/Spot Image, Google Image, DigitalGlobe; imagery from 2004)

karez gross flow of about 0.5 L/s per ha for Kajaki District (Helmand Province). Some karezes, especially in villages that do not have boreholes or wells, also supply households with domestic water; however, in the past, during times when outflow was abundant, domestic water use volumes were small compared to irrigation. Now, with the reduced outflow (discussed in the following), domestic uses have become relatively high in many locations (Table 4). For the karezes that supply domestic water, the number of reported households vary between 10 and 200 with an average of ~50 (FGD Farah Province).

Management of karezes

In most provinces in the Helmand Basin, karezes are managed by their respective 'water master' known locally as *mirab*. However, for some karezes especially within Helmand Province (Table 3), village elders manage the karezes. Irrespective of management type, karez waters continue to be distributed according to historic social norms and traditional practices. The size of farm-land holding forms the basis for the duration of the water distribution rotations and resources mobilization (Table 3). Each irrigation block receives water

Fig. 4 **a** Uncovered vertical karez air shaft with some trace of water inside (Herat Province), **b** Karez between two adjoining vertical shafts close to its outlet (Farah Province), and **c** open irrigation channel fed by a karez (Farah Province)

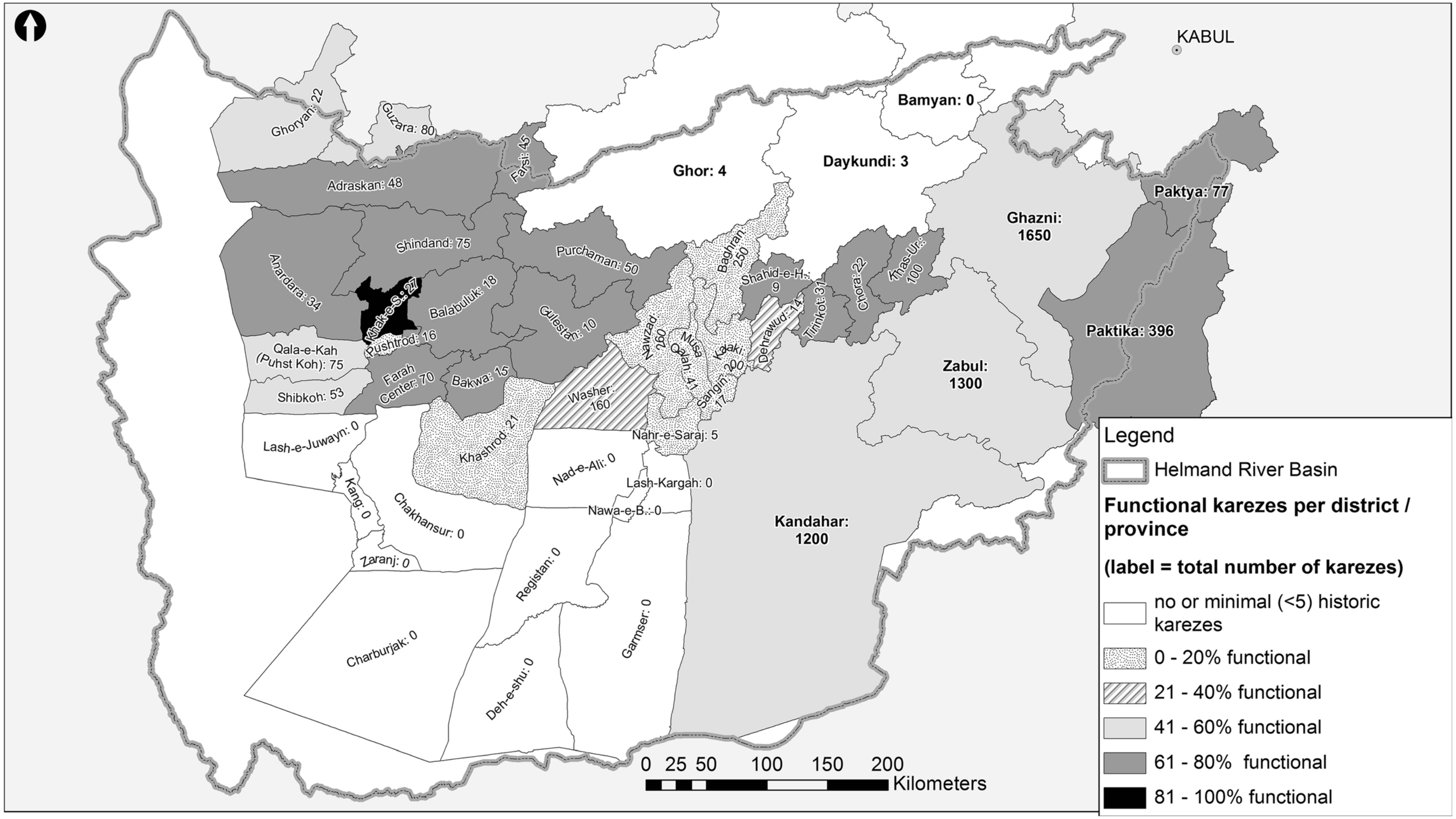

Fig. 5 Number of karezes and percentage still functional per surveyed district or province in the Afghan part of Helmand River Basin (data in Table 1)

for a specified number of hours that is related to the size of the irrigated area. The rotation cycle in winter season, when poppy (that dominates in northern Helmand Province) and winter wheat are grown, is 12–14 days (Table 3). Summers have higher evaporation and no precipitation and therefore a shorter rotation cycle of 6–8 days is applied to supply water to vegetable gardens (e.g. beans) and some fruits. For the qanats of Kashan (Iran), similar rotation periods for karez water were observed, 8 days in summer and 16 in winter (Jomehpour 2009). The farmers pay the mirabs/elders annually in proportion to the average number of hours they received water per rotation. During the FGD, all karez farmers perceived this as a fair system but reported that implementation is sometimes difficult because of a lack of good functioning water dividers/gates on the distribution system. Khan et al. (2015) also reported significant losses (~26% per km) in the irrigation conveyance system of three surveyed karezes in Ghazni. The annual payments are mainly used for the maintenance of the karez, which is discussed further in the following.

Drying of karezes in Helmand Basin

Number and functionality of karezes in Helmand Basin

GoA (1980) estimated that in the 1960s over 4,000 karezes existed in the Helmand Basin. The outcome of the recent FGDs indicates an estimate that is approximately a third higher, just over 6,000. Both datasets are presented in Table 1. As long as systematic field verifications remain a challenge due to insecurity, it will not be possible to say with certainty which source is more correct. It is not clear how GoA (1980) arrived at their estimate and if the estimate included all or only functional karezes. For the outcome of the FGD, it is believed that the number of karezes that have been counted at district level (Helmand, Farah, Nimroz and Uruzgan provinces) is likely to be roughly correct—as an example, for Farah province, the Provincial Ministry of Water prepared a complete list of all karezes for eight districts (Mott MacDonald 2013a). Possibly the number of karezes for some of the provinces for which district level estimates are not available (Kandahar, Zabul) has been overestimated.

Approximately 45% of the karezes in the basin are still functional. Figure 5 highlights the surveyed districts or provinces and the percentage of karezes still functional as reported during the FGD. In Helmand and Nimroz provinces, fewer than 15% are functional, while 60–80% in Uruzgan, Herat, Paktya and Paktika provinces are still in use. The causes for the reduction in number of functional karezes are discussed in the following.

Past water yield fluctuations of karezes in Helmand Basin

The water yield of a karez depends on the precipitation-fed recharge, the permeability of the aquifer at the upper end of the tunnel, the length of the karez tunnel below the regional water table and the condition of the tunnel. McClymonds (1972) who surveyed 80 karezes in Zamin Dawar (largely coinciding with the current Kajaki District, Helmand Province) reported on the basis of measurements and interviews that average yield from a typical karez had declined from ~31 L/s (~1950) to 25 L/s (~1960) to ~11 L/s in 1971. At that time, there were no boreholes and only approximately six inventoried hand-dug wells (11–16 m deep) in the area. McClymonds (1972) attributed the decline in karez yield to below average precipitation years. The historical estimates (Fig. 6, zone 1) confirm that the precipitation in the period before the survey (1958–1970 average: 385 mm/y) was about 25% less than a decade earlier (1948–1957 average: 512 mm/y). McClymonds (1972) reported that in response to the karez yield decline, part of the local population, who were almost entirely dependent on agriculture, migrated from the area.

In the Kandahar area, the number of active karezes was reported (Sammel 1971) to have decreased from 92 prior to 1950 to approximately 46 in 1971. There were about 20 drilled boreholes and an unknown number of hand-dug wells in the area. The estimated annual groundwater abstraction from these boreholes and wells was, at that time, still a minor fraction (~6%) compared to the water yield from the active karezes. Sammel (1971) does not discuss the possible causes for the 50% decline in the number of active karezes between 1950 and 1971 but again there was about 17% precipitation reduction (Fig. 6, zone 3) between 1948-1957 (average 442 mm/y) and 1958–1970 (average 369 mm/y) and this is the most probable cause. The average flow for the ~46 active karezes was in 1971, 'based on a relatively small sample that were visited', estimated at 21 L/s (Sammel 1971). The drying of karezes south of Kandahar City continued as most of these karezes were reported dry in late 2002 (USAID 2003). The two examples from the early 1970s discussed in the preceding demonstrate that water yield reductions and even drying-up of karezes as result of a period of reduced precipitation occurred in the past.

Recent water yield fluctuations of karezes in Helmand Basin

The reported (FGD Farah, Helmand and Uruzgan provinces) total irrigated area for still active karezes in years with a 'normal water flow' varies from 10 to 120 ha. The median size is approximately 20–30 ha in winter. This would imply, assuming 1 ha requires 0.5 L/s (discussed in the preceding), a karez yield of at least 10 L/s. The irrigated area in summer is approximately 15–30% of the winter area.

The FGDs conducted in the Helmand Province (Table 3) also examined present water availabilities in karezes and in

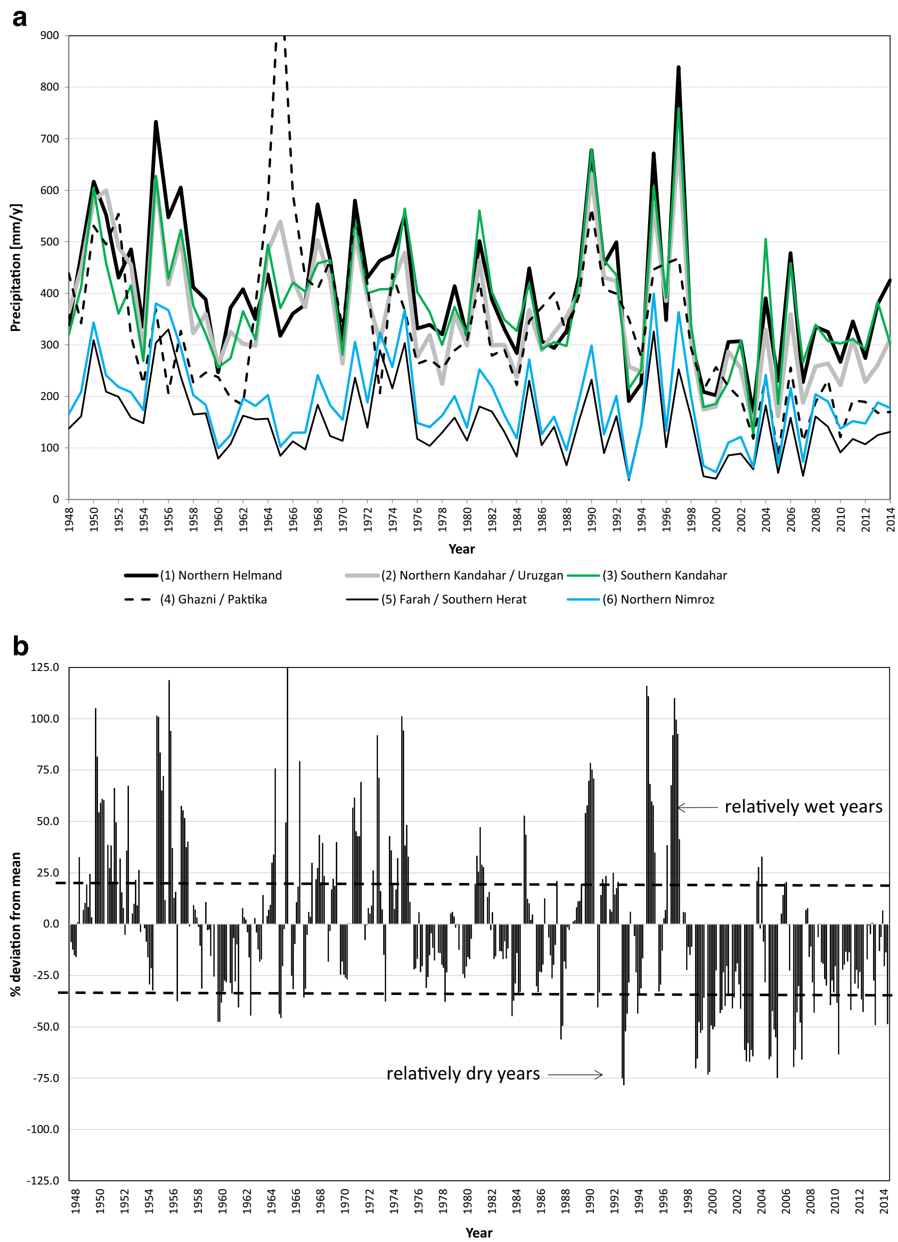

Fig. 6 **a** Annual 'NCEP Reanalysis 1' precipitation (1948–1949 to 2014–2015, 'water years') for six karez-irrigated zones (locations indicated on Fig. 2) in Helmand River Basin. **b** Annual 'NCEP Reanalysis 1' precipitation (1948–1949 to 2014–2015, 'water years') for six karez-irrigated zones in Helmand River Basin, showing relative deviation from the long-term mean

comparison with the past flow. Here, the term "past" is roughly defined as two decades ago (late 1980s/early 1990s; see Fig. 7 for comparison). On average, the reported flow reduced by approximately 75%; in winter from 7.9 to 1.8 polah and in summer from 4.3 to 1.0 polah. Water from karezes with very low yields (≤ ~1 polah) often only continued to be used for domestic purposes and no longer for irrigation (e.g. all karezes in the Sangin District and most karezes in the Baghran and Musa Qala districts, Table 4).

The FGDs reported (Mott MacDonald 2013a) that current (2012/2013) average yield of the still active karezes in Farah Province is also low, varying between 1 (Bakwa, Balabuluk and Farah Centre districts) and 2.5 (Anardara District) polah, while the flow in the past was not quantified but reportedly 'much higher'. The other provinces also report a (unquantified) reduction of water yields from still active karezes.

Causes for drying of karezes in Helmand Basin

As discussed in the preceding, approximately more than half the karezes in Helmand Basin have gone dry and flows in operating karezes have also declined drastically (on average by 75% in Helmand Province). The causes for the drying of karezes are discussed in the following; however, the main causes are a prolonged reduction in precipitation and an increased groundwater abstraction which has led to a decline in the regional water table in the karez recharge zone. Other causes include a decline in functionality of the karezes themselves.

Prolonged reduction in precipitation

Figure 6 presents the generated (NCEP Reanalysis 1) annual precipitation for the six main zones with karezes in the Helmand Basin (Fig. 2). The graph and the averages (Table 2) show that during the period 1948–2014, all zones experienced the longest and most pronounced drought period in recent years (1998–2014), with reductions in average precipitation of 30–50% compared to the long-term 1948–1997 mean. The incomplete (1959–1984, 2010–2012) measured annual precipitation data available for Ghazni (karez zone 4, Fig. 2) also show drought years for 2010–2012 and a short drought around 1970 (Macpherson et al. 2015). The recent drought (from 1998) has also been observed in reduced river flows at the downstream end of the Helmand River in Iran (Sharifikia 2013). This reduction in precipitation has contributed to the observed drying of the karezes; however, reduced precipitation is not the only, and in some parts of the basin, not even the main cause for a decline in water table and the current drying of karezes. Some zones with a low precipitation (zones 4 and 5, average annual precipitation 1998–2014: 184 and 102 mm respectively, Table 2) have a much higher percentage of still active karezes (40–80%, Table 1) than Northern Helmand (~15%, Table1), which still has, despite the recent drought, a relatively high precipitation (zone 1, average annual precipitation 1998–2014: 304 mm, Table 2). Nevertheless, it should be noted that, even if the regional water table is still close to the base of the karez tunnel, the part of the precipitation that raises the groundwater level and can actually end up as karez flow will vary between different karez recharge zones, depending on local hydrogeological characteristics like infiltration rate, permeability and effective porosity.

Increased groundwater abstraction

Almost all FGD participants from different parts of the basin reported a decline in the water table as a direct result of an increased extraction of groundwater since the late 1990s using gasoline pumps and also from 2010 using solar-driven pumps. However, authentic quantitative data are hardly available to support this argument since borehole databases are not being kept and groundwater levels are not being monitored in the insecure Helmand Basin. In the Kandahar area, groundwater level measurements in six wells showed a decline of 6.1–19.9 m between the late 1960s/early 1970s and 2003 (CDM 2003). Uhl (2006) also reported that there is anecdotal evidence of drying of karezes in the eastern Helmand River Basin following an increase in drilled well numbers. Banks and Soldal (2002) also give anecdotes ('various NGOs have reported') of groundwater level declines during a period of 3–4 years in the late 1990s in some provinces in Helmand basin ranging from 2 (Zabul), 2–4 (Herat) and 5–8 m (Kandahar). The authors attribute the declines to climatic trends with (for the largest declines) superimposed groundwater abstraction. For Helmand Province, ICARDA (2002) also reported, based on a questionnaire survey, a 'substantial use of tubewells that are installed without any permit or consent of the authority'. For the northern districts of Helmand Province (e.g. Nawzad District), there are also many verbal reports of a significant increase in deep (up to 100 m) boreholes along and close to (~50 m) karezes. The karez farmers reported during the FGD a groundwater level decline (sometimes >1 m/y) since approximately the year 2000. Mansfield (2015) also noted that the desert 'around original karez-irrigated areas' in northern Helmand Province have seen a large increase in poppy irrigation using boreholes with diesel-operated pumps. Also considering the still relatively high precipitation (Table 2), it is proposed that, although quantitative data are lacking, a large increase in groundwater abstraction from boreholes in northern Helmand Province is the main reason for the low percentage (~15%) of functional karezes in most districts in this province (Table 1; Fig. 5). Macpherson et al. (2015) modelled the effect of different water-table slopes, that is impacted by groundwater abstraction and seasonal variations, on karez flow rate. Karez farmers are well aware of the link between the increased groundwater abstraction and the drying of karezes (Table 3). ICARDA (2002) reported that, based on surveys in Ghazni, Herat and Helmand provinces, farmers using karez and spring water even showed contempt for deep wells.

Reduced maintenance of karezes

Karezes require regular cleaning and maintenance due to siltation, erosion and collapse. Common maintenance activities for a karez include sediment removal, and reinforcement of karez tunnels and covering of air shafts. The cleaning of karezes is not an easy task as it is done in a confined setting. There are several interrelated causes that have contributed to the reduced maintenance of karezes:

- As income from harvests from karez farms declines during a prolonged period of water table decline and decreased water yield, community interest and resources for maintenance starts to disappear as well. This is a self-amplifying mechanism because a lack of maintenance for a longer period, leading to collapse and extensive siltation of karez tunnels and air shafts, will lead to higher maintenance costs that are beyond the financial and technical capacity of the local population.

Table 2 Mean annual 'NCEP Reanalysis 1' precipitation (mm/y) for six karez-irrigated zones (locations indicated on Fig. 2) in Helmand River Basin

Period (water years)	Zone					
	Northern Helmand (1)	Northern Kandahar/ Uruzgan (2)	Southern Kandahar (3)	Ghazni/ Paktika (4)	Farah/ Southern Herat (5)	Northern Nimroz (6)
1948–1997	431	398	410	379	166	205
1998–2014	304	246	292	184	102	138
Reduction %	29%	38%	29%	51%	39%	33%

- The social cohesion of the local communities has reduced. This is related to several factors including over three decades of war and insecurity, and the introduction of tube wells. With the introduction of tube wells, people became more individualistic as traditional community approaches were no longer required. A manifestation of this reduction in social cohesion is that it is becoming increasingly difficult for mirabs and community elders to collect the annual payments from farmers (Table 3).
- In the recent past (up to ~1980s), several groups of Karez-Kans were available in Afghanistan, and farmer groups used to contract out karez cleaning jobs to them; however, this specialist labour force reduced because they looked for other opportunities due to reduced work as a result of drought and changing socio-economic conditions including three decades of war and urbanisation. Similarly, in neighbouring Iran, the education of new specialist karez-labourers (locally called *muqannis*) has faltered due to insufficient work and better paid alternatives (Jomehpour 2009). Cleaning of karezes is becoming more expensive due to a shortage in specialist labour. The cleaning costs of karezes for Helmand Province (Table 3) varied (2012) between USD 1,000 and 6,600 per km (average USD 3,700). The cost depends on thickness of sediment, layout of the karez (e.g. depth of tunnel and distance between air shafts) and its length. So the costs of keeping a karez with an average length of 3 km clean is ~11,000 USD per 2–3 years. Since gravity is used to surface up water there are no energy costs. In the past, when a functional karez that could irrigate approximately 25–30 ha in winter and 5–10 ha in summer, this would have incurred a water abstraction cost of approximately 100–150 USD/ha/season. As a comparison, the mean diesel costs for operating a deep irrigation borehole range between 250 (winter irrigation) to 375 (summer irrigation) USD/ha/season. So a functional karez, with sufficient water flow like in the past, has about half the operating costs per ha as deep diesel-powered irrigation boreholes. Still, operating costs of boreholes are reducing in some areas in Helmand and Kandahar where solar-powered tubewells with surface storage basins have been constructed recently (Mansfield and Fishstein 2016). The relative operating costs

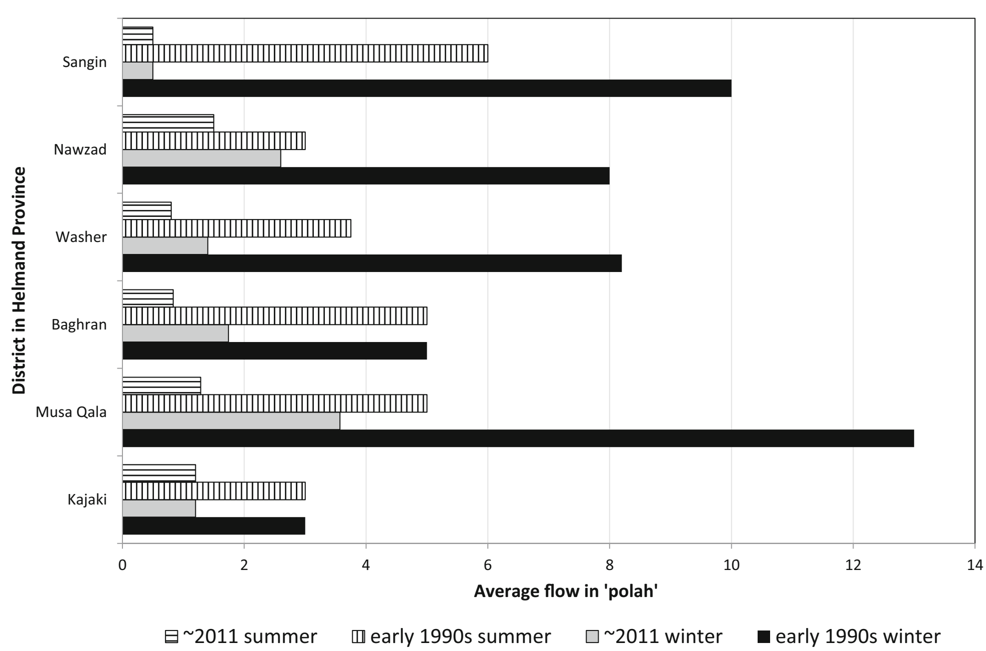

Fig. 7 Comparison of reported (FGD with karez farmers groups) past and present karez water yield in karez-rich districts in Helmand Province

difference between karezes and diesel-operated deep wells is comparable to an estimate made for Kashan (Iran) where the operating costs per ha for karezes was estimated to be approximately 40% of operating deep wells (Jomehpour 2009). The costs comparison is for water delivery only, and it does not account for water distribution. Only karez farmer groups who harvest sufficient crops (and thus have received water to irrigate sufficient hectares of land) can still pay the karez cleaning costs. Karez rehabilitation, which is discussed further in the following, is often completely beyond the financial capacity of karez farmers.

Flash floods

Flash floods leading to the destruction and siltation of karezes have been reported for karezes that are located in and near floodplains in Helmand Province (Table 3). Flash floods are also reported, by the Provincial Ministry of Water, as a cause for karez siltation in most of the districts in Farah Province.

Bombing of karez air shafts

Karez air shafts and tunnels were sometimes used as hiding places during fighting which lead to some of them being bombed. This was reported to have happened at some of the karezes in Helmand Province (Nawzad, Sangin and Washer districts, Table 3). The method used by the Soviets in the 1980s for creating a deadly over-pressure in karez air shafts and tunnels, stereophonic/quadrophonic blasting, is vividly described in Grau and Jalali (1998). Still, this is a relatively rare cause compared to the others described previously.

Karez rehabilitation

The legal foundation and past and possible future strategies for rehabilitating karezes in Helmand Basin are discussed in the following. It should be noted that poor security is the most critical, and often a paralysing factor, for applying Integrated Water Resources Management (IWRM) and implementing any water-related projects in the Helmand Basin (Goes et al. 2016). Poor security implies that karez rehabilitation work would need to be relatively simple and designed in such a way that it can be managed by staff from the area (NGO or Government) and implemented by local contractors together with the community. The financial costs of karez rehabilitation, are significantly higher than the aforementioned cleaning costs, so this fares negatively in comparison to the cost of drilling new boreholes. Still, on the other hand, karezes are part of the national heritage of Afghanistan, they can facilitate a much-required social cohesion and they do not over-abstract the aquifer.

Legal foundation by Afghan Water Law

The 2009 Afghan Water Law (IRA 2009) promotes the application of Integrated Water Resources Management principles and states that karezes have 'rights-of-way' and 'are protected from encroachment'. The water law also says that water uses need to take 'consideration for the praiseworthy customs and traditions of the people'. The use of water resources without a permit is, with the exception of a sizeable (5 m^3/day/household) drinking and/or livelihood water abstractions, prohibited under the Afghan Water Law. The Water Law further mentions that 'a license is required for digging and installation of shallow and deep wells for the commercial, agricultural, industrial and urban water supply purposes'; thus, in theory the drilling of non-domestic larger abstraction wells and boreholes could be stopped legally when a karez is affected. Still, this remains 'in theory' because implementation of a license system for boreholes has been and is likely to remain, with the exception of a few provincial capitals, impossible in the Helmand Basin under the current poor security.

Past karez rehabilitation efforts

The karez farmers in Helmand Province reported during the FGDs that measures had been taken by the farmer groups a few decades ago ('during their childhood') to try to enhance the flow in 'some' of the karezes (Table 3). This involved lengthening the karez through constructing usually three 30–50 m tunnels in different directions upstream of the mother well or by extending the tunnel even further and digging a new mother well. Still, this had limited success because, in some areas, hard rock was encountered and in other areas the water table in the area of the mother well had declined too much. McClymonds (1972) also reported that in response to the decline in karez yield some karezes were lengthened or deepened.

NGO-supported karez rehabilitation works have generally been reviewed poorly over the past decades. Anderson (1993) stated that 'it was a directly visible way of dispersing emergency relief money without having a defined and well-thought-out programme. Records were poorly kept and the locations of karezes cleaned were never clearly identified on a map except by a few organisations.'

One documented recent example of a karez rehabilitation was carried out by the Emergency Irrigation Rehabilitation Programme (documented in Rout 2008). The karez is located in Herat Province (Pashtun Zargun District that borders Helmand Basin in the north). The works included:

- Lining of damaged tunnel sections and air shafts
- Construction of an aqueduct across a floodplain
- Construction of a storage pond that takes 15 h to fill

The impact of these works has not been documented as far as is known. Banks and Soldal (2002) also reported that NGOs focussed their karez rehabilitation programmes on lining of air shafts with concrete rings and masonry, and lining tunnels with reinforced concrete ellipses. Still, the same authors also reported that the work was expensive, time-consuming and the yield improvement was often low compared with construction of a new borehole.

Strategies for rehabilitating karezes

Given competition with relatively cheap boreholes, the difficult working conditions and the limited evidence of past success, it is recommended to initially select the most promising karezes for rehabilitation, based on the following criteria:

- Karezes with a sufficient recharge potential, meaning having good local hydrogeological characteristics and being located in a relatively high precipitation zone (Table 2; Fig. 6) because these have the highest chance of having had a fair yield and thus also some resources (profit from harvest) for regular community-paid karez cleaning
- Karezes that are relatively easy to maintain, meaning with air shafts that are not too deep (<~25 m); this would also exclude the high maintenance 'tile' karezes
- Karezes that still have a fairly strong and coherent local farmers' community with a respected traditional leader (mirab or elder) which is prepared to manage a karez collectively and to discontinue boreholes
- Karezes in relatively isolated areas with no or few boreholes in and near the mother well

Three groups of measures could be adopted in revitalizing karezes in Helmand basin—maintain a sufficiently high water table especially in the karez mother-well zone; engineer improvements; and establish water efficiency measures.

A sufficiently high water table, especially in the mother well and recharge zone, needs to be maintained for feeding the karez (Fig. 1). This needs to be done through restricting groundwater pumping in those zones. Firstly, the karez mother well and air shafts, the recharge zone(s) and existing boreholes need to be mapped. Mapping individual karezes and their recharge zones is easily accomplished using freely available digital maps like Google Earth (Fig. 3; Luo et al. 2014), digital elevation maps and geological maps (USGS 2010; partly shown in Fig. 2). Mapping of existing boreholes near the karez requires more recent high-resolution imagery that is usually not free of charge, and/or a field survey. Then the local community (especially mirabs and farmers groups) would need to be consulted on their interest in developing and implementing a locally appropriate borehole management system with, in the long-term, no or very limited external (government, NGO) support. Based on drawdown calculations using the 'Theis equation' and various assumptions considered reasonable for the Quaternary aquifers in Afghanistan (e.g. abstraction rate and duration, hydraulic conductivity), Banks and Soldal (2002) recommended that 'irrigation wells should be situated no less than 500 m from karezes, as a general rule' and that 'wells should be situated 1,700 m apart.' Based on a groundwater model, the water capture zone for a typical karez for the Kandahar area was estimated to be at least 600 m wide and 50 m deep (Macpherson et al. 2015) . In addition, recharge enhancement measures could be considered through delaying surface runoff and stimulating infiltration through construction of bunds or leaky delayed action dams. Still, this measure should only be considered with extreme caution because of the siltation issues which have arisen when this was attempted in Pakistan as discussed previously.

Secondly, the following engineering improvements could be made to support the maintenance:

- Capping of air shafts to prevent damage by sediment and rain.
- Minimizing the risk of collapse of karez tunnel and airs shafts, which is one of the key maintenance problems. This can be achieved by building protection walls from river stones with concrete (locally done in Helmand Province) or by introducing pre-fabricated elliptical concrete rings or concrete pipes to strengthen these vulnerable zones. This is a very labour intensive measure but, as mentioned already, it has been tested in Herat Province.

Thirdly, the continuous water flow in karezes is frequently viewed as wasteful. Irrigation water is mostly needed during the daytime. Night flow could be stored in small reservoirs at the mouth of the karez for daytime use. Another measure might be to line the bottom of the downstream section of the tunnel (where it is above the water table) with low permeable sediment (e.g. clay or bentonite) or even a pipe to minimise water seepage from the tunnel into the ground. Furthermore, like most informal irrigation systems in Helmand Basin, the efficiency of the irrigation water conveyance system could be improved (Khan et al. 2015).

Conclusions

Most karezes in the Helmand Basin are 100s, possibly even over 1,000 years old. The karezes have been important for irrigation and domestic water supply. A functional karez, with sufficient water flow like in the past, has about half the operating costs per ha as deep diesel-powered irrigation boreholes. Still, the use of solar technology has been on the rise recently which will reduce the operating costs of boreholes and may make even still functional karezes financially less competitive.

It has been shown that there is a clear relation between the geology and karez locations. Most karezes are located within the gently sloping unconsolidated Quaternary mainly fluvial, alluvial, glacial and lacustrine deposits (conglomerates, gravels, sand and clay) of the middle part of the basin. There are also some kareze areas within more consolidated Tertiary sediments (i.e. conglomerate, silt stone, sand stone, and limestone) in the eastern part of the basin.

Drought periods leading to a reduction in water flow from the karezes were already observed in the early 1970s. Still, the status of the karezes is now much worse than then. Over half the karezes in Helmand Basin have gone dry; furthermore, yields from the still functional karezes have also declined drastically (on average by 75% in Helmand Province). The main causes are a prolonged reduction in precipitation (1998–2014); an increase in number of boreholes and tubewells especially since the late 1990s; and reduced maintenance of karezes. The reduced maintenance is related to underlying factors like limited funds due to decrease in agricultural yield, and people becoming more individualistic as a result of over three decades of war and insecurity and the introduction of tube wells and boreholes. The lowering of the water table as a result of the increase in number of boreholes and tubewells is by far the dominant cause for the drying of almost all (>85%) karezes in northern Helmand Province.

Poor security is a critical, and often a paralysing factor, which means that rehabilitation work needs to be relatively simple and designed in such a way that it can be managed by staff from the area (NGO or government) and implemented by local contractors together with the community. If only the financial costs and benefits of karez rehabilitation are considered, then the balance is negative in comparison to the drilling of new boreholes. In addition, the assessment of costs needs to recognise that there also has to be community-based licensing and management of boreholes in, at least, the karez recharge zone. This would be a difficult task in the insecure Helmand Basin. If achieved then there would be a foundation for sustainable groundwater use through boreholes and karezes alike, so why then still proceed with the more expensive karez rehabilitation? The remaining arguments in favour are that karezes are part of the national heritage of Afghanistan and that they facilitate a much-needed social cohesion.

Given competition from relatively cheap boreholes, the difficult working conditions and the limited documented success of past karez rehabilitation efforts, it is recommended to select the most promising karezes for rehabilitation which are karezes with sufficient recharge potential (good hydrogeological characteristics and relatively high precipitation); that are relatively easy to maintain (e.g. relatively shallow air shafts), that still have a fairly strong and coherent local community and have no or few boreholes near the mother well.

The measures that could be adopted in revitalizing karezes in Helmand basin are: maintaining a sufficiently high water table especially in the mother-well zone (e.g. through restricting groundwater exploitation through pumping), engineering improvements (e.g. capping of air shafts, providing concrete rings to strengthen vulnerable karez tunnel zones) and water efficiency measures (e.g. lining the karez tunnel).

The use of ‘NCEP Reanalysis 1’ data has been very useful to generate historical precipitation records for the data poor Helmand Basin. These generated data permitted assessment of the relation between precipitation and the drying-up/reduced water yield of karezes in recent years and in the early 1970s. The approach holds promise for application in other areas that are also significantly deficient in precipitation data.

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Appendix

Table 3 Outcome focus group discussions with karez farmers in Helmand Province in November and December 2012

Parameter	District					
	Kajaki	Musa Qala	Baghran	Washer	Nawzad	Sangin
No. of farmers	5	5	5	5	5	4
No. of karezes in district	200	41	250	160	260	17
No. of still functional karezes	14	7	25	60	34	3
Any memory from past generations on karez construction	No	No	No	No	No	No
Length of karezes [km]	4 (1.5–9)	3 (1–5)	1.5 (1–3)	2 (1.5–3)	4 (1.5–9)	2 (1.5–3)
Median distance between air shafts [m] (range)	50 (20–80)	40 (25–60)	20 (20–35)	30 (20–40)	50 (25–75)	30 (25–50)
Median depth 'mother well' [m] (range)	40 (18–60)	40 (20–60)	25 (20–30)	25 (15–45)	20 (10–30)	25 (15–35)
No. of water collecting tunnels at mother well	4	3	4	3	3	3
Karez lengthening reported in past[b]	Yes, some	Yes, some	Rarely	Yes, some	Yes, some	Rarely
Average past[b] winter flow [polah]	3	13	5	8	8	10
Average current winter flow [polah] in still functional karezes	1.2	3.6	1.7	1.4	2.6	0.5
Average past[b] summer flow [polah]	3	5	5	3.8	3	6
Average current summer flow [polah] in still functional karezes	1.2	1.3	0.8	0.8	1.5	0.5
Alternative water sources in your village?	Deep wells	Deep wells	Deep wells, springs, river	Deep wells (shallow wells ran dry ~10 years ago)	Deep wells (shallow wells ran dry ~10 years ago)	Deep wells (shallow wells ran dry ~10 years ago)
Karez manager	Elder	Mirab	Elder	Elder	Mirab	Mirab
Irrigation water rotation winter [days]	12	12	12	12	14	12
Irrigation water rotation summer [days]	6	6	6	6	7	6
Average payment to manager for water per winter season	No info	67.5 kg per Changul[a]	No info	No info	33.75 kg per Changul[a]	3.75 kg wheat per hr of water during rotation
Frequency karez cleaning in past[b]	1 per year	1 per year	1 per year	1 per year	Every 2–3 years	2 per year
Resource mobilisation for cleaning based on	Land size	Land size	Land size	Land size	Land size	Land size
Cleaning costs for a typical karez using voluntary labour [USD/km][c]	1,520	4,000	1,288	5,300	1,000	5,600
Cleaning costs for a typical karez contracting 'karez kans' [USD/km][c]	2,500	6,000	3,200	6,600	1,500	6,000
Reported 'mean' water-table depth [mbs]	80–85	75–85	50	45–55	60–75	45–50
Reported borehole depth [mbs]	Up to 150	85–100	80–90	100	100	60–70
Reported reasons[d] for karezes drying in perceived order of importance	1, 2, 3, 4[d]	1, 2, 4[d]	5, 4, 6[d]	1, 2, 4, 5, 7[d]	5, 4, 7, 1[d]	1, 5, 4, 7[d]

[a] A local land-surface-unit (undefined)

[b] Past is defined as during 'youth' of farmers (approximately late 1980s or early 1990s)

[c] Including cleaning 'mother well' and strengthening sections of eroded tunnels (note: average costs per km tend to be higher for shorter karezes probably because of fixed costs like mother-well cleaning)

[d] Reasons: (*1*) deep irrigation boreholes, (*2*) drought, (*3*) outward migration of people, (*4*) economic weakness and reduced social cohesion make it difficult to collect maintenance fees, (*5*) silted by floods, (*6*) lack of skills/equipment for maintenance, (*7*) bombing of air shafts

Adopted from Mott MacDonald (2013b)

Table 4 Outcome of focus group discussions with karez farmers in Helmand Province in November and December 2012

District	Other reported information in relation to karezes and irrigation
Kajaki	No proper distribution gates/dividers in irrigation canals
Musa Qala	5 out of 7 still functional karezes only for drinking,
	>1,400 deep wells in district,
	8 large springs in district also dried,
	Mud dams are used in as irrigation canal dividers
Baghran	Most still functional karezes only for drinking,
	There used to be ~400 springs, most dried or flow reduced by over 50%,
	Water pumped from holes in river bed is currently the most important irrigation water source,
	No proper distribution gates/dividers in irrigation canals
Washer	Drilling boreholes is much easier than constructing karezes,
	No proper distribution gates/dividers in irrigation canals
Nawzad	Drilling boreholes is much easier than constructing karezes
Sangin	The three still functional karezes are only for drinking

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