WATER KNOWLEDGE NOTE

Groundwater Management in Balochistan, Pakistan

A Case Study of Karez Rehabilitation

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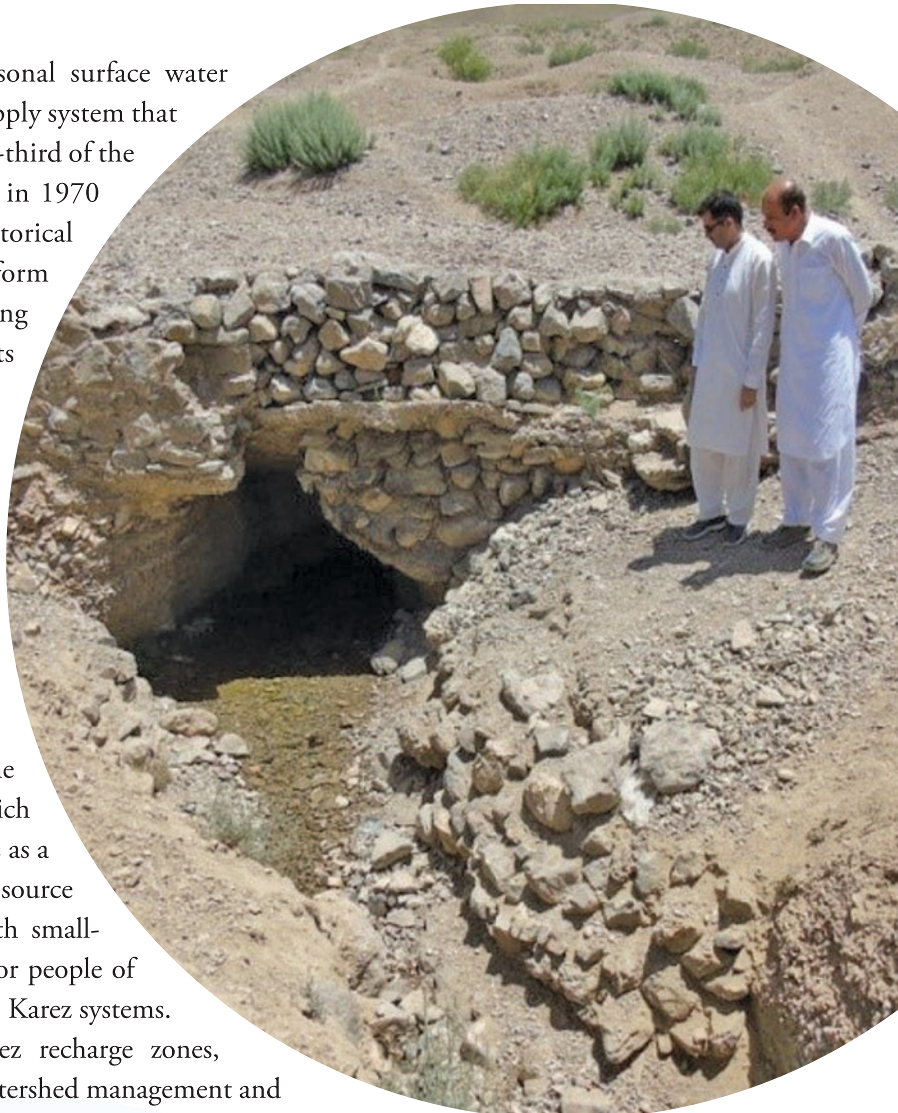

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Balochistan is an arid region with limited and seasonal surface water resources. It is also home to the ancient Karez water supply system that has long served as a buffer against droughts. About one-third of the 3,000 such systems that were believed to be in place in 1970 are still functioning. Aside from its cultural and historical significance, the Karez system has helped transform the agrarian landscape of the uplands, improving socioeconomic conditions. However, recurring droughts since the 1960s resulted in reduced recharge to groundwater supporting the Karez systems at a time of growing demands. To maintain their livelihoods, farmers installed tubewells, aided by energy subsidies from the provincial government.

The number of tubewells has increased from 5,000 to more than 40,000 during the since the 1970s. Correspondingly, groundwater has been diminishing at an accelerated rate, with the level in some basins declining by more than 5 meters per year. This decline has seriously impacted the Karez systems, many of which have dried up. Nonetheless, the Karez system still serves as a lifeline for the poorer members of the community as a source of drinking, domestic, and livestock water, along with small-scale agriculture. To safeguard water supply for the poor people of Balochistan, there is a need to preserve and enhance the Karez systems. Practical ways forward include identifying the Karez recharge zones, enhancing groundwater recharge through integrated watershed management and aquifer recharge techniques, and banning tubewells within the Karez recharge zones.

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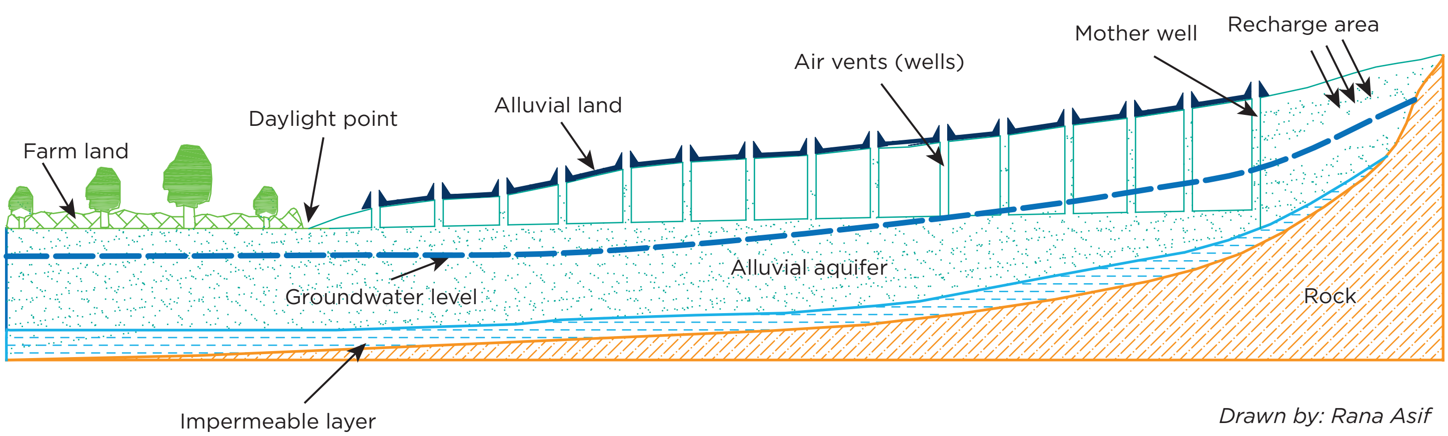
Background

Pakistan is an arid country with an average annual rainfall of just 297 millimeters. Balochistan, which covers 44 percent of the country's land mass and has a 770-kilometer-long coastline, is unique in its geopolitical significance. However, it is also the smallest province in terms of population at 12.34 million, according to the 2017 census. Its arid but diverse climatic zones have contributed to a rich animal and plant biodiversity while building a definitive cultural heritage that allowed survival in this rugged and harsh landscape. The province lies in the arid climatic region where rainfall is low and its spatial and temporal variability is high. Moreover, annual evaporation is about 10 times higher than rainfall. Lift irrigation, springs, and the Karez are the main sources of water for agriculture and domestic uses (Ashraf and Majeed 2006).

The Karez system is arguably the most interesting and oldest among gravity-fed irrigation systems, built centuries ago by the local people. It has been reported that some of the Karez were built in Balochistan before the arrival of the Mughals in 1525 A.D. (Kahlown, Khalil, and Munir 1988). Ideally, it provides safe and cost-free water for both irrigation and domestic purposes around the clock and throughout the year (Ashraf, Majeed, and Saeed 2016). The evaporation losses are minimal, and its underground coverage protects against sediment deposition from windstorms. Karez systems are owned and managed by the community, and every community member benefits from them, directly or indirectly. The Karez irrigation system is found in many countries, including those in Asia, Africa, and the Middle East, as well as the United States. These Karez are referred to by a host of names, including Afalaj (Oman, Arabian Peninsula), Auyoun (Egypt), Foggara (North Africa), Galleria (Spain), Kanerjing (China), Karez (Pakistan, Afghanistan, and India), Khotara (Morocco), Mambo (Japan), and Qanat (Iran) (Martin 1982; Okazaki 1980; Oostenbaan 1983). The Karez system is a long-standing and environmentally sustainable socioengineering solution that portrays the creativity of people living in water-stressed and dry areas of the world (Govindankutty 2016).

The physical components of a typical Karez system commence with a well, known as the mother well, constructed to tap groundwater upgradient from a community, often in an alluvial fan near the base of hills or mountains. This mother well serves as an outlet point for the upstream groundwater that then discharges into a gently sloping subsurface, subhorizontal channel and flows under gravity to the village, where it is routed through above-ground channels for various uses. The horizontal shaft is constructed in sections that include vertical shafts (manholes) at either end, spaced about 15 to 30 meters apart. At the time of construction, these vertical shafts are used for removing debris and later serve as air vents or wells. The main purpose of the air vents is to undertake operation, maintenance, and removal of accumulated debris from the underground horizontal shaft. They also provide ventilation, prevent accumulation of gases in the underground water galleries, and allow the fetching of water through bucket and pulley systems. The point where water comes out from the subsurface channel is known as a daylight point. From there, farmers construct surface channels, storage tanks, and diversion channels for agricultural, livestock, and domestic uses. A typical cross-section of the Karez is shown in figure 1.

FIGURE 1. Schematic Diagram of a Typical Karez



Source: Kahlown, Khalil, and Munir 1988.

The Karez system was designed in a way that its command area (the cultivated area supported by the system) was developed according to the flow rate of the Karez. This arrangement allowed for the sustainable use and management of groundwater and provided resilience to the local population against recurring droughts (Khan and Nawaz 1995). As recently as a few decades ago, the agricultural economy in the uplands of Balochistan was mostly dependent on the supply of Karez water.

Sociotechnical Context

The Karez system is an example of one of the engineering and technology monuments of the classic world (Oleson 2008), but unfortunately, few studies have been conducted on it. This system can serve as a cost-effective water supply for agricultural and domestic uses to the people living in the area, without using any energy. As water flows under gravity, water supply in Karez is continuous unless the horizontal tunnel is damaged or the mother well dries up from local groundwater level decline.

Sociocultural Context

The establishment of Karez systems allowed nomadic tribes of Balochistan to settle and grow fodder crops for their livestock. Therefore, a decline in the performance of the Karez strongly impacts the socioeconomic situation of its dependent community (Farooqi and Rehman 1998). The introduction of new technologies such as tubewells has brought about great change in the region, but the small landholders and poor communities still depend on Karez water. The kinship culture among tribes is also transferred to Karez water rights. Karez are not only a perennial source of water supply but also a system around which community attitudes and their social relations revolve (Farooqi and Rehman 1998).

The Karez-irrigated farming is threatened by a number of factors: (a) lowering of water tables and mining of groundwater resulting from indiscriminate development of deep tubewells, (b) reduction in flow because of siltation of channels as a result of deferred maintenance, (c) soil erosion affecting the mother well and the vertical shafts, (d) lack of skilled manpower, and (e) lack of support from the government regarding repair and maintenance of the systems (Ahmad 2007; Anwaar, Chaudhry, and Ambreen 2007; GWP 2015; Jamali and Hufty 2011; Mustafa 2014; Mustafa and Qazi 2007). As a result, most of the Karez are facing operational challenges, which are exacerbated by the emergence of tubewells and modern electric-powered pumps even within the irrigation command areas served by Karez. Khan and Nawaz (1995) and Rahman (1981) found that this might ultimately destroy the fragile ecosystem of Balochistan, including the age-old Karez irrigation systems.

The successful operation of a Karez system depends not only on its technical and structural arrangements but also on numerous social factors, including (a) opinions and aspirations of the shareholders, (b) the nature of social participation (cooperation and conflicts), (c) tribal values toward water management, (d) community leadership, and (e) the role of government functionaries. Clear understanding of these factors can help in setting up a feasible program for efficient operation of Karez.

Drought in Balochistan and Its Impact on Groundwater

There is growing concern about the increasing frequency and severity of drought in Pakistan, particularly because a significant increase in the frequency of heat waves, an indicator of forthcoming drought, has been reported. Drought has been observed to occur in approximately four out of every 10 years (Ahmad et al. 2016). Balochistan is among the most drought-prone regions of the country where severe droughts have been recorded in 1967–69, 1971, 1973–75, 1994, 1998–2002, and 2009–15 (Ahmad et al. 2016). There are four types of drought, and all exist in Balochistan, leading to unsustainable exploitation of the groundwater.

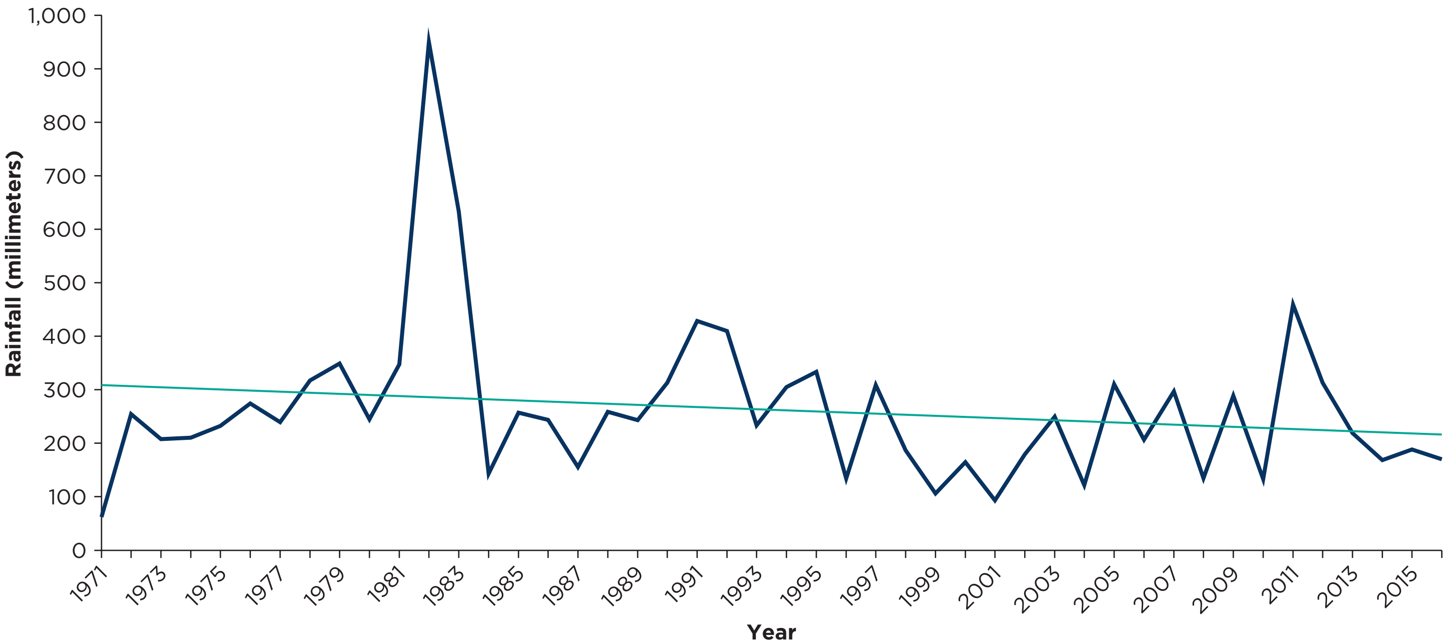
Meteorological Drought

This form of drought exists when precipitation is deficient in amount, intensity, and timing. This deficiency reduces water infiltration and effective runoff to make surface water available and limits deep percolation, negatively affecting groundwater recharge. Upland Balochistan is the most affected area of the province for this kind of drought. Rainfall has been decreasing since the 1980s, which has contribute to the drying up of surface water resources and decreased flows from springs and tubewells. Figure 2 shows a declining trend in precipitation in Quetta, the provincial capital. This situation has increased reliance on groundwater and further exaggerated its exploitation.

Hydrological Drought

Hydrological drought occurs from lower water availability in surface water bodies and is generally attributed to metrological droughts (Farzaneh, Eslamian, and Mirnezami 2014).

FIGURE 2. **Rainfall from 1971 to 2016 in Quetta Valley**



Source: Pakistan Meteorological Department, unpublished reports; UNDP 2014.

It is caused by a disturbance in the frequency of rainfall or snowfall, which leads to a shortage in surface water, lakes, and groundwater reservoirs. Many areas of the province have been experiencing a drought-like situation (UNDP 2014). In Balochistan, stream flow data are not as readily available to assess the hydrological droughts. Therefore, hydrological drought is estimated by groundwater abstraction and recharge, which shows a negative balance of 0.459 billion cubic meters per annum (van Steenbergen et al. 2015; table 1).

Agricultural Drought

Reduced precipitation in arid climates results in the loss of soil moisture, leading to agricultural drought (Hong et al. 2014). This drought is linked to various aspects of meteorological and hydrological droughts through the difference between actual and potential evapotranspiration, soil moisture loss, and increases in water demand—eventually causing further exploitation of groundwater resources (UNDP 2014). The drought of 1998–2002 was one of the worst in recent history and greatly affected agriculture and livestock sectors. About 80 percent of apple and other fruit orchards were damaged. The rangeland vegetation providing food to large numbers of livestock withered, resulting in the death of thousands of domestic animals (Ahmad 2008).

Socioeconomic Drought

Socioeconomic drought is different from other types of droughts in that it determines the impacts of the other droughts by widening gaps in supply and demand. The impacts are enormous because they affect people in terms of loss of livelihood sources: agriculture, livestock, and related enterprises (UNDP 2014). The drought of 1998–2002 was the major cause of reducing the economic growth from 12 percent in 1981–82 to only 2.6 percent during 1998–2002. The drought caused a loss of US$250 million to the national revenue during 2000–02 (PDMA 2012). During drought periods, groundwater supplies, particularly from Karez, played a crucial role in providing drinking water for human and livestock populations as well as for limited levels of agriculture.

Groundwater Situation Analysis

Groundwater in Balochistan is present in both confined and unconfined aquifers in all river basins and sub-basins and generally flows from catchment boundaries to the axis of the valleys. Thus, it largely follows the general trend of surface drainage and is found in the alluvial fans and piedmont plains. The Water and Power Development Authority (WAPDA) evaluated these resources from 1976 to 1980 for a number of basins. In 2007, Halcrow Pakistan (Pvt.) Ltd.

TABLE 1. Groundwater Balance in the River Basins of Balochistan

River Basin	Average recharge (BCM)	People (BCM)	Livestock (BCM)	Agriculture (BCM)	Total (BCM)	Balance (BCM)
Dasht	0.100	0.013	0.012	0.069	0.094	0.006
Gaj	0.070	0.001	0.001	0.070	0.072	−0.002
Gwadar-Ormara	0.040	0.004	0.003	0.017	0.025	0.015
Hamun-e-Lora	0.040	0.001	0.001	0.139	0.141	−0.101
Hamun-e-Mashkel	0.300	0.008	0.007	0.012	0.027	0.273
Hingol	0.200	0.005	0.007	0.156	0.168	0.032
Hub	0.080	0.001	0.001	0.086	0.088	−0.008
Kachhi Plain	0.180	0.017	0.012	0.140	0.169	0.011
Kadanal	0.030	0.000	0.005	0.110	0.115	−0.085
Kaha	0.190	0.000	0.004	0.315	0.319	−0.129
Kand	0.010	0.000	0.000	0.018	0.019	−0.009
Kunder	0.050	0.000	0.000	0.048	0.048	0.002
Mula	0.120	0.002	0.001	0.126	0.129	−0.009
Nari	0.270	0.006	0.004	0.171	0.180	0.090
Pishin Lora	0.170	0.024	0.029	0.513	0.566	−0.396
Porali	0.140	0.002	0.003	0.142	0.146	−0.006
Rakshan	0.050	0.003	0.003	0.075	0.081	−0.031
Zhob	0.160	0.002	0.001	0.267	0.270	−0.110
Balochistan	**2.210**	**0.091**	**0.054**	**2.474**	**2.659**	**−0.459**

Sources: Balochistan Irrigation Department and Re-assessment of Water Resources of Balochistan; Halcrow Pakistan reported in van Steenbergen et al. 2015.
Note: BCM = billion cubic meters.

(reported in van Steenbergen et al. 2015) reassessed the groundwater resources of 14 of 18 basins. The total annual potential was estimated to be 1,071 million cubic meters per year, out of which 604 million cubic meters had already been utilized. Table 2 provides details of the groundwater development potential in various river basins. The Pishin-Lora Basin, consisting of districts Mastung, Pishin, Quetta, and part of Kalat, forms the main deficit area, where the abstraction of groundwater exceeds the recharge (table 2).

The Mangochar, Pishin, and Quetta sub-basins are the areas where groundwater abstraction rates are alarmingly high. The Nari basin, in the districts of Loralai and Ziarat, is also in deficit, with no further groundwater potential left for exploitation. The Qila Saifullah sub-basin is an area with enough groundwater; however, recent commissioning of many tubewells has led water tables to decline in this basin. Because of favorable climatic conditions, improved communication networks, and the introduction of electricity with subsidized flat rates, there has been a tremendous increase in the drilling of tubewells. The number of tubewells has increased from 5,000 in 1985 to more than 40,000 by 2014 (figure 3) and has had a drastic impact on the functioning of Karez.

A high subsidy on the operational costs is the main cause behind expansion of privately owned tubewells in the province. As a result, extensive groundwater abstraction, followed by inefficient use of the pumped water, has led to declining water tables by as much as 5 meters per year in some areas. Because prevailing drought conditions are pushing farmers to pump more water for their survival, the groundwater balance in most of the basins is showing a negative budget (table 1), which is a serious issue in the era of growing water demand in almost all sectors. Indiscriminate installation of tubewells has been a major reason for the drying up and abandonment of Karez. The percentage of the total area irrigated by Karez decreased from 43 percent in 1971 to 11 percent in 2005 to 3.7 percent in 2015 (figure 4; Government of Pakistan 2016). Figure 4 shows that the major focus of the government has been on developing canal infrastructure with little or no focus on Karez. Still, these Karez are major sources of domestic and drinking water.

TABLE 2. Annual Groundwater Development Potential in River Basins

No.	River basin	Available potential (MCM)	Remaining potential (MCM)
1	Hamun-e-Lora	34	17
2	Kachhi	38	26
3	Nari	26	0
4	Pishin Lora	130	0
5	Porali	149	75
6	Hub	119	60
7	Windar Nai	11	6
8	Zhob	112	9
9	Dasht	46	37
10	Rakhshan	24	20
11	Hamun-e-Mashkel	61	56
12	Hingol	265	132
13	Gaj	34	16
14	Mula	23	14
Total		1,071	467

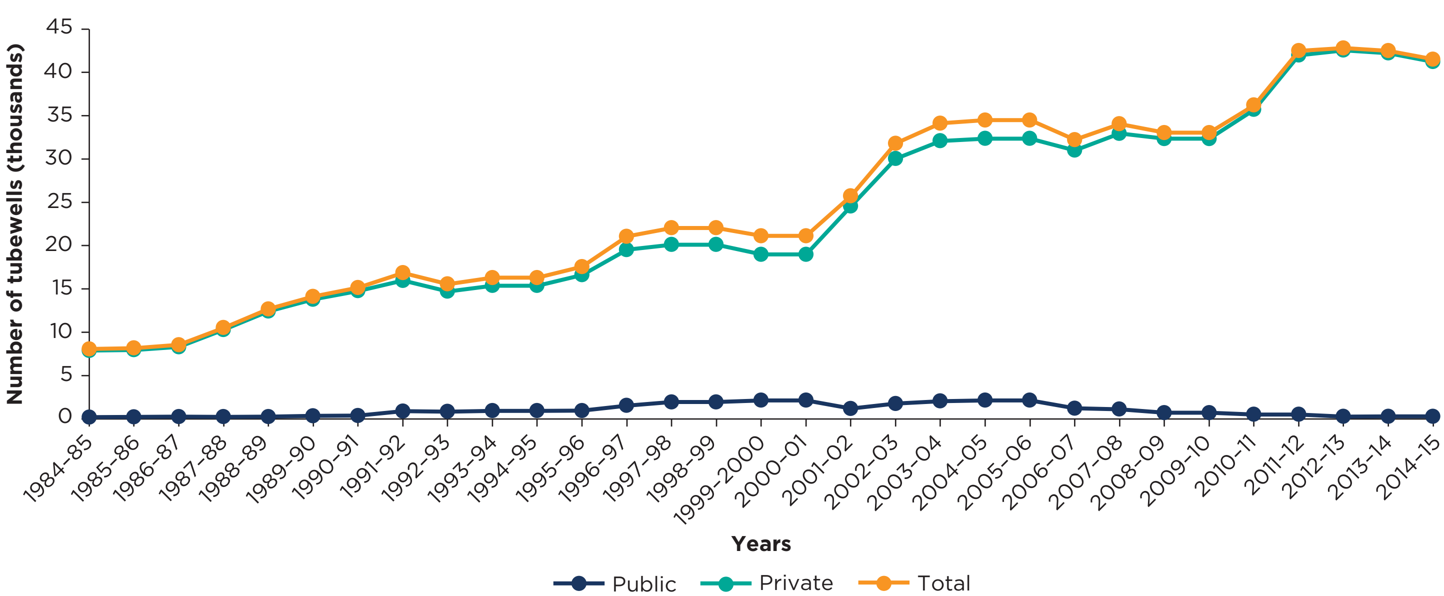
Note: MCM = million cubic meters.

A situation of prolonged droughts followed by overexploitation of groundwater has impacted conventional irrigation resources drastically. Ahmad (2007) reported that of 1,328 Karez in Balochistan, 270 were nonfunctional and many others were only partially functional in 2015 (table 3).

Political Economy of Groundwater

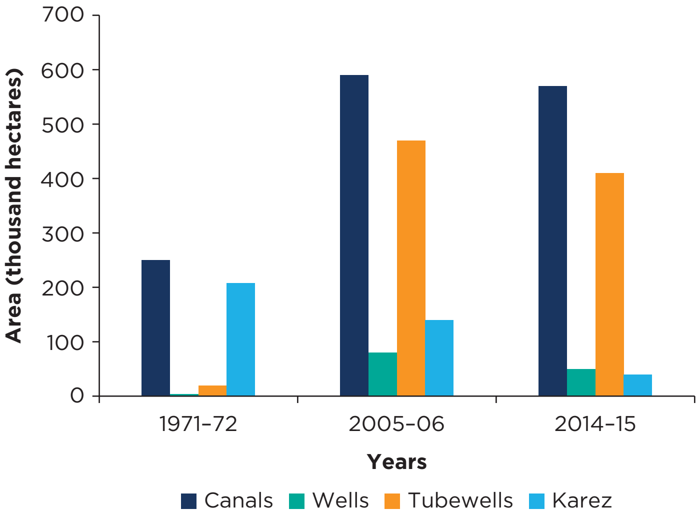
A major reason behind the sharp increase in tubewells is that the government provided flat-rate tariffs on electricity for tubewell operation from July 2001. During 2015–16, the subsidy provided by federal and provincial governments on electricity was on the order of PKR28 billion (UNDP, 2016) or US$280 million.[2] According to the Agricultural Statistics of Pakistan in 2014–15, there were 30,387 private electric tubewells in Balochistan. Therefore, the subsidy per tubewell comes to about PKR0.92 million (US$ 9,200) per year. Most of the large farmers own more than one tubewell. Only a small fraction (less than 0.3 percent) of the population receives direct benefits from this subsidy (Ashraf and Sheikh 2017). A tariff was proposed for the electric-driven tubewells in the draft Integrated Water Resources Management (IWRM) Policy 2006 by removing the flat rate of electricity. However, the Provincial Cabinet approved the IWRM policy for all the policy thrust areas except "electric tariff for the tubewells," highlighting that political decisions strongly affect the groundwater economy. Moreover, the advent of renewable energy has promoted solar-powered tubewells all over the country. The government of Balochistan is also promoting these

FIGURE 3. Increasing Numbers of Tubewells in Balochistan



Source: Government of Pakistan 2016.

FIGURE 4. Comparative Development of Irrigation Sources



Source: Agricultural Census of Pakistan 2015–16.

systems through subsidized schemes, and this may speed up unsustainable withdrawal of groundwater resulting from the high daylight potential of the province. This is pro-poor technology and the government of Balochistan has not invested in preserving traditional and indigenous heritage of the province such as the Karez irrigation system. In the 2006 IWRM policy of Balochistan, management of the Karez system has been neglected. In the National Water Policy 2018, the Karez have not been specifically mentioned, although considerable attention is devoted to groundwater management.

Water Rights

The Baloch, Pashtuns, and Brahvis are the three major linguistic groups in the province, and there are various tribes within these groups. Water rights vary from one group to the other and are governed mostly by the customary tribal laws,

TABLE 3. Number of Karez in Balochistan

No	District	Total number	Functional	Nonfunctional
1	Ziarat	32	30	2
2	Sherani	88	78	10
3	Khuzdar	19	15	4
4	Awaran	45	40	5
5	Chagai	13	12	1
6	Washuk	10	8	2
7	Kharan	10	9	1
8	Kech	235	171	64
9	Qila Saifullah	226	165	61
10	Loralai	59	50	9
11	Zhob	65	59	6
12	Qila Abdullah	183	173	10
13	Panjgur	85	85	0
14	Pishin	68	40	28
15	Jhal Magsi	20	15	0
16	Musakhail	40	33	7
17	Kohlu	12	7	5
18	Kalat	57	31	26
19	Mastung	36	16	20
20	Sibi	13	9	4
21	Quetta	12	7	5
Total		**1,328**	**1,053**	**270**

Source: Adapted from Ahmad 2007.

though sometimes they are modified according to water availability. Under such circumstances, local communities act as managers and make their own decisions. Traditionally, there is no restriction among any of the ethnic groups on the use of water from any source, including tubewells for domestic or livestock purposes. People can fetch water for their domestic uses but are not allowed to convey water by channels or pipes to individual households (Majeed and Qureshi 2000).

Pashtuns recognize the rights of water users along a stream or river for all uses. There are no such rights established among Balochs and Brahvis in the central and coastal parts of the province. For Karez development, the Pashtuns recognize that whoever owns the mother well also owns the water rights, and the conveyance tunnel transporting water must pass through the owners land. In rare cases, however, if the tunnel must pass through another's land, the owner of the mother well must pay compensation to the landowners. The Balochs and Brahvis allow construction of a Karez on land owned by several people, all of whom share the Karez water. In the Mekran coastal areas dominated by Balochs, a Karez can pass through any land without compensation as a common property. The share of water is in accordance with the investment made in the construction of the Karez, irrespective of water demand (Majeed and Qureshi 2000).

Legal and Institutional Framework

Balochistan is the only province of the country that has some sort of legal protection in terms of groundwater management. The government of Balochistan issued a notification in "the Balochistan groundwater rights administration ordinance, 1978" (GOB 1978). This ordinance was framed because there was no law in the province regulating the use of water from tubewells or open wells located within the vicinity of Karez. In some areas, there was a tradition that no well should be allowed to be dug within the distance of 250 meters of the first well of Karez in case of soft land (alluvium) and 500 meters in case of hard land (hard rock). The ordinance was therefore to provide a uniform policy for the entire province for regulating the use of groundwater, specifying that areas having groundwater resources are to be identified and declared as designated "groundwater basins" for which a law should be framed. Implementation of this ordinance is still uncertain because there is a lack of political commitment and the Karez do not serve the interests of the more endowed and powerful members of the community.

The Irrigation and Power Department of Balochistan is mainly responsible for the planning, investigation, design, and implementation of various water development projects. The Public Health Engineering Department is responsible for the supply of water for domestic purpose. Quetta's Water and Sanitation Agency (WASA) is responsible for supplying water for domestic use in Quetta City, which mainly comes from groundwater (deep tubewells). As per the WASA Groundwater Management Act of 1989, the functions related to groundwater management are:

- Approve all new, extension, or rehabilitation works on the water supply, sewerage, and sanitation system in the area; and
- Monitor and control water resources in the area, both surface and underground, and issue licenses for abstraction of water from such resources in the area in accordance with regulations made by the authority.

This act provides a legal authority to WASA for the development of new groundwater sources and to issue licenses for abstraction of groundwater. However, it has never been implemented in its true letter or even in spirit for political and cultural reasons.

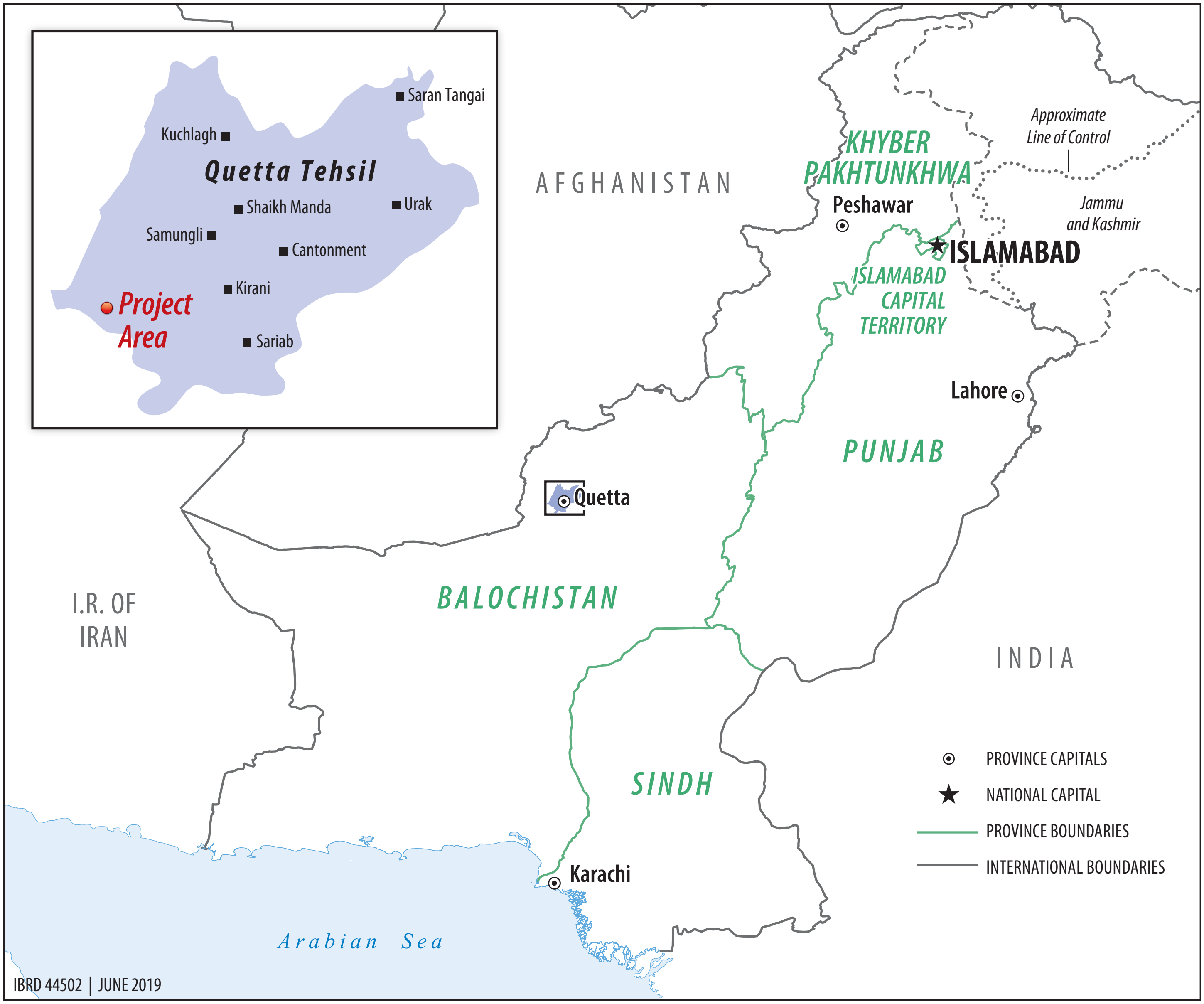
Rehabilitation and Sustainable Management of Karez in Balochistan: A Case Study

Pakistan pleaded the case to include Balochistan Karez in the sites suitable for inscription on the World Heritage list of The United Nations Educational, Scientific and Cultural Organization (UNESCO) in December 2015. Such a declaration could put peer pressure on the government and other stakeholders to preserve these systems. To develop a model site for this process, two partially notable Karez (Nau Sanjidi and Sanjidi) were selected. The Karez are close to each other and located at village Abdulzai in Quetta (map 1 and figure 5), which is situated 30 kilometers southwest of the city of Quetta. The landscape of the valley is mostly rocky, and the hills surrounded by the valley are dry and composed of coarse sand and gravels.

Baseline Survey

Following site selection, a complete area profile and data about the Karez were collected through a baseline survey. A questionnaire was developed to assess the socioeconomic, agricultural, and irrigation conditions of the beneficiary community. Informal, in-depth interviews with the community elders and community members were also conducted. Because the target population was small, there was scope to include all of them in the interview process.

MAP 1. Project Area



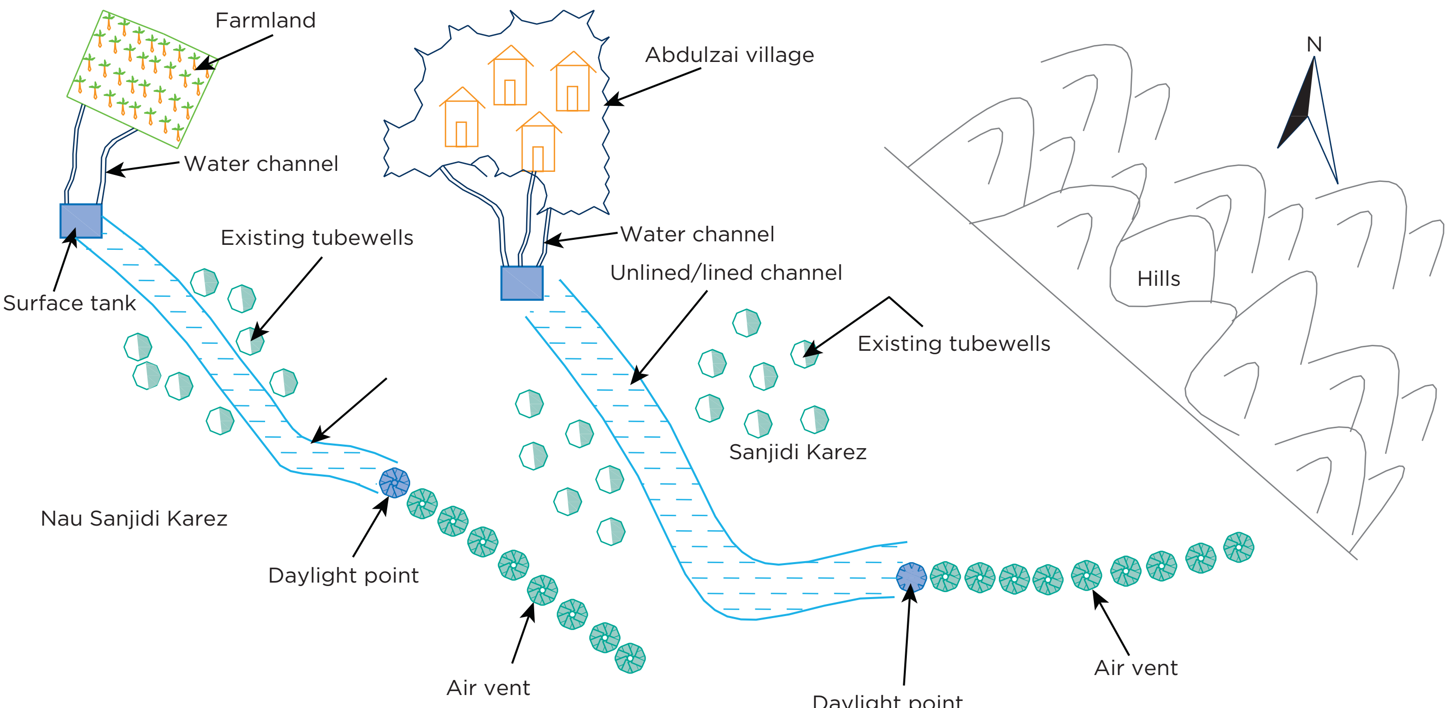
Socioeconomic Condition of the Area

The village is composed of 16 households with a population of 1,000 people. By definition, a household is a place where people live in one boundary, cook together, and eat together. This makes the family size quite big in Balochistan—about 63 people per household. All the households in the area depend on agriculture, and most of the male members are engaged in farming. Some household members also have other occupations such as government jobs, private business, and labor work. Monthly household income varies depending on multiple factors such as area of land owned and cultivated by the household, number of people employed, total members of the household, secondary sources, and so forth.

Agriculture and Irrigation System

All the households are engaged in agriculture and depend on it as their primary source of income. Annual cropping revolves around four major crops: wheat, onion, maize, and barley. In addition to conventional cropping, large orchards of grapes and apples also exist that are well-known for being of high quality. There are two main sources of irrigation: Karez and tubewell.

FIGURE 5. Schematic Diagram of the Karez at Abdullah Zai Village, Quetta



Drawn by: Rana Asif

Source: Author.

The entire village depends on these two Karez (Nau Sanjidi and Sanjidi Karez) and share water from them. A water user association (WUA) also exists in the village that is responsible for distribution, operating, and maintaining the Karez system. The WUA is composed of all the shareholders, and the members are heads of all the households. However, the two Karez have some distinctive physical, social, and political characteristics.

The Nau Sanjidi Karez starts in the foothills of Chiltan Mountain and flows to the west. It was constructed about 200 years ago. It has 50 air vents (wells) and the total length is 4.1 kilometers. The distance between the last well to the daylight point is 15.5 meters and the distance between the daylight point and the mother well is about 1 kilometer. The rest of the Karez flows in a lined open channel, although part of the channel is still not lined. The discharge was measured at the daylight and distribution points. During the physical survey, the discharge at daylight point was recorded at 4.48 liters per second whereas at the distribution point, it was 2.07 liters per second. The water loss between the daylight and distribution points was about 54 percent and was mainly caused by damaged channel and evaporation. The water rights of this Karez are distributed among five households. Among these households, water has been distributed into 15 shares. A basic unit for one shabana roz is defined as 43 hectares of land. The maximum share is five and the minimum is two, which means that the farmer will get five days' water and two days' water every 15 days, respectively. However, there is no onus on the farmer to take his share of five days or two days consecutively. If a farmer does not need water for the consecutive five days or two days, he would hand over the water control to the next farmer and irrigate his land at that farmer's turn instead. Thus, the farmers borrow their share of water from one another when it is needed and return it at their turn.

A pond has been constructed at the end of the Karez, in which the water is stored and used for irrigation. There are 98 hectares of land in the command area. However, this land is irrigated using both Karez and tubewell water, and it was difficult to estimate the exact area that was being irrigated through the Karez. There are seven tubewells installed by the community downstream of the Karez, the main reason for which is to tap the seepage water from the flowing Karez. These tubewells are thus used conjunctively with the Karez to maximize the irrigation water availability. Every member owns at least one tubewell, and these are mostly operated when the turn for Karez water goes to the tubewell owner. The tubewell water is mixed with Karez water and stored in the pond. However, sometimes farmers also operate these tubewells when they need water. On-site measurements reveal that average depth to groundwater level of these tubewells is 107 meters. All the tubewells were installed by using pipes with 7.6-centimeter diameters. Submersible pumps have been used in all the tubewells. Generally, the discharge of these tubewells is one-quarter of a cusec (about 7 liters per second). These tubewells are being operated on the flat rate of electricity—that is, PKR10,000 and PKR6,000 (US$100 and US$60) per tubewell per month in cities and rural areas, respectively.

Sanjidi Karez starts from the foothills of the Chiltan Mountain and flows in the northeast of the village Abdulzai. It is believed that the Karez was constructed more than 350 years ago. The total length of the Karez is 3.8 kilometers and the total number of air vents (wells) that contribute to the Karez is 31. The daylight point is at 8.9 meters from the last well and 840 meters from the mother well. The average distance between Karez wells is about 15 meters. Maximum depth of wells was measured at 21 meters, and the minimum depth of Karez was measured at 2 meters. The distance between the daylight point and the storage pond is 3.0 kilometers. The water flows through an open channel, which is lined in part with stone pitching. The discharge was 5.4 liters per second at the daylight point and 3.7 liters per second at the distribution point. There are several reasons for reduced discharge between the daylight point and the distribution point, including sloughing in the tunnel, seepage, landsliding, and evaporation. The water rights for this Karez system are divided into 15 equal shares among 16 households. These households own different sized areas of land around the Karez but downgradient from the mother well. The 15 shabana roz are distributed to each shareholder based on the area owned. The total area under irrigation is 306 hectares. However, the farmers use both tubewell and Karez as sources of irrigation. The water from both the sources is stored in ponds and subsequently used for irrigation. All the farmers grow a minimum of three crops per year. There are 18 tubewells installed downstream of the Karez that are owned by 15 members, and one tubewell, which is currently nonfunctional, was installed by Public Health Engineering.

Rehabilitation and Maintenance Work

Based on the results of the baseline survey, engineering structures (leaky dams, check structures, and ditches) and biological treatments (planting of shrubs) were designed and implemented for rehabilitation and improvement on the selected Karez (Ashraf and Sheikh 2017). The basic purpose of these interventions was to reduce the velocity of rainwater runoff and thereby maximize the opportunity for recharge to the aquifer. Low-cost gabion structures have been constructed using a cascade approach so that rainwater coming from the catchment area is harvested and no runoff water should leave the hydrological system (photos 1 and 2). Rehabilitation works were carried out to minimize water losses and to increase the conveyance efficiency of the channels.

The interventions started in October 2016, and by 2019, only 135 millimeters of rainfall was received with 11 complete dry months. Despite this measurement, a

PHOTO 1. Leaky Dam Constructed Upstream of the Karez (May 18, 2018)

Source: Faizan ul Hasan.

PHOTO 2. Check Dam and Ditches Constructed in Series (May 18, 2018)

Source: Faizan ul Hasan.

TABLE 4. Discharge Improvement in Nau Sanjidi Karez

Location	Before interventions (September 2016)	After interventions (October 2017)
Daylight point (lps)	4.48	4.8
Distribution point (lps)	2.7	3.1

Note: lps = liters per second.

noticeable increase has been observed in discharge at the daylight point of the Nau Sanjidi Karez (4.8 liters per second, a 10 percent increase) and at the distribution point (3.1 liters per second, a 38 percent increase) (table 4). One storage pond with capacity of 453 square meters is available at the distribution point. As reported by the community, it is now filled within 24 hours. Previously, it was filled in two to three days.

Total investment to rehabilitate (including introduction of recharge techniques and repair of the main Karez and channels) was about PKR25 million (US$25,000). The community also provided in-kind assistance to maintain the Karez and clean the storage water tank. With this small investment, free water is made available year-round to fulfill drinking water requirements of the community and its livestock, in addition to irrigating agricultural crops. However, some money must be spent for routine maintenance of the system, which may vary from PKR10,000 to PKR30,000 per year (US$100 to US$300 per year).

In contrast, there are seven tubewells for which the community must pay US$5,040 per year in electricity charges, in addition to repair and maintenance. The cost of drilling a tubewell for a depth of 150 meters and discharge of 7 liters per second is more than PKR1.0 million (US$10,000). Moreover, the government is bearing about PKR0.987 million (US$9,870) per year per tubewell (Ashraf and Sheikh 2017). The life of these tubewells is five to seven years, after which the farmers must sometimes redrill the tubewells to replace the pump/turbine or, in most cases, to deepen the tubewells. For effectiveness, Nau Sanjidi Karez is compared with an electric-driven tubewell. The total volume of water from the Karez is 415 cubic meters per day (that is, a discharge of 4.8 liters per second), whereas for the tubewell that is being operated 10 hours a day (with a discharge of 7 liters per second), the total volume of water collected would be 252 cubic meters per day. Therefore, a single tubewell provides a little more than half of the total volume of water provided by a Karez—but with large capital and operational costs. However, a Karez provides double this amount of water almost free of cost. Karez should be protected because they are masterpieces of engineering, part of the local cultural and social integrity, a buffer against drought, and the best hope for poor communities that cannot afford to continue to install tubewells.

Conclusions and Recommendations

Karez irrigation systems have been in place in Balochistan for many centuries, with about 3,000 believed to have been established throughout the province. These Karez systems provided enough irrigation and domestic water in the preindustrial era. However, rapid growth in population and improvements in socioeconomic conditions, along with the availability of new technologies, have led farmers to find alternate means to access groundwater, such as tubewells. The farmers started to grow crops on bigger areas of land than ever before. They also started growing high-water-use crops such as potatoes, onions, and apples, replacing wheat, barley, and maize, which require less water.

Although the Karez is a "poor man's technology," it reliably provides water for the community and its livestock free of cost around the clock and throughout the year. These systems act as a buffer and are resilient against droughts. Therefore, from the point of view of safeguarding the poorest households in rural Balochistan, they must be protected. One of the challenges is to develop a proper regulatory framework to control the placement of tubewells and enforce these rules effectively, given that subsidies provided by the government to operate tubewells have led to their proliferation and the corresponding neglect of Karez systems. The quantity and quality of water from these Karez can be improved by proper maintenance and watershed management activities in the catchment areas of the mother wells. These improvements can make the indigenous Karez system competitive with more energy and capital-intensive alternatives.

NOTES

1. Pakistan Council of Research in Water Resources, Islamabad, Pakistan.
2. US$1 @ PKR100 (Pakistani rupee) in 2017 (The State Bank of Pakistan, http://www.sbp.org.pk/ecodata/rates/war/2017/Months.asp)

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