Chapter 22

A Karez System's Dilemma: A Cultural Heritage on a Shelf or Still a Viable Technique for Water Resiliency in Arid Regions

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Abstract Karez system is considered as the global human heritage since it is not only a traditional water supply system of exploiting groundwater, but also it reflects the culture, socio-economy, and history of the ancient civilizations that had utilized them for thousands of years in arid and semi-arid regions of the world. However, with the explosive population growth and rapid development of pumping technology in the last century, the karezes dried up or were abandoned as pumping wells lower the groundwater table. This poses a dilemma to policy makers whether to facilitate large-scale utilization of pumping well technology over karez system and treat karez as a cultural heritage which is non-functional for food production, or to keep using and preserving the karez system as a sustainable way of groundwater management as part of the integrated water supply systems in the arid regions. In this paper, we reviewed the historical, socio-economic, and cultural importance of karezes in the arid regions. We also discussed the distribution of karezes in the world, their unique geographical characteristics, technological advantages and limitations. We observed that the karez system is not only economically robust over the long term, but also a viable water supply technique for irrigation and domestic uses. The karezes should be protected as indigenous human heritage, and at the same time, they can be utilized as a sustainable way of water resources management in the arid regions to enhance water resiliency under changing environment.

Keywords Karez system · Groundwater · Sustainable · Arid region
Cultural heritage · Viable technique · Pumping well

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L. E. Yang et al. (eds.), *Socio-Environmental Dynamics along the Historical Silk Road*,

https://doi.org/10.1007/978-3-030-00728-7_22

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22.1 Introduction

The ancient history of the world shows that civilizations centered near convenient sources of water. As humanity developed permanent settlements where they practiced agriculture and husbandry, a need for a reliable, permanent source of water became a necessity. As a result, in arid regions due to the scarcity of surface waters, people developed new systems to exploit groundwater. One of these systems is known as a “Karez”, and also called as “Qanat”, which has been used for several thousand years and is still being used as a main source of irrigation and domestic water supply in some arid regions of the world, particularly along the ancient silk road extent from Europe to China. A karez is a gently sloping underground tunnel that conveys groundwater using gravity to the land surface. Comparable to the vertical pumping well in our time now, the karez is essentially a horizontal well that extracts the groundwater by gravity, and therefore it is a sustainable way of management of groundwater resources. A typical karez system and its components are shown in Fig. 22.1.

A karez is constructed by digging a tunnel into a cliff or a base of the mountain for reaching a water-bearing formation. The tunnel is approximately horizontal with a slope to allow the groundwater to flow by gravity. The air shafts provide ventilation and access to the tunnel for construction and maintenance operations. A “mother well” is located at the high end of the karez which intersects at the groundwater level. The storage pond that is usually used to regulate the discharged water may not be included in all karezes. Figure 22.2 shows the distribution of vertical shafts, a closer look to a vertical shaft, the main tunnel, and a covered distribution canal for karez water for drinking purpose (the pictures were taken in Kageqak village, Tohsun County in Turpan Prefecture of Xinjiang, China). The length of the horizontal underground tunnels varies greatly, from 3 km up to 50 km. The size of the tunnel is between 0.5 to 0.8 m wide and 1.2 to 1.8 m high. The vertical shafts are located approximately 10–20 m apart in the lower reaches and 30–70 m apart in the upper reach for ventilation and maintenance of the karez. A storage pond (pool) located at

Fig. 22.1 Schematic view of a typical karez system (after Todd 1980)

Fig. 22.2 Vertical shafts, main tunnel, and covered canal of a karez system in Tohsun county, Turpan, Xinjiang, China

the end of the horizontal channel is used for storing water at night and may also be used for measuring and dividing water among different users (Sun et al. 2009).

Karez system is not only a way of extracting groundwater, but also represents the culture, history, and unique civilization of its builders in early times. The karez technology, from the construction process to management and maintenance and its adoption in agricultural production and ecological systems was based on the ingenious knowledge of people in the past that was supported by strong beliefs and traditions. Nearly 3000 years of its known history prove that the art of constructing, utilizing, maintenance of karez system was a tremendous success. Through the course of history, it has played invaluable role in the development of local society, ancient trading along the Silk Road, and more recently as the boomed tourist attraction in the karez irrigated areas that brings great social and economic benefits to the local community (Abudu et al. 2011, 2014). Karezes, by their very nature, have encouraged sustainable water use for many years since they can keep the underground water at a reasonable level and prevent depletion even in worst drought situations (English 1998). Karezes also prevent evaporation in arid regions and serve as drainage systems. Drainage through karezes has been beneficial and has prevented the rising of groundwater levels after intense precipitation. Karezes also play an important role in balancing the salinity of the water and protecting the downstream agricultural lands (Cenesta 2004). Throughout the history of humanity, karezes not only played an role in the formation of the cultural identity, but also remained as a major source, or the only source in some cases, of irrigation and domestic water supply in arid regions.

However, with the explosive population growth and rapid development of pumping technology in the last century, the karezes are facing rapid abandonment and disappearance due to the widespread utilization of pumping wells to meet the needs

of increased food production. This traditional water supply technique for irrigation and domestic water supply for human society that has proved viable for hundreds or even thousands of years are disappearing like endangered species. The main reasons for abandonment are, but not limited to, the introduction and widespread use of electric and diesel-pumping wells, agricultural expansion, growing demands of domestic and industrial water use, the difficulty of karez construction and maintenance operations (Beaumont 1989). Even though the current use of karezes is getting limited due to the improvements in technology that allows the use of pumping wells and high-power pumps, karezes are still being considered as one of the main ways of procuring water for irrigation and agricultural development in rural areas of countries along the Silk Road, such as Turkey, Syria, Jordan, Iran, Pakistan, Afghanistan, Uzbekistan, and China. With its known long history, the karez not only is a sustainable way of using groundwater, but also is a unique system illustrating the use of ingenious knowledge and wisdom in the sustainable management of land, water, and agricultural biodiversity (English 1998; Abudu et al. 2011; Manuel et al. 2017).

It is obvious that there are ongoing dilemma and arguments for policy makers and water managers on preserving karez system as cultural heritage which is non-functional for irrigation and domestic water supply, or continuing to use and preserve the karezes as a sustainable way of groundwater management in agricultural production as a portion of the integrated water supply systems in the arid regions. To illustrate the different perspectives, the authors reviewed the historical, socio-economic, and cultural importance of karezes in the arid regions. We summarized the distribution of karezes in the world, their unique geographical characteristics, inter-connections with the arid environment, contributions to agricultural biodiversity, and sustainability. The discussions throughout the paper were supported by the review of the literature regarding the karezes in worldwide, particularly in China. Some examples were illustrated based on the author's research and working experience in the Turpan Region, Xinjiang Uyghur Autonomous Region, China to support the perspectives that were sketched in the paper. Finally, some recommendations were proposed for proper utilization and preservation of karezes in the arid regions of the world.

22.2 Distrubution of Karezes and Geographical Characteristics

22.2.1 Distribution of Karezes in the World

Karez is a traditional irrigation system that built in the arid and semi-arid regions of the world. Many factors should be considered in constructing such a system, such as a climate, topography, hydrology, geology, and geographical characteristics of the regions (Abudu et al. 2011; Remini et al. 2014; Goes et al. 2017). Previous research on the distribution of karezes indicates that they can be found in over 30 countries in the world (Baboli and Labaf 2000; Motiee et al. 2006; Mostafaeipour 2010; Remini

Fig. 22.3 Distribution of karezes in the world. Reproduced from Mostafaeipour (2010)

and Kechad 2012; Rozi and Azizi 2016). The distribution of karezes by country is shown in Fig. 22.3 based on the literature (Mustafa and Usman 2007; Hussain et al. 2008; Wilkinson et al. 2012; Taghavi-Jeloudar et al. 2013; Remini and Kechad 2012; Abudu et al. 2014; Goes et al. 2017; Remini and Achour 2017). Their geographical extent has been documented from Western China to as far west as North Africa and Spain, and some parts of South America.

As can be seen from Fig. 22.3, three main regions were identified. They are (1) Silk Road regions, along the ancient Silk Road that connected Euro-Asian continent, spreading over the western region of China, Afghanistan, Pakistan, Iran, Iraq, Syria, Armenia, and Turkey. (2) Arabian Peninsula and Northern African Region, including countries such as Saudi Arabia, Oman, Yemen, United Arab Emirates, Egypt, Libya, Algeria, Morocco. (3) All other sporadic distributed arid and semi-arid regions, such as southern part of Spain and Mexico, and in Southern America Peru and Chile. The Arabs brought the karez (qanat) idea into Spain, and the Spanish brought it to the New World. Karez-like water-collecting tunnels are present in Los Angeles and elsewhere in Southern California. These countries are in the arid and semi-arid regions of the world, where characterized by an arid climate and limited surface water resources. Hence, the development of oasis-based societies in these regions is closely linked to the extraction of groundwater to meet agricultural and domestic water demands. This is the primary reason and motivation why karezes had been developed and utilized in this part of the world for thousands of years.

Based on the previous research and rehabilitation reports on the karezes (Baboli and Labaf 2000; Motiee et al. 2006; Abdin 2006; Mostafaeipour 2010), it was concluded that the highest number of karezes are built in the Silk Road countries. The largest numbers of karezes are in Iran, which has about 36,888 active systems with a total discharge of about 7 billion cubic meters of groundwater and account for 11% of annual aquifer discharge in the country (Estaji and Raith 2016). In the east end of Silk Road, there were over 1784 karezes with 5272 km underground channels in

Xinjiang, Western China based on 2003 survey data. Unfortunately, only 614 karezes are still flowing in 2003 at a total discharge of 9.58 cubic meters per second (or 302 million cubic meters per year), irrigating 11,500 ha of land (Wang et al. 2008). Many karezes are still being used in Afghanistan, Pakistan, and other countries along the ancient Silk Road (Hussain et al. 2008; Rozi and Azizi 2016). In the Arabian Peninsula and Northern African Region, there are still considerable karezes in use (Motiee et al. 2006). According to a report on the distribution of karezes in northern Africa (Mostafaeipour 2010), there are about 200 karezes that are still in use in the Tafilaft area of Morocco, about 600 karezes are in use in the Garamantes area near Jarma, Libya. The total length of karezes in Algeria is estimated to be thousands of kilometers. There are also many karezes that are still in use in the Arab world with about 4200 that are still operational out of 11,500 in sixteen Arab countries (Remini and Kechad 2012). The existence of sporadically distributed karezes in Mexico, Peru, Chile in southern America, in some European countries such as Spain, Cyprus is also documented in the literature (Motiee et al. 2006; Mostafaeipour 2010).

22.2.2 Geographical Characteristics and Features

Most of the karezes were constructed in semi-arid regions receiving less than 400 mm of annual precipitation. Lightfoot (1996) states that karezes are found in abundance in the regions that have a great discrepancy between precipitation and evapotranspiration (ET). For example, the Turpan Depression, Xinjiang, China, has a continental and extreme arid climate with average summer temperatures reaching 38 °C, has low annual precipitation (9–25 mm), well below the potential evaporation (about 3000 mm). Such climate conditions make the Turpan oasis an ideal place for developing karez irrigation system (Haakon and Shen 2006). Besides annual precipitation and ET, other factors must be considered for the existence of karezes in different areas such as topography, hydrology, geology, and the agricultural activity nearby. A typical karez system consists of a group of wells and a roughly horizontal tunnel intersecting with the wells located on a very gentle slope that enables drainage of groundwater by gravity. These gentle slope areas are mainly bounded by mountains and hills with mountain-front recharge zones to provide the water supply for the karez. Alluvial fans or synclinal rock structures at the base of mountains and hills form shallow aquifers that present favorable construction sites for karezes. Similarly, margins of large stream channels coming out of the mountains are the places along which shallow aquifers occur. These aquifers are the natural environments wherein karezes were developed. The combination of shallower aquifers with high transmissivity provides the best conditions for building karezes (Lightfoot 1996).

For example, the hydrologic setting in Turpan region presents a perfect example of such favorable conditions for karezes. In Turpan region, the surface water and groundwater are supplied from the glacier and snowmelts of northern and western Tianshan Mountains. As the rivers flow from the mountains, most of the water seeps into the Gobi Desert that has thick sediments of gross texture materials. At the

northern Gobi Desert, the depth of groundwater table declines from 100 to 150 m in piedmont to 20 to 30 m near the Flaming Mountain area. Except for certain gorges that water can pass through, the Flaming Mountain mainly acts as an obstruction for both the surface water and groundwater flows. After the flows leave the Flaming Mountain, part of the water recharges the shallow aquifer and becomes the water source for the karez in the south Flaming Mountain area. As there is a natural slope from the foothills at 900 m above sea level towards the deepest part of the Turpan Basin at 161 m below sea level, the topography of the area is favorable for this sophisticated irrigation system (Rozi and Azizi 2016). Thus, the unique combination of a desert climate, abundance of groundwater and suitable topographic conditions in the region provided ideal conditions for the development of the karez system in the Turpan Depression (Nuridin 2008).

Geology is another important factor for site selection of karezes. For example, in most of the steppe and desert regions of Jordan and Syria, deposits of silica such as quartz, chert, and flint often form impervious layers beneath the permeable calcium carbonate formations that are closer to the surface. In early ages, water-bearing strata were exploited to build karezes, by excavating most of the channels through solid beds of limestone or other calcium carbonate formations. In most of Syria, limestone and chalk aquifers are relatively shallow from a few meters to tens of meters deep, which represents favorable conditions for karez construction compared to the volcanic rock formations. Even though volcanic soils of the banks are better for agriculture than limestone soils, karezes were never dug through basalt zones due to the difficulty of excavating karezes through these stronger rock units (Lightfoot 1996). High tectonic activity zones do not provide favorable conditions for the karezes since the tunnels, and vertical shafts of karezes are not reinforced, they are susceptible to damage from natural events, such as earthquakes.

22.3 Historical, Cultural and Socio-economic Significance

22.3.1 *Historical and Cultural Significance*

Karezes had existed for several thousand years in the arid regions of the world. In some parts of the world, they had long become a way of life, a part of the cultural identity. They can be considered as a global heritage by their unique history, that reflects the social and cultural background of communities that relied on them for a living. Besides their cultural value, their contribution to water conservation and continuity of life in arid and semi-arid climates make this environmental-friendly method an important means of extracting groundwater. Many karezes can be used for several centuries through proper maintenance and operation. For example, the complicated karez system in the Xinjiang Uyghur Autonomous Region of China is considered as one of the three great construction projects in ancient China, along with the Great Wall and the Beijing-Hangzhou Grand Canal (Rozi and Azizi 2016). They are mainly

distributed in Turpan and Kumul districts in Xinjiang Uyghur Autonomous Region, where Turpan District is known as the location of large numbers of karez. The total length of these karezes would exceed 5000 km if they linked together. Hence, the system has also been called “the underground Great Wall” (Abudu et al. 2011).

In the past, the social arrangement in karez-based communities had been directly related to the karez system (Bonine 1989). The importance and value of people were judged according to their ownership rights to the amount of water from the karez, which also created a social hierarchy among them. The household location used to be a good indicator of the social or economic status of its residents. For example, in Iran, the residents of more eminent households of landlords, merchants, and religious leaders were in the upper section of the karez-based settlement areas where the water is clean and plentiful (Bonine 1989; English 1998). In karez-based communities, water rights and distribution of water were directly related to rules of ownership. Since each region had its unique ownership and management rules, the water rights and distribution schemes varied from one place to another in the past. However, the common tendency of communities was to use karez water cautiously, that helped this traditional system last hundreds of years without harming the ecological balance. The simple, yet effective, water distribution system was dependent on the share owned by each farmer. In other words, the amount of water was determined by the land rights that the landowner owned. The rule was that each landowner or farmer could only cultivate the area of land that he was able to irrigate with his share of water. This rule had brought a balance between water rights and the area to be cultivated. Once the water rights were fairly addressed, the descendants of the owners could divide their land in agreement according to inheritance laws. Emigrated people lost their rights to irrigation water unless they returned and claimed them back. This rule did not apply if the land was sold to somebody else (Wessels and Hoogeveen 2002).

Karezes have created strong cohesion among people owing to the traditions and beliefs attached to them (Goes et al. 2017). Religious beliefs and cultural traditions also helped the karezes to be protected and handed down from the past as a legacy. For instance, karezes were given genders depending on their nature. Ceremonies that resemble actual wedding events were performed between subtle, gentle karezes (female) and gushed, spurting karezes (male) as a ritual. These ceremonies usually took place when there is a dried up “mother well.” Some of the rituals are still being followed to some degree in the rural settlements and villages of Iran (Cenesta 2004). In Turpan region of China, the local people see karezes as the part of their history and cultural identity. The local people treat the karez builders as local heroes, braving the desert and bringing life to a village (Nuridin 2008). The difficulty in construction, the clean water and eco-friendly feature of karezes are the main topic for local Uyghur songs and other cultural celebrations in the local community (Nuridin 2014).

22.3.2 Socio-economic Importance

Karezes not only had a deep root in the life of people and were a strong part of cultural identity but also were an important part of the continuous development of the local economy and agricultural production. According to a report by the Cenesta (2004), about nine billion cubic meters of karez water is still being used for agricultural production in Iran. Hence, the restoration and maintenance of karezes can be a very effective strategy in food production there. Karezes remain one of the main sources of irrigation water in the Turpan region of western China. Despite a large decrease in the number of karezes used in the Turpan region, karezes are still contributing to the irrigation of more than 30% of agricultural land. More than 50,000 households and 100,000 livestock benefit from the karez system as a drinking water source (Nuridin 2008). Without the karez system, the landscape in the region would be desert (Haakon and Shen 2006; Sun et al. 2009).

Thousands of karezes were built by governments, local investors, even farmers in the arid regions throughout history, and they are diffused into every corner of many arid regions that are suitable for karez construction. However, with the introduction of well technology, construction of new karezes seems impossible due to the time, intensive and skillful labors, and cost of construction. Compared to the cost of pumping well drilling, the expenditure for the construction of a karez may be 8–9 times more than that of a well (Cenesta 2004). However, considering the lifespan of both, karezes are more economical since their service life can be more than ten times that of a well through proper maintenance. According to the cost and benefit comparison reported by the Cenesta (2004), the level of income of a farmer from a karez is 30% more than that from a well, and it has been shown that a karez is more economical in the long-term for agricultural and environmental purposes. Karezes have other economic advantages besides their use in irrigation and as a source for domestic water use. Due to their historical and cultural value, karezes can be a good attraction for tourists when combined with other cultural aspects that are unique to specific regions. For example, karezes are one of the most important tourist spots in the Turpan region of China with an annual contribution of 20 million Yuan (about 2.5 million U.S. dollars) to the local economy (Nuridin 2014; Pei et al. 2008).

22.4 Advantages and Limitations of the Karez Technology

22.4.1 Karez System Ensures Diversified Ecosystems

The main function of a karez system is to provide irrigation water for agriculture. A cultivation system in karez-irrigated agriculture is based on the principle of making the best use of limited water. To prevent karez water from being wasted, a collective system of cultivation needs to be followed by the farmers. The selected crops need to be diverse and complement each other in terms of water requirements. In addi-

tion, the seasonality of crops helps make maximum use of available water resources throughout the year and thus sustains the livelihood of farmers all year long. Hence, a sustainable cultivation system is practiced under karez-irrigated agriculture, that considers the crop types and seasonality to achieve multiple purposes of water saving, as well as improving soil texture and quality (Cenesta 2004). In this way, karez-irrigated areas have formed their unique collective system of agricultural management.

The diversity of crops is one of the main features of the karez-based agricultural system in arid areas. Karezes are not only used for the irrigation of agricultural crops but also used for large numbers of orchards and community and private gardens. The idea of making good use of karez water has resulted in a wide diversity of crop types. For example, in the Iranian plateau, the traditional orchards have always been dependent on karezes, especially those that were closer to karezes or nearer to villages (Cenesta 2004). The villagers use the karez water to irrigate a community garden to grow crops such as onions, cucumbers, tomatoes, and other vegetables. The garden also contains fruit trees such as mulberry, fig, and pomegranate. These perennial crops depend on the reliable supply of the karez for sustainable production. Moreover, they grow irrigated barley to provide feed for their sheep. Besides the irrigation of the garden, the karez water was also used to irrigate small-scale private plots for growing vegetables and herbs (Wessels and Hoogeveen 2002).

Karezes have provided a refuge for freshwater fishes for thousands of years in Iran. The good karez water quality and hydraulic features of the karez waters are influential in sustaining the diversity of the aquatic life. Since it is a covered system, water in a karez has a temperature that is not subject to extreme changes, unlike the surface waters. Also, shade within the karez provides protection against predation on adults, young and egg stages of freshwater fish species (Coad 2017). In the Golestan National Park in Iran, the karezes provide water to wildlife. This park is a living museum incorporating various plants and animals including diverse mammals, birds, reptiles, amphibious and aquatic species. Due to its favorable conditions, the park has been registered as an important world wildlife habitat by international organizations. Besides the natural waterfalls and springs in the park, the Mirza Bayloo karez provides significant amount of water to wildlife and the green landscape of the Museum of Wildlife in the park's territory (Coad 2017).

The karez system has created favorable growing conditions for a variety of species, including high value crops, fruits, and trees and other plants in an area where is supposed to be Gobi Desert, barren or very sparsely vegetated. Under karez water supply, the agricultural production and ecosystems and their coexistence are still well maintained in some well-preserved karez-irrigated areas in the Turpan Oasis of China. The key to crop diversity in the region is attributed to the traditional knowledge of the karez system management, which links irrigation water distribution to agricultural management, ensuring continuous biodiversity conservation and management according to indigenous knowledge of local people in food production throughout the history. The karez system becomes an important part of the ecosystem in the oasis. Karez itself is a unique ecosystem, which not only provides water for native vegetation in the oasis, but also plays an important role for the survival of wild lives

by providing habitats through underground tunnels, shafts, and pools (Zhao et al. 2009).

22.4.2 Karez System Maintains Good Water Quality

Karezes have usually been the main source of good quality domestic water supply for the people, livestock, and wildlife in karez-based communities. There is a close relationship between the quality of karez water and the topography of the region. The groundwater available farther from the mountains is more likely to be poorer in quality due to varying recharge zones or probable point and non-point source contamination. Closer to the mountains, the quality of groundwater is better as its quantity. It is known that the excess sedimentation and silting are the main threats to the sustainability of a karez unless the maintenance is performed periodically to clean up the tunnels from the sediment accumulated by the falling material through the air shafts. Since karez water travels a long distance under the ground very slowly, silt and clay particles tend to settle along the tunnel before the water reaches to the storage pool, which makes the karez water free from suspended particles and better for drinking.

It is not possible to prevent sedimentation and to silt completely along the main tunnel. Hence, maintenance and cleaning operations are vital and must be performed on a regular basis to keep karezes viable. Haeri (2003) states that the recharge through karezes keeps the salinity level of the soil under control since the fresh water is transferred from mountain plateaus to the lower plains that have saltier soils. A study performed by Cenesta (2004) reported that the karez water has positive effects on crop quality. The experience in Iran showed that crops irrigated with karez water were usually of better quality than crops irrigated with local groundwater. In Turpan region, karez water is also used as a drinking water supply due to its high quality. According to Nuridin (2014), all the karez water in the region meets requirements of China Sanitary Standard for Drinking Water (People's Republic of China National Standard 1985). Table 22.1 shows water quality parameters of a typical karez (Mehim Haji Karez) in Turpan sampled on June 27, 2006. As indicated in Table 22.1, most the measured water quality parameters were significantly below the maximum allowable limits or were in the desirable range.

22.4.3 Limitations

As illustrated in the previous sections, the karezes have many advantages such as energy efficient, less evaporation, eco-friendly, and have strong historical, cultural, and other social values. However, as with any other water management system, the karez system has its disadvantages, notably the challenge to make it an efficient and effective alternative in a modern society that increasingly overwhelmed by new

Table 22.1 Measured water quality parameters in Mehim Haji Karez in Turpan, China

Parameters	Units	Measured values	Desirable range/maximum values
Color	Hazen units	0	5
Odor	–	No odor	Unobjectionable
Taste	–	No taste	Agreeable
Turbidity	NTU	<3	5
pH value	–	8.0	6.5–8.5
Total hardness (as CaCO ₃)	mg/l	91.9	300
Iron	mg/l	<0.03	0.3
Chlorides	mg/l	12.5	250
Dissolved solids	mg/l	204	500
Copper	mg/l	<0.01	0.05
Manganese	mg/l	0.02	0.1
Sulphate	mg/l	44.4	200
Nitrate	mg/l	20	50
Fluoride	mg/l	0.22	1.0
Mercury	mg/l	0.0001	0.001
Cadmium	mg/l	0.01	0.01
Arsenic	mg/l	0.007	0.05
Cyanide	mg/l	<0.004	0.05
Lead	mg/l	0.01	0.05
Zinc	mg/l	<0.04	5
Chromium	mg/l	0.004	0.05

Reprinted from Nuridin (2008)

technologies and rocketed population growth (Khan et al. 2015). Karezes are usually unable to provide enough water for large-scale agricultural and human consumption (Qureshi 2002). This limits the capacity of the karezes to be only alternative and limited water supply for extensive agriculture. In addition, the karez system requires continuous cleaning to prevent silting and collapse. Its maintenance is thus a labor-intensive activity, which can be both difficult and dangerous (Hussain et al. 2008). Karezes require maintenance every year to keep karezes perform well. Karez excavation and maintenance are a hard-low-income job; sometimes there is a risk of life loss for the excavation and maintenance workers. This is one of the main factors that result in karez disappearance in the modern society.

The introduction of modern construction technologies in karez construction and maintenance is still a challenging issue. Although the modern technologies and developments can be utilized in karez maintenance operations up to some extent for safety, it may still be limited to the larger karezes rather than very small communities relying on karez water due to some financial and traditional concerns. Some socio-economic

factors are also less favorable for the utilization of karezes in modern society. For example, the urbanization process has accelerated, new generations prefer to work in the urban environment and have lost interest in traditional karez-based farming. Many karezes have been left without maintenance for a long time, and as a result, they have collapsed, malfunctioned, or eventually been abandoned as the flow rates decreased, and eventually, they have been abandoned. With the abandonment of karezes, the indigenous knowledge and community cooperation critical for karez preservation have also irreversibly disappeared, and more karezes have collapsed or dried up. This vicious cycle has been revolved very fast in the last decades with the widespread application of modern deep well technology in the karez-irrigated regions of the world. As a result, karezes that flourished for thousands of years have been disappearing at an alarming rate worldwide.

22.5 Dilemma—Cultural Relics or Viable Technology?

22.5.1 *Karez System Versus Pumping Wells*

The primary difference between the karez system and pumping well is the means of extracting groundwater. As we discussed earlier, the karez system does not require external energy to extract groundwater, the rate of flow of water in a karez is controlled by the level of the water table. The extraction of groundwater flow is restricted naturally, limits the human intervention on the groundwater exploitation, which ensures its sustainability and renewable resource. Pumping well, on the other hand, requires external energy to extract groundwater, it may extract groundwater based on demand regardless of recharge rate of the aquifer, and enables maximum intervention of human impacts if there are no strict and effective policy or law enforcement, that can lead to unsustainable groundwater resources due to overexploitation. In addition, to be sustainable-friendly, the karez system is energy-efficient as compared to pumping wells. As a karez uses the force of gravity for groundwater extraction, there is virtually no need for electric power, diesel, pump spare-parts or oil products for lubrication leading to cost recovery and significant energy savings. When compared with diesel motor-equipped pumping wells, karezes also contribute to the reduction of greenhouses gases emissions (Nasiri and Mafakheri 2015). Properly maintained karezes could have a significantly longer lifespan than modern pumps/wells. Pumps and wells have a lifespan of about 20 years while karezes have been known to function for centuries (Qureshi 2002).

The advantages and drawbacks of both karezes and pumping wells are a relative concept. Sometimes limitations can be advantageous depending on the problem. English (1998) stated that the self-limiting features of karezes that make them a sustainable technology could, however, be their biggest drawback, particularly when they are compared with the range of deep well technologies available today. Hence, in the areas where karezes still exist, the coexistence of karezes and pumping wells is

a challenging and complex issue. In some areas, pumping wells can also be utilized with no interference with karez; but in some areas, pumping wells destroy karezes. From the sustainability management point of view, the karez system has superiority over pumping wells that can naturally ensure the sustainability of the groundwater utilization. The ability of pumping wells to withdraw water more than an aquifer's recharge rate makes this modern technology very attractive for the short term. As a result, however, groundwater is becoming a non-renewable resource in areas where pumping wells are used due to lack of strictly sustainable management strategies or policies/regulations are not in place. From the point of meeting growing water demands, karezes may be considered as an insufficient source of water. In arid regions, increasing water demands resulted from the rapid population growth and agricultural expansion needs cannot be fulfilled by karezes anymore (English 1998). The pumping wells may facilitate the growing water demands of the population but may not be in a sustainable way. The pumping wells must be employed by establishing restricted extraction policies and regulations to sustain groundwater uses.

22.5.2 *The Dilemma*

These disadvantages of karez system, particularly the incapable of meeting the needs of the fastest growing population nowadays, resulted in the replacement of this ancient technology by the more productive pumping well technology for agricultural production and domestic needs. However, the pumping well technology has been used for about a half century. Although the use of well technology for groundwater exploitation has made a substantial contribution to the food production in arid regions over the decades, the rapid development of pumping wells has led to the overexploitation of groundwater resources and associated water quality problems. Eventually, the overexploitation of groundwater may pose a major threat to the environment, health, and food security. However, in the modern society, with the increased population and economic globalization, the farmers tend to shift to cash crops and of large-scale agricultural production, which, in fact, inhibit the use of limited karez water and consequently contributes the abandonment of the karezes. Therefore, governments and other investors in the karez-irrigated areas have abandoned these traditional, sustainable but less productive systems in favor of modern, more productive pumping well systems that contribute rapid and irreversible draw-downs in groundwater reservoirs (Beaumont 1989; English 1998).

In some regions of the world, policy maker and water managers no longer perceive karezes as the water management techniques/tools but rather treat them as a cultural heritage that is a non-functional system for water supply, and in turn, use them as a tourist destination and historical and cultural research sites. For example, in the Turpan region of China, the part of the management of karez system has been assigned to Bureau of Cultural Relics at different governmental levels instead of keeping the karez system management in the Water Resources Management Bureau. Similar trends are observed in the other regions of the world where karezes exist, such

as in Iran. This is an example of the indication of seeing karezes as a cultural relic as opposed to treating them as a functional water supply system that can contribute to the food production and domestic water supply for humans and livestock. This is the foremost dilemma for the policy makers in the karez irrigated area to preserve karezes as cultural heritage which is non-functional for irrigation and domestic water supply, or to keep using and preserving the karezes as a sustainable way of groundwater management in agricultural production as a portion of the integrated water supply systems in the arid regions.

22.5.3 *Recommendations*

From the sustainability perspective, many researchers argued that karezes should not only be considered as an indigenous human heritage but also, they are contributing to sustainable management of groundwater (Abdin 2006; Nasiri and Mafakheri 2015; Manuel et al. 2017). In most cases, the karez system is not only a hydraulic engineering structure to extract groundwater for both domestic uses and agricultural production, but also an integration of the history, culture, and unique knowledge of its builders (Cui et al. 2012). Even though the increasing number of pumping wells have resulted in permanent depletion of aquifers in some areas, the karezes can still be viable alternative means of water supply for irrigation and domestic water use in the arid and semi-arid regions. Some researchers (Nasiri and Mafakheri 2015; Abudu et al. 2011) advocate that karezes should still be used for irrigation in arid regions, as it may further improve the performance of this water supply system in its long and low maintenance service life in combination with the modern technology and tool for construction, maintenance, and management.

At present, the overexploitation of groundwater is becoming a global issue that poses a major threat to the environment, water quality, food security, and sustainable development. We believe that proper utilization of karezes as a part of integrated water supply systems in the arid regions where the karezes exist can be one of the most efficient ways to ensure sustainable exploitation of the groundwater and enhance the resiliency of water supply under changing environment such as climate change, frequent drought, land use change and increasingly water demand by rapid population growth. The government and local communities should join efforts to preserve and restore this ancient water supply system. There are successful stories in China's Turpan region and other parts of the world, such as Syria, Iran and Oman about rehabilitation of karezes through the local people participation in the state-led preservation and development programs where customary norms and values present within local water culture can coexist with laws and policies promoted by the government (Wessels 2008; Hussain et al. 2008; Abudu et al. 2011; Nuridin 2014; Middle East Institute 2014; Rozi and Azizi 2016). These success stories of the restoration of karezes should be shared among researchers, engineers, water managers in karez-irrigated regions of the world through various media platforms to develop confidence in the continued utilization of karezes and to raise the awareness of policy makers

seeing karez as a viable tool in securing sustainable food production and harmonic community development.

We recommend following measures and strategies in addressing the dilemma between the preservation as cultural relics and development as a sustainable water use technique: (1) Raise the awareness and knowledge of the policy makers and water managers in utilizing the integrated water resources management approach and tools by accepting the concepts of conservation, sustainability, environmental responsibility, and most importantly preserving cultural identity of local people that attached to the karez for thousands of years. (2) Encourage and convince them that karez system restoration is not only economically feasible but also environmentally sustainable. Previous and ongoing research and engineering projects concluded that karez system restoration may increase the quantity and improve the quality of the karez water. In addition, it can help developing eco-tourism, provide income for the local community and most importantly can contribute to social cohesion and unity among its users. (3) To integrate the karez irrigation system in the holistic water resources management approach in the arid and semi-arid region with karez tradition, following measures can be recommended for the policy makers and water managers: First, combining karez with modern irrigation techniques would be beneficial in terms of meeting the growing water demands and would also extend the life of karez. Second, due to their historical and cultural values, encouraging karez tourism in some karez regions would provide alternative income for the locals and governments. Finally, the establishment of comprehensive local databases on karez usage and maintenance of those databases by local governments would help improve understanding of these systems and keep them as a reliable source of water for irrigation and household use in arid regions.

22.6 Conclusions

Karez system is the traditional approach of exploiting groundwater, that also reflects the culture and history of the ancient civilizations that had utilized them for thousands of years. They have provided water for domestic consumption and agriculture and maintained a unique oasis ecosystem in the desert. They can enhance social and cultural diversity and may be considered as a global heritage. The advantages of karez such as their ability to prevent evaporation losses, good water quality, and availability of water all year long make them attractive for the small communities in rural areas. They are also environmentally friendly systems that are still being utilized for irrigation and domestic water supply in many arid and semi-arid regions of the world. However, with the rapid population growth and changing environment, in the regions with karez tradition, pumping wells have been widely preferred on the last century for uncontrolled, unsustainable extraction of groundwater resources over the more sustainable karez water supply system. Protection and preservation of existing karez was, in general, never a consideration in formulating groundwater use plans, laws, and regulations. As a result, karez have been abandoned and been disap-

pearing rapidly within the past few decades. The overexploitation of groundwater, the introduction of pumping well technologies due to increasing demands and natural disasters are among the factors that accelerate the abandonment of the karezes. Furthermore, socio-economic changes in the communities significantly affect the construction, maintenance and eventually existence of karezes.

There is a dilemma for the policy makers in the karez irrigated arid and semi-arid regions on whether preserving karezes as cultural heritage which is non-functional for irrigation and supply, or continuing to use and preserve the karezes as a sustainable way of groundwater management in agricultural production as a portion of the integrated water supply systems in the arid regions. In that sense, we reviewed the distribution, geographical characteristics, historical, cultural, and socio-economic importance of karezes in the arid regions of the world. The successful karez restoration projects and efforts around the world provided us insights and confidence in preserving karezes as a practical water supply system to continue to serve for food production and community development in karez-irrigated regions. Increasing the awareness of policy makers is very important in reinvigorating karezes and their continued operation in the local community. The karezes should be protected as a great human heritage, and at the same time should be utilized as viable technology and tools that combine the concepts of conservation, sustainability, environmental responsibility, and most importantly preserving the cultural identity of local people that attached to the karezes for thousands of years. They can be incorporated as an inseparable component of the integrated water resources management approach in the karez-irrigated arid regions to enhance water resiliency under climate change, frequent drought, land use change and rapid population growth.

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