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Sustainable Irrigation: Karez System in Afghanistan

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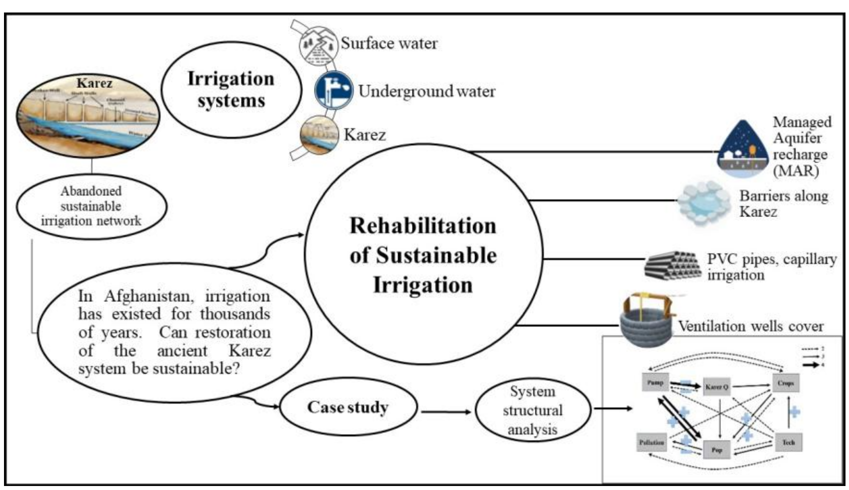
Abstract
In Afghanistan, water is mostly used for agricultural purposes. The water supply chain requires updating to ensure its sustainability. Different irrigation methods – such as surface water based irrigation (via canals), groundwater based irrigation, and the Karez irrigation system – are applied across the country. Considering the compatibility of the Karez system with the environment, it can be deemed the most effective irrigation scheme, as it allows collecting a significant amount of groundwater and conveying it to land surface via sub-horizontal tunnels using gravity. This article analyzes Afghanistan's Karez irrigation systems currently feeding water to over 170,000 ha of farmland with a potential to expand and become a component of sustainable water supply chain.

Keywords: Afghanistan, irrigation system, karez, sustainable water supply, agriculture.

Graphical abstract



1. Introduction

Geographically, Afghanistan is located in a semi-arid zone, in the arid belt of sub-Saharan and continental climate, resembling the climatic zones between 20° latitude and 35° longitude (CSO, 2014). A significant share of its 30+ mln population resides in rural areas and sustains itself thanks to agriculture. Afghanistan is a mountainous country with the highest number of mountains located in its central and northern parts, and some peaks reaching 7,500 meters (Qureshi, 2002). The mountains – including the Wakhan, Hindu Kush and Baba – are snow-covered and serve as a good water source. The Hindu Kush Mountain Range is one of the largest sources of meltwater in the country. The snow naturally accumulating during winter feeds hundreds of perennial and ephemeral rivers. Afghanistan has 75 bln m^3 (BCM) of potential water resources, including 55 BCM of surface and 20 BCM of groundwater (FAO, 1996). The lion's share of the national territory is characterized by arid and semi-arid climate with hot summers and cold winters (Broshears et al., 2005), with precipitation ranging between 50 and 1,000 mm and averaging 300 mm annually (Tünnermeier et al., 2005). Water manifests a critical resource for work and survival, as well as a technical – more specifically, with respect to its efficient harvesting and transportation – challenge. As in other dry and landlocked regions, Afghanistan's water supply is limited to modest precipitation and snow-melt in nearby mountains recharging surface and ground water reserves.

Snow and glacier melting during summer feed important rivers like the Amu Darya. The Amu Darya Basin alone holds over 55% of Afghanistan's water assets. Unfortunately, droughts and rising air temperatures have been reducing the size of glaciers on the territory of Afghanistan. Thus, the major glaciers in the Pamir and Hindu Kush have considerably retreated, while the smaller ones were reported to have vanished completely. The severe drought in 2001 prevented the feeding of the Sistan Wetlands via the Helmand River and, based on satellite imagery, by 2003 99% of their territory dried up. As the result, much of the Sistan Basin's natural vegetation died fostering accelerated soil erosion and sanding up of roads, farmland and settlements. The local waterfowl was likewise severely affected – based on the estimations of the mid-1970s, up to 150 different aquatic bird species had lived in the wetlands, with only few to none remaining today (Qazi, 2008).

In view of the challenges mentioned above, water represents an essential survival asset for the present generation and the most significant factor of agricultural sustainability (Favre, 2004). Water constraints and the ongoing population growth put additional pressure on agriculture, thus, it is high time to forge a fundamental targeted solution. It is necessary to focus on strategies and more efficient methods of water preservation and farm use. Their deployment will undoubtedly allow the country to advance economically and ensure water self-sufficiency of its agricultural sector. This technical paper reviews the irrigation systems currently operating in Afghanistan.

2. Methodology

The research included collection and analysis of data on existing irrigation schemes nationwide. Agricultural water demand analysis focused on different types of farmland and irrigation systems, including surface irrigation (canals) and underground irrigation with the emphasis on the *Karez* system, followed by subsequent system structural analysis to evaluate the importance and situation of the system as a case study example in the area.

3. Water demand in agriculture

The history of agricultural irrigation in Afghanistan goes back 5,000 years and is evidenced by the archeological excavations of an ancient settlement in Kandahar Province (ICARDA, 2002). Domestic economy is agriculture-based, and the majority of the population (80%) are engaged in farming and livestock husbandry, i.e. their livelihoods directly depend on water. In Afghanistan, over 95% of available water is used in agriculture (Anderson, 1993). Crop cultivation in the country is based on rainfed and irrigation schemes. Active farming is concentrated in the southwestern, western and northern parts of the central highlands and mountains. Irrigated and rainfed farmland distribution corresponds to the major river basins and types of water resources (see Table I). Thus, due to water abundance and favorable climate, it is possible to collect three harvests a year in Jalalabad and Laghman Provinces. In the western and northern parts of Kunduz-Badghiz Province, there are about 1 mln ha of potentially productive farmland along the Amu Darya and Murgab Rivers, yet this land remains underdeveloped and unproductive due to poor water technologies. Of the 75 bln m^3 of water available in Afghanistan every year (see Table II), it uses only approximately 20 bln m^3 (or 25%) with the remaining 75% going to neighboring countries. Simultaneously, farming is facing substantial water losses during transportation and due to multiple other challenges. Recently, water demand in the country has been growing because of water scarcity and water infrastructure damage in the course of the three decades of political unrest and civil war. Afghanistan also faces an array of environmental challenges making water a laborious and multifaceted problem.

Table I. Agricultural land by river basins (thou ha) (World Bank, 2004).

Type of land	Amu Darya Basin	Kabul Basin	Helmand Basin	Total
Active irrigated land	1,155	450	1,079	**2,681**
Inactive irrigated land	211	99	410	**720**
Rainfed farmland	2,428	9	197	**2,634**

Table II. Estimated surface and ground water resources (BCM/year) (FAO, 1996).

Type of water resources	Entire potential	Presently		Potentially	
		Used	Unused	Future use	Unused
Surface water	57	17	40	30	27
Ground water	18	3	15	5	13
Total	**75**	**20**	**55**	**35**	**40**

4. Water irrigation schemes in Afghanistan

Irrigation represents one of the oldest human activities primarily aimed at boosting agricultural production. In case of insufficient rainfall, a man-made irrigation system allows distributing water to penetrate soil for plant growth and crop production. Irrigation methods can be conditionally grouped into two main categories – surface- and groundwater-based – with the main difference between them being the type of force applied to distribute water. In the former case, water arrives at a farm by the force of gravity, hence its second name "gravity irrigation". In the latter case, pumps and pipes are used to transport water.

It is possible to divide all water irrigation systems currently operating in Afghanistan – surface water transportation (canals), underground water irrigation, and karez irrigation – into informal and formal providing 90% and 10% of irrigation, respectively (Rout, 2008). Considering the importance of irrigation to the sustainability of livelihoods, especially in rural communities, more efforts are needed to improve on-farm water management. The majority of farmers lack the actual knowledge on crop water requirements and schedule their watering efforts based on the visual assessment of soil surface dryness/moistness and the time after the previous water application. Flood irrigation is widely practiced leading to water wastage at the expense of farmers located farther away from water sources (ICARDA, 2002). Thus, it is critical to systemically evaluate various irrigation methods.

4.1. Surface water irrigation

Canal-type installations are commonly used in surface water schemes. They were designed based on traditional knowledge and experience, and were built using readily accessible and inexpensive materials. Canal is a water channel or an artificial waterway used for water conveyance and/or to service water vehicles and, thus, can be considered an artificial river.

In Afghanistan, about 85% of crops are irrigated. Canal irrigation is the most common method of water transportation supplying water to 75% or 1.9 mln ha of land. The majority of canal-irrigated land is located in the north, west, and southwest of the country (MAIL, 2002). The canals primarily get water from snowmelt rivers via small diversion (intake) points –

open or gate-fitted – along river beds. The overall efficiency of such irrigation systems, including traditional and modern schemes, averages 25-30% (Rout, 2008).

4.2. Constraints and potential improvements of canal systems

4.2.1 Constraints

- "Farmers lack knowledge on crop water requirements;
- Substantial seepage losses through earthen canals in traditional schemes;
- On-farm distribution losses (over irrigated and poorly leveled land) in modern and traditional schemes;
- Lack of control of high water flow and limited durability of construction materials;
- Restrictions due to inadequate financing, limited technical expertise and support, poor organization, and non-transparent electoral process;
- Significant need for equipment maintenance for de-silting diverged water;
- Inflexibility in allocation of water when faced with land use changes" (Rout, 2008).

4.2.2 Potential improvements

- "More controls, such as adjusting input to optimize and protect water distribution and control gates, drops and checks more effectively;
- Design canals to make water distribution more efficient and transport sediment in order to reduce scouring and sedimentation;
- Review existing practices and upgrade stakeholder skills toward better water allocation and improved financial sustainability and management" (Rout, 2008).

5. Underground water irrigation

In addition, the ongoing and projected climate change adversely affects irrigation systems. Reduced snowmelt and shrinking glaciers alter the size and dynamics of water flow in rivers and streams. As a result, during critical periods of the vegetation season water availability can be insufficient, and diversion and intake installations can become dysfunctional and/or damaged by infrequent floods. Canals and other irrigation installations likewise suffer from landslides, erosion and siltation getting more severe as a result of changing precipitation patterns, accelerated melting of snow and glaciers and vegetation degradation. All these make pumped groundwater irrigation an appropriate method.

"The total number of shallow wells in Afghanistan is 8,595 irrigating around 12,000 ha (1% of the total farmland). Individual farmer plots (not exceeding 3 ha) get groundwater which is lifted from large-diameter deep and shallow wells by pumping, specifically via animal-powered wheel (*arhad*) systems. In recent years, however, the use of modern well-drilling and pumping technologies has become widespread considerably increasing the number of wells and their capacity, yet simultaneously causing large scale groundwater depletion in some areas" (ADB, 2015).

The development of groundwater systems for irrigation and other uses is necessary and precautions must be taken to avoid adversely affecting the users of existing irrigation systems.

6. Karez irrigation

Karez is one of the most effective systems deserving further development. Karez is a traditional water management mechanism used throughout Afghanistan. Its conceptual diagram is presented in Figure 1. As a rule, a karez represents a large underground water tunnel exhibiting excellent craftsmanship, as well as an extraordinary cultural technical achievement balancing out the environment, economics and gravity. The scheme dates back several millennia. For centuries, peasants have been digging and protecting karezes across the country. Thus, karez is an economical method of using underground water not only for irrigation but also for human and livestock consumption. It also allows creating green areas and beautiful meadows.

9,370 karezes are operating in 19 Afghanistan's provinces with the majority of them concentrated on the eastern, southern and western flanks of the Hindu Kush Mountains. Geographically, this type of irrigation is more widespread in the southwest and south with fewer karezes in the north (Macpherson et al., 2015). Karezes provide sustained perennial flow and high-quality water, as well as demonstrate relative immunity to natural disasters and human war-related destruction. Karezes are usually operated by local communities, traditionally under a *karezkan* specialist responsible for the construction and maintenance of the subsurface section; and a *mirab* (water master) overseeing surface distribution operations. According to the 1978 report by the Ministry of Rural Rehabilitation and Development (MRRD), 168,000 ha or 8% of farmland were irrigated via 6,741 karezes; about 3,406 karezes (36%) had dried up; and the flow of the karezes still in operation had reduced by as much as 83% since the onset of the multi-year drought in 1998. A typical karez is 1-2 km long with cross-sections of 1-2m^2 and gradients of 1m km^{-1}. An average karez can irrigate 22 ha of land, however most of them supply water to 10-200+ ha (Anderson, 1993).

Karez's efficiency is impacted by climate change, low precipitation in the last two decades, improper use of groundwater (especially through deep wells and water pumps), irregular and poor maintenance, overcrowding, war, insecurity, etc. (Macpherson, 2015). Many karezes are drying up, thus to preserve this cultural heritage and one of the most valuable water supply models it is necessary to rehabilitate them as a vital and invaluable mechanism for addressing water scarcity and irrigation challenges in Afghanistan.

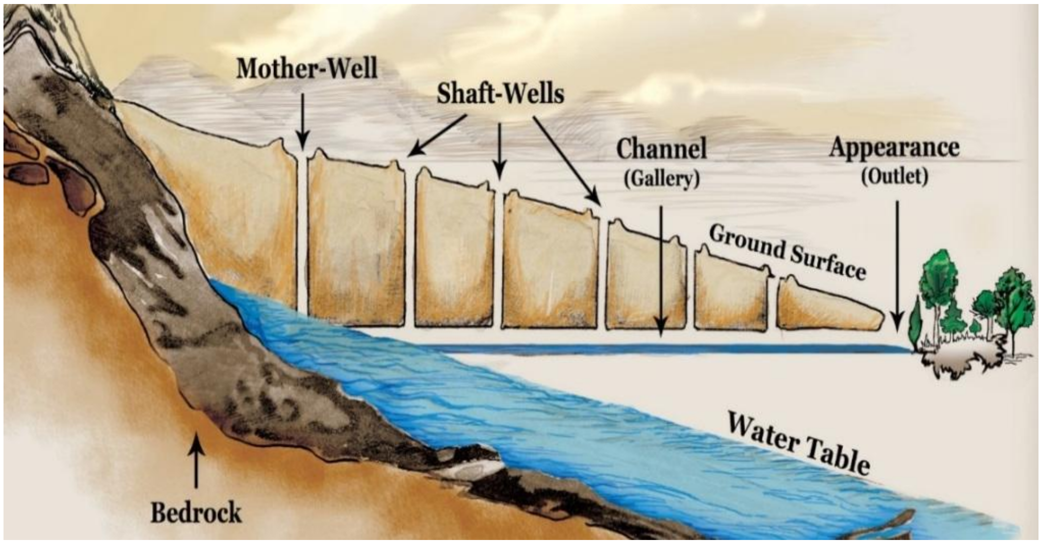


Figure 1. Karez conceptual diagram (Stanikzai, personal collection, 2020).

6.1. Reviving karezes

The reasons explaining why reviving karez systems is essential include the following:

- Karez networks already cover 8% of Afghanistan's total irrigated land;
- Karezes are dual-purpose (potable and irrigation water supply), i.e. they are the only source of water in the majority of rural communities in southern and southwestern regions of Afghanistan;
- Karez systems are energy-efficient, as their use and operation do not require any additional powered equipment;
- Zero carbon footprint, as karez use and operation do not require fuel;
- Efficient water transportation without any evaporation and minimum infiltration losses;
- High water quality – water is not exposed to atmospheric pollution with hazardous material; the only contamination may be present due to geological formation features;
- Natural treatment of water during infiltration, i.e. water flows naturally and infiltration occurs in the underground tunnel;
- Sustainability – due to durable design and continuous flow, water is always available even in dry periods;
- No aquifer depletion because excessive usage is impossible. This makes the karez system more sustainable than other groundwater extraction schemes such as pumps and equipped wells which may deplete the water table;
- Sufficient water consumption without paying water-related bills;
- Suitable and viable tool for irrigation and potable water supply in hot and arid regions, especially for underdeveloped countries like Afghanistan;
- Continuation of a peaceful and traditional community-based water management system;

- Low maintenance costs;
- Opportunity to recognize and enhance Afghanistan's contribution to global cultural heritage.

6.2 Images of karezes

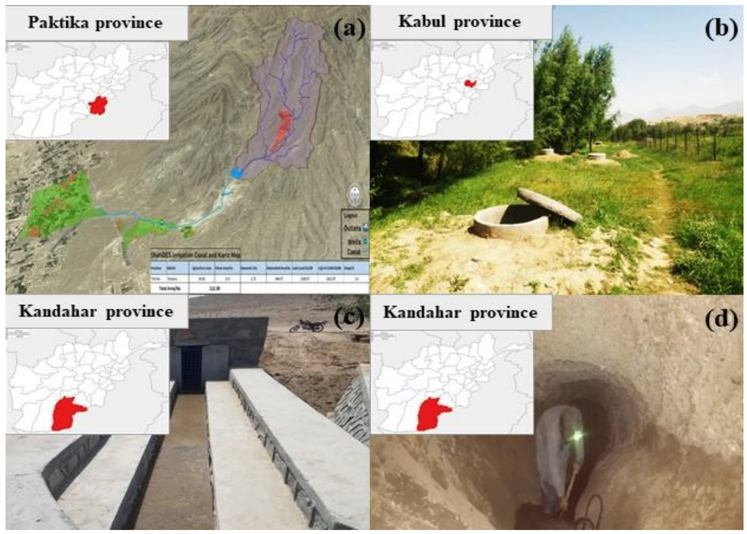


Figure 2. a) Enhanced Google Earth image of irrigation canal and karez map (GoogleEarth); b) Ventilation or access wells (*Chahs*) along karez; c) Karez daylight point (*Awkhura*); d) Karez tunnel cleaning process (Stanikzai, personal collection, 2020).

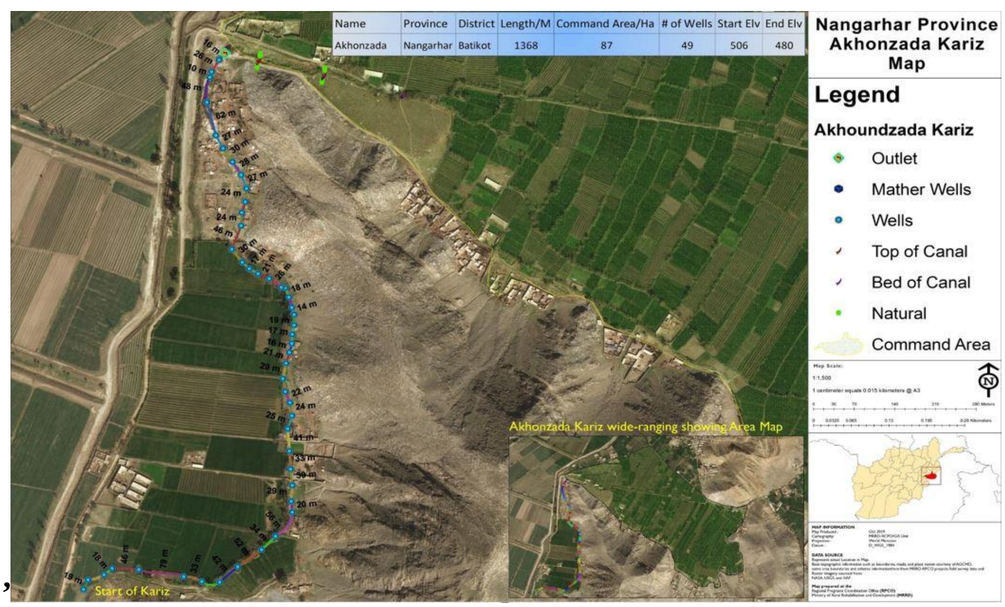


Figure 3. Akhonzada Karez in Nangarhar Province (Stanikzai, personal collection, 2020).

6.3 Karezes in saffron cultivation

In 2014-2015, agriculture contributed 24.32% to Afghanistan's GDP, as well as employed up to 59% of the able-bodied population (CSO, 2014).

In semi-arid regions like Afghanistan, due to its low water demand saffron represents a suitable crop even against the background of water scarcity. At present, saffron is one of the most important components of Afghanistan's export. Recently, the national Ministry of Agriculture Irrigation and Livestock (MAIL) announced an unprecedented saffron yield, and that its production has increased by 23% during 2018-2019, making Afghanistan the third largest producer and exporter of saffron after Iran and Spain. For eight consecutive years (from 2012 till 2019) Afghanistan's saffron ranked first in terms of quality and taste (Khamma Press, 2019).

90% of Afghanistan's saffron is produced in the western Herat Province. Since 2010, an increasing number of farmers in 23 provinces have turned to saffron cultivation, especially in Bamyan, Daikundi, Panjshir, Badakhshan, and Nuristan Provinces (Katawazy, 2013).

Saffron can become a legal alternative to opium poppy. It is a commodity that fits the market-led approach of the Afghanistan's agricultural sector, and is a crop which can boost employment. According to MAIL reports, the current annual domestic production of saffron is estimated at 10.5 metric tons. Returning to agricultural production of additional 15,000 ha may allow increasing it up to 70-100 metric tons per year, creating up to 4 mln workdays, as well as generating at least 200 mln USD of profit (MAIL, 2015).

Karezes could become the best irrigation scheme for saffron growing, since they already exist in areas where the crop is currently grown, as well as have proved their efficiency, particularly in Herat and Kandahar Provinces. For example, the Bawran Khan Karez in Pashtun-Zarghun District of Herat Province currently supplies water to 50 ha of saffron plantations and is estimated to be capable of irrigating up to 200 ha (Rout, 2008). The case study presented in this article is just one such example with hundreds of other karezes across the country possessing the same potential.

6.4 Rehabilitation

6.4.1. Conditions for rehabilitation

Thousands of karezes were destroyed due to drying up, over-exploitation by water pumps, increased demand for deep wells, and poor protection and maintenance (Himat and Dogan, 2017). The degree of degradation and dryness of individual karezes is determined by the scale and frequency of the aforementioned factors. Some of them can be recovered at a low cost; rehabilitation of others will require significant funding; some cannot be recovered at all. In certain cases, the cost of drilling a new well is less than the cost of repairing an existing one.

Thus, the following preconditions and questions should be considered before proceeding with rehabilitation:

- How suitable are the local hydrogeological conditions, i.e. is there a potential for reinforcing karez flow with rainwater and/or snowmelt, and is precipitation sufficient? If so, then the karez can get filled with groundwater. Subsequently, favorable cultivation and crop yields can be achieved so that local residents consuming water for irrigation will be capable of covering annual maintenance costs;
- Does karez still play a major role in the livelihoods of local farmers sharing it? Do local residents respect the management of karez by *mirab* (water master), and/or could the elders, traditionally and collectively, prevent digging deep wells (Khan, 2015)?;
- Is it possible to restore karezes in remote and isolated areas by digging 2-3 wells around the mother well?;
- Groundwater level should be sufficient for water to flow into karez, especially in the mother well area, and the mother well should be located in a rainfed area in order to feed the karez. This requires limiting water pumping from wells;
- There should be no deep irrigation wells near karez (Nasiri, 2015);
- To keep the inside of karez tunnel clean, access wells should be covered to protect entry of sediment;
- Karez water has been often used during daytime. To prevent water wastage, it is necessary to collect it in storage ponds at nighttime at the daylight point (mouth) of underground gallery.

In one words, karezes can maintain their value under favorable physical and social conditions. A robust social framework can ensure proper water care and management, i.e. people themselves supporting the efforts to protect the karez system. Since water scarcity is becoming increasingly problematic around the world, particularity in arid regions, karezes can continue playing their key role in addressing water use and availability issues.

6.4.2. Groundwater recharge

Artificial groundwater recharge manifests a new method for rehabilitating karezes. In arid regions with high evaporation, soil pores are filled with air impeding water penetration. In case of heavy rain, water does not penetrate the ground but flows on the surface causing floods and destruction. This can be prevented by building small dams to accumulate surface runoff. This way, rainwater will penetrate the ground and end up underground, thus, recharging the aquifer and staying available for irrigation during the cultivation season. Corresponding technical studies will allow preventing water losses and stimulating underground water storage.

Research shows that groundwater is accumulating in many areas. However, as a result of climate change some of the rivers across Afghanistan have dried up and are no longer capable of feeding water sources. It its turn, it leads to water table depletion. Therefore, if the groundwater used for irrigation is not supplied naturally or is restricted, it should be fed artificially. One of the ways to achieve this – i.e. raising the water table in karez area – is to build recharge dams (Majeed, 2006).

Based on the research in Kandahar and Helmand Provinces, the karezes located downstream of the Kajaki and Dahla Waterway Dams have remained active despite constant droughts due to groundwater flows (Goes, 2017). Yet, multiple other karezes in the same two provinces have already dried up due to lack of water.

Figure 4. Recharge Dam in Kandahar Province (Stanikzai, personal collection, 2020).

6.4.3. Construction of barriers along karez tunnels

Irrigation water demand drops in late fall and remains low throughout winter, except for warm areas in other regions where agriculture is not prevalent. However, during this time the water in karezes is still flowing and is not used productively. Based on our previous research, about 25% of water is wasted. Building 1-2 dams in the tunnel bed and/or a ditch at the mouth (daylight point) may allow blocking the water flow. Thus, it will be stored underground to be released in spring/summer when it is needed the most. To meet the public need for potable water in the karez area, its small amount can be incrementally released during fall and winter months. To save even more water, the tunnel bed and/or mouth can be fitted with a gate to allow free water flow if necessary. Otherwise, the barrier should remain closed to prevent water loss.

Local geological and hydrogeological conditions should undergo thorough investigation before constructing the aforementioned barriers, so that water accumulates in places with the corresponding capacity, as well as to avoid tunnel slipping and damage.

6.4.4 Closing ventilation and mother wells

Leaving ventilation and mother wells open during rainfall leads to their collapsing and filling with mud. Subsequently, it results in well narrowing and, thus, reducing/blocking the water flow and, in some cases, clogging up completely. Farmers are aware of such breakdowns and their destructive aftermath, so if possible they cover wells with lids, as well as line wells with stones, wood, metal or concrete to allow quick rehabilitation if necessary. Closing wells as described above will prevent their destruction. Thus, it is necessary to temporarily cover well heads even during repair and cleaning to prevent water and other substances entering them (Mostafaeipour, 2010).

In addition, 2-3 ventilation wells along one karez should remain open to allow ventilation of moisture inside karez to the surface and, thus, preventing damage to their walls. The same measure will enhance karez safety, i.e. will prevent accidents with human and animal falling into karezes. Based on the statements by several karez experts, closing wells makes it unnecessary to clean them annually, with 5-year cleaning cycles sufficing.

6.4.5. Application of PVC pipes

Polyvinyl chloride (PVC) pipes can be manufactured in different diameters, shapes and capacities, with or without filters and pores. The pores can be present on one, two or three sides, or around the pipe. The filters can be installed along karez floors and in mother wells to allow groundwater penetration into the pipe from all sides. Pipes without filters can be used in karez sections with few or no watery floors. Fitting karezes with PVC pipes, on the one hand, will prevent water losses, and on the other hand, will allow sufficiently extending the time periods between cleanings.

PVC joints can also be of different diameters and lengths depending on the circumference of a particular karez section and relative water flow rates. Because of their designed durability, PVC pipes will not bend due to sliding tunnel walls. The abundance of PVC pipes on Afghanistan’s market makes them one of the most effective and cost-efficient options for this purpose.

7. Case study of Zambar Karez

The Zambar Karez is located in Sabary Yaqoby District of Khost Province in eastern Afghanistan. According to reports, the local soils are mostly sandy clay with relatively high hydraulic conductivity. Table III below shows data for the Zambar Karez before and after rehabilitation.

Table III. Zambar Karez condition before and after rehabilitation (Stanikzai, personal collection, 2020).

Khost Province, Sabary Yaqoby District, Zambar Karez		
	Before rehabilitation	After rehabilitation
Status	Active	Active
Discharge	15 lit/sec	190 lit/sec
Irrigated land	80 ha	260 ha
Beneficiary	2,900 families	2,900 families
Labor days created	7,137	
Total cost	169,000 USD	

Figure 5. Zambar Karez in Khost Province, discharge before and after rehabilitation (Stanikzai, personal collection, 2020).

8. System structural analysis

The research included the 6-parameter system structural analysis for the Zambar Karez in Khost Province. The following matrix (Table IV) and Fig. 6. and 7. show that the parameters of population, well pump and technology development impose the highest impact on the remaining parameters. Vice versa, population and crop choices are most influenced by the other parameters. The magnitude of all the parameters was considered based on the current situation in Khost Province.

Table IV. System impact matrix (based on Stevens, 2005).

Parameters	Karez Q	Well Pump	Population	Water Pollution	Tech Develop	Crop Choices	Sums	
Karez Q		2	2	0	1	3	8	
Well Pump	4		4	1	1	2	12	
Population	1	4		3	2	2	12	
Water Pollution	0	1	2		1	2	6	**Cause**
Tech Develop	2	2	3	2		3	12	
Crop Choices	0	2	3	1	1		7	
Sums	7	11	14	7	6	12	**Avg: 57/6=9.5**	
Effect						**0-4 relative scale factor**		

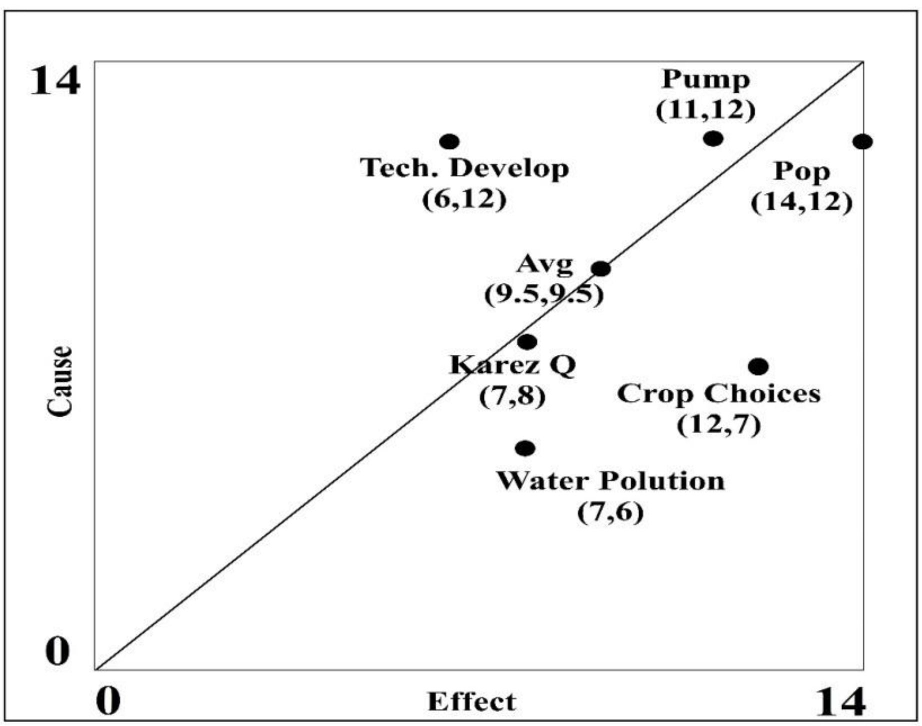


Figure 6. Cause-and-effect system plot: the selected parameters in the system are all active, both causing and undergoing change (based on Stevens, 2005).

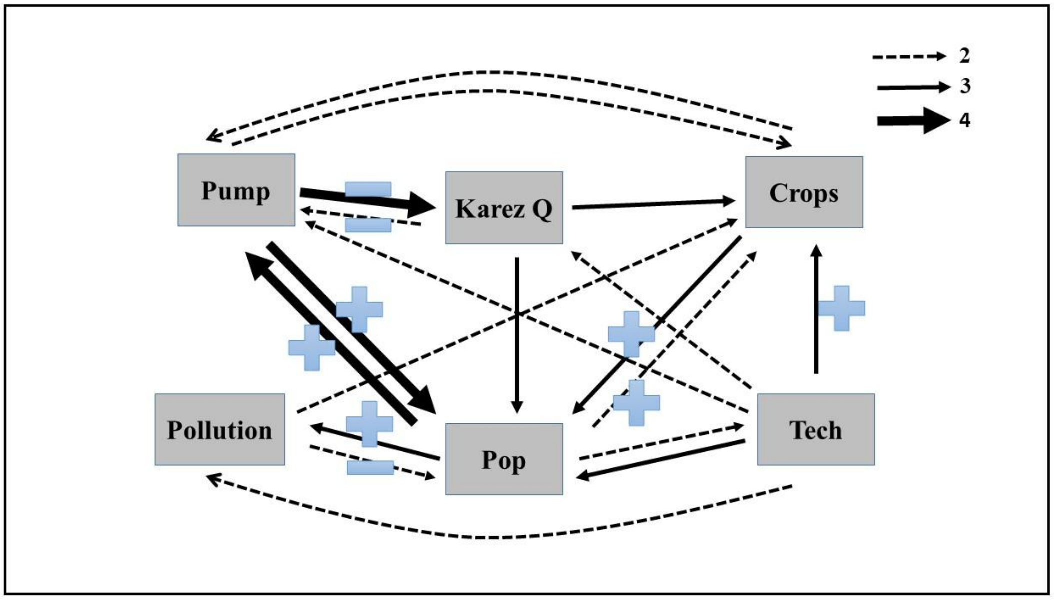


Figure 7. Negative feedback loops want to stabilize the system, and positive feedback loops want to de-stabilize the system (based on Stevens, 2005).

9. Results

Different irrigation methods – surface (via canals), underground, and karez-based – were investigated in the course of the study. Transferring water through a canal system with surface water storage is a widely used irrigation scheme characterized by losses due to evaporation and sedimentation. Active groundwater extraction has led to a significant water table drop, with the adverse effects especially evident in the Kabul Basin – the groundwater level there has lowered from 2-3 m in 1965 down to 9.5 m in 2004 (Tünnermeier et al., 2005). Karez – a series of wells draining water from aquifers and gravity-channeling it to the surface via slightly sloping tunnels without any effect on groundwater – manifests a truly sustainable water transportation and irrigation model. Currently, karez networks supply irrigation water to 160-170,000 hectares of land and thousands of rural residents in Afghanistan (Macpherson, 2015). Possessing a huge expansion and agricultural irrigation and domestic use potential, in the nearest future karezes can certainly foster saffron production requiring little water and generating high end product profits.

10. Conclusion

This article aimed to analyze the current Afghanistan's irrigation system from the viewpoints of sustainability and water supply efficiency. Considering the issue of water losses especially due to evaporation, it is still possible to irrigate more land with proper water resources management. It is necessary to forge a sustainable water supply chain and efficient water saving technologies in agriculture. Combining old traditional irrigation methods with modern engineering solutions can not only revive but also amplify the efficiency of the water supply chain, as well as make it more sustainable. The rehabilitation of the ancient karez network can play a key role in the country's economic and social progress. In addition, the art of karezes and use of groundwater are deemed Afghanistan's cultural heritage. Subsequent studies could focus on the two main trends as to irrigation system improvements: construction of large dams and water reservoirs feeding water to farmland via a network of irrigation canals; and restoring ancient karez tunnels and upgrading them using modern sustainable technologies. In order to mitigate the water crisis, India's Paani Foundation (Paani, 2020) has been promoting the second approach, i.e. combining old traditional manually built channels with cutting-edge managed aquifer recharge technologies supported by intensive scientific research. Further investigation of this model – combining ancient traditional models with modern sustainability efforts and improvising with value chains – appears instrumental to support its adaptation in Afghanistan.

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References

1. Katawazy, A.S., 2013. A Comprehensive study of Afghan saffron. *Report of Research, Planning and Policy Directorate, Afghanistan Investment Support Agency.* Kabul, Afghanistan;
2. Himat, A., Dogan, S., 2019. Ancient Karez System in Afghanistan: The Perspective of Construction and Maintenance. Akademik Platform Mühendislik ve Fen Bilimleri Dergisi [Academic Platform Mugendism and the Journal of Science Knowledge], 7(3), 347-354. DOI: 10.21541/apjes.466757;
3. Asian Development Bank, ADB, 2015. Preparation of the Afghanistan water resource sector development strategy. Vol. 2 annexes. TA 7994 AFG;
4. Anderson, I.M., 1993. FAO Program for the Rehabilitation of Afghanistan: Rehabilitation of Informal Irrigation Systems in Afghanistan. Design Manual;
5. Broshears, R.E., Akbari, M.A., Chornack, M.P., Mueller, D.K. and Ruddy, B.C., 2005. *Inventory of ground-water resources in the Kabul Basin, Afghanistan*. U.S. Geological Survey;

6. Central Statistic Organization, CSO, 2014. Afghanistan External Trade, Statistic Yearbook, Ansari Walt, Kabul, Afghanistan, pp. 177-200;
7. Majeed, A., 2000. Natural and artificial recharge techniques for Baluchistan. IUCN Baluchistan programme, water programme document series. Available at: http://www. waterinfor. net. pk/pdf/nartb. pdf;
8. Favre, A. and Kamal, G.M., 2004. Watershed atlas of Afghanistan;
9. Klemm, W., 1996. Promotion of Agricultural Rehabilitation and Development Programs in Afghanistan. *Water Resources and Irrigation*, FAO, Islamabad, November 1996; a report part of the "Afghanistan Agricultural Strategy", FAO, Rome, 1997;
10. Goes, B.J.M., Parajuli, U.N., Haq, M. and Wardlaw, R.B., 2017. Karez (qanat) irrigation in the Helmand River Basin, Afghanistan: a vanishing indigenous legacy. *Hydrogeology Journal*, *25*(2), pp. 269-286.
11. Habib, H., 2014. Water related problems in Afghanistan. *International Journal of Educational Studies*, *1*(3), pp. 137-144;
12. International Centre for Agricultural Research in the Dry Areas, ICARDA, 2002. Needs assessment on soil and water in Afghanistan. Future Harvest Consortium to rebuild agriculture in Afghanistan. International Center for Agricultural Research in the Dry Areas [online] Available at: https://afghanag.ucdavis.edu/irrigation-natural-resource/files/soil-access-water.pdf [Accessed on April 5, 2020];
13. Khamma Press, 2019. Afghanistan's saffron ranked first in the world for eight consecutive years (last updated December 21, 2019). Available at: https://www.khaama.com/afghanistans-saffron-ranked-first-in-the-world-for-eight-consecutive-year-2019 [Accessed April 1, 2020];
14. Khan, M.J., Pacha, G., Shahzad Khattak, M. and Oad, R., 2015. Water distribution of traditional karez irrigation systems in Afghanistan. *Irrigation and Drainage*, *64*(2), pp. 169-179;
15. Macpherson, G.L., Johnson, W.C. and Liu, H., 2017. Viability of karezes (ancient water supply systems in Afghanistan) in a changing world. *Applied Water Science*, *7*(4), pp. 1689-1710;
16. Ministry of Agriculture Irrigation and Livestock, MAIL, 2002. Afghanistan Natural Resources and Agriculture Sector Comprehensive Needs Assessment (Draft Report), Multi Donor Phase II Mission, Kabul, Afghanistan. Available at: https://think-asia.org /bitstream/handle/11540/6189/pass-Afghanistan%20-%20Natural%20resources% 20%26%20agriculture%20sector%20comprehensive%20needs%20assessment%20-%20Final%20draft%20report%20Jul02.pdf?sequence=1 [Accessed May 20, 2020];
17. Ministry of Agriculture Irrigation and Livestock, MAIL, 2015. Afghan saffron on media. Available at: https://www.mail.gov.af/en/afghanistan% E2%80%99s-saffron-media) [Accessed April 9, 2020];

18. Mostafaeipour, A., 2010. Historical background, productivity and technical issues of qanats. Water history, 2(1), pp. 61-80;
19. Nasiri, F. and Mafakheri, M.S., 2015. Qanat water supply systems: a revisit of sustainability perspectives. *Environmental Systems Research*, *4*(1), pp. 1-5;
20. Qazi, A. 2008. Afghanistan Water Resources and Pollution. Afghanistan online. Available at: www.afghan-web.com/environment/water/ [Accessed April 9, 2020];
21. Qureshi, A.S., 2002. Water resources management in Afghanistan: The issues and options (Vol. 49), International Water Management Institute;
22. Rout, B., 2008. How the water flows: a typology of irrigation systems in Afghanistan. Afghanistan Research and Evaluation Unit Issue Paper 1-58;
23. Stevens R. L., Jankowski M., Larsson O., 2005. Multi-Criteria Evaluation of Sedimentation in the Göteborg Archipelago, Göteborg University;
24. Tünnermeier, T., Houben, G. and Himmelsbach, T., 2005. Hydrogeology of the Kabul Basin, part I: geology, aquifer characteristics, climate and hydrography. *Foreign Office of the Federal Republic of Germany*, *AA-Gz'GF07*, *885*(3), p. 16.