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# Karizes and Current Prospects for Their Use in Kazakhstan

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***Abstract***

*The kariz (karez, qanat) represent one of the ancient water supply systems in arid zones. Natural collection of groundwater coming down from the mountains and its transportation to irrigated fields is the main advantage of the kariz systems. This article aims to introduce into the community of Central Asian hydrologists, hydrogeologists, and farmers the idea of the possibility of applying the kariz technologies and constructing them based on the experiences of neighboring countries and the ancient settlement of Sauran (Turkestan Region, Kazakhstan). Satellite imagery allowed identifying 3 (three) karizes around Sauran. The subsequent geomorphological analyses of the digital elevation model was carried out using the specialized ECO GIS-software. Further on, the maximum catchment areas (MCA) of mother wells (kariz beginning) were calculated. As the result, it was revealed that the target karizes themselves were located in the areas with low MCA. However, the mother wells were located in close proximity to the areas with high MCAs. 300 hectares was enough to collect groundwater to feed the entire irrigation system in ancient times. Modern examples from neighboring countries and the archaeological sites on the territory of Kazakhstan prove the possibility of using the kariz technology in current conditions. The introduction of this practice will allow introducing the foothill land in Southern Kazakhstan into agricultural circulation, as well as eliminating water losses due to evaporation during storage and transportation.*

**Key words:** kariz, karez, qanat, drainage, Sauran, Central Asia.

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## 1. Introduction

A karez (kariz) represents an ancient underground water channel. The karez network includes the underground network of tunnels connected to the aquifer at different points (Anderson, 1993) transferring water downstream by gravity for the final, mostly irrigation, use.

Due to the use of multiple languages and dialects, different terms have been utilized in historical and present-day sources. In Central Asia, they are usually denoted as *karez(es)* or *kariz(es)*; in Afghanistan and Iran – as *qanat(s)*; in Spain and Latin America – as *gallery(ies)*.

In the past, for centuries humans had been using these systems in drylands for accumulating, storing and transporting water. The geographical distribution of karezes was documented from Western China (Mustafa, Qazi, 2007) to Northern Africa (Hussain et al., 2008) and Spain (Wilkinson et al., 2012). The opinions about the exact time of the invention of karez vary, generally falling on the period of 2,000-3,000 BC (Fattahi, 2015). The majority of researchers believe that the karez was first invented in or around Iran (Wilkinson et al., 2012).

Whereas in the past, karezes were widespread across the areas along the Great Silk Road, and nowadays are actively used in China, Iran and Afghanistan, they got almost completely forgotten in Central Asia, with only archeology reminding Kazakhstan of this ancient know-how. To mainstream it into current practices, it is necessary to conduct a series of specialized geomorphological and hydrological studies seizing modern research methods and applications. Today, the most important strategic task is to investigate karez's potential in terms of rational use of water resources.

This article aims to introduce into the community of Central Asian hydrologists, hydrogeologists, and farmers the idea of the possibility of applying the *karez* technologies and constructing them based on the experiences of neighboring countries, and the ancient settlement of Sauran (Turkestan Region, Kazakhstan). With this article, the authors intend to attract the attention of scientists, as well as encourage them for active thematic research.

## 2. Karez: literature review

### *2.1. Karez design*

Karez (kariz, kanat or qanat, falai, rettara, etc.) represents a hydraulic installation designed for gravity-based withdrawal of groundwater to land surface. The key element of karez is an underground vaulted gallery-type waterway with minimal inclination angles, with its one end entering an aquifer, and the other one coming onto the ground surface. Karez cross section and top view are presented in Fig. 1.

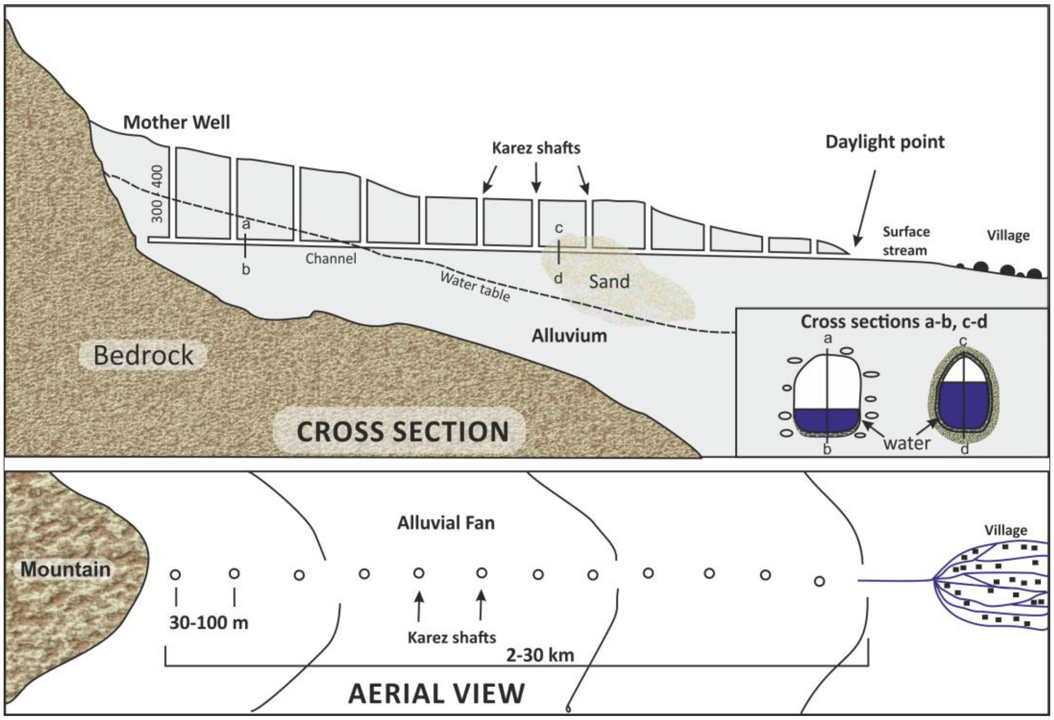


**Figure 1.** Karez cross section and plane view (English, 1998).

Karezes are mainly built in low-inclined desert and semi-desert foothills to supply water to agricultural oases and their urban centers (Smagulov, 2003). Favorable topographic conditions for relatively short karezes often occur at the mouths of dry alluvial valleys. Long karezes are built as water conduits starting at available groundwater sources (Alemohammad, Gharari, 2017).

Due to karez's capability to ensure reliable and sustainable access to previously inaccessible groundwater reserves, dryland communities accept their use despite considerable financial, construction and maintenance costs.

In his notes, Grum-Grzimailo (1896) describes the design and operating principle of karezes (old Russian "*karyss(es)"*) as follows: "In an area known to the population for a relatively shallow occurrence of water-containing layers, they dig a head "dudka" (old Russian "*well"*), i.e. a narrow and deep well ending in these layers; at 4 *sazhens* (*author's note: old Russian measure of length equal to 2.13 meters*) [about 8 meters] increments <... > they dig the second same well, and then the third, fourth, hundredth, until the well's depth reaches 1 *sazhen*; after that, starting from the last one <... > they connect the wells with each other by a conduit cutting through the entire length of the water-containing soil layer. <…> [I]n order to increase the inflow of karyss water, the main conduit is supplemented with branches <... > From a bird's eye view, most of the [land] surface may appear as pitted by some Soricidae, with the only difference, however, of the huge soil piles <... > stretched out by orderly lines. These are the karysses."

According to Sala (2008) and Smagulov (2010), the concept of karez operation is based on the intention of raising groundwater level along its entire route. Karez does not use underground galleries built over an impervious stratum, but reaches and cuts through the aquifer itself.

In his study, English (1998) describes the design of karizes, or qanats, in Iran, noting that their successful operation is predetermined by two decisions made by the *Mukanni* (professional karez diggers in Iran) prior to the actual karez construction. The first one is the correct identification of the mother well location to ensure karez's maximum distance from a settlement; the second one is the correct and accurate calculation of karez inclination between the mother well and destination point. When choosing a potential site for digging the mother well, the Mukanni dig one or more test wells reaching the water table, as well as take into account many geographical factors of the area where these wells are located, including local slope conditions, terrain, minor changes in vegetation, accessible groundwater, and alleged water flow direction. As reported by English (1998), after the test well manifests water, the responsible Mukanni has to be sure that the diggers have penetrated into a relatively lasting groundwater source located above an impermeable bed. If so, it becomes the qanat's mother well, with its length measured from this point to the destination point (*mazkhara*). Then, the Mukanni needs to accurately measure the level and inclination of the qanat tunnel – the most complicated engineering task in the entire construction process. The tunnel level should ensure the connection between the water-filled bottom of the mother well and the destination point, i.e. point where water comes onto the ground surface, via a low-angle tunnel. If the level is calculated incorrectly, and karez exits the ground at a distance from the set outlet point, and then the water will flow down from this point along an open channel to the household or fields, thereby increasing both evaporation and percolation. If the tunnel inclination is too steep, the gravity-driven water will destroy the tunnel walls and the karez itself. If the inclination is too gentle, the water in the tunnel will form a pond and stagnate. In many cases, karez tunnels follow an indirect and winding pathway to its destination, bending to maintain proper inclination on steep slopes. Vertical technical shafts (wells) connect the tunnel with ground surface approx. every 50-100 meters.

Despite the considerable labor, construction and maintenance costs, karez system's independence from seasonal fluctuations represents their obvious advantage. With low moisture loss due to evaporation, such systems are capable of providing settlements with a stable supply of clean and cold drinking water. Water loss due to percolation can be reduced by lining tunnels with clay (ceramic) rings and/or an impervious clay coating as the tunnel passes through loose sandy soil (Abbasnejad et al., 2016).

MODFLOW simulations show that karez water flow can be modeled by applying a high correlation ratio of karez hydraulic conductivity to aquifer hydraulic conductivity split into cells representing the karez. Macpherson et al. (2017) developed a model sensitive to hydraulic conductivity, as well as gradient and length of kariz coming into contact with groundwater table. This study characterizes karez hydraulics, possibility of reduced groundwater replenishment due to climate change, and likewise the effect of population growth on karez water flow.

Karez design indicates that with proper construction and operation, such water supply systems represent one of the acceptable options for arid and semiarid climates (Taghavi-Jeloudar et al., 2013; Megdiche-Kharrat et al., 2019). In addition, their environmental friendliness allows rational water use without any additional pumping costs. Present-day studies utilizing modern modeling tools show the applicability and possibility of improving the karezes built in the past.

*2.2. Karezes in Iran, Afghanistan, China and Spain*

Karezes were especially widespread in the arid Iranian plateau during the Achaemenid Era, i.e. VIII-III centuries BC (Beaumont, 1971). The first karezes were probably built to divert water from grooves and mines. In any case, it was precisely such drainage systems in Kurdistan mountains that were first mentioned by Polybius (II century BC). In the era of ancient states (Iran, Urartu, Assyria, Media, etc.), the construction of karez irrigation systems became part of the state policy (Avni, 2018). Since that time to the present day, multiple large cities in Iran like Tehran, Nishapur, Yazd, Qom, etc., as well as entire agricultural oases have been supplied with water exclusively via karezes numbering many thousands across the country (Hussain et al., 2008). An example of Iranian karezes is given in Fig. 2.


**Figure 2.** Karezes in Iran identifiable as chains of spots (Google Earth, 2020).

Afghanistan communities living far from rivers have traditionally relied on karez-delivered groundwater. A typical karez in Afghanistan has a length of 1-2 km, cross section of 1-2 $m^2$, and inclination of 1 (one) m per 1 (one) km of length. A space image of such a karez is shown in Fig. 3. Afghan karezes collect unconfined (non-artesian) groundwater in alluvial circuits mainly replenished by melting snow from the Hindu Kush, the country's central mountain range. After years of the drought that had started in 1998, many karezes have failed.


**Figure 3.** Typical karezes in Afghanistan identifiable as chains of light-color spots (Google Earth, 2020).

Precipitation data for Afghanistan is scarce, although regional-level studies show a long-term downward trend in snow cover and, therefore, high probability of reduced aquifer recharge. In addition, Afghanistan's population has increased over the past few decades. An assessment covering 6 (six) districts in Kandahar Province – where karezes represent the most traditional way of collecting and transporting water – shows that water demand could lead to a 0.8-5.6 m drop of groundwater table, which is more than enough to stall karez operation. The assessment findings suggest that water influx to karezes is not sustainable with the current climate change and population growth trends (Macpherson et al., 2017).

In antiquity, karez systems penetrated into North Africa; later, in the early Middle Ages, they became widespread in China (Mächtle et al., 2019). Satellite imagery in Fig. 4. shows that in the Turfan Valley, Western China, karez systems continue to be actively used for farmland irrigation.


**Figure 4.** Karezes in the Turfan Depression, China, identifiable as long chains of light-color spots (Source: Google Earth, 2020).

In Spain, karezes are called gallery systems. The karez technology came to Spain with the Arabic culture, and later the Spaniards brought it to the New World. In Spain, karez systems are mostly concentrated in the southern and central parts of the country. The University of Valencia established a thematic working group to classify and study karezes (Gerrard, Gutiérrez, 2018). The importance of karezes in the overall Spain's development is confirmed by the fact that even the reservoir at the Royal Palace in Madrid was supplied with water through a network of underground galleries or karezes (Martínez-Santos, Martínez-Alfaro, 2014).

Thus, it can be inferred that originating in Iran the karez technology had actively spread along the Great Silk Road; then – under the influence of Arabic culture – penetrated into Spain; and even later was brought to the New World by the Spaniards. Over time, the system has been enhanced, and is now actively used to supply clean water to communities and farmland in multiple countries. Moreover, Iran's karezes and Spain's galleries possess the status of cultural heritage and represent popular tourist attractions.

### *2.3. Karezes in Kazakhstan*

Karezes in the territory of modern Kazakhstan are first mentioned in the works of Mahmud Wazifi, 15$^{th}$ century Tajik writer. In his book *The Incredible Events*, he mentions the Turkestan oasis and the fact that the Muslim sheikh Mir-Arab presented the ancient town of Sauran with two karez lines built by 200 Indian slaves and feeding a wonderful garden (Wazifi, XV century). Wazifi also refers to the wells' depth – 200 (two hundred) *gyazes*, with 1 (one) gyaz equaling 60.6 centimeters (Imazhanov, Beisenbayeva, 2002), thus making them approx. 120 meters deep.

The medieval sources inspired researchers to the first archaeological excavations and studies of the karezes of the Turkestan oasis in the 50s' of the XX century. However, it became possible to detect them only by analyzing satellite images in 1969. The 1986-1988 archaeological expedition allowed discovering 3 (three) karez lines, although during the excavation of wells down to 4 meters deep no underground galleries were found (Groshev, 1996).

The 2003-2005 expedition allowed detecting 256 (two hundred fifty-six) karez lines (without excavation) with the total length of 110 km and including approx. 900 wells (Sala, Deom, 2006). In addition, in 2010 the *Sauran 2010* Expedition took place in the vicinity of Sauran settlement. The excavation allowed discovering and registering 18 objects, including 12 medieval dwellings, 2 karezes, 3 household outbuildings, and 1 ecclesiastical *chillyakhana*-type building (Archaeological Examination LLP Website, 2020).

Kazakhstan's national encyclopedia (2004) refers to the karez well close to the building of the *Aulie Kumshik-Ata Chillyakhana* (underground religious chamber) and 1 km southeast of *Khoja Ahmed Yassavi Mausoleum* accidentally found in the town of Turkestan. Its field survey allowed tracing the entire well stratigraphy, as it was for the first time that the excavation had reached the aquifer, and it was possible to establish its actual depth.

Thus, via the Great Silk Road the Persian and Arabic cultures had evidently impacted not only the economy and culture of medieval Kazakhstan, but also the construction engineering of the then hydraulic installations. The example of the ancient Sauran proves the relevance of karez systems in the Middle Ages in the territory of modern Kazakhstan, which points to the idea of the need to introduce these technologies and structures at present as alternatives to open aryks (***kaz.*** *channels*) and reservoirs.

## 3. Research area

The section of the article describing the findings of the field survey is based on the analysis of the karezes located adjacent to Sauran settlement in Turkestan Region of Kazakhstan. Fig. 5. shows the map of the corresponding ancient settlements and karezes. The research area is located in the alluvial plain between the southern slopes of the Greater Karatau Mountains and the right bank of the Syr Darya River's midstream. The plain gently (4/1000 m (0.4%)) slopes towards south-southwest between 320 and 200 m ASL, and is intersected by the deltoid mean low flow of 3 seasonal watercourses. Overall, the research area represents a typical desert landscape of the Northern Tien Shan of Karatau District characterized by light-brown desert soils and shrub vegetation of hummock-and-hollow semi-deserts (Sala, 2008).

The deltoid mean low flow tributaries (mainly seasonal) of 3 rivers – the Tastaksay in the west, Maidantal 10-12 km to the east, and Aksay between them – going from north to south from the southern Karatau Mountains towards the Syr Darya cross the area. The Tastaksay River is 60 km long, and ends southwest of Sauran. The 75 km long Maidantal

River, the only out of the three occasionally reaching the Syr Darya, enjoys the largest influx of surface and ground water.

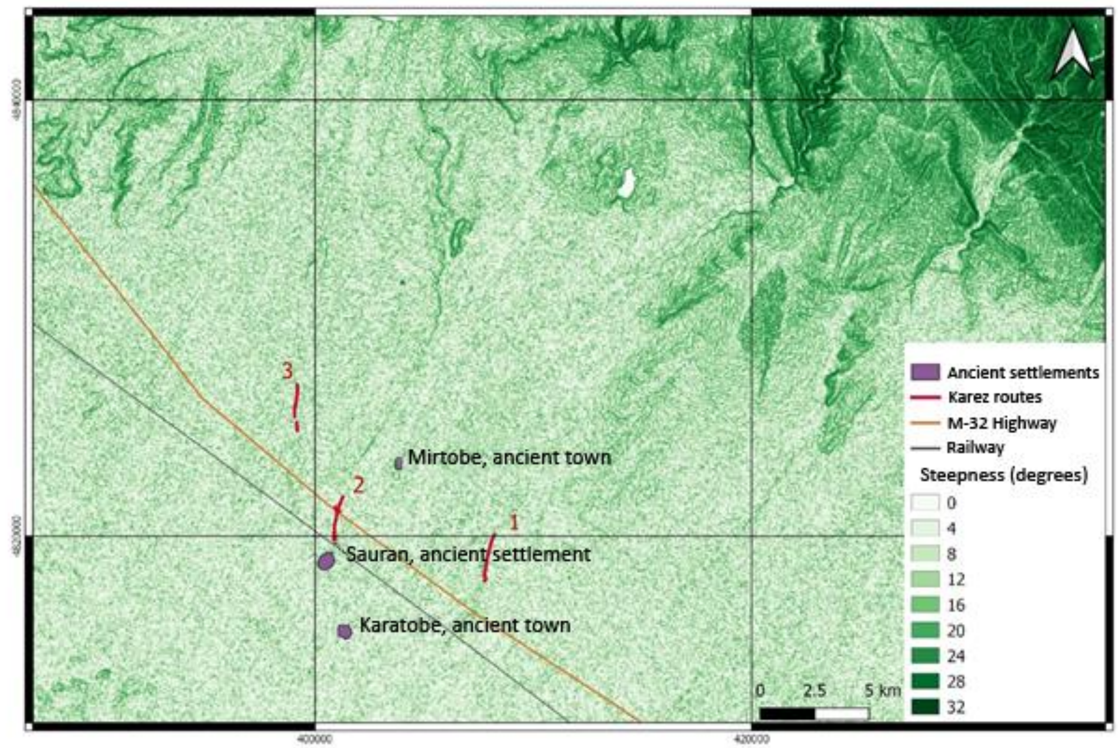


**Figure 5.** Map of ancient settlements of Sauran, Karatobe and Mirtobe.

Only 25 km long and ending prior to reaching Karatobe, the Aksai River is certainly the least relevant, but due to its central and depressed position, its mean low discharge is supported by the confluenting dry watercourses and groundwater of other streams. With the exception of some segments of the main Tastaksay and Maidantal canyons – supplying although meager yet stable flow all year round – all other riverbeds either completely dry up or are periodically active only in spring. The mid-low streams of the 3 rivers have sophisticated parallel, diverging and converging branches; in principle, represent 3 deltas combining their groundwater and coming together in the proximity of the ancient towns of Karatobe and Sauran (Sala et al., 2010).

Humid climate phases occurring over decades and centuries, can profoundly alter the hydrological conditions of an area stimulating a much higher-water regime, floods and perennial swamps. The Soviet-time construction of 2 large foothill reservoirs on the Tastaksay and Maidantal Rivers had reduced the hydrological and hydrogeological resources of the area's southern sections (Sala et al., 2010).

The main geomorphological features of the alluvial plain in question are predetermined by the characteristics of the 3 delta watercourses described above. They allow distinguishing 3 high-altitude strips (stretching from north to south) likewise demonstrating differing hydrogeological features, and thus associated with specific water use technologies. The northern strip between 320 and 260 m ASL – formed by the immediate foothill plain with 1% inclination – is cut by separate longitudinal small streams operating all year round. The central strip between 260 and 215 m ASL – where the riverbeds acquire the deltoid shape and their channels begin to converge – has a more abnormal relief, consisting of alternating hills and depressions. The southern strip between 215 and 200 m ASL – located at the final convergence of the three deltas – is extremely flat with poor drainage and vast seasonal swamps (Sala, Deom, 2006).

Thus, the area's climatic conditions were favorable for using karez systems in the past. It deserves re-emphasizing one of the prerequisites for successful karez construction, i.e. presence of neither too steep nor too gentle sloping, clearly observed in the research area. In other words, the local landscape was well suited for karez construction in ancient time and continues to be such presently.

## 4. Methodology

To detect the exact location of the karez systems, space imagery of Turkestan Region around the ancient settlements of Sauran, Mirtobe and Karatobe were analyzed in an attempt to identify specific chains of wells and especially the mother well location. 2018-2019 satellite images with up to 0.3-0.5 m resolution were harvested from Google Earth open sources (Google Earth Website, 2020).

For land surface analysis, the digital elevation model (DEM) with 1 arcsec (or 30 m) resolution – developed under the well-known SRTM Project (USGS EROS Customer Services, 2018) – was used.

The DEM was re-projected to an equilateral metric coordinate system using Q-GIS algorithms. The maximum catchment area (MCA) was mapped based on the adjusted model using ECO GIS analytical software (Shary et al., 2002). The MCA for a given DEM is defined as the maximum area from which the material moving down the slope may collect, and is measured in square meters ($m^2$). In reality, MCA reflects both the potential and realized network of hydrological channels without distinguishing them. The darker a matrix element, the higher the MCA (Shary et al., 2002).

The methodology of this study was based on the available open data sources like remote sensing imagery, DEM and GIS tools. These materials and tools allowed carrying out tabletop experiments with minimum budget.

## 5. Results

Table I contains the coordinates of start (top) and end karez points obtained by interpreting space imagery for the karezes indicated on the map (Fig. 5.). The detailed maps of karez location and MCA matrices are shown in Fig. 6., 7. and 8. Table II shows the coordinate points with maximum MCA values close to karez mother wells.

**Table I.** Coordinates of start (A) and end (B) karez points (as per WGS84 UTM42).

| Karez № | Point № | X (m) | Y (m) | Z (m) |
|---|---|---|---|---|
| 1 | k1-A | 408,211.27 | 4,820,037.56 | 223 |
| 1 | k1-B | 407,762.76 | 4,817,943.03 | 214 |
| 2 | k2-A | 401,276.39 | 4,821,789.63 | 213 |
| 2 | k2-B | 400,865.44 | 4,819,814.63 | 208 |
| 3 | k3-A | 399,179.26 | 4,826,937.81 | 240 |
| 3 | k3-B | 399,189.26 | 4,824,852.29 | 227 |

**Table II.** Maximum MCA values around mother wells.

| Point | MCA, ha | Height, m | X, UTM 42 | Y, UTM 42 |
|---|---|---|---|---|
| 1.1 | 303 | 220 | 408,200 | 4,820,320 |
| 1.2 | 636 | 217 | 407,720 | 4,819,780 |
| 2.1 | 3,624 | 210 | 401,120 | 4,821,910 |
| 2.2 | 1,224 | 212 | 401,510 | 4,821,760 |
| 3.1 | 333 | 238 | 399,410 | 4,827,190 |

On satellite images, karezes can be distinguished as chains of light-color spots, i.e. circular well mounds (Fig. 6., 7. and 8.). Their diameter is 4-7 m, and the distance between them averages 15-20 m.

The discovered karezes are located along highland water divides along valleys (Fig. 6., 7. and 8.). Most likely, the valleys limiting the karezes themselves were always dry, although the formation of temporary surface watercourses at certain periods during the year cannot be ruled out.

The top ends of the studied karezes do not penetrate into the actual watercourses, but come close to dry valley floors. The valleys' maximum surface runoff area close to the top karez points varies (Table II). The measurement points are shown in Fig. 6-8. for each karez separately. Interestingly, analyzing the catchment area map it is obvious that the MCA at the points of well location approaches zero, which is due to the fact that the karez line follows the water-divide line.

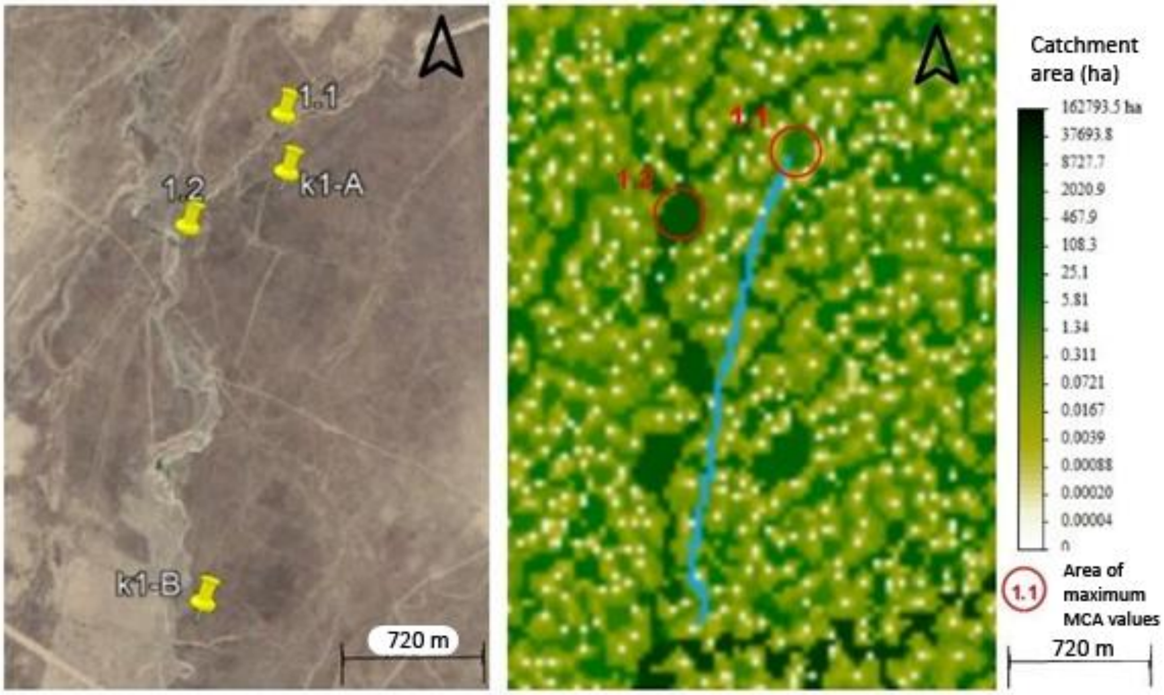


**Figure 6.** Karez №1 on the satellite image (Google Earth, 2020) and MCA map (k1-A and k1-B correspond to karez start and end points; 1.1 and 1.2 correspond to maximum MCA values around the mother well).

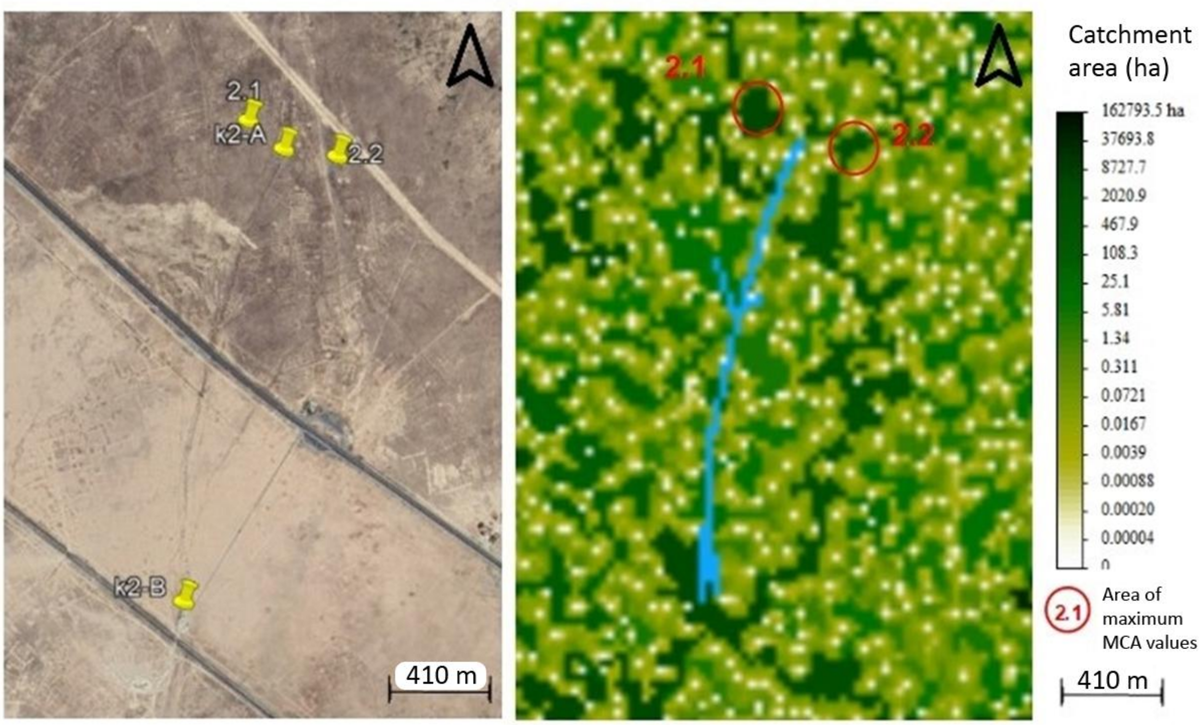


**Figure 7.** Karez №2 on the satellite image (Google Earth, 2020) and MCA map (k2-A and k2-B correspond to karez start and end points; 2.1 and 2.2 correspond to maximum MCA values around the mother well).


**Figure 8.** Karez №3 on the satellite image (Google Earth, 2020) and MCA map (k3-A and k3-B correspond to karez start and end points; number 3.1 correspond to maximum MCA values around the mother well).

Based on the analysis of satellite imagery, land surface and catchment area maps, it was found that the Sauran karezes are located in the watershed area with low MCA, yet their mother wells are always located in close proximity to the areas with high MCA (Table II). This applies to both Karezes №1 and №3 located away from the modern watercourse; and Karez №2 located in the immediate vicinity of the modern river channel.

## 6. Discussion

### *6.1. Karezes in antiquity*

The archaeological research and interviews of long-term residents of Turkestan settlements and adjacent *auls* (villages) conducted by the expedition team point to the legends about underground galleries around Turkestan (Tuyakbayev, 2002). Likewise, the Code of Historical and Cultural Monuments of Kazakhstan (Code of Monuments..., 1994) refers to the auls in Turkestan's vicinity the names of which are etymologically associated with the term "karez", for instance, Kariz, Kyryk-Kudyk, and Juka-Kariz. Thus, in ancient times, the area had actively developed thanks to a network of karezes. Based on Table II, an MCA of approx. 300 hectares was sufficient for the mother well to accumulate enough groundwater. Therefore, it can be assumed that the depopulation of Sauran and nearby settlements occurred not only due to the Mongol invasion (Abuseitov, 1975), but also due to the onset of a different climatic period and cessation of karez recharge.

*6.2. Karezes at present*

Today, effective restoration and rehabilitation of karezes to ensure rational water use represents a relevant task. Applying the corresponding technologies of neighboring countries, it is possible to build a system of underground galleries to transport, store and accumulate water coming from temporary watercourses and precipitation, thereby preventing evaporation and regulating groundwater table.

In an interview, Professor Burlibayev, PhD in Technical Sciences (2020), expressed the opinion that the practice of building large reservoirs disrupts natural processes and misbalances ecosystems. For example, water evaporability from the surface of the Besaryk Reservoir amounts to about 4.5 mm or 8,894.1 $m^3$ per day (Yapiyev et al., 2019). These are impressive losses, especially considering the poor precipitation in Turkestan Region and the major part of Southern Kazakhstan in summer. Does it really make sense to build open reservoirs in such conditions?

Numerous examples of neighboring countries show that the karez technology is equally viable in the $21^{st}$ century. For instance, India's Paani Foundation (Website of Paani Foundation Fund, 2020) is promoting irrigation practices to ensure rational use of irrigation water. The main technologies that the Foundation is focusing on are associated with underground water storage and transportation via underground channels resembling underground galleries. Upgrading the conventional karez technologies based on modern engineering and hydrological knowledge, Kazakhstan can get a unique chance to save water and simultaneously develop agricultural land in the arid foothills of Turkestan and southern constituencies.

Unfortunately, the karez knowledge – previously passed down from generation to generation – was lost in Central Asia, preventing swift mainstreaming of this technology into the training of future reclamation specialists, hydrogeologists, and hydrologists. In addition, the technology requires rethinking in modern engineering terms, since construction of karez systems using the ancient methods is quite labor-intensive.

The authors propose to continue the research of karezes in Central Asia to analyze the feasibility of their use nowadays. It is also necessary to expand cooperation with the specialists of countries already using this technology in agriculture, as well as continue inventorying Kazakhstan's archaeological sites related to rational water use in antiquity.

## 7. Conclusion

Against the backdrop of the climate challenges which Central Asia is currently facing, the karez technology could play an important role in adapting local communities to new conditions. The authors hope that this article will become a bridge fostering the knowledge flow from the archaeological community to the community of modern urban and rural water supply experts.

The main achievements of this study include the following:

1. Introduction of important English-language literature describing karez design, operation and agricultural application into the Russian-speaking research community;
2. Showcasing the karezes operating in the neighboring countries of Iran, Afghanistan, China, etc.;
3. Overview of archaeological materials about the ancient town of Sauran in Turkestan Region of Kazakhstan;
4. Based on geomorphological analysis, discovering that Sauran karezes are located in the water-divide area, yet their mother wells are located directly in the zones with the MCA amounting to 303-636 ha at a distance from surface watercourses. The mother well of Karez №2, located near a permanent surface watercourse, is adjacent to the zones with the MCA between 1,224 and 3,624 ha.

Technological enhancement of remote sensing tools, i.e. acquiring a 1-meter resolution digital elevation model, will allow calculating the morphological indicators more precisely and analyze the landscape to design a model capable of detecting the potential sites for building new karezes.

*Karez technologies possess the following advantages:*

- Environmental friendliness – no fuel/energy maintenance costs;
- Employment – karezes require regular cleaning and care; attracting a large number of special workers will help reducing local unemployment;
- Cost-effectiveness – frugal maintenance associated with the need to clean the channels and absence of expensive equipment;
- Rational use of water resources – the accumulated water comes from precipitation and melting, in addition allowing to regulate groundwater table;
- Speed of water transportation – stable water flow due to slope inclination;
- Cultural value – ancient karezes represent cultural heritage; and their restoration will foster local tourism business.

*The main tasks to be performed to revive the karez technology:*

- Create a methodology for calculating mother well location and karez route;
- Build practical capacity for designing and building karezes using modern means;
- Close the shortage of competent local- and regional-level karez specialists to ensure their proper operation in Kazakhstan and entire Central Asia.

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