THE INGENIEUR

Turpan Karez Wells – Ancient Underground Aqua Channel System

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Turpan basin is located in the eastern region of Xinjiang province of Western China. It lies in the third deepest inland depression in the world. Along the northern rim of the depression is a range of high mountains with snow-capped peaks called the Bogda Mountains.

Desert climate of Turpan region

The Turpan Depression Basin proper covers an area of 28,600km^2 (11,000 sq. miles). The Aydingkul Lake lies in the centre of the basin which has an elevation of 154.5m (507ft) below sea level, the sixth lowest exposed elevation on the Earth's land surface. It is the lowest surface point in China. The Turpan Basin has a harsh, continental desert climate in which the precipitation is far less than the potential evaporation.

Since temperatures tend to rise as elevation goes down, the hottest spot occurs at the lowest point of the Turpan Basin — Aydingkul Lake. This lake used to cover 153km^2 but today it is almost dried up. At 154.31m below sea level, the former lake's bed is the second lowest point in the world after the Dead Sea at 422m below sea level.

During the day, the ground absorbs energy from the sun, and this heat warms the ambient air from the bottom up. In the Turpan Basin, ground temperatures during summer often exceed 75°. The Turpan Basin is not only the hottest part of China, it is also the driest, with an annual precipitation of less than 20mm. The potential evapotranspiration reaches as high as 3,000mm/a in Turpan, so snowmelt water from the high cold mountains becomes the main water source for human use and natural needs. The satellite photo in Figure 1 shows the steep mountain range and the flat plain of the Turpan region.

A lot of water is released as the snow melts on the mountains and the locals had to think of a way to bring it down to the basin without the water evaporating or being lost by ground seepage. As a result, they made underground tunnels. The locals took advantage of the big difference in elevation to make gently sloping underground tunnels (qanats or karezes) to carry the water into the valleys where they farm and live.

People in the oasis were entirely dependent on irrigation in the past. Compared to surface irrigation, karez wells or qanats can avoid high water losses from evapotranspiration as well as seepage into the very dry and coarse ground surfaces, so they can transport water over greater distances.

During ancient times, when caravan traders passed through the area as they went to or from the Gansu Corridor to the east, the Turpan area was a place to trade, get provisions, and rest. There was a string of forts, cities, and small kingdoms along the northern rim of the Turpan Basin and the Taklamakan Desert.

During the Tang Dynasty (618–907), there were two fortified cities called Jiaohe and Gaochang in the Turpan area which were about 44km (27 miles) apart. The caravans needed fodder for the camels and other animals and food for the guards, traders, and travellers. This meant there was a high demand for water and food to support the traffic through Turpan, and so the karezes were used to supply some of the water.

Figure 1: Satellite photo shows the steep mountain range and the flat plain of the Turpan region

The Turpan Basin has special hydrogeological features favourable for the building of large qanat systems. The basin has high temperatures and scarce precipitation, and is extremely dry. With a maximum summer temperature of more than 40°C, it earned its name "Land of Fire".

The climate in the mountains in the north and western parts of the basin is cold and wet. Once summer arrives, vast amounts of snowmelt flow down in streams, and most of the water seep into the coarse gravel as the streams flow across an 8–10km wide Gobi belt with a relatively steep slope. Both the surface runoff and groundwater flow towards the lower basin areas. This provides rich water sources for the lower basins that are mainly covered with fine sand and loess soil.

With an altitude of about 800m and located at the northeastern edge of the basin, the Flaming Mountain intercepts part of the groundwater recharged into the gravel layers of the Gobi belt and raises the groundwater table. As a result, many springs flow out into the northern foot of the mountain, then run through hills and valleys, and ultimately seep into the alluvial fans. The qanat systems in the Turpan Basin generally tap groundwater from the northern and northeastern alluvial fans and transfer it to the lower basin areas towards the Aiding Lake.

Components and Construction

A qanat system generally consists of four components:

a. vertical wells/shafts,
b. tunnels for conveying water
c. open channels, and
d. collection ponds.

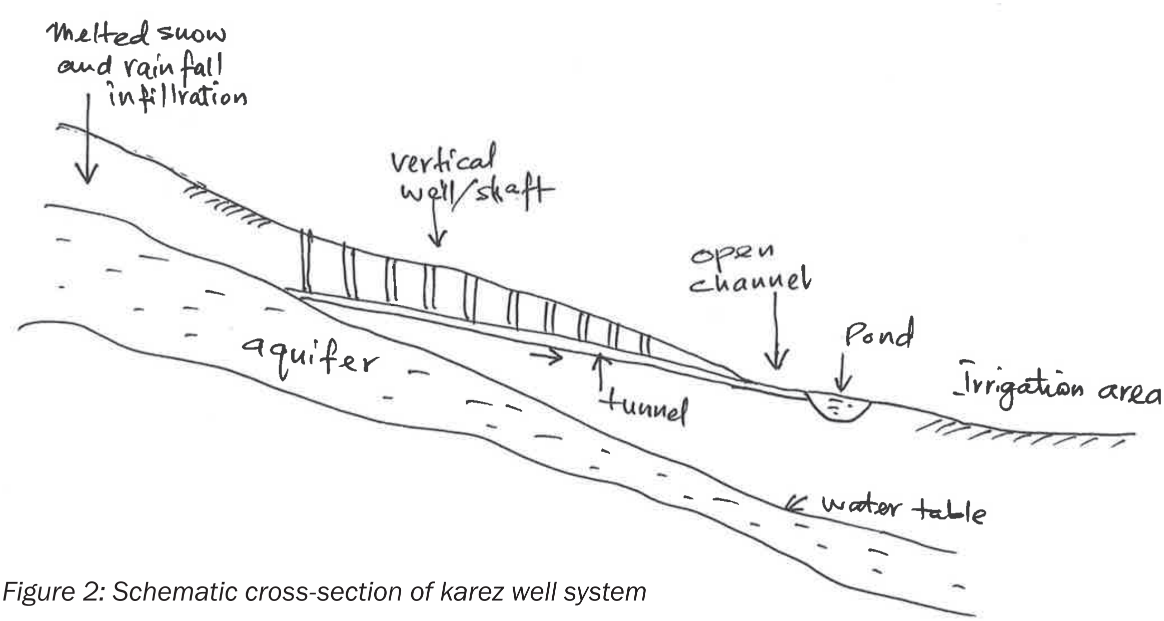

Figure 2: Schematic cross-section of karez well system

The infiltration section of a tunnel is the groundwater collection section, where the groundwater table is located, so groundwater can seep into the tunnel to provide a water source for the system. The vertical shafts in the infiltration section are also called mother wells and are dug first to explore the aquifer. The initial digging of the mother wells is usually at the outcrops of rich springs, which are locally called the Digging Springs, the Expanding Springs and the Extending Springs in sequence.

Vertical wells

Once the mother wells are successfully located, an array of vertical shafts (locals call them wells) are constructed along the downslope of the alluvial fan to align the tunnels, provide ventilation and facilitate future maintenance (e.g. cleaning silt sediment). The interval between two adjacent shafts generally ranges from 60m to 100m in the upper section, 30m to 60m in the middle section and 10m to 30m in the lower section. The diameter of the shafts is about 1–1.5m. The depth decreases progressively down the slope, generally ranging from 40m to 70m in the upper section (to a maximum of 100m), 20m to 40m in the middle section and 3m to 15m in the lower section.

Water conveying tunnels

The conveyance section of a tunnel is used to transport collected groundwater to low soil surfaces adjacent to farmlands. The length of the tunnel varies from 3km to 5km, and the longest in Xinjiang is more than 10km. The tunnel has an appropriate slope gradient to ensure water transport by gravity. The tunnel gradient mainly depends on soil conditions, and is normally less than that of the slope on the ground. The inner size of a tunnel is large enough so that the tunnel can accommodate at least one person for excavation operation. The cross-section of many tunnels is oviform, about 2m high and 1m wide, but existing old tunnels have irregular shapes.

Once the vertical shafts are completed, they are connected by a single tunnel. The excavation tools are mainly a mattock and a short-handled spade. A windlass is usually installed at the mouth of the shaft. Workers on the surface, with the help of the windlass, raise a bucket loaded with silt unearthed by an underground worker. A cow is

Figure3: Models at the museum demonstrating winching method to lower workers into the well

Figure 4: Models at the museum demonstrating another winching method to transport earth materials from the tunnels

sometimes used to raise the bucket, especially in the case of a deep excavation. The silt sediments are usually piled around the mouth of the shaft to prevent floodwater intrusion. In most cases, tree branches, crop straws, etc. are used to cover the mouth of the shaft to prevent sandstorm intrusion and icing.

Open channels and collection ponds

The outlet of a tunnel is also called the dragon mouth and connects to an open channel to transfer the groundwater to nearby farmlands or in a residential area. The locals even put their beds above or near the ground canals, so they will get a cool environment for sleeping.

Small collection ponds are often constructed at the end of the open channels to store water. There are usually many trees growing around the small reservoir and people can take water from it.

The system helped to make the Turpan area an oasis on the Silk Road route. It also helped to make Turpan an important fruit and vegetable growing area in China. It is said that in 1949, about 600 karezes were in use and they supplied most of the water used for irrigation.

Primitive Instruments used for the construction of tunnels

Sighting along the parallel rods

Two straight rods are tied together with two ropes of the same length, so that one rod hangs parallel to and below the other rod.

One rod is sighted along above the tunnel to set the correct direction and slope, and the other rod under the ground would replicate the angle and could be sighted along for the direction of the tunnel.

By levelling above ground and multiplying the inclination by the distance between wells they calculated what the depth of the next well should be. Then, by sighting along the two rods above ground, they make sure the rods are aligned identically.

Then the worker can dig the tunnel according to the direction the underground stick is pointing in. The stick method allows for underground tunnels to be dug successfully between two vertical wells.

Figure 5: A section of tunnel with blue lights shining on flowing water

Figure 6: A section of open channel with water flowing out of tunnels

Figure 7. Parallel rods to guide the direction of digging of tunnels

Oil Lamp and Shadow

Unlike the two-rod method that requires people sighting along rods above and below ground, the oil lamp method simply requires digging a tunnel in the direction of the shadow cast.

An oil lamp is seated in the middle of a tunnel several meters back from the digging face, and a worker turns his back to the oil lamps and face his shadow. The oil lamps used have a special design so that they only cast light in one direction.

This method is so effective that two workers could dig two tunnels according to the direction of the shadows in front of them until they finally connected.

The karez wells in the Turpan area totalled up to over 100 sets, among which 538 sets are in Turpan city, 418 sets in Shanshan and 180 sets in Toksun. The annual runoff volume of these karez wells amounts to 294,000,000m^3 which accounts for 30% of the total irrigated areas in Turpan area.

However, some Western documents mentioned that the Turpan karez systems are like the qanats that were used in Persia and the Middle East. It is not known who originally created this technology. Some documents mentioned that qanats started to be used in Central Asia in about 800 BC.

Origin of Karez Wells

Chinese historical documents show that the sinking method of the karez wells inside Xinjiang including the Western Region was introduced by the Han people. The majority of the ethnic minorities of the northwest borderland had not mastered the sinking technology by that time. It was Lin Zexu who stood out among all the people who advocated and promoted the karez wells as the most powerful and influential voice in modern times. Ever since then the karez wells have been part of the irrigation works.

Modern Technology and the Karez System

With advances in irrigation technology, deep wells have been drilled to pump groundwater to meet growing demands for household and agricultural use as well as the development of oil fields in the Turpan area. As a result, the groundwater level in a shallow aquifer, from where a karez system draws its water, continues to decline. According to Guan, *et al*, groundwater has declined 25m over 10 years in some areas of the Turpan Basin. As a result, many karezes lost their source water and went dry.

This is a typical example of the Javons paradox, which occurs when technological progress facilitates exploiting a resource and thereby increases the rate of consumption of that resource. With advances in pumping and irrigation technology to improve efficiency, there is an increase in the consumption of limited water resources in arid regions such as Turpan. The repercussion is that the groundwater reserve is being mined much faster than the aquifer is being replenished.

However, the karez system has its own limitations that curb its ability to compete with new technologies, such as a low discharge rate and — despite its low level of technology — intense labour requirements and high costs for construction and maintenance.

Preserving the Karez System

With karezes disappearing at an alarming speed, the United Nations and national Governments have raised concerns about their preservation. To protect the historic and cultural value of the karez system, multiple measures have been undertaken by agencies in Turpan. These include establishing and implementing Government rules and regulations for the protection of karez systems, designating select karez systems as protected areas, controlling the development of surface water systems at the headwaters of a karez, and curtailing the exploitation of deep groundwater in areas where the karez system will be preserved.

Efforts have also been made to preserve the karez system as a UNESCO World Heritage Site. Nowadays, the karez systems in Turpan attract thousands of Chinese and international tourists. In fact, a museum has been established to showcase the karez system in Turpan. Because karezes constitute a global heritage of human civilization, such international co-operation to protect karezes and to formulate strategies and technologies for their continued utilisation should be encouraged.

The karez is an impressive hydraulic engineering project as well as a cultural achievement. In China it is recognised as one of three major ancient engineering projects, along with the Great Wall and the Beijing-Hangzhou Grand Canal. Because the karez system has provided a safe and reliable water supply over the centuries, the communities that rely on it have referred to it as the "mother river" and "spring of life." This is particularly true in the Turpan and Hami prefectures in Xinjiang, where most of the region's karez systems are located.

However, karez systems have faced great challenges over the past several decades, including drying up, abandonment, damage, and pollution as a result of over-exploitation of groundwater through deep wells, the construction of reservoirs upstream, the development of oil fields, and other human and natural activities. In recent years, the United Nations and national Governments have raised concerns about and recognised the importance of karez systems. Plans have been drawn up and implemented to revitalise some karezes for use and to preserve some for cultural purposes.

In most cases, the karez system is not only a structure to extract groundwater, but also an integration of the history, culture, and unique knowledge of its builders. Karezes have created strong cohesion in their communities owing to the traditions and beliefs attached to them. Religious beliefs and cultural traditions also helped the karez system to be handed down as a legacy. In the past, the social arrangements in karez-based communities were directly related to the karez system. Essentially, people's importance and value were judged according to their water ownership rights in the system. A household's proximity to the system was a good indicator of the social or economic status of its residents.

The karez system is an important part of the ecosystem as well, as karezes provide water for native vegetation and play an important role for the survival of wildlife by providing water to these habitats through underground tunnels, shafts, and pools. ■

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