Survey of ancient water technologies in semi-arid and arid regions: traditional knowledge for the future
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ABSTRACT
There are many people on Earth today that live with severe water shortages and severe lack of sanitation, particularly among the poor. These people for the most part do not understand the knowledge base of methodologies of harvesting and conveying water and sanitation methods that have been around for thousands of years. A survey of ancient water technologies used in semi-arid and arid regions is presented in this paper. The survey will include methodologies used by Mesopotamians, the Persians, the Egyptians, and the Nabataeans. The attempt here is to explore how these traditional methods developed by the ancients in semi-arid and arid regions of the world could possibly be used to help solve the present-day water resources sustainability problems, especially in developing parts of the world. The advantages of the traditional knowledge of ancient water technologies are explored with the goal of determining ways to help poor people with water shortages and sanitation.

Key words | ancient water technologies, arid, semi-arid, traditional knowledge, water harvesting

THE BEGINNING OF WATER TECHNOLOGY

The physical and climate characteristics, as well as the hydrologic characteristics of arid and semi-arid regions has been discussed in detail by Mays (2001). Development of ancient water technologies had a beginning in the Fertile Crescent (see Figure 1). Modern-day countries with significant territory within the Fertile Crescent are Iraq, Kuwait, Syria, Lebanon, Jordan, Israel, Palestine, Cyprus, and Egypt, including also the southeastern fringe of Turkey and the western fringes of Iran. Water harvesting has always played a major part in water supply in semi-arid and arid parts of the world. ‘For millennia, traditional water harvesting systems in arid lands provided a means of sustaining human populations in areas that are otherwise barren’ (Hassan 2006). Methods of water harvesting are generally distinguished by the source of water they harvest e.g. groundwater, surface water, rainwater and floodwater (Haut et al. 2015). Since the early Babylonians and Mesopotamians in Asia (ca. 4000–2500 BC) (De Feo et al. 2014), and the Minoans in Europe (ca. 3000–1100 BC) (Angelakis & Durham 2008), harvested rainwater was used extensively in urban areas as is demonstrated by research reported around the world. The use of cisterns in semi-arid and arid lands has been well documented in the literature (Mays 2010, 2013; Mays et al. 2007, 2014).

FERTILE CRESCENT

Mesopotamia on the east side of the region referred to as the Fertile Crescent is where agriculture flourished and the earliest civilizations were born more than 8,000 years ago (Tamburrino 2010). On the alluvial plain of Lower Mesopotamia agriculture based on irrigation developed. A complex system of canals and waterworks developed, with the dual function of ensuring irrigation and being used as waterways (Tamburrino 2010).

The first wastewater drainage of the early cities began in the Fertile Crescent. Evidence of the oldest known wastewater drainage is in the Neolithic Age around 6500 BC in El Kowm (or Al Kawm), located between the Euphrates River and the city of Palmyra in Syria (Stordeur 1983; Cauvin 1997). This location was one of the first places where domestic infrastructure for water and wastewater was built (Violett 2005, 2007). El Kowm has been explored by the French archaeologist Danielle Stordeur, who also published a detailed report (Stordeur 2000). El Kowm had well-constructed and compartmented houses, many of which were built with drains for domestic wastewater. The houses also had lateral plaster-lined gutters between rooms, drainage holes through doorsteps or walls or combined systems that drained water from room to room before discharging it outside through the wall (Stordeur 2000). In the middle of a street at El Kowm, a 10-cm-wide semi-circular gutter was discovered that drained water from two adjacent houses (Stordeur 2000). According to Cauvin (1997), and de Contenson & van Liere (1966), similar drainage pipes have been discovered in Bourqras (Syria).

The early cities in Mesopotamia at the end of the 4th millennium BC or the beginning of the 3rd millennium BC had networks of wastewater and stormwater drainage. Cities included Habuba Kebira, Mari, Eshnunna, and Ugarit. Wastewater disposal facilities such as drainage facilities were available in the Late Uruk Period (ca. 3300–3200 BC) at Habuba Kabira, which is in modern Syria (Strommenger 1980). Habuba Kabira was a planned city built on elevated ground above the Euphrates River. The city had walls on three sides and the river on the fourth side. Cylindrical pipes (made of pottery) that obviously served as wastewater drainage pipes have been excavated.

**THE ANCIENT EGYPTIANS**

Throughout history humans have been fascinated with the Nile River, especially the Egyptian part of the Nile. Around 5,000 years ago this Nile River civilization started depending entirely on the Nile River and its annual inundation. The ancient Egyptians not only depended upon the Nile for their livelihoods, but they also considered the Nile to be a deific force of the universe, to be respected and honored if they wanted it to treat them favorably. Its annual rise and fall were likened to the rise and fall of the sun, each cycle equally important to their lives, though both remaining a mystery. Since the Nile sources were unknown up until the 19th century, the ancient Egyptians believed it to be a part of the great celestial ocean, or the sea that surrounds the whole world (Mays 2010).

The first actual recorded evidence of water management was the mace head of King Scorpion, the last of the Predynastic kings, which has been interpreted as a ceremonial start to breaching the first dike to allow water to inundate the fields or the ceremonial opening of a new canal (Strouhal 1992). Similarly others have interpreted the main part of the mace-head of the king as depicting irrigation work under his supervision. This mace-head indicates that the ancient Egyptians began practicing some form of water management for agriculture about 5,000 years ago.
One of the key unknowns in Egyptian history is the time when people began artificial irrigation, in particular canal systems, consciously as a means to improve the natural effect of the Nile (Strouhal 1992). Canals allowed the flow of floodwater to locations that could not be reached otherwise, and when the Nile flood levels were low, canal networks made artificial watering easier. Canals also were built for water traffic and for the drainage of marshes. The shift from natural to artificial flood irrigation was accomplished by late Predynastic times. As long as the annual Nile floods were consistently good, the Predynastic population density was not large enough to warrant artificial irrigation. The average Nile flood would allow a single crop season over a possible two-thirds of the alluvial surface.

Artificial irrigation was established by the 1st Dynasty (Butzer 1976). This included deliberate flooding and draining using sluice gates and water contained by longitudinal and transverse dikes. Artificial irrigation increased the area of annual cropland in relation to the flood stage, retained water in the basin after smaller floods, and allowed second and even third crops in some basins. This form of water management, called basin irrigation, consisted of a network of earthen banks, some parallel to the river and some perpendicular to the river that formed basins of various sizes. Floodwaters were diverted into the basins where the water was allowed to saturate the soil with the remaining water drained off to a downstream basin or to a canal. After the draining process was completed in a basin, crops were planted. King Menes, the founder of the 1st Dynasty in 3100 BC traditionally has been known as the first to develop a major basin irrigation project. Basin irrigation was carried out on a local scale as opposed to being centrally managed on a national scale.

Artificial basin irrigation was based upon the inundation of the Nile floodplain starting in early August. The floodplain was divided into basins ranging in size from 2,000 feddans (1 feddan = 4,200 m²) in the upper part of Egypt to 20,000 feddans in the Nile Delta (Said 1993). Figure 1 illustrates the concept of basin irrigation in which the basins were supplied with water by feeder canals. The bed level of the feeder canal was midway between low Nile and ground level with a natural downstream slope less than the slope of the Nile. Each canal supplied water to an average of eight basins arranged in succession. Dikes (levees) separated the basins with controls (masonry regulators) on the earthen embankments to control the flow of water into the basin. Average depths of water in the basins varied according to the local flood volume and stayed in the basins for 40–60 d after which the basins were drained (Said 1993). The basins were very level as a result of the water-laden alluvium that was deposited in the basins. During years of low flow in the Nile, basins were drained into the next downstream basin instead of back to the river.

Improvement of irrigation technology continued through the Dynastic period. The shift to lift irrigation was well under way during the 18th Dynasty and was effective by Roman times (Butzer 1976). Sometime after 1500 BC the ancient Egyptians began lift irrigation with the shaduf (shadouf), already in use in Mesopotamia, for irrigating small plots. This device allowed the irrigation of crops near river banks and canals during the summer. The shaduf had a bucket and rope attached to one end of a wooden arm with a counterbalance at the other end of the arm. This device typically lifted water up to 1.5 m. One shaduf could irrigate approximately 0.12 ha of land in 12 h.

The Sadd-el-Kafara dam (Dam of the Pagans) was constructed about 2600–2700 BC (Garbrecht 1985). Professor Henning Fahlbusch (personal communication) has confirmed that the dam was constructed around 2650 BC from his dating studies. This dam was the first attempt at storing water on a large scale (Murray 1955; Garbrecht 1985). Possibly older dams include the Jawa reservoir in Jordan and diversion dams on the Kasakh River in the southern part of the former Soviet Union. However, these structures were much smaller than the Sadd-el-Kafara dam, allowing us to refer to this dam as the world’s oldest large-scale dam (Garbrecht 1985; Schnitter 1994). This dam was constructed in the Wadi Garawi, approximately 30 km south of Cairo on the eastern Nile bank, for flood protection of installations in the lower wadi and in the Nile Valley. The dam was still in the construction phase (about 8 to 10 years) when it failed as a result of a flood catastrophe. There was no channel or tunnel to divert the river around the construction site (Schnitter 1994). It was another eight centuries before the Egyptians constructed another dam. The Sadd-el-Kafara dam was discovered in 1885 by the German archaeologist G. Schweinfurth (Smith 1971).

The Faïyum (or Fayum) Depression, located about 60 km southwest of Cairo, is a huge (1,700 km²), geological depression (below sea level) that begins 20 km west of the
Nile Valley, extending into the western Libyan desert region. A vast saltwater lake (Lake Moeris) was in the heart of this region until the Paleolithic Period. Historically, a natural channel, the Bahr Yusuf, branched off the Nile River about 334 km south of the Faiyum Depression, located along the valley’s western escarpment, and connected the Faiyum to the Nile River through the Hawara Channel. High water levels in the Nile resulted in the formation of a lake within the Faiyum. During the Old Kingdom a permanent lake existed in part of the depression. In the Middle Kingdom the kings directed that the Hawara Channel be cleared to permit excess floodwaters from the Nile to enter the depression, sparing the Delta from flooding. After the flood the water drained from the Faiyum back to the Nile. Flood control was no longer deemed necessary by the time of the Ptolemaic kings (Graeco-Roman period) and the Faiyum was exploited for agriculture. The Bahr Yusuf was used to convey irrigation water into the depression and then was dispersed by canals across the fields. Drainage water was conveyed to the deepest part of the depression to collect in Lake Qarun. Prior to the time of the lowering of the lake, the Faiyum Depression was a natural storage for a large portion of the floodwaters, protecting the lands of Lower Egypt.

THE BRONZE AGE: INDUS VALLEY CIVILIZATION

Urban hydraulic systems are dated back to the Bronze Age (ca. 3200–1100 BC) in arid regions. Mohenjo-daro, once a major urban center of the Harappa Culture or Indus Civilization, is an example of an early Bronze Age civilization that had impressive water supply and effluent disposal systems. Mohenjo-daro is located about 400 km north of modern-day Karachi, Pakistan, and was built around 2450 BC. According to Jansen (1989) there were around 700 wells (with an average frequency of one in every third house) more than 15 m deep and often located in houses that had bathing rooms and often latrines. Clay pipes drained wastewater from rooms. The pipes were constructed through walls to gutters covered with slabs. Wastewater then flowed into brick-covered channels that were dug under the walkways and then into larger collectors. Settling basins were also used to collect debris to prevent blockage (as described by Jansen (1989) and Violett (2007)). Figure 2(a) shows the excavated ruins of Mohenjo-daro, with the Great Bath in the foreground and the Buddhist stupa in the background. Figure 2(b) shows a water chute and inspection chamber joining the main drain at Lothal.

Figure 2 | Excavated ruins of Mohenjo-daro and Lothal: (a) Great Bath at Mohenjo-daro in the foreground and the Buddhist stupa in the background (Source: Wikipedia, by Saqib Qayyum, licensed under Creative Commons, the GNU Free Documentation License) and (b) water chute and inspection chamber joining the main drain at Lothal (Rao 1979).
PERSIA AND THE QANATS

‘A qanat is a collection and conveyance system for groundwater that was developed in Persia. A qanat [illustrated in Figure 3] consists of an underground tunnel which uses gravity to convey water from the water table (or springs) at higher elevations to the surface of lower lands. Qanats also have a series of vertical shafts that were used for excavation of the tunnel and provided air circulation and lighting’ (Mays 2008). The oldest qanats have been found in the northern part of Iran and date back to around 3,000 years ago when the Arians settled in present-day Iran (Javan et al. 2006). The longest (71 km with 2,115 vertical shafts) and oldest (over 3,000 years) is to the ancient city of Zarch. Qanat comes from the Semitic word meaning ‘to dig’ (Moosavi 2006). Presently there are about 33,000 operational qanats in Iran (Javan et al. 2006).

During 550–331 BC Persian rule extended from the Indus to the Nile, during which time qanat technology spread. As this technology transferred to other civilizations, it was known by different names: khettara (Morocco), karez (Afghanistan and Pakistan), kanerjing (China), falaj (United Arab Emirates), and joggara and fughara (North Africa). Qanats were constructed to the west of Persia from Mesopotamia to the Mediterranean and southward into parts of Egypt. Qanats were also constructed to the east of Persia in Afghanistan, in the Silk Route oases settlements of central Asia and to Chinese Turkistan. The Persians introduced qanats to Egypt around 500 BC.

The Nabataeans

AbdelKhaleq & Alhaj Ahmed (2007) discuss rainwater harvesting used in ancient civilizations in Jordan. Alkhaddar et al. (2005) discuss water harvesting techniques in Jordan. Nabataean Petra (located in Jordan) began around 300 BC from nomadic settlement origins. The city was also occupied starting around 106 AD with final occupation to the 7th century AD. Petra was located between Egyptian, Babylonian, and Assyrian territories. Petra’s location, as an intersection for caravan trade from Arabia, Africa, and the Far East, sustained the life and wealth of the city. Special water supply infrastructure was developed for its survival as a result of the complex topography and the limited water resources of the area. The Nabataeans had a tremendous understanding of the natural flow of water in the unique surroundings. Water infrastructure included terraces, channels, settling basins, aqueducts, dams, rainwater harvesting, flood harvesting, groundwater harvesting, a large range of size and types of cisterns, reservoirs created by dams, water distribution tanks, and springs. Throughout the Petra area there are hundreds of cisterns. Rainwater harvesting was used extensively in and around Petra by the Nabataeans. This meant using the technology on the high places and on bare sandstone walls with many innovations.

The Nabataeans used various types of cisterns that they carved out of the rock and waterproofed using chalk. These cisterns ranged from small pools on the highlands to catch runoff to rectangular-shaped cisterns at the bottom of the natural drips (see Figure 4(a)). Small pools were carved out of the highlands and evolved into bell-shaped cisterns.
Figure 4(b) shows a large cistern at the Triclinium of the Garden which measures 18.2 m long, 6 m wide and 3.6 m deep. These large cisterns are similar to large rooms carved out of vertical walls into which complex canals and pipe networks flow (Laureano 2001, 2006). What is so unique is that the Nabataeans used every slope and surface as a means to harvest rainfall and stored every water source from a few drops to the large floods. This is why Strabo, the 1st century geographer, described Petra as ornamented with fountains and basins (Laureano 2001, 2006).

The Nabataeans also used khottara, which collect traces of moisture and night condensation of fog and dew by harvesting the condensation (humidity) by dripping into tanks, cisterns, or channels that catch the water on the walls and convey it to pools. These structures provide water year round. At the other extreme, one cistern called Bir Huweimel at the bottom of Ras as-Slimane actually traps floodwater using a large room (depth of 9 m) excavated in the riverbed. Floodwater is diverted to water intakes and decanting basins to fill the large cistern where the water is stored. A staircase is used to enter the cistern and water is drawn from the cistern from a well.

Humayma was a small trading post and caravan way-station, founded by the Nabataean King Aretas III in the 80s BC. The water management system was impressively developed for the settlement area taking into account the runoff potential of the area and the ability to design the settlement to capture the water. Figure 5(a) shows an underground cistern that is part of a flood harvesting/rainwater harvesting system. The cistern has arches that were used
to support a roof system that would have decreased the amount of evaporation. Beckers et al. (2012/2013) provide a discussion of ancient water harvesting in arid regions of the Mediterranean and western Asia with more detail on the water harvesting at Humayma. Figure 5(b) shows a rock-cut cistern with plaster on the walls and support locations for the arch cover at Humayma.

CONCLUSIONS: WHY IS TRADITIONAL KNOWLEDGE IMPORTANT?

Mays (2007a) defined water resources sustainability as ‘the ability to use water in sufficient quantities and quality from the local to the global scale to meet the needs of humans and ecosystems for the present and the future to sustain life, and to protect humans from the damages brought about by natural and human-caused disasters that affect sustaining life’. The ancients, for the most part, practiced sustainable water use through building water structures that were adapted to the environment and were fitted into nature (Mays 2010).

‘Traditional knowledge are the ancient techniques and practices of a territory passed on through the generations and used for water harvesting, soil management, use, and protection of natural areas, rural architecture, and for organizing urban centres’ (Laureano 2006). The United Nations Convention to Combat Desertification (UNCCD) selected a Science and Technology Committee to look at the inventory and classification of traditional knowledge. The following definition of traditional knowledge was developed:

‘Traditional knowledge consists of practical (instrumental) and normative knowledge concerning the ecological, socio-economic and cultural environment. Traditional knowledge originates from people and is transmitted to people by recognizable and experienced actors. It is systematic (inter-sector and holistic), experimental (empirical and practical), handed down from generation to generation and culturally enhanced. Such a kind of knowledge supports diversity and enhances and reproduces local resources.’

‘Modern technology aims at an immediate efficiency through a high specialization of knowledge supported by dominant structures able to mobilize resources external to the environment’ (Laureano 2001, 2006). An example of modern technology would be to dig deep wells and pump to an extent that would harm water supplies for the future, which has been done in so many places in both the developing and developed parts of the world. Traditional knowledge would have relied on a system for harvesting meteoric water or exploiting run-off areas using the force of gravity or water catchment methods that would allow the replenishment and increase the durability of the resource (Laureano 2001, 2006).

The looming present-day water crisis must be faced using traditional knowledge and techniques inherited from the past in addition to our present-day technological capabilities for more sustainable ways of dealing with water scarcity, particularly in developing parts of the world. Many present-day water problems could be solved using the traditional methods developed and used for hundreds of years by the ancients. In parts of the western world, the philosophy of ‘having it all and all at once’ unfortunately has spread around the world. This has blinded many people to the forgotten sustainable ways of the ancients. So in reality highly advanced methods are not required to solve many water problems, particularly in many of the poor and developing parts of the world. A large part of the future will be to live in concert with nature, not trying to defy it. There are many references addressing the use of ancient water technologies that can be used for the purposes of addressing the water sustainability issues of the poor in the world today, including: Angelakis et al. (2012), Hassan (2006), Laureano (2001, 2006), and Mays (2007a, 2007b, 2010, 2014).

REFERENCES


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