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HISTORICAL EXPERIENCE OF ARCHITECTURAL AND ENGINEERING SYSTEMS OF RAINWATER HARVESTING

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Abstract

At present, under conditions of the water crisis, unconventional water resources (UWR) are becoming increasingly important. One of such alternative water resources is rainwater. Studying the history of the development of ancient civilizations, it is possible to observe how the collection, management and reuse of rainwater provided water security for cities and settlements. This article analyzes methods of rainwater management in ancient times. The hydraulic engineering structures of the ancient city of Petra, the water collection systems of Ancient Greece and Byzantium, Indian stepwells and Central Asian sardobas are considered. Their design features, principles of water accumulation and storage, applied construction materials and waterproofing methods are analyzed. It was established that the structures were adapted to natural and climatic conditions in order to minimize water losses and rationally use atmospheric precipitation. Based on historical experience, possibilities for implementing technologies in modern conditions to solve the problem of water scarcity are also highlighted, especially for regions with an arid climate experiencing water deficiency.

Keywords: rainwater harvesting, sustainable management, water crisis, water resources management, water security, reuse.

Introduction

Water has been the most important resource at all times; however, the amount of water on the Earth's surface is limited and under threat. Of the 1.4 billion km³ of water in the world, 97.5% is saline water and 2.5% is freshwater. The distribution of freshwater is 69.5% in polar glaciers, 30.1% in groundwater and 0.4% in surface water resources. The solution to the problem of water stress may be hidden in an invisible source of water surrounding us everywhere, namely rainwater.

Beginning with the earliest civilizations, populations of arid and semi-arid regions actively used rainwater harvesting. They struggled to control the water resources around them, creating complex water storage systems and pipelines to ensure the survival of their communities. Archaeological evidence indicates that rainwater harvesting was already practiced in Crete during the Neolithic period (approximately 7000–3200 BC). Later, during the Bronze Age (3200–1100 BC), the improvement of water harvesting systems was associated with the need for effective water resource management, adaptation to the climatic conditions of the region, and ensuring the water security of settlements.

Over time, many strategies for the conservation and management of water resources were applied, but only a few of them proved successful. One of the effective strategies for providing water to arid territories was the collection and storage of rainwater. Rainwater harvesting is a set of methods for collecting rainwater and storing it on the ground or underground, in soil or in reservoirs for various purposes. Studying the historical experience of managing, collecting and filtering precipitation for its reuse may help modern sustainable development approaches to apply these technologies.

Petra. In the ancient city of Petra in Jordan, where mountainous relief prevailed, scarce precipitation and reserves of spring water were always observed (Selvaraj et al. 2022). The local inhabitants, the Nabataeans, known for their ingenuity, created a unique system of cisterns, dams, channels, wadis, barriers and water terraces for water storage (Akasheh et al. 2002). Numerous stone cisterns were waterproofed with chalk-based hydraulic plaster, which contributed to their preservation and allowed many of them to survive to the present day (Bellwald et al. 2003). The Nabataeans scaled and adapted the ideas of the Mesopotamians, Egyptians, and Hellenists in a vertical, arid landscape where riverbanks were replaced by rocks and floods occurred without warning. They created a complex network for diverting seasonal water consisting of more than 200 kilometers of rock-cut channels, pipelines and clay pipes, dozens of aqueducts, and hundreds of rock-cut cisterns. Every drop of rain mattered (See Fig. 1).

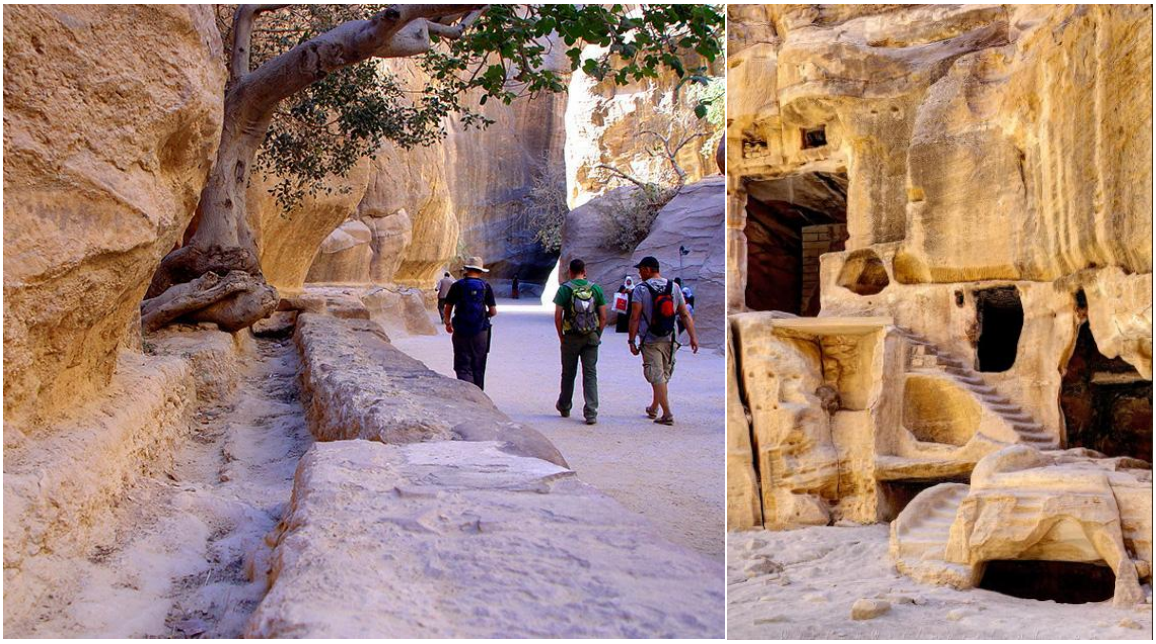


Figure 1. Ancient aqueducts and cisterns carved into rock. Nabataean period. Petra. Jordan.

Ancient Greece. In Greece and other countries of the Mediterranean, the collection, storage and use of rainwater are a tradition counting thousands of years (Angelakis et al., 2025). During the flourishing of the Minoan civilization (approximately 3200–1100 BC), various advanced technologies for the use of unconventional water resources were applied, including wells, cisterns, drains, fountains, canals, settling tanks and aqueducts (Mays et al., 2013). Ancient Greeks and Romans used roofs and inner courtyards for the accumulation of atmospheric precipitation and their use for domestic needs (See Fig. 2). Such roofs with an opening in the roof were called compluvium. Rainwater entering the sunken basins located in the center of the atrium of a Roman house (impluvium) was usually diverted into an underground cistern for storage and household use (Dobbins & Foss, 2007). Archaeological evidence indicates the possible reuse of wastewater for irrigation of agricultural lands. Small cisterns in the Palace of Phaistos were equipped with coarse-grained sand filters for preliminary purification of rainwater collected from open inner courtyards (Angelakis et al., 2025). This is an example of the early development of the principles of sustainable water use and adaptation of architecture to natural and climatic conditions (Ahmed et al., 2020).

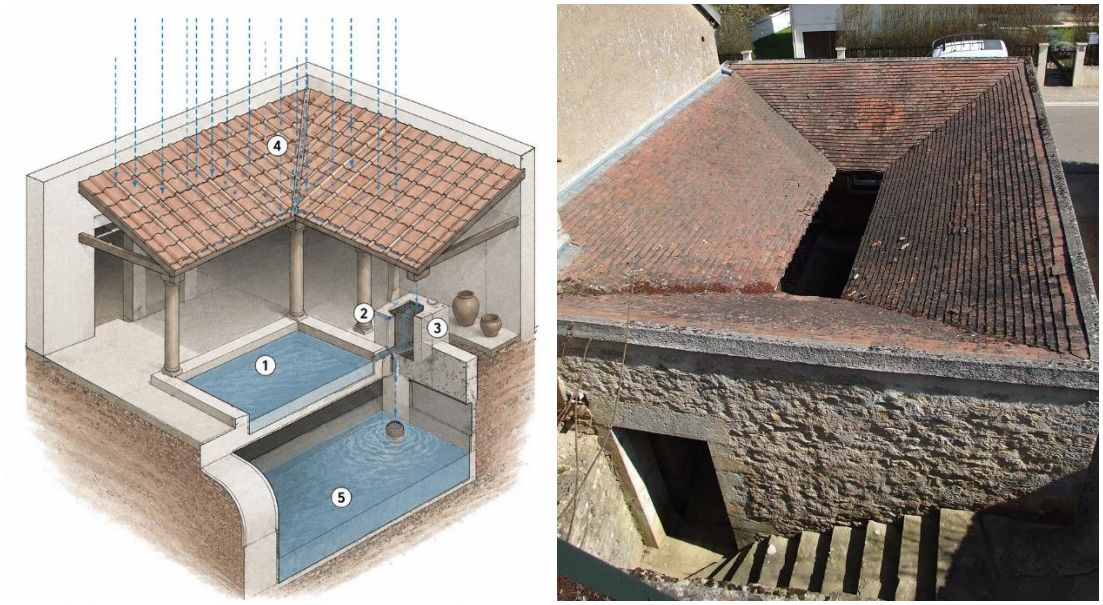


Figure 2. Ancient Roman domus with an opening in the roof for rainwater collection.

Byzantium. During the Middle Ages in the Byzantine Empire, with its capital in Constantinople, the traditions of hydraulic engineering construction were preserved, where a complex system of water accumulation and distribution functioned (Haut et al., 2018). The water security of Constantinople was ensured not only by covered cisterns filled through aqueducts, but also by large open reservoirs. According to researchers, the total capacity of the underground cisterns of the city was about 200,000 m³, whereas open reservoirs could accumulate up to 800,000 m³ of water (Mays et al., 2012). One of the most famous examples of open reservoirs is the Cistern of Aspar (Xerokepion) or ("Dry Garden"), built in the 5th century AD. It was a large rectangular reservoir intended for the accumulation of significant volumes of water in the urban environment. To ensure the waterproofness of such reservoirs, a special waterproof coating was used, preventing water filtration through the base and walls of the structure, and the bottom was lined with large stone slabs (Sevimli 2021). Today, in modern Istanbul, the territory of the Cistern of Aspar is used as the urban park Çukurbostan Parkı, which translated from Turkish means "Park in a Sunken Garden". This is an example of blue-green infrastructure in modern practice within the concept of nature-based solutions (See Fig. 3).



Figure 3. Cistern of Aspar and later "Park in a Sunken Garden". Istanbul. Turkey.

India. Throughout history, Indians developed various methods of accumulating and using rainwater to prevent its shortage. Small wells gradually evolved into structurally complex stepwells intended for storing water for both current and future needs. One of the most striking

examples of traditional Indian underground structures for rainwater collection is the Chand Baori stepwell in the state of Rajasthan (See Fig. 4). Built between the 9th and 10th centuries, this monument of ancient architecture has a depth of more than 30 meters with 3,500 steps on 13 levels (Chandra, S 2015). Water in these wells accumulated during the monsoon season and was preserved for the dry months.

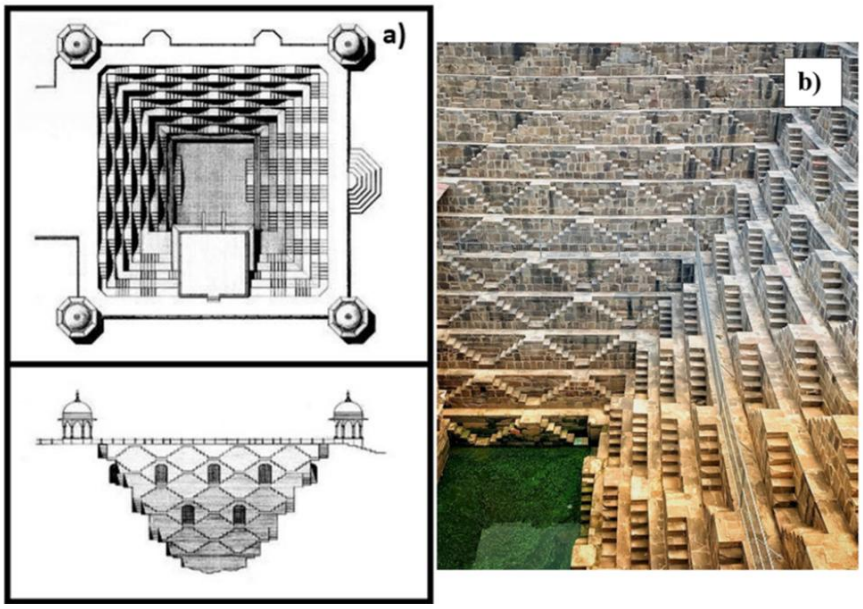


Figure 4. Chand Baori stepwell in the state of Rajasthan.

As construction materials, a wide variety of stones, bricks, lime, clay and wood were used depending on the geographical and geological characteristics of the area. In the production of Lahori bricks, agricultural waste, such as rice husk, was used, which is closely connected with the principles of the circular economy (Selvaraj, 2022). The features and structural aspects of stepwells completely depended on the ruler's instructions and on the geographical and topographical suitability of the location.

Central Asia. Sardoba. From the beginning of the 9th century to the beginning of the 13th century, the flourishing of trade and crafts, as well as socio-economic relations and science in Central Asia, led to a significant increase in construction along trade caravan routes, including the construction of sardobas (Mahmatqulov, 2024). A sardoba is a basin for collecting, storing and using fresh drinking water, sunk into the ground and covered with a stone dome. The dome of the sardoba — gumbaz — reduced water evaporation, protected against dust and sand storms, and also provided constant shade (Masson, 1935). Sardobas provided safety and water for long-distance caravan transportation in the harsh conditions of the desert regions of Central Asia (Usarov, 2025). The place for the construction of a sardoba was selected carefully, placing it in a lowland where meltwater and rainwater flowed naturally over the clay surface. The depth of sardobas ranged from 10–15 m to 38–40 m depending on the location, the wall diameter was 12–16 m, and their thickness was 1–1.5 m (See Fig. 5). The dome of the sardoba was made of high-quality brick and a special mixture called "Kir" (Khasanov, 2016). A completed sardoba was a very expensive structure because it was built under the supervision of a master-usto for about 5–7 years. The usto was an architect, an engineer, a builder, and a technical supervisor of construction.

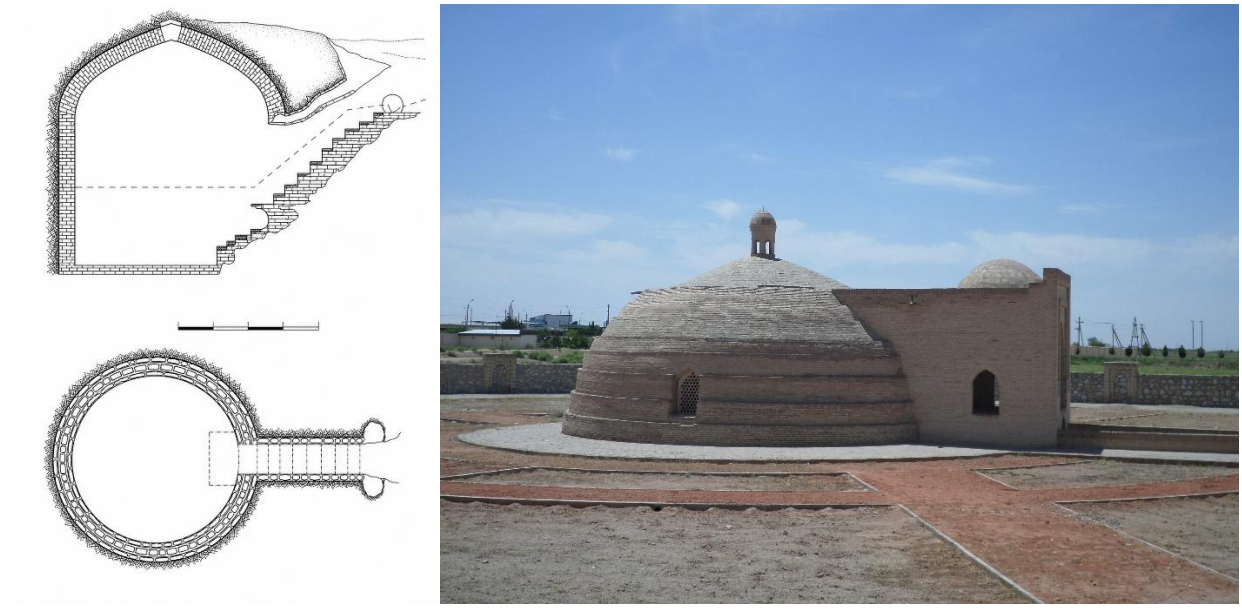


Figure 5. Malik Sardoba. Navoi. Uzbekistan.

The basis for the construction of sardobas was bricks made of heat-resistant clay extracted in the lower reaches of the Amu Darya. To achieve waterproof and heat-insulating properties, the clay-gel was mixed in a special way with the addition of camel wool. The design of sardobas included entrance openings and a system of internal descents to the water, as well as ventilation openings providing air exchange inside the structure (Masson, 30–33 p. 1935).

Conclusion

The conducted analysis of historical experience showed that ancient societies sought the accumulation, storage and rational use of atmospheric precipitation through the construction of cisterns, reservoirs, stepwells, aqueducts and other hydraulic engineering structures. Different civilizations developed effective ways of adapting to conditions of limited water resources through the creation of architectural and engineering rainwater harvesting systems in accordance with geographical location and climatic characteristics. The analysis showed that many principles of the historical water harvesting systems of Petra, Ancient Greece, Byzantium, India and Central Asia were based on the use of local construction materials, waterproofing of structures, protection of water from evaporation and ensuring its long-term storage. The historical experience of rainwater management can be adapted for modern cities and settlements, especially in regions with an arid climate and a growing shortage of water resources.

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