Historical development of rainwater harvesting and use in Hellas: a preliminary review

S. Yannopoulos, G. Antoniou, M. Kaiafa-Saropoulou and A. N. Angelakis

ABSTRACT

The uneven temporal and partial distribution of water resources in Hellas, and especially southeastern regions, has resulted in the construction of various water systems for collection and storage of rainwater, since their very early habitation. Ever since, technologies for the construction and use of several types of cisterns and other relevant hydraulic strictures have been developed. The main diachronic achievements in rainwater harvesting and use in Hellas from the earliest times of humankind to the present is studied. Emphasis is given to the periods of great achievements such as the Hellenistic and the Roman. The major necessity of water justifies not only the innovations found throughout the historical time-line of these constructions but also the most advanced engineering of each era applied to these constructions. Also, the importance of this hydrotechnology and the concept of the value of water-saving to present and future times is considered. Aspects referring to hygienic precautions for the purity of the water collected and stored are another issue that is worth examining.

Key words | Bronze Age, classical and Hellenistic periods, flood risks, modern and future times, rainwater harvesting, Roman and post-Roman times

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INTRODUCTION

The English term 'rainwater harvesting' has been internationally widely accepted (Koenig & Sperfeld 2006). Moreover, it is interesting that emphasis is not on the utilization of rainwater but on its harvesting. The noun 'harvesting' means crop or yield and it is a synonym for 'gift of nature'. So, 'it goes without saying that the harvested should be also utilized and every yield is preceded by its own activities'.

However, there is no unified definition of the term 'rainwater harvesting' commonly accepted by the scientific community. Researchers employ a wide variety of terms and definitions to describe the various methods aimed at using, collecting and storing rain runoff in order to increase the availability of water mainly for domestic and agricultural uses in arid and semi-arid areas (Haut *et al.* 2015). Namely, they use terms depending on their own purposes and they do not attempt to give any strict definitions. Generally speaking, the term rainwater harvesting is used as an umbrella term for a range of methods of concentrating and storing rainwater runoff, including from roofs (rooftop harvesting), the ground (runoff harvesting) and from channel flow (flood water harvesting), from various sources (rain or dew) and for various purposes (agricultural, livestock, domestic water supply, environmental management). In fact, rainwater harvesting is the collection, conveyance, and storage of rainwater for future use (domestic, agricultural, livestock, environmental management), while a water harvest system can be defined as a system of catching and storing rainfall until it can be beneficially used. For the purposes of the present paper, we adopt the definition of

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Antoniou *et al.* (2014) according to which rainwater harvesting is the collection of atmospheric precipitation, usually collected and stored in artificial reservoirs known as *cisterns* in order to be used for household purposes such as bathing and washing, as well as irrigation and other urban uses and after appropriate treatment to be used in dwellings, offices, housing estates, industry, horticulture, and parks.

Rainwater harvesting for supplying drinking water in urban areas has a long history especially in semi-arid areas. From establishing the first permanent settlements in the late Neolithic to early Bronze Age period, people in Mesopotamia (e.g. today Iraq and Jordan) realized that life is not possible without water and one of the first practices for water supply was rainwater harvesting. Such water supply systems are known in Minoan Crete and in the Indus valley *ca.* 3rd millennium BC where purposeful construction and operation of water supply networks and bathrooms have been discovered (Angelakis 2016). Water harvesting was also used in India and China from the 3rd millennium BC (Oweis *et al.* 2004). Runoff originating from rainwater over a surface (e.g. roof, yards, and other open urban areas) could be collected and used for various uses. It is an old practice that has widely been used to provide urban dwellers with a potable water supply in many parts of the developing world (Handia *et al.* 2003).

Rainwater harvesting is a non-conventional technology, used to overcome the increasing demand for water due to climate changes and/or variability (Amin *et al.* 2014). This applies especially for arid and semi-arid climate conditions, such as the regions around the Mediterranean basin and especially in southeastern Hellas, where water resource availability is extremely limited mainly during the summer (Mays *et al.* 2013). Hellas has a great history in rainwater harvesting since prehistoric times and in addition very low water availability is faced particularly in southeastern regions (Angelakis *et al.* 2014a). Thus, old Hellenic water management practices could offer lessons and challenges for improvement of today's and maybe future water technologies.

Harvesting, conservation and reuse of rainwater are a sustainable practice by which not only water availability could be substantially increased but also flood risks could be eliminated (Haut *et al.* 2015). In the future, decentralized multi-purpose rainwater harvesting systems should be useful infrastructure to mitigate water-related disasters such as flooding, sudden water break and fire events, especially in highly developed future urban areas (Pazwash 2016). Nowadays, the art of collecting rainwater has received renewed attention and interest in many countries of the world as a viable decentralized water source (e.g. German, Italy, and Spain in Europe; India, China, Malaysia, Korea, and Japan in Asia; Kenya, Ethiopia, Syria, and Tunisia in Africa; several states of the USA and Canada in North America; Brazil in South America; and Australia and New Zealand).

The aim of this paper is to present the main diachronic achievements in rainwater harvesting and use in Hellas, from the earliest times of humankind to the present. Emphasis is given to the periods of great achievements. Also, the importance of this hydro-technology for present and future times is considered.

PHYSICAL SETTINGS

Hellas is a rather mountainous area of 131,962 km^2, located in southeastern Europe. It has one of the longest coastlines in the world, almost 16,000 km. Half of the aforementioned length includes the approximately 6,000 Hellenic islands (EOT 2012). Hellas has a strategic location, positioned between Asia, Africa and Europe and forming a natural and vital bridge between the three continents. This unique geographical position has determined its historical course throughout both ancient and modern times. The total population of Hellas is 11,200,000 inhabitants.

Climate

The Hellenic territory has a generally warm, temperate type of climate, which is characterized by mild, rainy winters and dry summers. According to the Koppen climate classification, based on temperature and atmospheric precipitation, the climate of almost all the country falls in the category **Csa**. The category **C** refers to the humid climate with mild winters, the first subclassification **s** concerns the dry summer and the second one the long and warm summer. That means the Mediterranean climate, characterized by mild, wet winters and mild, hot and dry summers, because of the influence of subtropical anticyclones (Koutsoyiannis *et al.* 2008).

Hydrology

Although Hellas receives enough rainfall to meet all its needs for water, unfortunately the water resources of the country are mismanaged. The total annual volume of precipitation averages 116,330 Mm^3/yr, putting Hellas at least equivalent with many other European countries (CCISC 2011). Concerning hydrology Hellas confronts many complex situations among which the most predominant are: (a) uneven temporal distribution of precipitation, namely during the wet season (winter) falling as 85% of the total precipitation and the rest (dry season) taking place during the summer; (b) highly uneven spatial distribution of precipitation; (c) the northern part of the country being affected by transboundary waters (four major rivers originating in neighboring countries, namely the rivers Strymon, Nestos and Evros from Bulgaria and the Axios River from FYROM); (d) imbalance of water demand with peak abstraction for irrigation and tourism purposes in the summer months, when the available water resources are at a minimum (practically no rainfall); and (e) highly uneven spatial distribution of demand, as a result of overconsumption associated with the excessive concentration of people in the urban centers, semi-arid touristic islands, and other areas.

A decrease in atmospheric precipitation in recent years is indicated (Koutsoyiannis *et al.* 2008). The available measurements show that, in the course of the past century, precipitation decreased by around 20% in western Hellas and by 10% in eastern Hellas (CCISC 2011). However, in regard of there being a more permanent climate change in the country, the limited range of reliable hydrological time series in connection with the inherent complexity and large climate variability and uncertainty does not allow safe conclusions (Markonis & Koutsoyiannis 2013). Such trends, which are universal phenomena throughout the period of history for which there are measuring data around the planet, and all geophysical processes constitute the conceptual basis of the physical behavior known as long-term persistence or the Hurst phenomenon (Markonis & Koutsoyiannis 2013). Regardless of the causes of the observed trends or changes in climatic conditions and anthropogenic influences on them, climatic variations and the Hurst phenomenon should be taken into account in the management of water resources as an important additional source of uncertainty.

PREHISTORIC TIMES (*CA.* 3200–1100 BC)

Minoans developed remarkable technologies for collecting and transporting water to settlements on Crete and other islands (Mays *et al.* 2013). Different techniques were applied to ensure the water supply, as (a) management of spring and runoff water locally and (b) transportation and storage of water. These techniques were differentiated according to local hydrogeological conditions and the size of the settlements (Angelakis *et al.* 2014b). Also during Minoan times, the focus of water and wastewater management was on sustainable small-scale, water safety, cost-efficient, and environmentally friendly management practices.

Due to very dry summers, rainfall collection was accomplished from open surfaces (e.g. roofs of buildings and yards). Hydraulic structures associated with rainfall collection were found in Knossos, Phaistos, Tylissos, Aghia Triadha, Myrtos Pyrgos, Zakros, and Chamaizi (Figure 1(a)). These hydraulic structures include large stone conduits with branches that were used to supply collected water to cisterns. Terracotta pipes were also used to convey rainwater to cisterns (Angelakis 2016). In Myrtos, Pyrgos, such a terracotta pipe of rectangular cross-section supplied the nearby cistern system with stormwater collected from the rooftops (Cadogan 1978). By the collecting systems water was conveyed into cisterns, a technique still practiced today in rural areas of the Hellenic islands. This technology of rainwater storage for water supply was very well developed and was continuously used up to modern times (Mays *et al.* 2013). The Minoan water cisterns were of cylindrical shape, constructed with stones under the soil surface, with a diameter ranging from 1.5 to 7.0 m and depth from 2.5 to 5.0 m.

One of the salient characteristics of the Minoan era in Crete was the treatment devices used for water supply in palaces, cities, and villages from the beginning of the Bronze Age (Spanakis 1981). The major such treatment devices are terracotta filters and sand filters (Figure 1(b)).

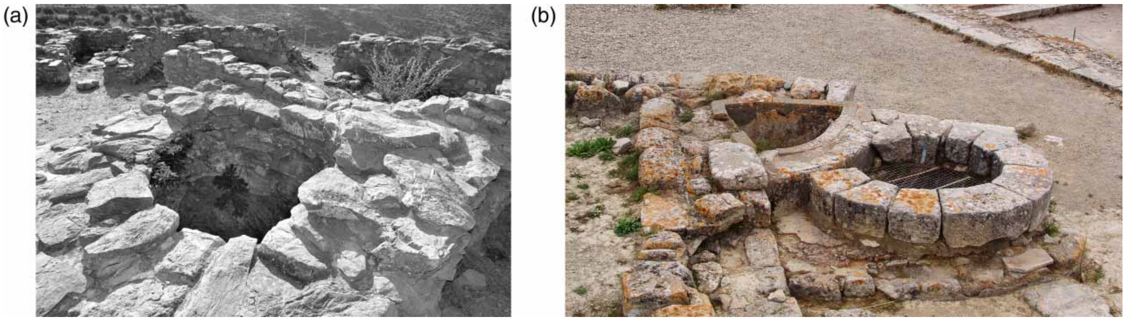

Figure 1 | Minoan rainwater cisterns: (a) in Chamaizi village and (b) sand filter and water cistern in Phaistos palace.

HISTORICAL TIMES (*CA.* 500 BC–AD 330)

Classical and Hellenistic periods

As Koutsoyiannis & Patrikiou (2013) pointed out, the most important centers of the so-called *poleis* (plural of *polis*) or *city-states* were built in the driest areas of ancient Hellas. Although the exact reasons are unknowns, it is assumed that ancient Hellenes might have considered a dry climate as more convenient (i.e. protection against floods) or healthier (i.e. protection from water-related diseases). Thus, all the most important Hellenic cities since the Bronze Age, lasting for millennia, were established in areas under water scarcity (Yannopoulos *et al.* 2015).

In many of these *poleis*, mainly the Aegean Islands, classical and Hellenistic Crete and other waterless regions of the mainland and in their *acropoleis* (plural of *acropolis*) there existed no springs, deep wells or any other source of water inside the fortified settlements. To ensure a water supply for the inhabitants, especially in case of siege, the ancient Hellenes built cisterns to collect rainwater during the rainy season.

It is a fact that both in archaic and classical times, and furthermore during the Hellenistic era, rainwater cisterns were widely used and improved. Indeed, the appearance and the wide spread of aqueducts in Hellenic cities from the 6th and 5th centuries BC did not displace the role of rainwater tanks. In some cases, as in Morgantina or Delos (Bezerra de Meneses *et al.* 1970), rainwater collectors constituted organic elements of the buildings, especially the most luxurious. For example, regarding Morgantina the earliest cisterns of the *ca.* 5th century BC were of irregular shape, wide mouthed, hewn and lined with stucco, while those subsequent, of the 3rd century BC, had a narrow mouth, long neck and bottle-shaped profile (Crouch 1993).

During the different historical periods, archaic, classical, and Hellenistic, Hellenes were improving the technology of the Minoans and Mycenaeans with regard to cisterns. Over time the technology of the construction of cisterns showed further progress. Especially during the Hellenistic period, the water supply in several cities all over Hellas was dependent entirely on precipitation, since the ancient Hellenes here harvested rainwater from the roofs, yards and other open spaces of establishments into cisterns.

They were varied in construction methods and building materials and capacity, as their dimensions depended on their private or public use and the needs that had to be covered. The medium (for that era) capacity of the water tank of the *ca*. 2nd century BC in Aiani (Kozani), which approached 40 m^3, justifies its public use. It is a deep circular rock-cut cistern lined with masonry in its upper part (Karamitrou-Mendesidi 1989). In contrast, large-scale rainwater cisterns undoubtedly had public use, such as the 500 m^3 cistern at Orraon. In that case the cistern is located by the main gate of the Hellenistic town and was inside an enclosure. There are reconstructions which show it either covered (Hoepfner 1999) or uncovered (Antoniou *et al.* 2006). In general there was an effort to ensure the quality of the water, building either an enclosure around the tank or a roof or in many cases both. The surface of the enclosure or/and the roof were the runoff surfaces of the cistern.

Water was usually led to them from the buildings' roofs by downspouts. Round or rectangular in ground plan, roofed or not, they were always coated with impervious material, and most usually were built below the ground level. Waterproofing was achieved by coating all the internal surfaces with hydraulic mortar; however, this method was not the only one. In a small rectangular tank on Stageira of Chalkidiki the inner surfaces, were covered with, instead of cement, a thick lead sheet, which means that its content was intended for other needs than drinking (Sismanidis 2003). Frequently the mouth of rainwater collectors was narrower than the rest so as to ensure limited access and evaporation, for which these water constructions were known as 'bottle cisterns' (Hodge 1992). This type of flask-shaped cistern was quiet common in the 5th century BC and was still preferred during the Hellenistic period. Rectangular and circular cross-section storage cisterns have been found in many public and private buildings all over Hellas (e.g. Lato, Dreros, Stageira, Santorini, Amorgos, Pella, and Delos). In some castle areas, cisterns were even totally or partly cut into rocks, as on the island of Rho (Antoniou 2012a). That location was rather for saving space in the above-ground areas and to be as low as possible to provide better and larger collection, even from internal yards, than providing cooler and more pleasant water. In addition the subterranean construction in all cases – public or private – provided the essential strength of the structure to support the huge loads of the water pressure on the side walls.

In the southern hill of Olynthus, where the archaic city was situated, a few hydraulic coated water tanks have been identified. Moreover, in parallel with the aqueduct of the classical city, on the northern hill, cisterns were located in courts of at least eight houses in the early 4th century BC, depending on rain water flowing in from the surrounding roofs, which in two cases were directly above (Robinson 1938). They were all hewn in the rock and well waterproofed, with a smaller sedimentation tank nearby, unfortunately with no indication about the covering or the way the water was hoisted. These flask-shaped cisterns of Olynthus were, actually, very similarly constructed to Morgantina's water tanks, with narrow mouth and long neck, walls gradually widened to the bottom, and the bottom sloped to a bowl-like depression where silt and debris were collected (Figure 2(a) and 2(b)).

The type of bottle-shaped cisterns was also very common both in Athens and Piraeus, especially from the end of the *ca.* 5th century BC, when rainwater cisterns became very popular and replaced for at least one century the water wells of the city (Hodge 1992; Crouch 1993; Stroszeck 2014), possibly due to the decrease of the underground

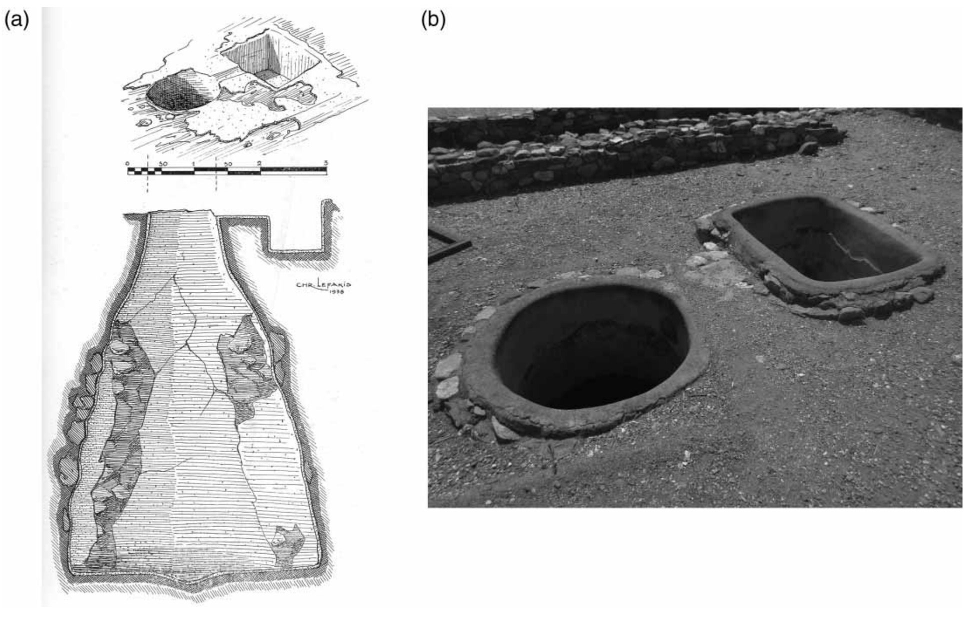

Figure 2 | Olynthus, bottle-shaped water cistern with a shallow sedimentation tank nearby: (a) drawing of the upper part and section (Robinson 1938) and (b) photograph of the visible part after restoration (Kaiafa personal archive).

water reservoirs, caused by over-drawing (Lang 1968). Moreover on the nearby arid island of Aegina several rainwater cisterns, either flask-shaped or tank-shaped, are still in use (Antoniou 2006). Their name, *mpourthechtis,* preserves even now the ancient Hellenic term, *omvrothechtis* which means rain collector. Some of those that were earlier, even archaic (Faraklas 1982), located near the Elanion sanctuary were almost rectangular, cut partially in the rock and most possibly covered, as research under completion by the German excavator has testified.

The public rainwater harvesting installation on the same waterless island, Delos, was the Minoan *krene*, which is a rectangular cistern of the third quarter of the *ca*. 6th century BC, hewn in the rock, with a stepped access in one side down to the water level. The inhabitants were trying to protect its valuable content, rainwater. Thus, a *ca*. 4th century BC inscription lists the fines for washing anything or throwing anything into it, in order to restrict evaporation.

With the passing of the years, until the *ca*. 1st century BC, a continuous effort is observed to increase the capacity of the storage cisterns, so as to reduce overflows and ensure greater water quantities. Thus, firstly, during the 4th century BC one more complicated cistern type was used in order to manage stormwater, which is the two-chambered cisterns. Actually, that was a system composed of two flask-shaped cisterns, of nearly the same depth, cut down into the living rock, and covered by stucco, as they were intended for the storage of rain water. These two waterproofed chambers were connected by a tunnel, near their floor levels. These bottle-shaped tanks were roofed usually by one or more piers (Figure 3) (Stillwell 1933). A similar water system, a bit more complicated, consisting of three bell-shaped chambers connected by two tunnels, has been also recently found in a classical bathhouse located in front of the Dipylon gate (Stroszeck 2014). Apart from in Athens this type of two-chambered cistern has been found once in Olynthus. In its general features it is similar with the three double cisterns already found in Athens, consisting of two bell-shaped underground chambers, opening above in bottle-neck mouths and connected by underground passages (Robinson 1938).

Similar installations, although much more complicated, have been found in Piraeus. More specifically, the water supply of the whole city was mainly based on underground

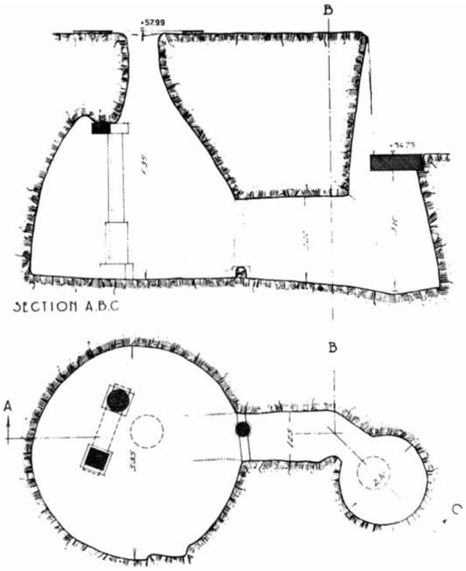

Figure 3 | Two-chambered cistern in Hellenistic Athens (Rotroff 1983).

rainwater harvesting systems consisting of waterproofed double or multi-chambered cisterns, bottle- or well-shaped (more than 600 have been found, in addition to the wells), all carved into the rock. These were linked to one another with a grid of vaulted tunnels and wellshafts. This stormwater harvesting network was developed under the city, and constructed gradually after *ca.* 420 BC.

People, very much influenced by the Peloponnesian war, started to construct these systems in order to reduce overflows and to increase the volume of collected water, so as to ensure water sufficiency (Koutis & Bentermacher-Gerousis 2015) (Figure 4).

In Delos, an island without any water resources other than rainwater, both in the classical and Hellenistic periods, the inhabitants used to manage stormwater by constructing underground storage cisterns, so as to confront the small quantity of water on their barren and arid island. Cisterns in Delos were also well plastered, round or rectangular, placed under the floor of the house peristyle and fitted with marble well-heads and usually supplemented by a stairway so as to be cleaned. Water was hoisted up with clay buckets on a rope or a chain lowered by the users. Traces of rope marks have been found on cistern well-heads, which were just like with those on well-mouths and very often ornately decorated. In many cases, cisterns coexisted with wells (Bezerra de Meneses *et al.* 1970). The presence

Figure 4 | Piraeus, rainwater harvesting system, multi-chambered rock-cut cisterns, linked with wells through vaulted tunnels (https://ocw.aoc.ntua.gr/courses/CIVIL100).

of a rainwater storage cistern and water well in the same yard and their simultaneous use is not a Hellenistic development. These two hydraulic installations, cistern and well, were found in the palace of King Assur in the city of Nimrud, Mesopotamia, from the *ca.* 9th century BC (Drower 1954).

As for Hellas a similar installation has been found in Akanthus of Chalkidiki, where a rainwater cistern coexists with a well in the central courtyard of a Hellenistic building (Trakosopoulou-Salakidou 1987). The cistern was situated next to the stylobate so that rainwater was collected from the surrounding roofs and directed by a vertical pipe toward the cistern's mouth, on which a separate stone ring was seated, probably covered, both for safe water-drawing and for dirt protection. The lead sheet cover of its bottom confirms the supplemental role in daily consumption. Lead affected the quality of stored water and made it unsuitable for drinking and cooking. For these needs the users were drawing water from an adjacent well. Therefore, the rainwater gathered in the cistern was intended for other uses: domestic and physical cleaning, residential irrigation, craft consumption or workmanship.

The public granite-built vaulted cistern located just below the theatre in Delos is another very interested example of rainwater harvesting management. It is 22.50 m long and 6.00 m wide, with the missing roof resting on eight arched foundations. The runoff surface of this underground communal reservoir was the cavea of the theatre, the area of the spectators' seats (Antoniou *et al.* 2014). Rainwater was collected in the open gutter around the semicircular orchestra and poured into the cistern through an underground conduit (Fraisse & Moretti 2007).

The extended use of the newly applied arches in the construction of cisterns as in Delos proves the importance of the rainwater cisterns and the implementation of the most modern technologies in their building aiming not only at the quality of the structure but mainly at increasing their capacity.

Roman period (1st century BC–4th century AD)

The Romans focused on several infrastructure technologies such as roads, aqueducts, and ports. Some of their most significant constructions dealt with water supply. Besides the impressive aqueducts (Adam 2004) and the well-engineered water network, often made of lead pipes (De Feo *et al.* 2012), they constructed not only reservoirs for storing the aqueduct water but also rainwater cisterns in cases where there was water need or scarcity. Besides the numerous Roman cisterns fed by aqueducts, all over their Empire (Mays *et al.* 2013) there were many examples of rainwater reservoirs. In Italian territories there are several well-known rainwater cisterns as at Fermo (Paretti 1995) and at Baiae (Döring 2002). Several examples present even today the incorporation of their mass-scale engineering into rainwater harvesting constructions.

A major aspect of the essential increase of the capacity was the construction of large vaults which exploited much Roman cement-type mortar. The large public rainwater cisterns were covered with single (Figure 5(a)) or multiple (Figure 5(b)) vaults. In addition the load-bearing abilities of the Roman walling permitted the construction of large, above-ground reservoirs like the one in Minoa (Figure 5(a)). Besides the large-scale rainwater examples there were

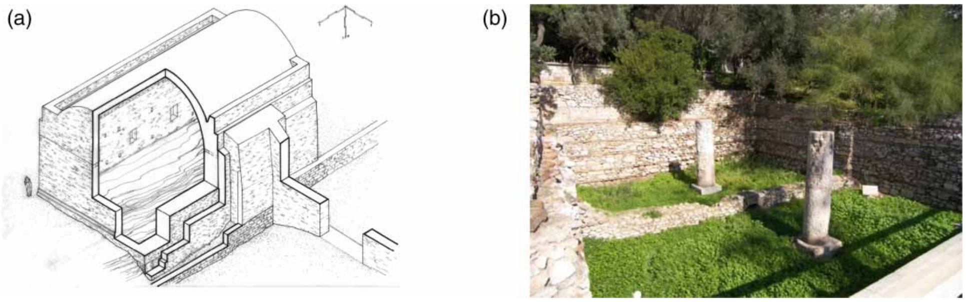

Figure 5 | Roman rainwater cisterns at (a) Minoa on Amorgos (G. Antoniou) and (b) the south foothills of the Acropolis, Athens (Mays *et al.* 2013).

small-scale, mostly residential, water storing and management constructions which often – in areas with water scarcity – operated as rainwater harvesting constructions.

POST-ANTIQUITY AND MEDIEVAL TIMES (*CA*. 5TH–15TH CENTURIES)

Following the transformation of the Roman Empire to the Byzantine, building technologies, in general, and cistern technologies, in particular, were widely practiced for the construction of the infrastructures of the new capital, Constantinople. There the huge (244×85 m^2) open-air Aetius cistern with capacity of approximately 300,000 m^3 (Müller-Wiener 1977) was either a distribution reservoir or an auxiliary rainwater harvesting tank. Undoubtedly its vast size collected large quantities of rainwater. The engineering legacies are prominent since they were also used at the relevant, but smaller, cistern of Aspar not far away from the Aetius. In addition the retaining-wall technology of the Romans continued and therefore large, semi-on-ground cisterns such as the one east of Chora Monastery in Constantinople were able to be built. Unfortunately the skilled technological practices faded with time due to lack of enough funds. Moreover the barbarian invasions reduced somewhat the construction of public infrastructure. On the other hand smaller rainwater cisterns continued. The best preserved examples are found in monastic complexes, palaces or fortresses (Figure 6(a) and 6(b)) and reflect the typical Byzantine practice of incorporating small- and medium-size vaults and domes, regular or lowered ones. In every case the cisterns are located in secure places and in most cases are below ground level.

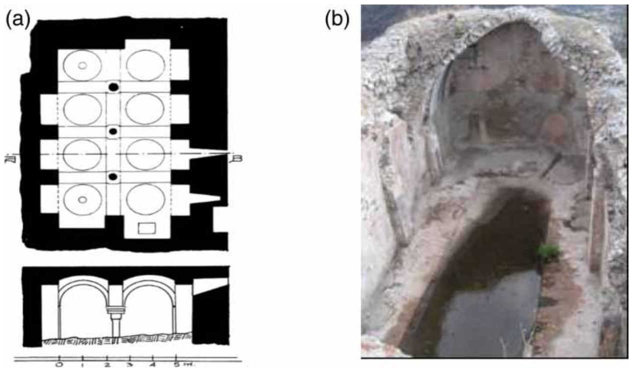

Figure 6 | Byzantine-era cisterns at (a) Osios Loukas monastery in Boeotia, Hellas (Orlandos 1926) covered with a lowered dome (notice the intake spout) and (b) the Goulas of the castle at Leontari Arkadias (G. Antoniou).

Similar techniques were applied in smaller regional and rural (Figure 7) constructions. In many cases in front of the intake spout there was a small sedimentation tank.

Figure 7 | Byzantine-era cisterns in Amorgos: a small, vaulted one with an orifice (Mays *et al.* 2013) and another flask-shaped on the left along with the partially paved runoff surface (G. Antoniou).

PRACTICES DURING THE VENETIAN AND OTTOMAN PERIODS (15TH–18TH CENTURIES)

With the presence of westerners in the Hellenic territories, rainwater harvesting was improved by the implementation of advanced techniques introduced by the Venetians in Crete (Angelakis 2016) and in a few other islands, from the early 13th century. The construction and maintenance of the runoff surfaces became not only extensive and well articulated but were also protected from humans and livestock. The large cisterns at Monemvasia, dated to the post-Byzantine period (Mays *et al.* 2013), are characteristic examples. But also in smaller examples as in castle of Kalymnos in the Dodecanese, the articulated and protected runoff surface (Figure 8) should be related to western influences. It should not be omitted that hygienic precautions seem to become an issue of greater importance than previously.

Byzantine traditions such as those of placing cisterns under churches can be traced at the double-vaulted rainwater cistern under the southern extension of the Aghia Sofia Byzantine church in Monemvasia (Antoniou *et al.* 2014). It can be concluded that during that era there was an increase in rainwater cisterns. That is not only due to the better financial capabilities of the western states but also to the increase in the workshops of various kinds during that period that increased the need for water and therefore the construction of cisterns. Some of them are characteristically located in the vicinity of oil press workshops, providing them with the essential water for olive oil production.

The Ottomans – besides the extensive construction of aqueducts in the Hellenic region (Antoniou 2012b) – not only repaired and improved rainwater harvesting construction which preexisted, such as the cistern in the castle of Mytelene (Figure 9(a)), but also formed a specific type of rainwater cistern where the runoff area is the outer surface of the dome. The intake was through sloped strip around the perimeter, through (usually several) spouts (Figure 9(b)).

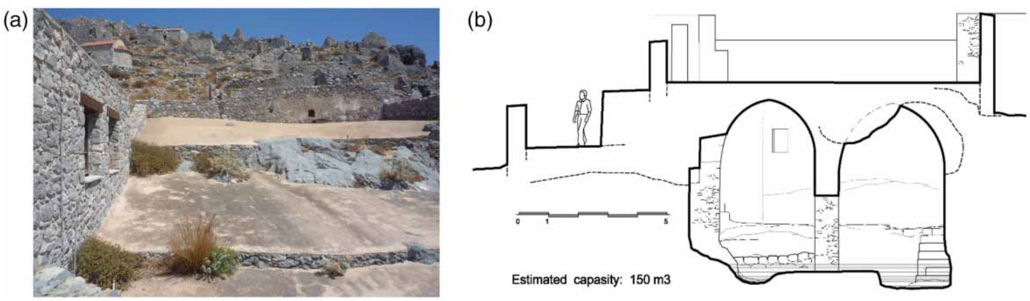

Figure 8 | Post-Byzantine cisterns: (a) the stepped runoff of the main communal cistern at the castle of Pothia in Kalymnos and (b) that at Kato Lakkos in Chora, a partially rainwater and partially water abstraction tank (Antoniou 2009).

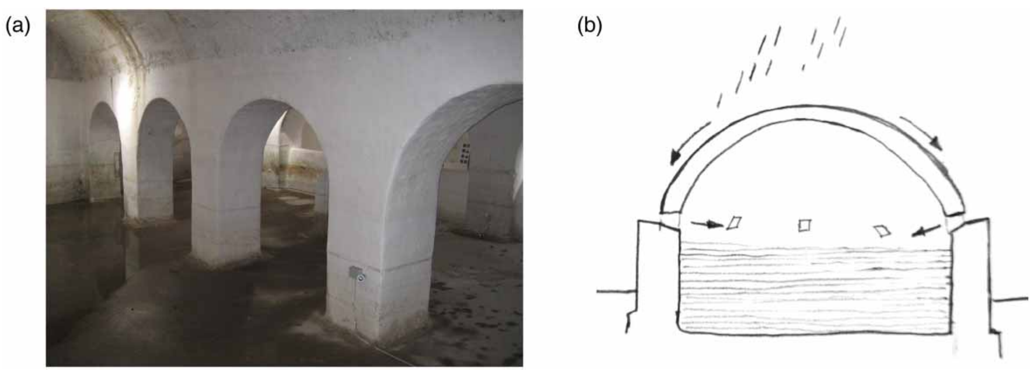

Figure 9 | Ottoman-era cisterns: (a) the cistern modified by the Ottomans at the castle of Mytelene and (b) typical formation of Ottoman rainwater cistern where the runoff area is the outer surface of the dome (G. Antoniou).

EARLY INDUSTRIAL AND MODERN TIMES (19TH AND 20TH CENTURIES)

The early industrial and industrial eras for Hellas were related to the independent Hellenic state. New, for that time, water technologies started to be developed all over the country. They were based on past technologies as well as on new ones such as deep wells, pumps, pipes, and so on. At that time the growth of populations required an increase in agricultural production. In addition, in many cases the steep terrain highly increased the scale and the cost of the required hydraulic projects (Koutsoyiannis & Angelakis 2004). Meanwhile, the water supply of urban areas was facing similar problems due to population increase (Antoniou 2014b). Thus, the collection, storage, and use of rainwater in several urban areas in southeastern Hellas were still practiced during the middle of the last century and still are for stockbreeding purposes (Antoniou 2009). On the other hand although some traditional techniques and materials continued during the 19th and early 20th centuries, modern materials and techniques were implemented in the ancient method of rainwater harvesting, like the rainwater runoff surfaces and tanks at Ithaki made of reinforced concrete (Antoniou *et al.* 2014).

FUTURE TRENDS

Urbanization has had a drastic impact on the natural process of stormwater runoff. It has increased both the peak and the volume of runoff, has reduced infiltration, and has caused water pollution. Structural stormwater control measures are designed to reduce the volume and pollution of stormwater by harvesting and reusing it, infiltration into porous surfaces, and facilitating its evaporation. Acceptable strategies by which flood risks will be eliminated and conservation and reuse will be increased include the use of impermeable surfaces, such as green roofs, pervious pavements, grid pavers, and nonstructural techniques such as rain gardens, vegetated swales, disconnection of impervious surfaces, and of course harvesting and reuse of rainwater. A cost-effective and environmentally friendly solution is the harvesting and reuse of stormwater runoff, in general, and particularly from roofs (Pazwash 2016).

In addition to flood risks, urbanization causes thermal pollution from dark impervious surfaces, such as roofs and streets. Urban development alters the natural hydrologic process. As this trend continues, the need for conservation and reuse of water becomes a challenging reality. In the future rainwater harvesting and reuse will grow not only in areas with low water availability but also in areas with rainfall more than 1,000 mm annually. In Florida, Georgia, and the Carolinas, for example water reuse has been established for some time (Pazwash 2016). Also special programs have been developed by which people are encouraged to use measures for rainwater conservation and reuse. We should be concerned about our limited water supplies and take measures to collect stormwater for our use. To achieve long-term water sustainability, local and state agencies and schools need to adopt challenging actions in leading the public to promote conservation and reuse of runoff in general, and roof rain in particular.

CONCLUSION

Rainwater is both renewable and sustainable. Thus, since the Minoan era rainwater harvesting management has been developed and expressed with a sophisticated technology not only of rainwater storage cisterns, public or not, but also of runoff surfaces and collecting constructions as well. In any case and any period, people have collected rainwater directly from roofs and stored it cisterns of various sizes, capacities and types. Sometimes stone access stairways have been common.

As Heggen (2000) pointed out, in the last few decades there has been an increasing interest in the use of harvested water with an estimated 100,000,000 people worldwide currently utilizing a rainwater system of some description. Nowadays, both rainwater and stormwater harvesting are recognized as practical and cost-effective tools for water supply and stormwater management in arid and semiarid lands. Worldwide, rainwater harvesting has recovered its importance as a valuable water resource, alternative or supplementary, in conjunction with more conventional water supply technologies. If rainwater harvesting is practiced more widely, many water shortages, actual or potential, can be alleviated.

Until the mid-20th century, one in three Hellenic houses in the villages and in remote rural and island areas had underground water tanks. However, in recent decades with the expansion of the municipal water supply network this technique has gradually been abandoned. Despite that, in several areas with water scarcity, the municipal water supply was supported by rainwater tanks and relevant concrete paved runoff surfaces, as for example on the very rainy island of Ithaki (Antoniou 2014a). Today, rainwater in urban areas of Hellas is discharged by 10% through a combined sewer system, by 75% through a separate drainage system and by 15% flowing in the streets and directly draining into surface or ground waters. At the present time, there is no recorded information about the number of homes that have rainwater collection facilities for drinking or for additional uses such as watering and washing. On the other hand the new Building Regulation Decree, as well as the preexisting regulations and relevant legislation for the Aegean islands, excludes the surface of rainwater cisterns from the total one permitted, promoting, somewhat, in that way their construction in areas with water shortage. That kind of promotion along with the increased cost of the water supply in such areas results in many cases in the incorporation of rainwater cisterns in newly built houses.

Since 2008 a private company of the refreshment industry sponsored in cooperation with the international organization Global Water Partnership-Mediterranean (GWP-Med) a rainwater collection program on 28 islands of the Cyclades and Dodecanese, which installed or repaired 50 rainwater collection systems and three drinking water plants, to achieve annual savings of 62.4×10^6 L of water. The aim of this interesting initiative was the promotion of sustainable methods to enhance the availability of water at the local level and the education of young people in the proper management of water. Apart from individual private initiatives, rainwater harvesting should be revised at country level and be imposed by a legislative framework on all new construction in arid and semi-arid areas. As aforementioned, in many countries of Europe, Asia, Africa, America, and Australia rainwater harvesting is obligatory not only to address water scarcity, but to hold stormwater and to reduce flood risks. Undoubtedly, 'our past can teach us a lot'.

Finally historical studies on rainwater harvesting, collection, and storage technologies provide insights into possible responses of modern societies to the future sustainable management of water resources. In a highly urbanized future world, rainwater harvesting and water reuse systems should be highly important. These systems could contribute to (a) increase in water conservation, availability and use efficiency and (b) reduction of energy production costs and flood risks.

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