



Prehistoric and historic hydraulic technologies in stormwater and wastewater management in Greece: a brief review

Aristidis Golfinopoulos, Ioannis K. Kalavrouziotis*, Vasiliki Aga

School of Sciences and Technology, Hellenic Open University, Tsamadou 13-15 & Saint Andrea, Office A12, Patras 262 22, Greece, email: arisgolf2@hotmail.com (A. Golfinopoulos), Tel. +2610 367546, +6944726906; Fax: +2610 367528; emails: ikalabro@eap.gr (I.K. Kalavrouziotis), vasiliki_aga@hotmail.com (V. Aga)

Received 11 February 2016; Accepted 13 April 2016

ABSTRACT

Development of urban settlements during ancient years in Greece created the need for sewerage and drainage system infrastructures. For the first time, open sewerage systems mainly stone-built are found in the Minoan Civilization. Back in those times, extensive collection systems and use of storm-water has been recorded. At the same time, wastewater was used in order to fertilize agricultural land. Developed knowledge and technology on hydraulic and sewerage systems was also found in Cycladic and Mycenaean Civilization where significant irrigation systems were found. After a period of stability, throughout the Geometric period, gradual progress was observed, which peaked in Classical and Hellenistic period from 479 BC until 67 BC. During Roman Era, baths, toilets, and sewerage systems were established.

Keywords: Wastewater management; Sanitation; Sewerage; Ancient Greece

1. Introduction

The history of humanity on the earth started 25,000 years ago. During most of this time, humans lived as hunters without permanent shelters but functioned as nomads seeking food. This particular way of life did not cause any environmental problems and there was no concern about hygiene issues.

These issues were introduced when men started cultivating the land and became farmers as permanent shelters were built. As small settlements were formed, hygiene issues appeared due to continuous waste production in a confined area. In order to deal with these issues, people designed and constructed sewerage systems [1].

Sewerage and drainage systems are known in the Mesopotamian kingdom in Iraq since 4000 BC. Well-organized sewerage systems are introduced for the first time in mankind history, during the Minoan civilization (3000 BC), in the island of Crete. At the same time, similar findings are recorded in the civilization of Indus valley (Harapios). Minoans and Indies are considered to be pioneers in designing and constructing sewerage systems [2,3].

Later on, Greeks and Romans improved technology on water management, sewerage, and drainage systems using accumulated knowledge.

In this study, a brief review of the historical evolution of stormwater and wastewater management in Prehistoric and Historic Greece is presented with emphasis on the most significant technological developments. Furthermore, in order to contribute to

*Corresponding author.

solutions of current problems such of water shortage and contamination of surface and groundwater, disposal and reuse of wastewater are discussed.

The main periods among Prehistoric and Historic Greece are presented in Table 1.

2. Sewerage and drainage systems in Minoan civilization (3000–1000 BC)

Crete is known to be inhabited since Neolithic era. Inhabitants originally lived mainly in caves as well as in small organized settlements. In 3000 BC, new population probably originating from Asia settled on island of Crete. After that time, a major population growth was recorded followed by cultural, economic, commercial, industrial, and technological development. Going along with the lifestyle of that time, a perfect sewerage and drainage system was constructed as well as hygiene facilities [4].

In Minoan Crete, infrastructures for collecting and restoring stormwater in tanks were developed. As found in various palaces, water collected through a drainage system consisting of grooved stones or clay pipes or combination of these two (e.g. as in Knossos palace) was led into storage tanks. In many cases, various external corridors and streets were designed to serve two purposes. They were built in a way that allowed people to walk without stepping on water and at the same time, cavities formed in between functioned as conduits for water transfer. In designing the system for stormwater collection and drainage, in order to avoid wide inclinations as well as erosions, parabolic tracks were used [5].

It is reported that drainage system for stormwater in Agia Triada villa, and in Tylissos houses, included sedimentation tank before the main tank in order to

treat the collected water. It is evident that in Minoan Crete, stormwater was being managed in an ecological way since the environment was considered as a valuable resource. In Minoan Civilization, in addition to the advanced knowledge on drainage and sewerage systems, a central authority existed that was responsible for the effective management of the wastewater [6].

In Minoan Crete, sewerage and drainage systems were designed and constructed in order to serve needs of urban population. In many cities, sewerage systems were covered by stone and wastewater was mixed with rainwater. This technique resulted in a more effective cleaning of the system as well as in elimination of odors. In some cases, rainwater was collected from building roofs into small tanks for various purposes, as sewer and toilet cleaning [7].

In Minoan palaces, each sector had its own sewerage system which was connected to the main one. This system consisted of vertical pipes for multiple functions. Firstly, they collected and drained rainwater and at the same time, they were used for ventilation. When heavy rain occurred, which was common at that time and area, rainwater coming into the sewerage system resulted in its effective cleaning. In conclusion, the above-mentioned techniques resulted in the sewerage system running effectively, with fine hygiene conditions, a fact that indicates that people had advanced knowledge on hydraulic, water management, and hygiene issues [8].

In Knossos palace, total length of sewerage system exceeds 150 m. Wastewater coming from the central court in Knossos palace was handled through a high capacity underground channel, which was stone built. This channel, located beneath the passage leading to north entrance, received several flows from various quarters. The most explored part of the palace sewerage system is the one running beneath the floors of the residential quarter. The system was designed to create a great loop and sewerage was achieved through five light wells. The system drained also rainwater from roofs, being connected with toilets on upper floors. Conduits were built of stone blocks, lined with cement. The main channel was big enough to allow a person to enter for cleaning and maintenance. Construction details (Fig. 1) as well as complicated connections between conduits and light wells indicate advanced knowledge on hydraulic issues [7].

Hydraulic expertise of that time was so advanced that in Knossos palace sewerage and drainage system, visiting-wells were constructed in order to maintain or check on system function [9].

Advanced sewerage systems were found in Phaistos and Zakros, which were also Minoan palaces.

Table 1
Ancient periods chronologically

<i>Prehistoric Period</i>		
Stone era	Paleolithic period	25000–9600 BC
	Neolithic period	9600–3000 BC
Bronze era	Minoan civilization	3000–1000 BC
	Cycladic civilization	3000–1100 BC
	Mycenaean civilization	1600–1100 BC
<i>Historic period</i>		
	Geometric period	1000–750 BC
	Archaic period	750–479 BC
	Classical period	479–323 BC
	Hellenistic period	323–67 BC
	Roman period	67 BC–330 AD



Fig. 1. Remains of central sewerage and drainage systems at Knossos “Little Palace” and Palace, respectively (A.N. Angelakis, with permission).

In this case, to allow effective wastewater collection and cleaning, sewerage system was built of stones with wide cross section. Smaller sewers were ceramic [7].

In many cases, sewerage systems are still functional even in our days. These systems consist of open clay conduits and open stone channels [10]. Bigger conduits, large enough to allow a man to enter and clean, have been discovered in Knossos, Phaistos, and Zakros palaces [2].

In Zakros palace, there were three types of conduits in the sewerage system. One type was made of clay and had the shape of reversed “π.” There was also another type made of stone and finally, there was a narrow type also made of stone with an opening on the top [11].

One of the most sophisticated sewerage as well as drainage systems was discovered in Agia Triada villa in Crete (Fig. 2). The drainage system exists even today, 4000 years after it was built, and is fully functional [12]. This particular system has been admired by various observers. For example, while visiting the

area during intense rain at the beginning of the twentieth century, Italian writer Angelo Mosso observed that drains functioned perfectly and stated: “I doubt if there is any other instance of drainage system acting after 4000 years” [7].

In general, constructions of this time period were designed in a way to last long. This is a practice friendly and respectful for the environment [13,14].

3. Sewerage systems in Mycenaean civilization (1600–1100 BC) and in Cycladic civilization (3000–1100 BC)

As far as the Mycenaean civilization is concerned, wide-scale water management irrigation works, such as draining of lake Kopaida, flood-control works in Pheneos, Tiryns, and Thisbe as well as developed sewerage systems, were recorded [15]. In Midea, which was a significant center of Mycenaean Argolis, part of the sewerage system consisting of built stone pipes, which resulted in an underground tank being discovered inside the buildings [16].

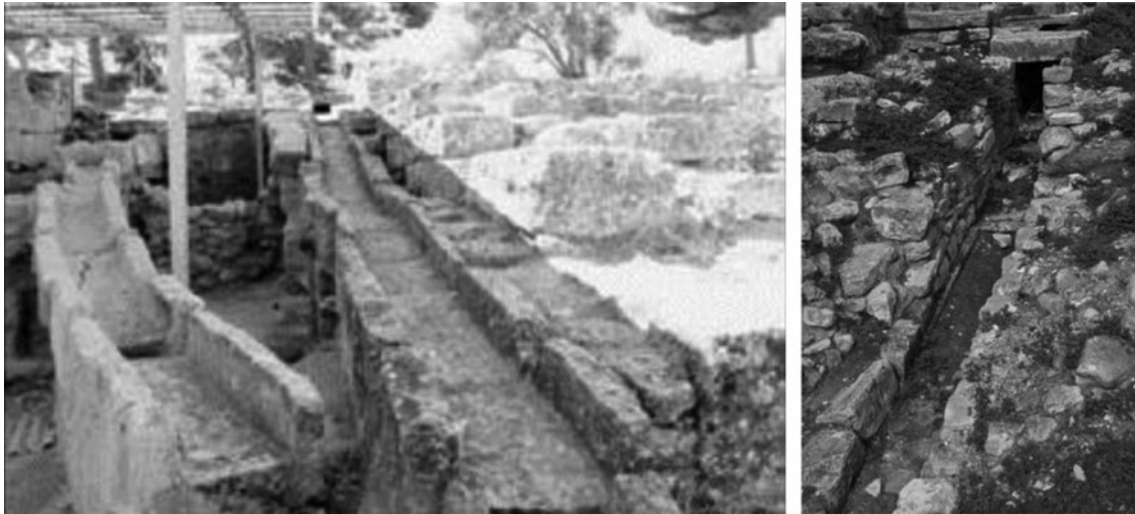


Fig. 2. Remains of central sewerage and drainage system of Minoan palace, Hagia Triada and Phaistos palace, respectively (A.N. Angelakis, with permission).

Significant findings were recorded in Dimini that was an important settlement of the Mycenaean civilization in Thessalia which peaked in 1400 BC. More specifically, on both sides of a street, 4.5 m wide, houses were found which had clay basins and sewerage system. This system collected and transferred house-hold wastewater through a network of stone-built ditches. Its width was 0.4 m, and it was made of two parallel rows of stones covered by slates [17].

In the island of Thira, city of Akrotiri is still well preserved since it was fully covered by volcano lava. The sewerage system of this city consisted of a central axis which descended sloping toward the sea. This central channel received sewage at several cross sections from secondary channels. Connections from building sewers to the central axis have also been discovered.

In the settlement, one of the residences was found in fine shape. It was used as basis to study connections between houses and central sewerage system as well as connection with the network that served hygiene facilities on the upper floor [18].

On the upper floor, where resident facilities were located, one hygiene facility was found, isolated from the rest of the house by a plinth wall. In a cavity of the external wall, two benches, 0.43 m high, were built among which there was gap, 8–10 cm wide. This gap corresponds to a hole on the floor considered as sewer entrance. Building sewerage system consisted of vertical pipes–built in the walls–which resulted in an opening on the wall and finally on a light-well outside the house. This light-well connected to the main channel, covered by a plaque while it could be visited. Indicative of the technological and hydraulic knowledge of

the time is the fact that plaques were installed in the sewers in such a way to accelerate water flow. Sewers worked also as odor traps, and had the ability to control smell and vapor, a fact that implies advanced technology on hydraulic and hygiene issues [19].

4. Sewerage systems in archaic period (750–479 BC)

This period in archaic Greece is characterized by an immigration flow to various places and colony formation. In Ambrakia, colony of Korinthos, long and narrow building areas formed a central sewerage stone-built system which was found beneath the main streets that separated these building areas [20].

In Lefkada, which was also colony of Korinthos, the above-mentioned urban planning was applied. In the street separating the building areas, a central sewer receiving household waste was also found along with the only toilet facility found in this settlement. This facility was located on a secondary building right next to the central sewer where a small ditch was opened by the floor, sending waste to the main channel. Furthermore, next to a well, bath facilities were discovered which were supplied with water from the well, while wastewater resulted to the main sewer through a small underground conduit [21].

5. Sewerage systems in classical and Hellenistic period (479–67 BC)

Greeks in classical and Hellenistic period had realized based on knowledge acquired from the archaic period that hygiene has an impact on their life quality

and therefore, they developed baths, toilets, and sewerage systems.

In the urban environment, in many cases sewerage systems were constructed in order to remove wastewater and rainwater. More specifically, many cities, during the Classical period, adapted Ippodameios building system which introduced long straight streets as well as organized building squares, with parallel streets around central market. This building system provided better conditions for construction and function of sewerage and drainage systems.

Characteristic of this system is the development of small conduits which cross through houses and connect with bigger conduits which cross through streets. These conduits collect toilet wastewater from smaller ones, from vertical pipes that served other house holding needs as well as other infrastructure for stormwater collection.

Sewerage system is completed by connecting of street conduits with bigger channels which transfer wastewater to the chosen recipient.

Regarding construction, conduits are mainly stone-built but there are recorded cases of clay made, also. In most cases, channels are underground. Occasionally, open canals for wastewater collection and transfer are also found. Sewerage systems often include light-wells used to collect wastewater or to clean and protect system from high pressure.

During classical period, classical Athens leaves monarchy and introduces democracy. City moves from Acropolis to the Market, which becomes the center of political, social, and commercial activity. Advanced hydraulic technology on water convention using pumps and other devices was applied in this era [22]. Heron of Alexandria, was the first who achieved to convert thermal energy to kinetic energy, by the aeolipile, a step before the use of steam for industrial purposes [23]. Gradually, hygiene technologies were developed in the area of the Market. Additionally, life quality and healthy living became gradually very important and public toilets as well as baths were built. A big channel for sewage transport outside the city was built. This channel was one meter wide, with stone-built sides, tile-made basis and it was covered by stone plaques [24].

Sewerage system in classical Athens initiated as stormwater drainage system, but at the beginning of the *ca.* fifth century BC, started to accept urban wastewater. This system resulted to a huge sewer (channel) [25].

In the Hellenistic period, Athens was destroyed by Persians but it was rebuilt using Ippodameios building system. This particular structure with parallel

streets allowed building bigger and more effective hygiene facilities. At that time, both sections of the Market's sewer were constructed. Sewerage system was developed and improved by becoming more complex. Mainly underground sewers were built in order to transfer wastewater away from the cities whereas inspection of their function is assigned to the police of those days [26].

Athens' sewerage system, in the fourth century BC, is being equipped by holes through which houses are being connected. Conduits from these houses were stone made and covered by plaques or reversed tiles. These interventions might have led to an epidemic outbreak, which was recorded at that time. Impressive is the fact that sewerage system created to meet with needs of the ancient agora of Athens as well as of the area that surrounded the agora is still functional in our days [27].

Hellenistic Athenians realized early enough, hygiene importance on life quality and therefore introduced laws, regarding proper use of water and pollution. Such a law was discovered on an inscription, and aimed in preventing pollution from tanneries as well as pollution of Iridanos River from waste [28,29].

In most cities, sewerage system was developed in four levels. Firstly, there was the part of the system initiating from buildings and resulting to bigger conduits on the streets. These ones sewed to even bigger channels which resulted into the main city sewer. Such sewerage system was discovered between Acropolis and Pnyka Hill, where archeologists discovered a series of canals converging to a single collector [30].

Hellenistic Athenians and other Hellenistic Greeks had public toilets since 300 BC (Fig. 3). These facilities were drained in conduits which carried wastewater and stormwater to a collection basin, allocated outside the city. Starting from that point, brick-built conduits led waste to agricultural land.

Wastewater from baths was also used to clean toilets. Stormwater was used to clean sewers and also to dilute wastewater to make it appropriate for agricultural land irrigation. Growth of domestic basin usage was observed. As a result, water for various house holding activities was restored, whereas stormwater volume needed to be managed was minimized [31].

Gradually, design and construction of an effective sewerage system became very important. As an example, city of Delos is used, which had a technically sophisticated and effective sewerage system. In this system, each house had a single conduit which supplied wastewater to main underground rectangular sewers. These sewers carried wastewater into the sea, taking advantage of the sloping street track, while all



Fig. 3. Hellenistic period toilets in Corinth and Ephesus (A.N. Angelakis, with permission).

necessary light-wells were available. It is a fact that 68% of 102 domestic settlements of the island had toilet facilities [32].

Olinthos used a carefully designed sewerage system. There was connection through a small conduit, between each house and a stone-built conduit. This conduit crossed beneath each narrow alley which divided each building block. The city was built in blocks consisting of 10 houses each. The above-mentioned conduits were connected to central sewers with crossed beneath central streets [33].

In Argilos, which met a building growth during the *ca.* fifth century BC, bath facilities were found in one house. These bath facilities had a built-in base intended for lavatory placement. A built-in conduit used to transfer bath wastewater outside the house was also found. In the yard there was a stone-covered canal and a shallow tank which accepted stormwater [34].

Classical Pella is a city of long history which was permanently settled since Early Copper period and became capital of Macedonian Kingdom at the end of the fifth century BC. The city had urban planning with rectangular building blocks which were uniformly separated by streets 6–9 m wide. Beneath the streets, a well-organized water supply and sewerage system was developed. Built in rock, galleries supplied water coming from mountain springs. Baths were discovered in various houses as well as in public buildings [35].

In the city one of the most ancient baths with underfloor heating, was found. There were innovative watering and sewerage systems while the bath was equipped by swimming pool, sauna as well as personal and group wash basins. These facilities are dated back to *ca.* 325–300 BC and there is evidence that they were modernized later on, around 2 *ca.* 75 BC a technological innovation of the time was under-

ground heating, where underground pipes with cold and hot water were used. This indicates that Roman systems are possibly a result of the knowledge acquired in ancient Pella. Conclusively, there was a very well-organized town, similar to modern cities with fine hygiene conditions.

In classical Pella, sewerage system was mixed, built of stone and covered by plaques. It transferred excess stormwater and urban wastewater, to swampy areas, outside the city. Central sewers, which run the streets, accepted waste from smaller conduits coming from public and private land or buildings. Smaller conduits were stone-built canals covered by plaques, stone ditches, clay pipes circular or square as well as other small ditches, but also pipes made of lead.

Stormwater from buildings was collected, using stone ditches of horseshoe shape. These ditches were constructed in the inner side of the column, located in the yard of houses or other buildings. Such facilities were located in the central Market in order to remove excessive water in the House of Dionysus and another building [35].

In Kallithiros, a city located 9 km south of Karditsa city, in the old settlement, which was built in 320 BC, a small superficial conduit was discovered. This conduit crossed through city-walls, removing wastewater outside the city. This ditch was 0.4 m wide and 0.6 m height. On both ends as well as in the middle of the ditch, small stone-made pessiskoi were built, in order to diminish the possibility for enemy penetration [36].

6. Drainage and sewerage system in Roman era (67 BC–330 AD)

During Roman era, there was further development of the sewerage system (Fig. 4). At that time, houses were equipped with built in walls, horizontal or



Fig. 4. Parts of Roman era drainage and sewage system in Thassos (Antoniou et al. 2014).

vertical systems, which led wastewater outside the house into central sewers. These sewers run beneath the streets and transferred wastewater to the sea or other recipients.

Central sewers were built of stone without internal lining.

Back then, excessive water from fountains (innovation of the time), was either used to water house gardens or it was removed by sewerage system. This system cleaned wastewater at the same time and therefore dealt with odor issues. Incorporation of this water in the sewage system, for its dilution, for cleaning the system and other purposes indicated advanced knowledge on hydraulic engineering, on waste management, and hygiene issues [35].

In Patras, a city which developed significantly, during Roman era, domestic wastes, through built-in conduits or clay pipes, resulted in large underground sewers. These sewers run beneath central streets and resulted into the sea. There is one recorded case where sewerage system is still functional.

In the Roman theater, stormwater descending from tiers, resulted into a light-well located in the middle of the tier and it is finally drained in a central drainage system, which has not been discovered yet. This drainage system functions fully since it was discovered, 100 years ago, without causing any problem [37].

Since Roman era and until the middle of the nineteenth century, there was no real progress on waste management, sewerage system construction, or hygiene facilities.

In various cities, wastewater run free in house yards or streets, causing epidemic outbreaks, which were a severe problem in medieval cities. Characteristic example of this attitude of that time but also of modern history, is that of Versailles Palaces, where no sewerage system was constructed [9].

The first remarkable sewerage system construction with modern specifications was in Hamburg in 1842, after city was destroyed from fire.

Lethal epidemic spread, as cholera, demanded that sewerage systems should be constructed. Consequently, in 1855, in London a mixed sewerage system was developed as well as in Paris in 1880 [38].

7. Disposal and reuse of wastewater in Minoan Greece

Sewers' exits in Minoan cities seem to be similar. Recipient for wastewater coming from Knossos Palace was torrent Kairetos. Sewage from Zakros palace resulted into the sea. In all cities, there were tanks for collection and reuse of stormwater. Before the main, there were smaller sedimentation tanks in order to

clean collected water [5]. There is also evidence that in Phaistos Palace as well as in Agia Triada palace, domestic waste was disposed and used on agricultural land [7].

Historic evidence that in 2700 BC, Minoans were the first to reuse wastewater on a wide scale for irrigation purposes, is available [39]. We can also reach to this conclusion based on the presence of sewers which result into fields [40,41].

In 2600 BC, citizens of ancient Athens, Sparta, and Katerini also used wastewater for land irrigation [39]. In this way, they accomplished waste management, as well as increase of crop production. Additionally, there are two references in the Bible for waste use in fields [39,40].

In Minoan civilization, stormwater was collected and reused, which is an environmental friendly practice [13,14]. This water was initially used to clean toilet and sewers. Later on, diluted sewage was disposed on open fields, as it can be assumed, people had observed its beneficial impact on irrigation and plant growth for the production of wood or/and fruit.

Usage of waste on land covered by trees and other plants, due to evapotranspiration, had the advantage of reusing great volume of waste, without causing any problems. At the same time, soil microflora decomposed, through natural processes wastewater disposed on land. Waste disposal on open fields, combined with the beneficial impact of sun and air, resulted to anaerobic bacteria killing and consequently odor removal.

Minoans had an ecological symbiosis with nature, as they had the ability to understand natural cycles. There was a circular transaction between urban center and countryside. The nutritional elements of the food chain after consumption were returned to the agricultural fields via wastewater reuse.

This practice is definitely environmentally friendly. It also has the advantage that wastewater, after going through a natural cleaning process into the soil, will enrich groundwater table. In that way, springs could continue to supply water. This practice indicates that Minoans had understood the hydrologic cycle [42].

8. Conclusions

The first well-organized sewerage system is found in mankind history, in Crete in 3000 BC, developed during Minoan civilization. Minoan sewerage system consisted usually of stone open conduits, but also clay made ones. There was a practice for stormwater collection whenever less water was needed to be removed.

In the Minoan civilization, there was significant knowledge regarding water management and drainage and sewerage systems construction. From the construction point of view, stone and clay, open or closed networks were used. Additionally, there was wide collection and reuse of stormwater.

In the Mycenaean civilization, significant technological evolution on use of water for agricultural purposes was recorded. Therefore, there were significant irrigation works as well as dams in order to achieve best use of available water.

In Greece, during classical and Hellenistic periods, water quality and hygiene conditions were very important, therefore baths toilets, and sewerage systems are developed at that time. Sewerage systems of those days were of closed type, organized in four levels. Wastewater flowed from a conduit to a bigger street channel, which resulted into even bigger main sewers, which finally was connected to a unique recipient.

Hydraulic, drainage, and sewerage systems in Greece were designed and constructed in an environmentally friendly way. Environmental friendly materials were used in a moderate scale and they served real needs without exaggerations. As other monuments of those days, they were compatible to the principles of viable architecture. The quality of materials as well as the way of construction, made those infrastructures long lasting.

In Roman era, there was further development of hygiene facilities followed by construction of improved baths, toilets, and sewerage systems. An innovation of the time was continuous collection of water coming of the fountains and its usage for toilet cleaning.

As a general conclusion, it can be stated that on technological basis, hygiene facilities in classical and Hellenistic Greece can be compared only to modern water hygiene systems constructed in Europe and North America from the second half of the nineteenth century until today. Some lessons learnt include:

During the above periods, certain hydraulic technologies were developed in order to improve life quality regarding hygiene.

Hydraulic constructions of those days were designed and executed in an environmental friendly way.

The size of those infrastructures was adequate to serve the real needs of the habitants without exaggerations. Additionally, environmental friendly materials were used.

There was also, collection and reuse of stormwater.

In various cases, wastewater was used for irrigation and fertilization of agriculture, a technique that we are trying to implement even today.

As far as the Mycenaean civilization is concerned, irrigation constructions are believed as a strong reason that led to its blooming.

Acknowledgments

We would like to thank Dr Andreas Angelakis for the information and photos that he gave us permission to use.

References

- [1] J. Brown, G. Lofrano, Overview of wastewater management through the Ages, in: I.K. Kalavrouziotis, A.N. Angelakis (Eds.), *Regional Symposium on Water, Wastewater and Environment: Traditions and Culture, e-Proceeding*, Hellenic Open University, Patra, 2014, pp. 849–861.
- [2] A.N. Angelakis, F. Giovanni, P. Laureano, A. Zourou, Minoan and etruscan hydro-technologies, *Water* 5 (2013) 972–987.
- [3] G. Feo, G. Antoniou, H. Fardin, F. Gohary, X. Zheng, L. Reklaityte, D. Butler, S. Yannopoulos, A. Angelakis, The historical development of sewers worldwide, *Sustainability* 6 (2014) 3936–3974.
- [4] A.N. Angelakis, S.V. Spyridakis, A brief history of water supply and wastewater management in ancient Greece, *Water Sci. Technol. Water Supply* 10(4) (2010) 618–630.
- [5] M. Chatzakis, A. Lyrintzis, D. Mara, A. Angelakis, Sedimentation tanks through the ages, in: A.N. Koutsoyiannis (Ed.), *1st IWA International Symposium on Water and Wastewater Technologies in Ancient Civilizations. Symposium Preprint Book*, Typokreta, Iraklio, Greece, 2006, pp. 757–761.
- [6] A. Lyrintzis, A.N. Angelakis, Is the labyrinth a water catchment technology; a preliminary approach, in: A.N. Angelakis, D. Koutsoyiannis (Eds.), *1st IWA International Symposium on Water and Wastewater Technologies in Ancient Civilizations. Symposium Preprint Book*, Typokreta, Iraklio, Greece, 2006, pp. 163–173.
- [7] A.N. Angelakis, D. Koutsoyiannis, G. Tchobanoglous, Urban wastewater and stormwater technologies in ancient Greece, *Water Res.* 39 (2005) 210–220.
- [8] H. Gray, *Sewerage in ancient and medieval times*, *Sewage Works J.* 12 (1940) 939–946.
- [9] D. Koutsoyiannis, *Design of Urban Sewerage Systems*, National Technical University of Athens, Athens, 2011.
- [10] A. Angelakis, D. Koutsoyiannis, P. Papanicolaou, On the geometry of the Minoan water conduits, in: *IWA Specialized Conference on Water&Wastewater, Technologies in Ancient Civilizations*, Istanbul-Turkey, 2012, pp. 172–177.
- [11] G.P. Antoniou, A.N. Angelakis, Latrines and wastewater sanitation technologies in ancient Greece, in: Mitchel (Ed.), *Sanitation, Latrines and Intestinal Parasites in Past Populations*, Ashgate Publishing, Farnham, 2015, pp. 41–67.
- [12] A.N. Angelakis, S.V. Spyridakis, Major urban water and wastewater systems in Minoan Crete, Greece, *Water Sci. Technol. Water Supply* 13 (2013) 564–573.
- [13] I. Kalavrouziotis, P. Koukoulakis, P. Drakatos, Water and wastewater management in antiquity in the context of an ethically oriented environmental protection, *Int. J. Global Environ. Issues* 14 (2015) 226–237.
- [14] M. Diamanti, I. Kalavrouziotis, Water resources management and natural environment changes in ancient Pleurona, Greece, *Water Sci. Technol. Water Supply* 13 (2013) 590–598.
- [15] A.N. Angelakis, N. Mamassis, E.G. Dialynas, P. Defferaios, Urban water supply, wastewater, and stormwater considerations in ancient hellas: Lesson learned, *Environ. Nat. Resour. Res.* 4 (2014) 95–102.
- [16] K. Dimakopoulou, N. Divari-Balakou, Mycenaean Acropolis of Midea, Ministry of Civilization and Tourism, Athens, 2010, pp. 8–21.
- [17] V. Zaharopoulos, The Mycenaean settlement in Dimini, *Magnisia* 13 (2009) 10–15.
- [18] E. Griva, Data base of Aristotle University of Thessaloniki Ancient Hydraulic Works, National Technical University of Athens, Athens, 2008.
- [19] K. Palivou, Hygiene facilities, *Kathimerini* 1 (1998) 18–19.
- [20] G. Pliakou, Residence in Amvrakia during the archaic period, *Archeol. Arts* 112 (2009) 31–37.
- [21] M. Fiedler, Ancient Lefkada and its houses, *Archeol. and Arts* 112 (2009) 38–46.
- [22] T.P. Tassios, Selected topics of water technology in ancient Greece, in: A.N. Angelakis, D. Koutsoyiannis (Eds.), *1st IWA International Symposium on Water and Wastewater Technologies in Ancient Civilizations. Symposium Preprint Book*, Typokreta, Iraklio, Greece, 2006, pp. 2–26.
- [23] T.P. Tassios, A potential steam-powered force-pump in Hellenistic times (ca. 330–67 BC), in: M. Salgot, and A. Angelakis (Eds.), *IWA Specialist Group on Water and Wastewater in Ancient Civilizations (WWAC), Water and Wastewater in Ancient Civilizations, Newsletter*, 2015, pp. 11–14.
- [24] E.D. Chiotis, L.E. Chioti, Water supply of athens in the antiquity, in: A.N. Angelakis, L.W. Mays, D. Koutsoyiannis, N. Mamassis (Eds.), *Evolution of Water Supply Throughout Millennia*, IWA Publishing, London, UK, 2012, pp. 407–442.
- [25] G. Feo, P. Laureano, R. Drusiani, A.N. Angelakis, Water and wastewater management technologies through the centuries, *Water Sci. Technol. Water Supply* 10(3) (2010) 336–349.
- [26] N. Zarkadoulas, D. Koutsoyiannis, N. Mamassis, S.M. Papalexioi, *Climate, Water and Health in Ancient Greece*, European Geosciences Union General Assembly, Vienna, Austria, 2008.
- [27] D. Koutsoyiannis, A. Patrikiou, Water control in ancient greek cities, *Water Urban.* 1 (2013) 130–143.
- [28] D. Koutsoyiannis, Water control in the Greek Cities, in: T. Ostigard (Ed.), *Water Systems and Urbanization in Africa and Beyond*, Uppsala University, Uppsala, 2012, pp. 1–50.
- [29] A. Pappas, *Water Supply in Ancient Athens*, Free Thought, Athens, 1999.

- [30] G. Lofrano, J. Brown, Wastewater management through the ages: A history of mankind, *Sci. Total Environ.* 408 (2010) 5254–5264.
- [31] D. Crouch, *Water Management in Ancient Greek Cities*, New York Oxford University Press, New York, NY, 1993.
- [32] M. Trümper, Residence in post-hellenistic dilos, *Archeol. Arts* 114 (2010) 15–27.
- [33] D. Malamidou, Residence and urban planning in Argilos, *Archeol. Arts* 113 (2009) 18–25.
- [34] M. Lilimpaki-Akamati, Houses of Pella, *Archeol. Arts* 113 (2010) 25–35.
- [35] A. Kaiafa, *Watering and Sewerage Systems During Hellenistic and Roman Period in Macedonia*, University of Thessaloníki, Thessaloníki, PhD Thesis, 2008.
- [36] M. Intzesiloglo Kallithira, Organization of urban environment in an ancient settlement, *Archeology* 112 (2009) 58–66.
- [37] M. Petropoulos, The cult and the use of water in Ancient Greece with emphasis the ancient city Patras, in: I.K. Kalavrouziotis, A.N. Angelakis (Eds.), *Regional Symposium on Water, Wastewater and Environment: Traditions and Culture*, e-Proceeding, Hellenic Open University, Patra, 2014, pp. 15–25.
- [38] G. Markantonatos, *Wastewater Management and Disposal*, P. Markantonatos, Athens, 1990.
- [39] V. Tzanakakis, N. Paranychianakis, A. Angelakis, Evolution of land treatment practise for the management of wastes, in: A.N. Koutsoyiannis (Ed.), *1st IWA International Symposium on Water and Wastewater Technologies in Ancient Civilizations*. Symposium Preprint Book, Typokreta, Iraklio, Greece, 2006, pp. 71–79.
- [40] A.N. Angelakis, A.S. Snyder, Wastewater treatment and reuse: Past, present, and future, *Water* 7 (2015) 4887–4895.
- [41] A.N. Angelakis, X.Z. Zheng, Evolution of water supply, sanitation, wastewater, and stormwater technologies globally, *Water* 7 (2015) 455–463.
- [42] D. Koutsoyiannis, A.N. Angelakis, Hydrologic and hydraulic science and technology in ancient Greece, in: B.A. Stewart, T. Howell (Eds.), *Encyclopedia of Water Science*, Dekker, NY, 2003.