SKRIFTER UTGIVNA AV SVENSKA INSTITUTET I ATHEN, 8°, 23
ACTA INSTITUTI ATHENIENSIS REGNI SUECIAE, SERIES IN 8°, 23

# Going against the flow

## Wells, cisterns and water in ancient Greece

Edited by Patrik Klingborg

STOCKHOLM 2023

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Published with the aid of grants from Enboms donationsfond, Riksbankens jubileumsfond, Helge Ax:son Johnsons stiftelse and Gunvor och Josef Anérs stiftelse
The English text was revised by Rebecca Montague, Hindon, Salisbury, UK

ISSN 0081-9921
ISBN 978-91-7916-067-8

Printed by Taberg Media Group Stockholm, Sweden

## ABSTRACT

Despite the prevalent picture of the water supply in the ancient world as being dominated by fountains and aqueducts, the large number of excavated wells and cisterns show that these were the primary water sources for most individuals. Yet, little research has been done on their construction, function and use. This prompted the organization of the workshop *Going against the flow. Wells, cisterns and water in ancient Greece*, held at the Swedish Institute at Athens on 28–29 September 2017, and subsequent publication of the contributions in this volume. The ten papers presented here offer new evidence as well as a wide range of new perspectives on the use and function of wells and cisterns in ancient Greece. Considering the ubiquity of these installations in every type of setting during antiquity, from pan-Hellenic sanctuaries and civic centres to domestic workshops and remote farmhouses, it is hoped that the breadth of interest among the authors will allow other scholars to advance their own work further, illuminating new and exciting aspects of life in ancient Greece.

*Keywords:* wells, cisterns, water supply, ancient Greece, archaeology, climate, sanctuaries

https://doi.org/10.30549/actaath-8-23

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Cover illustration: section of typical ancient Greek cistern, by Patrik Klingborg
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HAMISH FORBES

# 9. Cisterns and *loutses* in a traditional Peloponnesian village

## Aspects of function, use and monumentality

### Abstract

This contribution focuses on rainwater harvesting facilities in the recent past in a traditional community on the Methana peninsula in the Peloponnese. Discussion of the basic requirements of rainwater harvesting systems, including water collection and filtration features, precedes an outline of the ethnographic situation. Some of the main elements of the system as described were dependent on industrial materials unavailable before the later 19th or 20th centuries. Possibly because of the requirements of skill, time and materials, cisterns were the first secular structures in the 19th century to be monumentalized with dates and personal initials. The subsequent discussion of the hygiene levels of rainwater harvested with traditional technologies incorporates a range of studies from around the world alongside practices used on Methana for collecting and filtering rainwater. The conclusion is that rainwater harvested in cisterns generally has higher levels of biological and other contaminants than is expected in the piped water of Western nations. Nevertheless, if the kinds of collection and filtration practices described on Methana are employed, cistern water can be considered safe to drink, and it generally contains significantly fewer microbial contaminants than water from streams, rivers and wells, which are the only water supply of many communities around the world.*

https://doi.org/10.30549/actaath-8-23-09

## Introduction

The chapters in this volume demonstrate clearly that there is considerable evidence for the construction of cisterns in antiquity, yet there are numerous *lacunae* in our understanding of how they were used, their meanings to their owners and users, and to others, and the question of how hygienic they might have been. This contribution seeks to provide pointers to some of these unknowns, starting with an examination of ethnographic evidence gathered during a two-year residence in a traditional Peloponnesian community where cisterns had been the only source of water in the immediate environs of the village for generations. As part of that discussion I shall consider the impact of recent technological developments, especially the introduction of explosives and plastics, on cistern construction and the harvesting of rainwater by

* Grateful thanks are due to Patrik Klingborg, both for inviting me to the original workshop and for his considerable editorial efforts on my behalf during the writing up of this chapter. I am also particularly grateful to Tobias Schorr for permission to publish his photograph in *Fig. 3*. My thanks are also due to the Editorial Committee and the two reviewers whose comments contributed materially to this chapter: any remaining infelicities are purely my responsibility, however. Finally, I acknowledge the essential contribution of all those Methanites and others who provided the information on which this chapter is based.

the local community, as well as issues of social worth and the monumentality of cisterns.

During the course of my research into rainwater harvesting more generally as background to this chapter, it became apparent that there is much scholarly interest in the health aspects of consuming harvested rainwater stored in cisterns, especially in terms of microbial contamination.[1] In such discussions there is frequent mention of particular aspects of rainwater harvesting systems such as "first flush" procedures, whereby the water of the first rainfall after a long dry spell is diverted away from the cistern, to avoid contamination of the water supply from a build-up of waste of all sorts on the surfaces from which rainwater is collected. Discussion of whether cistern water in specific locations contains contaminants is also widely discussed.

Questions of the health aspects and potential contamination of harvested rainwater seem particularly relevant to our understanding of cisterns and their use in antiquity. Therefore I also discuss comparative evidence on current practices in the use of rainwater harvesting and storage technologies and on cistern use, especially relating to studies in the Near East. Besides issues relating to microbial contamination of harvested water, the question of potential phthalate contamination in contemporary systems links back to the use of plastics for rainwater harvesting on Methana and elsewhere. A brief consideration of health risks in piped water systems in the Western world puts the issue of the levels of hygiene (or otherwise) associated with rainwater harvesting and storage in any period into a different perspective: harvested rainwater may contain higher levels of biological contaminants, but piped water may on occasions have significantly higher levels of chemical contaminants, including carcinogens.

I conclude this introductory section with a cautionary statement, however. During my two years of ethnographic fieldwork living within a traditional Peloponnesian community, I generally treated traditional rainwater storage as part of the background scenery in my research into traditional farming methods and environmental knowledge. Although cisterns and *loutses*, the latter being a simpler and less-developed form of cistern, appeared frequently both within villages and beyond in the wider countryside, I did not subject them to systematic study. Thus what I shall present here represents a far from complete understanding of the topic.

The lack of attention that I paid to cisterns seems to be symptomatic of the lack of consideration which traditional rainwater storage systems in general seem to have suffered, certainly in comparison with wells and especially fountains, both in archaeology and in the study of traditional technologies in more recent periods. There are some notable exceptions, as this volume testifies, and recently a few archaeological field studies in Greece have also paid attention to various forms of historically recent cisterns.[2] However, a significant proportion of the limited number of the articles on rainwater harvesting systems in the ancient world seem to be written by a relatively small group of enthusiasts, all covering much the same ground.[3] This means that it is hard to flesh out some of the gaps in my knowledge by reference to published studies of cistern construction and usage elsewhere in the northern Mediterranean, although a relatively small number of relevant studies has been conducted in the Near East. Nevertheless, my experience in the field allows

[1] E.g. Al-Salaymeh *et al.* 2011; Daoud *et al.* 2011; Gould 1999; Gumbs & Dierberg 1985; Masterman 1918; Radaideh *et al.* 2009; Zhu *et al.* 2004.

[2] E.g. Tzortzopoulou-Gregory & Gregory 2017; Germanidou 2018.

[3] See e.g. Angelakis 2013; Antoniou *et al.* 2006; 2014; Koutsoyiannis *et al.* 2008; Lontra 2014; Mays 2008; Mays *et al.* 2013.

me to present some ethnographic observations on cistern construction, function and use which, alongside the comparative data presented here, will I hope, lead to a somewhat better understanding of current and recent rainwater storage as well as how it most likely functioned in the ancient world.

## Sources of information

At the heart of this chapter is a description of the construction and use of facilities for harvesting rainwater in a rural Greek community in the 19th and 20th centuries. It provides an essential springboard for the broader discussion of such facilities globally, and through time. The data are derived from my ethnographic field research conducted between 1972 and 1974 on the peninsula of Methana in the Peloponnese, employing the standard ethnographic practice of participant observation. I have explained in considerable detail elsewhere how the ethnographic data were gathered.[4] Here it is sufficient to note that the information that I gained from conversations and observations was initially written down in note form as soon as possible after the event, and then typed up, with diagrams sometimes added to aid descriptions. Photographs were also taken where appropriate. This is standard ethnographic practice: in this way the ethnographer is not reliant on memory. Since the field notes may in due course provide a resource for others as well as for the original ethnographer to return to, they must be both comprehensive and comprehensible. The only exception to that rule was that the names of all informants/consultants were changed in the field notes. This was especially important because my fieldwork was conducted during a period of military dictatorship: there was a potential risk that my field notes might be confiscated and searched for any evidence of wrong-doing by villagers.

In attempting to place the technology of rainwater storage on Methana into a broader technological perspective, I was unable to find in the scholarly literature any technical information or discussion of how rainwater harvesting systems function overall. Nor does the scholarly literature provide "how-to" detailed technical manuals on the construction of such a system, nor the functioning of first flush systems, sediment traps, etc., which are frequently used in rainwater harvesting systems—as they were on Methana also. Much of this information is, however, quite widely available in more ephemeral sources, such as company websites, blogs, and pamphlets produced by governmental and non-governmental agencies in various parts of the world, primarily in the form of internet resources. Significantly, even scholarly discussions of rainwater harvesting systems may refer to technical manuals and government guidance documents for their design.[5]

The same situation holds true for the recent water contamination scandal in Flint, Michigan, in the USA, which I discuss in a section on the health aspects of piped water sources. The scholarly literature almost exclusively examines in detail one or two aspects of what happened,[6] but overviews of the whole sequence of events are primarily available from ephemeral sources such as news organization websites.[7] These internet publications provide important information but would not under most circumstances be considered by the scholarly community as valid sources of information since they are inherently ephemeral, and certainly not peer reviewed. However, the one scholarly journal publication that I have found which gives a general overview of the scandal itself relies

[4] Forbes 1982, 8–17; 2007, 97–108.

[5] E.g. Campisano *et al.* 2017.

[6] E.g. Hanna-Attisha *et al.* 2016; Pieper *et al.* 2017.

[7] E.g. *CNN* 2018; Ganim & Tran 2016; *The Guardian* 2018.

heavily on news stories to be found only on the internet.[8]

The issue of the use by scholars of relatively ephemeral information available only on the internet is something which interests me with my training in cultural anthropology. It is connected to the issue of potential mis-matches between purely oral data and information contained in written documents, which I have explored elsewhere.[9] Anthropologists rely very heavily on verbal communications with informants/consultants, and in scholarly circles reports of these conversations or interviews are considered perfectly acceptable, even though there is no corroborative evidence to back up the reports. On the other hand, written evidence which is available via "hard" sources such as paper, or permanent servers (typically in the form of academic books or journals) is considered crucial in scholarly circles. So, how should scholars treat sources such as blogs or relatively short-lived technical pamphlets or even company web sites which are written evidence but more ephemeral than scholarly publications? My approach is to treat them as essentially liminal but viable sources, neither fully "hard" (e.g. academic journal) sources, nor purely oral sources: they are known in the social sciences as digital ethnographic sources. Where information from reputable academic sources is lacking, they provide useful information. As long as their providers (e.g. reputable news organizations, government agencies, etc.) seem to be reliable, I shall use them as sources of information. Sources such as blogs can also provide indications of a particular viewpoint, even though the information presented cannot necessarily be independently verified: they are the equivalent of informant/consultant verbal statements.

[8] Masten *et al.* 2016.

[9] Forbes 2000; 2009b.

## Water storage—general features

The term cistern in English simply refers to a water storage receptacle, such as the small tank which is part of the flushing system of a toilet or, at the other end of the scale, some of the massive rainwater storage facilities built by the Romans and Byzantines.[10] In traditional water management systems, cisterns can be roofed or unroofed, and filled via streams or by the collection of rainwater. A good example of a traditional (Early Modern period to present-day) water management system using both roofed and unroofed cisterns filled from a seasonal stream has recently been documented on the Greek island of Kythera.[11] In this chapter, however, I shall concentrate only on facilities which store harvested rainwater.

Rainwater harvesting systems are known in arid or semi-arid parts of the world which lack sufficient alternative sources of water, and are particularly well known from the Near and Middle East, both archaeologically and in literary sources.[12] They demonstrate three significant characteristics:

1. They are very flexible, being readily integrated with other sources of water and, as long as their structural integrity is maintained, may provide healthier supplies of water than wells, as will be discussed below.
2. They are remarkably enduring: in Greece in certain areas such as some of the islands, and in parts of the Near and Middle East they have been in use for millennia.[13]
3. The ability to construct cisterns below ground—the standard feature of most traditional cisterns—is dependent on an interplay between geology and the availability of particular kinds of technology, as will be discussed in more detail below.

[10] See e.g. Mays *et al.* 2013, 1923–1930.

[11] Tzortzopoulou-Gregory & Gregory 2017, 356–358.

[12] E.g. Mays *et al.* 2013, 1917.

[13] Mays *et al.* 2013, 1917; Antoniou *et al.* 2014, 691. See also e.g. Cadogan 2007.

To begin with, let us first consider the basic minima necessary for rainwater storage in a traditional cistern. Essentially, rainwater storage systems consist of three components: first, the collection area, second the conveyance system which takes water to the storage facility, and third the storage facility itself which can be above or below ground.[14] Here I am focusing on underground systems, and will not consider the collection and storage of water above ground in relatively small installations such as barrels or large storage jars.

Focusing on the third component, the storage facility, the first consideration is a hole in the ground: while an obvious statement, I shall demonstrate that it presupposes an interplay between specific types of available technology and local geology. There are examples of large above-ground water storage structures, especially with the advent of modern materials, but also from antiquity. However, the substantial pressure of water against the sides of above-ground water storage structures meant that they tended to be rare without the availability of concrete and brick for construction.[15] It is also generally easier for the second component—the conveyance system—to direct water into underground systems with the use of limited technological means of constructing conduits dependent entirely on gravity. Where the available technology is very limited (e.g. before the widespread use of metal tools) and the underlying rock is very hard, it is unlikely that communities will be able to construct underground storage facilities of any significant size. In this study I shall argue that, in the ethnographic example to be described, a technological development—the availability of high explosives—had a major impact on both the ease of cistern digging and the sizes of the cisterns that could be dug.

The second necessity is a waterproof lining for a cistern.[16] In most cases a lack of waterproof lining would lead to the loss of stored water either through permeable rock or through cracks in impermeable rock. In densely occupied settlements where pit toilets are common, a waterproof lining also eliminates the risk of contamination of cistern water from groundwater polluted with sewage.[17] There are some generally rare situations in which the underlying bedrock is both reasonably soft, so it can be excavated with simple technologies, and yet it is also completely impermeable, so that no lining is needed. On Methana these are the localized situations in which one finds *loutses*, to be discussed in more detail later. The technology for producing hydraulic plaster or cement for such linings has received some attention in the archaeological and scientific literature.[18] I will also touch on this topic in due course.

A third necessity, certainly for longer-term storage of clean water under Mediterranean conditions, is some form of covering of cisterns. A cover serves the purpose of severely limiting water loss via evaporation—a major problem in Mediterranean summers. It also minimizes the chances of foreign bodies—including animals and humans—falling into the water and polluting it: writing about Jerusalem in the later 19th century, Conrad Schick notes the problem of rats and cats falling into cisterns, presumably because these cisterns lacked fitted lids.[19] Cov-

[14] Da Franca & Dos Anjos 1998, 374.

[15] Klingborg 2017, 17.

[16] Klingborg 2017, 43–45.

[17] See e.g. Masterman 1918, 58 for early observations in the Near East. The role of sewage contamination of drinking water in disseminating epidemic diseases such as cholera in Europe was already well known by this date: see e.g. Snow 1849.

[18] E.g. Coutelas *et al*. 2004; Elsen 2006; Genestar *et al*. 2006; Maravelaki-Kalaitzakia *et al*. 2003; Moropoulou *et al*. 2005; Pavía & Caro 2008; Silva *et al*. 2005.

[19] Schick 1878, 135–136. During my ethnographic fieldwork a young goat dislodged an ill-fitting lid to a house cistern and fell in. It was with much difficulty and a great deal of luck that the animal was retrieved before it drowned.

ers to cisterns also reduce the problem of mosquito breeding and the development of algae in the water—a factor that has been recognized for at least a century.[20]

A fourth necessity is a means of collecting and concentrating rainwater—the first component noted above. Even in regions such as the Mediterranean, where rainfall events can often be much more intense than in the temperate zone, they are inadequate on their own to fill a cistern which lacks a collection surface, especially one with a narrow mouth.[21] Therefore, a wide surface, such as a roof area or an extensive area of ground, is necessary to capture and concentrate substantial amounts of rainfall which can then be diverted into a cistern. Patrik Klingborg considers that ground surfaces in ancient Greek cities were rarely used as catchment areas, in large part because of the risk of water contamination.[22] Indeed, as will be discussed below via recent and modern studies, ground surfaces are very prone to contamination from a wide range of substances, with faecal matter being a particularly significant biohazard. Be this as it may, it is not certain that ancient communities before the emergence of the germ theory of disease, recognized the potential disease risk of such biological contamination if the water discharged into a cistern was visibly clear. For example, writing of fieldwork in a Greek village in the 1950s, Ernestine Friedl describes the standard habit of removing visible dirt from plates with filthy aprons—clean meant visibly clean, not hygienically clean.[23] Nevertheless, there are examples in ancient Greek cities of ground surfaces which deliberately slope away from cisterns, indicating that water collected on ground surfaces was considered unsuitable for cistern use. On the other hand, while evidence for water collection from house roofs is far more abundant in ancient Greek cities, there are ancient Greek examples of water collection from ground surfaces in rural locations.[24]

An additional feature of many conveyancing systems is a facility to trap foreign bodies, both floating and sedimentary (e.g. dust) from entering the cistern, such as a sedimentation pit or tank.[25] A sedimentation tank or pit (*prolakkion* in ancient Greek[26]) in its simplest form is a generally smallish pit close to a cistern into which water flows, allowing sediments in suspension to settle to the bottom before they enter the cistern, while a channel leading from the top of the pit conducts sediment-free water into the cistern. Most small pieces of floating debris can also be filtered out by relatively simple means, such as packing small cushion-forming shrubs, like spiny burnet (*Sarcopoterium spinosum*) into the entrance hole to the cistern, through which the water can pass but which retains floating particles. Although they are very unlikely to have survived in archaeological examples of cisterns, these kinds of filters may well have existed, even without sedimentation pits, since small floating foreign bodies would be the most obvious sign of contamination on the surface of water in a cistern. Filters of this type would also prevent the problem of rodents and even cats falling into cisterns, as discussed above, having accessed the water entry point.

Although there are some important exceptions, such as the illustration of a Venetian system at Monemvasia and the more extensive general discussion by Klingborg for the Archaic to Hellenistic periods,[27] in archaeological publications on post-medieval cisterns, facilities for

[20] Klingborg 2017, 32; WHO no date. For an example of diseases caused by uncovered cisterns, see Masterman 1918, 58–59, 62.
[21] E.g. Antoniou *et al*. 2014, fig. 1, left, fig. 12, left (not right as stated in caption).
[22] Klingborg 2017, 34.
[23] Friedl 1962, 43.
[24] Klingborg 2017, 34–35.
[25] E.g. Antoniou *et al*. 2014, fig. 1, right.
[26] Klingborg 2017, 38–40.
[27] Mays *et al*. 2013, 1931, figs. 18a–b; Klingborg 2017, 38–40.

trapping and filtering sediments etc. have been the aspects which have been most consistently ignored. Moreover, they also rarely receive mention in scholarly discussions of modern rainwater harvesting systems, which focus more on the need for additional water sources in areas of water shortage or else the potential biohazards associated with drinking cistern water.[28] Nevertheless, information gained from both providers of modern rainwater harvesting systems and governmental authorities indicates that there are considerable technological considerations involved in capturing adequate amounts of rainwater in cisterns while ensuring that it is relatively clean.[29]

A final observation: modern systems of rainwater capture from tiled sloping roofs are completely dependent on the use of plastic, or possibly metal, guttering and piping, combined with generally quite complex filtration systems, even for non-potable water. In earlier centuries, other systems were in use. While evidence of cisterns has been claimed to date as far back as the Neolithic in parts of Greece and the Near East,[30] discussion of how water was conducted to cisterns and how it was filtered is much more limited (although some exceptions have been noted above). Some rare examples from Greece discussed in the literature indicate that specialized items in ceramic (and more rarely, stone) and lead have been used in the past. Wooden pipes may also have been used in Greece in the past.[31] Although no such pipes seem to have survived, they are well known from Roman contexts elsewhere.[32] Both ceramic and stone materials are brittle and inflexible and must be largely tailor-made to a specific situation. Lead is somewhat more flexible but expensive and toxic: since rainwater is mildly acidic, there are significant risks of normally low levels of dissolved lead entering the cistern. However, although the Roman writer Vitruvius considered that water in lead pipes was harmful to human health, the level of health problems associated with lead plumbing has only relatively recently been recognized: lead was widely used for plumbing in antiquity and continued to be widely used in places like Britain into the 20th century.[33] Indeed, heavy metal—especially lead—toxicity is a known problem in some contemporary rainwater harvesting systems.[34] It seems probable that before modern systems of guttering and pipework were introduced, even where roofs provided a major catchment area, most systems for filling cisterns, especially in domestic establishments, would have depended on water falling onto the ground and being routed to the cistern via surface channels. Such a system increases the risk of microbial contamination, as will be discussed below.

## Background to the ethnographic situation

I conducted ethnographic fieldwork on traditional agricultural techniques and environmental knowledge for two years between 1972 and 1974 on Methana, on the south-west side of the Saronic Gulf. It is a small peninsula, almost entirely volcanic in origin, with numerous volcanic cones, domes and lava features as well as generally steep slopes, barely 10 km across but rising to almost 750 m in the in-

28 For references to some of these studies, see the section below: "Health aspects".

29 See e.g. Akruthi Enviro Solutions no date; Highland Tank no date; Ling & Benham no date; Debord 2011.

30 Miller 1980; Fitzsimons 2011; Mays *et al.* 2013, 1917. It should be noted that lined pits from the Near Eastern Neolithic may have been for food storage and not water. Without evidence of conveyanc systems it is difficult to determine their specific function.

31 Angelakis 2013; Koutsoyiannis *et al.* 2008; Klingborg 2017, 34–36; Mays 2008, 474.

32 See e.g. Oleson 1988, 156, n 13; Burgers 1997, 4, 9, 24, 26–27; Ponel *et al.* 2000, 1058.

33 Prioreschi 1998, 279.

34 See e.g. Gumbs & Dierberg 1985; WHO no date.

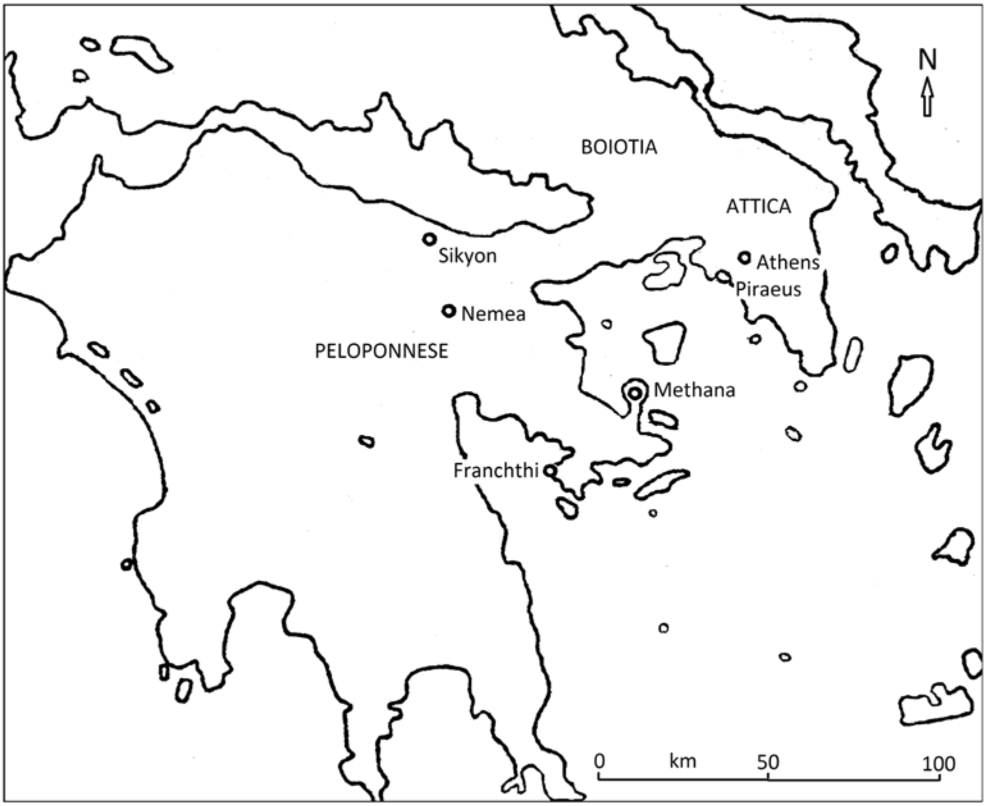


*Fig. 1. Methana: location map. Illustration: Hamish Forbes.*

terior (*Fig. 1*, see also *Fig. 3* in *Chapter 1*). In addition to Loutra, the main town on the south-east coast with its spa, there were ten small villages, primarily inhabited by subsistence farmers supporting themselves and their families on holdings which averaged a little over 30 *stremata* (= 3 ha) (*Fig. 2*).[35] At that time mechanization in agriculture was virtually non-existent, although with the recent construction of a vehicular road at that time, threshing of cereals was mostly done by machine rather than on traditional threshing floors. Other aspects of farming were dependent on mules and donkeys for traction and transport, and on family labour for tasks such as harvesting cereals, digging vines, etc.[36]

The spa on the coast was established in the later 19th century. The other villages were all located away from the coast, in a band around the peninsula, at an altitude of about 150–250 m above sea level, all but one being founded in the years following the Greek War of Independence.[37] This location was a result of the fear of pirate raids in the past: villages' po-

[35] Forbes 1982, 89, fig. 11.

[36] For details on the agricultural situation at that time see Forbes 1982, *passim*.

[37] See *Fig. 2*.

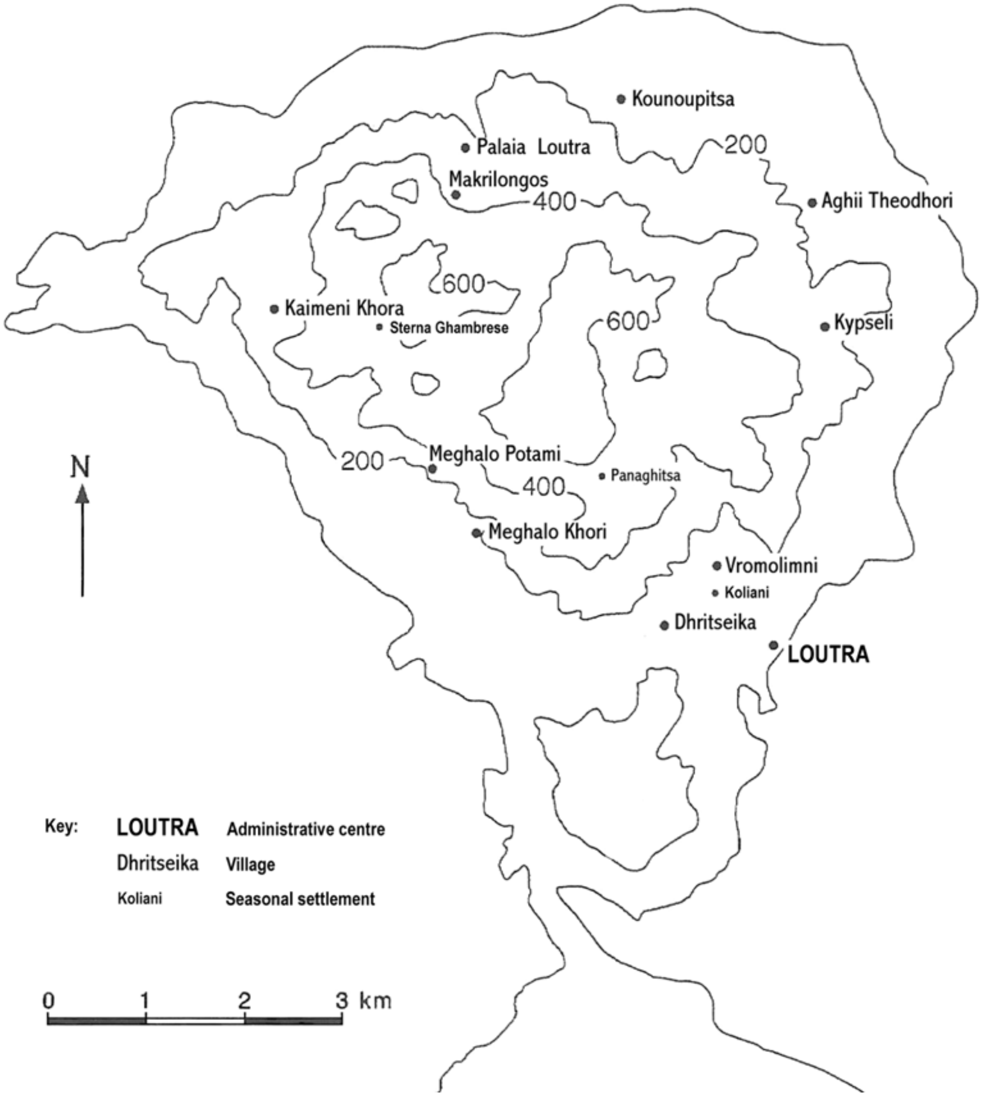


*Fig. 2. Settlement pattern on Methana, with traditional villages located away from the coast. Illustration by Hamish Forbes.*

sitions allowed their inhabitants to escape into the mountainous interior before raiders could reach their villages.[38] Natural water sources were very limited. Wells, with mostly brackish water, existed close to the coast and there was a single spring, about 20 minutes' walk from one of the villages. Obtaining water from these sources entailed a round trip of 40 minutes or more with mules or donkeys laden with water containers. The alternative was to harvest rain-water and store it in cisterns and in *loutses*, the

[38] Forbes 2000.

latter being used primarily for watering animals and for water for limited amounts of laundry.

When I first arrived on Methana, not all villages had electricity or running water. The village where I was based had had both installed only two years or so prior to my arrival, but already all habitable houses had electricity and most had been connected to the main water supply. Nevertheless, cistern water in particular was very important in everyday life. Some people also still used water from *loutses*, especially for watering animals, since "bought" water was considered very expensive. Methanites were also very dubious about the quality of piped water, fearing that it might have harmful chemicals in it. They therefore preferred to drink cistern water obtained from house roofs, which they considered healthier, and which during the summer months at least, was much cooler.

## *Loutses* on Methana

The word "*loutsa*" is regularly used in Greece, in the phrase "έγινε λούτσα", meaning that something or someone is soaking wet. Yet, in my searches of Greek sources of any kind, I could not find a single mention of an actual *loutsa* in any publication. Its use as a place name, however, suggests that they could be found in areas well beyond Methana.

On Methana a *loutsa* was a form of cistern lacking any form of hydraulic plaster lining, sunk into areas of impermeable geology, its sides lined with unmortared natural stones. Unlike a cistern it did not have a built cover with a cistern head. Instead it had a covering of brushwood spread over stout poles which were laid across the top. The covering reduced evaporation, and the framework of poles meant that anyone who might fall onto the top would at least have a hope of being supported. Nevertheless, in a dispute between two brothers who shared ownership of a *loutsa* in the period after piped water had been introduced, one brother filled it in on the excuse that it was no longer needed and it represented a danger. I also heard stories which involved people falling into *loutses*.

*Loutses* were cylindrical and generally had a diameter of over 2 m but not more than approximately 3 m. The maximum diameter was at least in part determined by the lengths of timber locally available to span the top. I do not recall seeing the bottoms of *loutses* but I would imagine that they were at least 3 to 4 m deep, since a number of cisterns were said to be converted *loutses*. It is possible that some may have been as much as 5 m deep. They tended to be located on unusually broad terraces—on Methana, that meant anything over 3–4 m wide. Rainwater capture was by means of a furrow cut diagonally across the terrace and leading into the *loutsa.* It was made using a simple ard plough. In heavy rains the run-off flowing across the very gently sloping terrace surface was trapped by this ephemeral furrow and channelled into the *loutsa*. Thus, every time the surrounding field was ploughed, the final task of the person ploughing was to renew the furrow. I never saw any *loutsa* with facilities for trapping sediment or other foreign bodies from the water inlet. Since the water was not used for human consumption, this did not seem to be considered a problem, although from time to time owners would presumably have been constrained when a *loutsa* ran dry to remove layers of sediment which had collected at the bottom.

The main use of *loutses* was for watering livestock and for providing water for a limited amount of clothes washing. While they tended to be concentrated in fields surrounding villages, they could be found almost anywhere where there were broad terraces and impermeable geology, as indicated by toponyms at considerable distances from any village, such as Loutsa

*Fig. 3. A cistern. The sedimentation tank is just visible at the front edge of the cistern apron. Photograph: © Tobias Schorr, www.methana.com.*

Kodzia, Loutsëzë,[39] etc. In the late 19th and earlier 20th centuries these extra-mural *loutses* provided much-needed water for the substantial numbers of sheep and goats owned by families in those days. Many *loutses* were located high in the interior where traditionally much of the grazing was concentrated. One of these featured in a story of a child minding their family's animals on the mountain, who fell into it and drowned.

## Cisterns on Methana

Cisterns were also cylindrical but differed from *loutses* in being fully lined with hydraulic plaster and having a masonry cap over the top, which was paved with flat stone slabs on its top surface to form a sort of circular apron. A cistern head (also known as a *puteal*[40]) was placed centrally (*Fig. 3*).[41] It should be noted that the cylindrical shape is not the only form that recent cisterns designed for single households may take in Greece. In Outer Mani, for instance, they are rectangular.[42] Although I was unable to inspect the undersides of cistern caps directly, it seems fairly certain that they were domed. The cistern head normally had a hinged metal lid to close it.

39 Virtually all toponyms on Methana were in the local Albanian dialect, known in Greek as *arvanitika*, for which speakers, on the rare occasions when they wrote it, used the Greek alphabet. The symbol ë used here and elsewhere in this chapter is that used in standard Albanian for the sound represented by the symbol ə (schwa) in the International Phonetic Alphabet.

40 Klingborg 2017, 40–42.

41 See also Clarke 2000, 181, fig. 9.6; Forbes 2007, 247, fig. 7.4.

42 Germanidou 2018.

Because cisterns were normally locked it is difficult for me to indicate the size range. However, diameters seemed to be in the range of at least 2 and often 3 m. Since almost all cisterns had water in them it was very difficult to estimate depths, but on the basis of the very few empty ones that I saw, I estimate perhaps 5 m. On this basis, a completely full 3 m-diameter cistern would hold about 35 $m^3$.

In the village where my research was based, some cisterns were located immediately adjacent to houses. These exploited the expanse of the tiled roof to collect water, which was then channelled via plastic gutters and plastic pipes into the cistern. This system minimized the amount of sediment and also restricted the risk of contamination from animal sources. As an additional precaution, villagers ensured that the water from the first substantial rainfall of the autumn, after a long rainless spell over the summer, was not channelled into the cistern. Instead the initial rainfall was used to flush out the whole rainwater collection and conveyance system of dust, bird droppings, etc. so that subsequent rainwater which actually entered the cistern was much cleaner. As indicated by studies worldwide, harvested rainwater has much lower levels of microbial contaminants where such first flush systems are used.[43] This system is used elsewhere in the world where there is a distinct intra-annual periodicity in rainfall, such as modern rainwater capture systems in some parts of the USA and Australia.[44]

Other cisterns were located on broad terraces close to the village but outside it. They trapped water in much the same way as *loutses*, with a diagonal furrow across the surface of the terrace. These cisterns, however, had no first flush system, but had a sediment trap at the point at which the water entered. This consisted of a relatively small stone-lined pit, with a floor perhaps 20 cm lower than the bottom of the entrance hole into the cistern. In addition, the hole was densely packed with one or two small spiny bushes which acted to strain out any debris floating on the surface of the water which might otherwise have entered the cistern.

Prior to the installation of piped water, under normal circumstances most households depended primarily on harvested rainwater. All stored rainwater was therefore precious: locked cistern lids were not only to prevent children dropping items or themselves into the water, but also to prevent surreptitious thefts. The limited supplies of stored water meant that in the period before the mid-20th century, when villagers kept considerable numbers of sheep and goats, after substantial rainfalls they would drive their animals high up onto the mountain to drink from several seepage springs. These only ran for a few days at most, but they helped conserve the supplies of stored water. Additionally, for processes which required substantial amounts of water such as washing large floor rugs or large amounts of clothes, and for the initial washing of wool prior to carding and spinning, people would go to the shore to use well water or sea water, taking not only the items to be washed, but also large metal *kazania* (cauldrons) for heating water, and the fuel for the fire. It was also not unknown during severe droughts for stored rainwater to run out. People and animals would then have to undertake daily journeys down the mountainside to access brackish water from coastal wells.

## Dates of cisterns and *loutses*

In most cases it is impossible to date cisterns and *loutses*. A few cisterns in the fields close to the village had dates carved on their cistern heads, but many cistern heads were undated: those on cisterns adjacent to houses were often

[43] WHO no date.
[44] See e.g. Rain Harvesting no date; Masterman 1918, 58 for Palestine in the early 20th century.

made in reinforced concrete, but their actual cisterns may well have been from an earlier period. *Loutses*, with their simple construction techniques, are undatable. However, it is probably safe to say that almost all cisterns and *loutses* date to the second half of the 19th century or to the 20th century. The reason for this belief is that, with the exception of a single village, all the settlements on Methana were founded during the later stages of the Greek War of Independence or its aftermath.[45] Over the years, villagers have discovered and often reused numerous examples of older cisterns. However, all of those that I examined were a great deal smaller than the main ones. The largest of these that I examined was associated with a small Late Roman period villa site: I estimate that it had a maximum volume of about 1.50 $m^3$, as opposed to a suggested 35 $m^3$ for the recent ones. In addition, the older cisterns lacked a domed top, instead having a neck, somewhat like that of a bottle.

## Technology

The geology underlying many, if not most of the more gently sloping parts of Methana, where cisterns and *loutses* were generally located, consists of a compacted matrix of volcanic ash and volcanic blocks of all sizes, up to and including massive boulders weighing many tonnes. As documented by the geological team on the Methana Archaeological Survey, these deposits reach depths of some 50 m in places.[46] The lack of a solid hard bedrock enabled Methanites to open up the substantial holes required for cisterns and *loutses* with ordinary hand tools in many areas, as long as they did not encounter particularly massive boulders. However, the introduction of high explosives in the later 19th century allowed them to break up such massive boulders relatively easily when they encountered them, in both terrace and cistern construction. It is probably fair to say that the large sizes in comparison with earlier cisterns, and the large numbers of *loutses* and cisterns, were heavily influenced by the introduction of explosives.

These large cisterns required substantial amounts of hydraulic plaster (called κουρασάνι in modern Greek)—villagers described it as a mixture of hydrated lime and ground-up ceramic material, although it may have had additional sand filler. Hydraulic mortars using lime, crushed ceramic and other artificial pozzolanic materials have a long history in Greece and the Near East.[47] It was widely used by the Romans, but scientific analyses have clearly documented occasional examples in Late Bronze Age contexts in Greece and Cyprus, and Iron Age contexts dated to about 1000 BC in the Near East.[48] Hydraulic plaster containing pozzolanic materials has also been documented from a cistern at Kameiros on Rhodes dating to about 500 BC.[49] It is clear that for many centuries before Roman times it was widely recognized that the addition of crushed ceramic produced a waterproof plaster: tests on mortars used for waterproofing the surfaces of cisterns from these periods indicate that they generally contain pozzolanic materials such as crushed ceramic, whereas mortars for bedding masonry do not.[50] On Methana, lime had to be bought in since the absence of any limestone in the volcanic landscape precluded lime-burning, but pottery was ground up in primitive crush-

45 Forbes 1997, 107–110; 2009a, 216–220.

46 James *et al.* 1997, 13.

47 Coutelas *et al.* 2004; Elsen 2006, 1419; Maravelaki-Kalaitzaki *et al.* 2003; Masterman 1918, 58; Mays *et al.* 2013, 1918; Moropoulou *et al.* 2005.

48 Regev *et al.* 2010; Theodoridou *et al.* 2013. Mays *et al.* 2013 claim that the Late Bronze Age Minoans used hydraulic plaster in cisterns but do not refer to scientific analyses to support their claim.

49 Moropoulou *et al.* 2000, 295; Malinowski 1981.

50 Moropoulou *et al.* 2000; Silva *et al.* 2005.

*Fig. 4. A crusher, the traditional uses of which included crushing pottery for making hydraulic cement. Photograph: Hamish Forbes.*

ers such as that in *Fig. 4*. Oral tradition suggests that in the period when substantial numbers of cisterns were being constructed, the most difficult material to obtain was sufficient pottery to provide the crushed ceramic, since few ceramic vessels were in use and broken tiles were very rare until the beginning of the 20th century, because most houses had flat mud roofs up to that time. In one village a smallish ancient site some 20 minutes' walk away was systematically mined for its pottery and tile.

## Monumentality

Archaeologists readily associate monumentality and memorialization with burial of the dead. Possibly most would automatically think of funerary monuments when considering memorialization. This was not the case traditionally on Methana, where gravestones indicating the identity and dates of individuals do not appear until the later 20th century.[51] The earliest carved memorializations in the post-Roman period are associated with churches. A graffito dated 5 December 1685 on the inside wall of an extramural Byzantine church records that the priest Stamatis worshipped St George, and a carving dated 1824 on a quoin stone of a church in the centre of a village presumably indicates the construction date.[52] Only in the later 19th century do dates appear on secular structures. For Methanites, houses are the location of personal identity, linking individuals to their family lines stretching back into the past. Many traditional houses bear dates and/or an indication of the identity of the household head at the time of construction. Thus rather than graves, these houses stood as lasting memorials to their identity.[53]

However, the earliest dated secular monuments, which may also bear the initials of their original owner, are cistern heads.[54] This phenomenon seems to relate to the importance of cisterns and their contents, but it presumably also reflects the amount of effort, and above all the amount of bought-in skill, invested in such facilities. Much if not all of the labour involved in opening up the original hole for the cistern and the construction of its walls in rough stone

[51] Forbes 2007, 259–261.

[52] Koukoulis 1997, 236–238.

[53] Forbes 2007, 228–229.

[54] Forbes 2007, 245, fig. 7.4.

could have been accomplished with family labour, given the generally large sizes of families in those days.[55] But substantial amounts of lime would have been purchased, and, on occasions, probably explosives as well. Additionally, the construction of the domed support for the apron covering the cistern and the carving of the cistern-head from a single large block of stone would have required specialist craftsmen, who would have been paid for their services. In an extremely cash-poor, almost entirely subsistence-based society, the construction of a cistern would be an overt demonstration of both the energy and the wealth of the household. It would also represent an element of luxury, inasmuch as a source of stored rainwater close to the village would save household members the daily chore of travelling down to the coast to collect brackish well water. The lack of necessity for women to spend large amounts of time on a daily basis collecting water from coastal wells would almost certainly have been an important plus point when it came to marriage negotiations between families, since women almost always moved to their husband's residence on marriage.[56]

Dates start to appear on houses only at the end of the 19th or the beginning of the 20th century, at a time when there was a spate of house rebuilding in a significantly higher status style. Methanites stated that when their ancestors arrived on the peninsula they built houses with only the materials which lay to hand: rough stones, mud to bed them in, and relatively short tree trunks supporting flat mud roofs. Like *loutses*, these were limited to about 3 m in width by the availability of local timber. They also tended to be primarily single-storey structures, although being built perpendicular to hill slopes, they had a low basement under a raised floor, generally also of mud, at the downhill end. By comparison, the houses bearing dates were full two-storey structures built with bought-in timber and ceramic tiles for a pitched roof, constructed to a considerably wider plan than the older houses. They also had craftsman-worked masonry around windows and doors.[57] Again, therefore, these houses, like the cisterns built by an earlier generation, represented both relative wealth and also luxury in comparison with many surrounding households.

Finally, in terms of the cognitive aspects of *loutses* and cisterns, they also played an important role in how people perceived their landscapes. As far as I am aware, there was only one place name on Methana which related to a cistern—*Shterna Ghambresë* (the Cistern of the Bridegroom), a small abandoned seasonal settlement high in the interior of the peninsula. However, substantial numbers of toponyms in the countryside referred to *loutses*. As noted previously, names such as Loutsëzë, Loutses, etc. were widespread. In the later 19th and earlier 20th centuries, when households owned substantial numbers of sheep and goats and when stored rainwater and wells were the only water sources available, these place names would have influenced daily decisions on where to go to graze a household's livestock.

## Health aspects

A final issue is whether harvested rainwater is safe to drink. Klingborg discusses at some length the contradictory opinions of both ancient and modern writers on the quality of cistern water, *inter alia* making the important observation that it is misleading to use modern standards of the water purity of centralized piped water systems.[58] The rainwater harvest-

[55] Forbes 2009a, 224–227.
[56] Forbes 2007, 144–146. For an illustration, see Clarke 2000, 181, fig. 9.6; Forbes 2007, 247, fig. 7.4.
[57] Forbes 2007, 228.
[58] Klingborg 2017, 83–86.

ing consultant John Gould notes that there is no simple answer to the question "is rainwater safe to drink?" since no water supply is 100% safe to drink all the time. Instead, the primary issues are "what is an acceptable level of risk" and "what is the quality of alternative water supplies?"[59] In relation to this latter question, although springs are usually considered to be sources of "pure" water, the safety of the water can be compromised by a variety of dissolved minerals, and even sewage.[60]

In modern discussions of cistern water quality, it is also important to consider whether a Western perspective on the "primitiveness" of many communities employing rainwater capture may affect, at least in part, our views on its quality. Most of us in Western nations have always used piped water, which we consider safe to drink: it has been treated so that it contains minimal levels of dangerous or unpleasant minerals (e.g. lead, arsenic, calcium), and proper purification has removed any sediment and, particularly important, any biological contaminants such as coliform bacteria.

With this inbuilt assumption it is therefore tempting to view non-Western communities relying on facilities such as rainwater cisterns, in which the water has not been treated via a variety of processes, as "primitive". By comparison with our "civilized" water supplies, cistern water could be considered "unsafe". Nevertheless, treatments such as chlorination of water to kill harmful bacteria have only been in existence in the developed world for a little over a century: several of the earliest examples were in response to epidemics of serious water-borne disease.[61] Even now, the recent scandal over the contamination of water supplies in Flint, Michigan, in the USA reinforces Gould's observation noted above: harmful levels of both mineral and biological contaminants can occur or recur over substantial periods even in modern water supplies.[62]

In the case of the water scandal in Flint, Michigan, there were problems with coliform bacteria in the municipal water supply, followed by very high levels of carcinogenic by-products of the high levels of chlorine used to combat the bacteria. However, the most serious factor was contamination of the water by lead caused by a switch to an acidic water supply which leached lead from the plumbing used widely in the city until well into the 20th century, despite the centuries-long recognition of the dangers of lead poisoning. Lead pipework is still widespread in many cities in the Western world, meaning that there is at least the potential for some level of widespread lead contamination in water supplies in many Western cities. Similarly, the use of chlorine to eliminate biohazards in drinking water has been recognized for more than three decades as causing a substantial risk element for a range of cancers, yet most water supplies are still chlorinated.[63] These issues need to be borne in mind when considering whether cistern water should be defined as more or less "safe" than the water in Western public water supplies.

In terms of cistern water purity, it would seem that much depends on the surfaces used for collecting rainwater, and the kinds of cleanliness practices employed. I previously noted that Methanites considered cistern water preferable to piped water for drinking. Yet, as I have also noted, ensuring that harvested rainwater meets modern standards of potability is technologically relatively complex. The likelihood, therefore, is that Methanites were drinking water from cisterns fed from roof run-off that was free of contaminants such as chlorine but

[59] Gould 1999, 1.
[60] See e.g. Masterman 1918, 57, 59.
[61] See e.g. Howard 1928; IARC 1991; Turneaure & Russell 1901.
[62] Butler *et al.* 2016; *CNN* 2018; Ganim & Tran 2016; *The Guardian* 2018.
[63] E.g. Goitlieb *et al.* 1982; King & Marrett 1996; Koivusalo *et al.* 1997; Morris *et al.* 1992.

would have had levels of biological contaminants somewhat higher than in Western municipal systems. Nevertheless, there is no reason to believe that levels of biological contaminants were above levels considered safe by international standards.

A number of publications discuss the potential health risks of harvested rainwater in traditional communities. Uncovered water storage facilities (such as *loutses*) encourage mosquito breeding, and sunlight reaching the water will promote algal growth.[64] Additionally, microbial contamination by *E. coli* is quite common on a worldwide basis and a range of pathogens have also been detected in rainwater. Wind-blown dirt, leaves, faecal droppings from birds and animals, insects and contaminated litter on catchment surfaces can all be sources of contamination. This is especially likely if the first flush after a long dry spell is stored in the cistern.[65] In ancient Greece lead pipes leading rainwater to cisterns are known, although not common.[66] Since rainwater is slightly acidic, there would have been the potential for the water to dissolve some of the lead in the pipes. However, since the lengths of lead pipes were generally limited, lead poisoning from this source seems unlikely.

A report on hygiene and disease in Palestine published in 1918 speaks in favourable terms of the water in cisterns in the region generally, noting that where roof water alone is used the amount of sediment found at the bottoms of cisterns is surprisingly small. The author notes, however, that "careful people" exercise a first flush regime.[67]

A 21st-century study of harvested rainwater in the Palestinian Authority area of the West Bank indicated the absence of a number of pathogenic bacteria, which was explained by a combination of roof cleaning and the operation of first flush systems, along with the practice of covering cisterns.[68] The importance of the first flush was also documented by a study in northern China, where the level of organic contaminants derived from roof-yard harvesting systems which did not operate a first flush could be more than double that of systems which did. Nevertheless, even non-first flush systems had levels of contamination just within the WHO's maximum permitted contamination (MPC) figure, while rainwater harvested entirely from ground surfaces was well outside the MPC figure. On the other hand, levels of coliform bacteria were tremendously higher than the WHO guidelines for drinking water, even for water from roof-yard systems.[69]

A case study of cisterns in the Hebron area of southern Palestine detected faecal coliforms in just over half of all cisterns tested, which they linked in part to factors such as not cleaning collection surfaces on the ground and not operating a first flush regime.[70] This state of affairs is also reflected in the West Bank study previously noted, where two thirds of all water samples contained faecal coliform bacteria, and a study in Jordan stated bluntly that in general the harvested rainwater that was tested was so heavily contaminated with microbes that it was unsuitable for drinking.[71] In the community in southern Palestine, the water collection surfaces of approximately one third of all cisterns included surfaces other than roofs (e.g. gardens, house yards and streets). The authors note that the non-roof surfaces contained a wide range of potential contaminants, including those from animal and human waste. All cisterns were used to provide drinking water.[72]

64 E.g. Masterman 1918, 58.
65 WHO 2004, 65–66, 141; WHO no date.
66 Klingborg 2017, 35–36.
67 Masterman 1918, 58.
68 Daoud *et al*. 2011, 530.
69 Zhu *et al.* 2004, 499–502.
70 Al-Salaymeh *et al*. 2011, 1731–1733.
71 Daoud *et al.* 2011, 529–531; Radaideh *et al*. 2009, 28.
72 Al-Salaymeh *et al*. 2011, 1727–1728.

On Methana water from *loutses*, which did not have a proper cover, was not used for drinking by humans, and mosquito-borne diseases such as malaria were not a problem on the peninsula, although malaria was a serious problem on the adjacent Mainland until the middle of the 20th century. Hence the greatest problem with *loutses* was the danger of someone falling in. The earliest cisterns built in the study community, which seems to have been founded in the mid-19th century, seem to have been those out in the fields close to the village. These collected run-off water from the surfaces of fields, which at certain times of year provided grazing for animals. At other times they were intensively cultivated, requiring the deposition of stable manure. Since stables were sometimes used as toilets in the past, low levels of human waste would also have been deposited on fields. These observations suggest that although Methanites were careful to strain out visible water contaminants, micro-organisms such as pathogens from both animals and humans may have entered these cisterns. However, cisterns which harvested water from house roofs can be assumed to have contained water of a relatively high standard. Villagers were assiduous in ensuring that particulate matter did not enter these cisterns, not least by ensuring that the first substantial rainfall of the autumn was not collected.

In the more distant past, however, it is likely that Methanites drank water from cisterns located out in the fields, which were to a greater or lesser extent contaminated by micro-organisms. However, we should bear in mind the WHO's observation that open bodies of water, such as streams and rivers, often used as sources of drinking water, generally carry larger amounts of such organisms.[73] As Gould notes, the issue of the potential safety or otherwise of harvested rainwater is complex.[74] Although numerous studies of stored rainwater have indicated a level of microbial contamination, this of itself does not mean that the water is unsafe: some authors have suggested accepting more realistic levels of contamination in developing regions than the very stringent ones advised by the WHO. Furthermore, relatively small cisterns used by single households are less likely to be sources of widespread disease outbreaks than larger municipal systems.[75]

Information gained during fieldwork in 2017 helps to put these considerations into broader perspective. A retired resident of Askri, a Boiotian village, stated that before piped water was installed, although most houses had their own wells, only about 10% had potable water for humans, the rest being contaminated by the large numbers of livestock owned by residents. Most villagers therefore needed to walk to a spring on the edge of the village for drinking water despite having their own wells. Thus, viewed in relative terms, in the past Methanites' extra-mural cisterns probably held water of a higher quality than that to be found in many villages which were completely dependent on wells, even though it would not meet present-day standards for drinking water. It should also be noted that while modern rainwater harvesting systems that use plastic guttering and pipework are likely to have reduced microbial contamination compared with systems which collect water from ground surfaces, little research has been conducted into the level of phthalates in the water derived from the use of plastic in these systems. An Australian study has noted the presence in roof-harvested rainwater of phthalates commonly used as plasticisers in flexible PVC products. While the author could not identify the exact source of phthalate esters, she proposed that they had migrated from plastic elements in the rainwater catch-

[73] WHO no date.
[74] Gould 1999.
[75] Gould 1999.

ment system.[76] The jury is therefore out on whether modern technology associated with rainwater harvesting is simply exchanging one form of contamination for another.

## Concluding remarks

This study indicates that the industrial revolution has had a major impact on cistern technology, including the health aspects. First, modern cheap forms of guttering and pipes make it easy and relatively cheap for households to harvest roof water directly into cisterns, thus ensuring relatively high standards of cleanliness, since the collected water is not in direct contact with potential contaminants on the ground. Pre-industrial systems would mostly have relied very heavily on materials such as lead or ceramic, the one being expensive and having a certain level of toxicity, and the other being fragile and inflexible. In the past also, many cisterns would have depended on a simple system in which roof water was allowed to drop onto the ground before being channelled into them, raising considerably the potential for contamination.

Second, the role of explosives was frequently crucial in the sinking of cisterns on Methana, even though Methanites were not quarrying solid bedrock. This fact suggests that making large water storage facilities in pre-industrial times would have normally required more labour and/or financial resources than single subsistence-based households could possibly afford unless the underlying rock was unusually soft and easy to work. Construction of cisterns of any significant size would thus probably have required the intervention of governing bodies or relatively wealthy individuals or groups with significant resources of labour and capital.

Third, it seems highly probable that in the past, most cistern water was contaminated with human pathogens to a greater or lesser extent, although water could have been relatively safe if suitable cleanliness procedures were in place, and probably safer than other sources such as wells and rivers. However, palaeopathological studies indicate that past human populations carried a substantial burden of endoparasites and enterobacteria, whether or not they used cisterns. Particularly significant in this regard is the finding that certain strains of human coliform bacteria evolved long before cisterns, somewhere between 270,000 and 35,000 years ago.[77] It is therefore likely that any microbial contamination in cisterns in the past would to some extent have reflected disease burdens in populations at large, rather than being simply their immediate cause.

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## Bibliography

Akruthi Enviro Solutions no date. *Rainwater harvesting methods*. http://www.neoakruthi.com/blog/rainwater-harvesting-methods.html

Al-Salaymeh, A., I.A. Al-Khatib & H.A. Arafat 2011. 'Towards sustainable water quality. Management of rainwater harvesting cisterns in southern Palestine', *Water Resources Management* 25, 1721–1736. https://doi.org/10.1007/S11269-010-9771-0

Angelakis, A.N. 2013. 'Evolution of rainwater harvesting and use in Crete, Hellas through the millennia', paper presented at the 13th International Conference on Environmental Science and Technology, Athens, Greece, 5–7 September.

[76] Morrow 2012, 12, 107.

[77] Pupo *et al.* 2000.

https://www.gnest.org/proceedings/cest2013/public_html/papers/0202.pdf

Antoniou, G., N. Kathijotes, D.S. Spyridakis & A.N. Angelakis 2014. 'Historical development of technologies for water resources management and rainwater harvesting in the Hellenic civilizations', *International Journal of Water Resources Development* 30:4, 680–693. https://doi.org/10.1080/07900627.2014.900401

Antoniou G., R. Xarchakou & A.N. Angelakis 2006. 'Water cistern systems in Greece from Minoan to Hellenistic period', in *Proceedings of the 1st IWA International Symposium on Water and Wastewater Technologies in Ancient Civilizations. Atlantis Hotel in Iraklio, Greece, 28–30 October 2006*, eds. A.N. Angelakis & D. Koutsoyiannis, Heraklion, 457–462. https://doi.org/10.13140/RG.2.1.2511.1287

Butler, L.J., M.K. Scammell & E.B. Benson 2016. 'The Flint, Michigan, water crisis. A case study in regulatory failure and environmental injustice', *Environmental Justice* 9:4, 93–97. https://doi.org/10.1089/env.2016.0014

Burgers, A. 1997. The water supplies and related structures of Roman Britain, Ph.D. thesis, University of Leicester.

Cadogan, G. 2007. 'Water management in Minoan Crete, Greece. The two cisterns of one Middle Bronze Age settlement', *Water Science & Technology. Water Supply* 7, 103–111. https://doi.org/10.2166/ws.2007.012

Campisano, A., D. Butler, S. Ward, M.J. Burns, E. Fiedler, K. DeBusk, L.N. Fisher-Jeffes, E. Ghisi, A. Rahman, H. Furumai & M. Han 2017. 'Urban rainwater harvesting systems. Research, implementation and future perspectives', *Water Research* 115, 195–209. https://doi.org/10.1016/j.watres.2017.02.056

Clarke, M. 2000. 'The changing household on Methana, 1880–1996', in *Contingent countryside. Settlement, economy and land use in the Southern Argolid since 1700*, ed. S.B. Sutton, Stanford, California, 169–199.

*CNN* 2018. Time Warner, 'Flint water crisis. Fast facts', *Cable News Network*. https://edition.cnn.com/2016/03/04/us/flint-water-crisis-fast-facts/index.html

Coutelas, A., G. Godard, P. Blanc & A. Person 2004. 'Les mortiers hydrauliques. Synthèse bibliographique et premiers résultats sur des mortiers de Gaule romaine', *Revue d'archéométrie* 28, 127–139. https://doi.org/10.3406/ARSCI.2004.1068

Da Franca, N. & R. Dos Anjos 1998. 'Source book of alternative technologies for freshwater augmentation in Latin America and the Caribbean', *International Journal of Water Resources Development* 14:3, 365–398. https://doi.org/10.1080/07900629849277

Daoud, A.K., K.M. Swaileh, R.M. Hussein & M. Matani 2011. 'Quality assessment of roof-harvested rainwater in the West Bank, Palestinian Authority', *Journal of Water and Health* 9:3, 525–533. https://doi.org/10.2166/wh.2011.148

Debord, D.E. 2011. 'Rainwater harvesting system design', *Consulting-Specifying Engineer Magazine* 2011, 38–42.

Elsen, J. 2006. 'Microscopy of historic mortars—a review', *Cement and Concrete Research* 36:8, 1416–1424. https://doi.org/10.1016/J.CEMCONRES.2005.12.006

Fitzsimons, R. 2011. 'Excavation in the Archaic civic buildings at Azoria in

2005–2006', *Hesperia* 80:1, 1–70. https://doi.org/10.2972/hesp.80.1.0001

Forbes, H.A. 1982. Strategies and soils. Technology, production and environment in the peninsula of Methana, Greece, Ph.D. thesis, University of Pennsylvania.

Forbes, H.A. 1997. 'Turkish and modern Methana', in *A rough and rocky place. The landscape and settlement history of the Methana peninsula, Greece*, eds. C.B. Mee & H.A. Forbes, Liverpool, 101–117.

Forbes, H.A. 2000. 'Security and settlement in the medieval and post-medieval Peloponnese, Greece. Hard history versus oral history', *JMA* 13:2, 204–224. https://doi.org/10.1558/jmea.v13i2.204

Forbes, H.A. 2007. *Meaning and identity in a Greek landscape. An archaeological ethnography*, Cambridge. https://doi.org/10.1017/CBO9780511720284

Forbes, H.A. 2009a. 'Connecting the archaeological past with the ethnographic present. Local population records and settlement development on 19th century Methana', in *Medieval and post-medieval Greece. The Corfu papers* (BAR-IS, 2023), eds. J.L. Bintliff & H. Stöger, Oxford, 215–232. https://doi.org/10.30861/9781407305981

Forbes, H.A. 2009b. 'Researching ekina ta khronia [times past] in a rural Greek community', *Public Archaeology* 8:2–3, 88–107. https://doi.org/10.1179/175355309X457169

Friedl, E. 1962. *Vasilika. A village in modern Greece*, New York.

Ganim, S. & L. Tran 2016. 'How tap water became toxic in Flint, Michigan'. https://edition.cnn.com/2016/01/11/health/toxic-tap-water-flint-michigan/index.html

Genestar, C., C. Pons & A. Más 2006. 'Analytical characterisation of ancient mortars from the archaeological Roman city of Pollentia (Balearic Islands, Spain)', *Analytica Chimica Acta* 557:1–2, 373–379. https://doi.org/10.1016/j.aca.2005.10.058

Germanidou, S. 2018. 'Mapping agro-pastoral infrastructure in the post-medieval landscape of Maniot settlements. The case-study of Agios Nikon (ex. Poliana), Messinia', *Journal of Greek Archaeology* 3, 359–404.

Goitlieb, M.S., J.K. Carr & J.R. Clarkson 1982. 'Drinking water and cancer in Louisiana. A retrospective mortality study', *American Journal of Epidemiology* 116:4, 652–667. https://doi.org/10.1093/oxfordjournals.aje.a113448

Gould, J. 1999. 'Is rainwater safe to drink? A review of recent findings'. http://www.eng.warwick.ac.uk/ircsa/pdf/9th/07_04.pdf

*The Guardian* 2018. A. Clark, '"Nothing to worry about. The water is fine". How Flint poisoned its people', *The Guardian*, 3 July 2018. https://www.theguardian.com/news/2018/jul/03/nothing-to-worry-about-the-water-is-fine-how-flint-michigan-poisoned-its-people

Gumbs, F.A. & F.E. Dierberg 1985. 'Heavy metals in the drinking water from cisterns supplying single-family dwellings', *Water International* 10:1, 22–28. https://doi.org/10.1080/02508068508686293

Hanna-Attisha, M., J. LaChance, R.C. Sadler & A. Champney Schnepp 2016. 'Elevated blood lead levels in children associated with the Flint drinking water crisis. A spatial analysis of risk and public health response', *American Journal of Public Health* 106, 283–290. https://doi.org/10.2105/AJPH.2015.303003

Highland Tank no date. 'Pure rainwater system'. https://www.highlandtank.com/rainwater-harvesting-system-how-it-works

Howard, N.J. 1928. 'Modern aspects of chlorination of water', *American Water Works Association* 19:5, 546–552. https://doi.org/10.1002/J.1551-8833.1928.TB13583.X

IARC 1991. IARC working group on the evaluation of carcinogenic risk to humans, 'History of chlorination of water', in *Chlorinated drinking-water; chlorination by-products; some other halogenated compounds; cobalt and cobalt compounds*, International Agency for Research on Cancer, Section 1.1, Lyon.

James, P., M. Atherton, A. Harvey, A. Firmin & A. Morrow 1997. 'The physical environment of Methana. Formation, exploitation and change' in *A rough and rocky place. The landscape and settlement history of the Methana peninsula, Greece*, eds. C.B. Mee & H.A. Forbes, Liverpool, 5–32.

King, W.D. & L.D. Marrett 1996. 'Case-control study of bladder cancer and chlorination by-products in treated water (Ontario, Canada)', *Cancer Causes and Control* 7, 596–604. https://doi.org/10.1007/BF00051702

Klingborg, P. 2017. Greek cisterns. Water and risk in ancient Greece, 600–50 BC, Ph.D. thesis, Uppsala University.

Koivusalo, M., E. Pukkala, T. Vartiainen, J.J.K. Jaakkola & T. Hakulinen 1997. 'Drinking water chlorination and cancer—a historical cohort study in Finland', *Cancer Causes and Control* 8, 192–200. https://doi.org/10.1023/A%3A1018420229802

Koukoulis, T. 1997. 'Catalogue of churches' in *A rough and rocky place. The landscape and settlement history of the Methana peninsula, Greece*, eds. C.B. Mee & H.A. Forbes, Liverpool, 211–256.

Koutsoyiannis, D., N. Zarkadoulas, A.N. Angelakis & G. Tchobanoglous 2008. 'Urban water management in ancient Greece. Legacies and lessons', *Journal of Water Resources Planning and Management* 134:1, 45–54. https://doi.org/10.1061/(ASCE)0733-9496(2008)134:1(45)

Ling, E. & B. Benham no date. *Rainwater harvesting systems*. Pamphlet, Virginia Cooperative Extension, Virginia State University. https://vtechworks.lib.vt.edu/bitstream/handle/10919/56059/BSE-116.pdf?sequence=1

Lontra, P.A. 2014. Διαστασιολόγηση δεξαμενών ομβρίων υδατών στην Ελλάδα για αστική χρήση, Ph.D. thesis, National Technical University of Athens.

Malinowski, R. 1981. 'Ancient mortars and concretes—durability aspects', in *Proceedings of the symposium on mortars, cements and grouts used in the conservation of historic buildings, ICCROM*, Rome, 341–349.

Maravelaki-Kalaitzaki, P., A. Bakolas & A. Moropoulou 2003. 'Physico-chemical study of Cretan ancient mortars', *Cement and Concrete Research* 33:5, 651–661. https://doi.org/10.1016/S0008-8846%2802%2901030-X

Masten, S.J., S.H. Davies & S.P. Mcelmurry 2016. 'Flint water crisis. What happened and why?' *Journal of the American Water Works Association* 108, 22–34.

https://doi.org/10.5942/jawwa.2016.108.0195

Masterman, E.W.G. 1918. 'Hygiene and disease in Palestine in modern and in biblical times', *PEQ* 50, 56–71. https://doi.org/10.1179/peq.1918.50.3.112

Mays, L.W. 2008. 'A very brief history of hydraulic technology during Antiquity', *Environmental Fluid Mechanics* 8, 471–484.

Mays, L.W., G.P. Antoniou & A.N. Angelakis 2013. 'History of water cisterns. Legacies and lessons', *Water* 5:4, 1916–1940. https://doi.org/10.3390/w5041916

Miller, R. 1980. 'Water use in Syria and Palestine from the Neolithic to the Bronze Age', *WorldArch* 11:3, 331–341. https://doi.org/10.1080/00438243.1980.9979771

Moropoulou, A., A. Bakolas & K. Bisbikou 2000. 'Investigation of the technology of historic mortars', *Journal of Cultural Heritage* 1:1, 45–58. https://doi.org/10.1016/S1296-2074%2899%2900118-1

Moropoulou A., A. Bakolas & S. Anagnostopoulou 2005. 'Composite materials in ancient structures', *Cement and Concrete Composites* 27:2, 295–300. https://doi.org/10.1016/J.CEMCONCOMP.2004.02.018

Morris R.D., A.-M. Audet, I.F. Angelillo, T.C. Chalmers & F. Mosteller 1992. 'Chlorination, chlorination by-products, and cancer. A meta-analysis', *American Journal of Public Health* 82, 955–963. https://doi.org/10.2105/AJPH.82.7.955

Morrow, A.C. 2012. Variations in inorganic & organic composition of roof-harvested rainwater: Studies at the regional & individual site level in Eastern and Southern Australia, Ph.D. Thesis, The University of Newcastle, Australia.

Oleson, J.P. 1988. 'The technology of Roman harbours', *International Journal of Nautical Archaeology and Underwater Exploration* 11, 147–157. https://doi.org/10.1111/J.1095-9270.1988.TB00635.X

Pavía, S. & S. Caro 2008. 'An investigation of Roman mortar technology through the petrographic analysis of archaeological material', *Construction and Building Materials* 22:8, 1807–1811. https://doi.org/10.1016/j.conbuildmat.2007.05.003

Pieper, K.J., M. Tang & M.A. Edwards 2017. 'Flint water crisis caused by interrupted corrosion control. Investigating "ground zero" home', *Environmental Science and Technology* 51, 2007–2014. https://doi.org/10.1021/acs.est.6b04034

Ponel, P., V. Matterne, N. Coulhard & J.-H. Yvinec 2000. 'La Tène and Gallo-Roman natural environments and human impact at the Touffréville rural settlement, reconstructed from coleoptera and plant macroremains (Calvados, France)', *JAS* 27:11, 1055–1072. https://doi.org/10.1006/JASC.1999.0514

Prioreschi, P. 1998. *A history of medicine* 3. *Roman Medicine*, Omaha, Nebraska.

Pupo, G.M., R. Lan & P.R. Reeves 2000. 'Multiple independent origins of Shigella clones of *Escherichia coli* and convergent evolution of many of their characteristics', *Proceedings of the National Academy of Sciences, USA* 97, 10567–10572. https://doi.org/10.1073/PNAS.180094797

Radaideh, J., K. Al-Zboon, A. Al-Harahsheh & R. Al-Adamat 2009. 'Quality assessment of harvested rainwater for domestic uses', *Jordan Journal of Earth and Environmental Sciences* 2, 26–31.

Rain Harvesting no date. 'First flush water diverters'. http://rainharvesting.com.au/products/first-flush

Regev, L., A. Zukerman, L. Hitchcock, A.M. Maeir, S. Weiner & E. Boaretto 2010. 'Iron Age hydraulic plaster from Tell es-Safi/Gath, Israel', *JAS* 37:12, 3000–3009. https://doi.org/10.1016/J.JAS.2010.06.023

Schick, C. 1878. 'Die Wasserversorgung der Stadt Jerusalem in geschichtlicher topographischer Darstellung mit Originalkarten und Plänen', *ZDPV* 1, 132–176.

Silva, D.A., H.R. Wenk & P.J.M. Monteiro 2005. 'Comparative investigation of mortars from Roman Colosseum and cistern', *Thermochimica Acta* 438:1–2, 35–40. https://doi.org/10.1016/j.tca.2005.03.003

Snow, J. 1849. *On the mode of communication of cholera*, London.

Theodoridou, M., I. Ioannou & M. Philokyprou 2013. 'New evidence of early use of artificial pozzolanic material in mortars', *JAS* 40:8, 3263–3269. https://doi.org/10.1016/J.JAS.2013.03.027

Turneaure, F.E. & H.L. Russell 1901. *Public water-supplies. Requirements, resources, and the construction of works*, New York.

Tzortzopoulou-Gregory, L. & T.E. Gregory 2017. 'The Karavas Water Project. An archaeological and environmental study of interaction and community in northern Kythera', *Journal of Greek Archaeology* 2, 343–376.

WHO 2004. Guidelines for drinking-water quality. Recommendations, Geneva.

WHO no date. 'Rainwater harvesting'. http://www.who.int/water_sanitation_health/gdwqrevision/rainwater.pdf

Zhu, K., L. Zhang, W. Hart, M. Liu & H. Chen 2004. 'Quality issues in harvested rainwater in arid and semi-arid Loess Plateau of northern China', *Journal of Arid Environments* 57:4, 487–505. https://doi.org/10.1016/S0140-1963%2803%2900118-6