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BEYOND THE THEME

REVIEWS

Pietro Todaro, Giuseppe Barbera,
Angelo Castrorao Barba, Giuseppe Bazan*

Qanāts and historical irrigated landscapes in Palermo's suburban area (Sicily)

The city of Palermo and its surrounding valley is an important historic irrigated landscape, characterized by underground hydraulic structures and by a long tradition of irrigation systems inherited from the Islamic presence in Sicily throughout the Middle Ages (9^{th}-11^{th} century). The Islamic "green revolution" radically innovated the irrigation systems of Sicily and thus also lead to the introduction and diffusion of new irrigated crops. In Palermo's suburban areas, 63 hydraulic infrastructure and drainage tunnel sites have been surveyed and classified into 4 hydraulic categories: 1) *qanāt*s; 2) blind *qanāt*s; 3) connected wells; 4) emerging drainage galleries. These structures, notwithstanding some doubts concerning their exact dating, seem to be typical of the Medieval period. The Norman Favara / Maredolce castle and park (12^{th} century) is a particularly interesting case study in evaluating the role of Islamic heritage in Palermo valley water management and is an extraordinary example of how Islamic hydraulic engineering was used to demonstrate royal power.
Keywords: historical water systems, hydrogeology, historical landscape ecology, Islamic archaeology, medieval Sicily

La città di Palermo e la sua valle circostante sono un importante paesaggio storico irriguo, caratterizzato da strutture idrauliche sotterranee e da una lunga tradizione di sistemi di irrigazione ereditati dalla presenza islamica in Sicilia nel medioevo (IX-XI secolo). La "rivoluzione verde" islamica ha radicalmente innovato i sistemi di irrigazione siciliani e questo portò all'introduzione e alla diffusione di nuove specie coltivate. Nell'area suburbana di Palermo sono stati indagati 63 infrastrutture idrauliche e tunnel di scolo, classificati in 4 categorie: 1) qanāts*; 2)* qanāts *ciechi; 3) pozzi collegati; 4) gallerie di scolo emergenti. Queste strutture, nonostante alcuni dubbi circa la loro esatta datazione, sembra siano tipici del periodo medievale. Il castello normanno di Favara / Maredolce e il suo parco (XII secolo) è un interessante caso studio per valutare il ruolo del patrimonio islamico nella gestione dell'acqua nella valle palermitana ed è uno straordinario esempio di come l'ingegneria idraulica islamica fosse usata per dimostrare il potere reale.*
Parole chiave: *sistemi idraulici storici, idrogeologia, ecologia del paesaggi storici, archeologia islamica, Sicilia medievale*

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1. Introduction

1.1. The Islamic "green revolution" and the formation of irrigated agricultural landscapes in Medieval Sicily

The Muslim conquest of Sicily (Amari 1854-1872; Metcalfe 2009) was one of the main accomplishments of the Aghlabid dynasty, which ruled the Ifrīqiya from 800 to 909. The Islamic fleet left Tunisia and landed on the Western Coast of Sicily in 827 in Mazara del Vallo. In 831, Palermo was conquered, becoming the capital Madīnat Balarm (Bagnera 2013; Maurici 2015) and Syracuse – the most important city of Byzantine Sicily – fell later in 878. Sicily was ruled by the Fatimid dynasty from 909, followed by the Kalbid governors. In 1071, the Normans conquered Palermo. However, the Norman kings maintained and developed the multicultural dialogue that was typical of medieval Islamic culture; this integration between two different worlds created a new cultural system and a new landscape.

Like other medieval Islamic regions, irrigated agriculture was widespread all over the island as part of a more complex productive system (Barbera 2007): new plantations (new crops, new techniques) were developed, intensified and integrated with non-irrigated agriculture and husbandry. The most radical innovation of what's called the "green revolution" (Watson 1981) or the "Arabic agricultural revolution" (Watson 1983) concerned the irrigation systems and the spread of those species or varieties that could only be grown on irrigated land. This "green revolution" may have had such a huge impact not only thanks to new agricultural and technical innovations, but also because of the continuing innovation and improvement of agronomic techniques that had already been invented in the Classical period by the Greeks, Phoenicians, and Romans. The great novelty of medieval Arab agriculture lies in the fact that new techniques, new species, and new social and economic conditions come together. This holistic vision of farmland, which we may define as agro-ecological, conceives a relationship between the physical and biotic environment, the available resources and the agronomic knowledge and technique.

The scientific background and techniques that lead to the success of the "green revolution" in Medieval Sicily (Barbera 2007) can be traced back to the Iberian agronomical texts of al-Andalus (Carabaza Bravo, García Sánchez 2009). The Arabic domination of this region lead to proper agronomic schools being opened in Cordoba, Toledo, and Seville (Bolens 1981; Carabaza Bravo, García Sánchez 2009), where the Greek-Byzantine, Latin and Mesopotamian geoponic texts were translated (Ibn Wahshiyya 1993-1998). The relationship between al-Andalus and Sicily (García Sánchez 2007) regarding the agronomic sciences can be seen in written records attesting to the contact and sharing of experiences between the regions. From the Andalusian texts, we learn that Sicilian farmers were not only the receivers of techniques developed elsewhere but also took on an autonomous role as experimenters. Ibn Baṣṣāl (11th century) (Ibn Baṣṣāl 1995), who seems to have been in Sicily to collect plants during his pilgrimage to Mecca, refers to the cultivation of cotton on the island and the expertise of his farmers who are able to cultivate it on heavy soil through dry-farming techniques and by tilling it up to ten times (Ibn Baṣṣāl 1995). An anonymous drafter (late 11th-early 12th century) of a pharmaceutical botany text writes about information from the same Ibn Baṣṣāl about the cultivation of papyrus, blue lily and jasmine in Sicily (Vallicrosa 1955), and even Ibn al-'Awwām (1988), around the late 12th century, shows knowledge of Sicilian agriculture through references to onion cultivation. The treatise on agriculture by Abū l-Khayr al-Ishbīlī (probably 12th century) is also rich in references; he cites more than thirty species in Sicily (including apricot, canola, garlic, watercress, anise, calabash and tarragon) that he collected himself or whose presence he was certain of on the island (Abū l-Khayr al-Ishbīlī 1991). Other information comes from a citation of a lost text by the botanist, Ibn al-Rūmiyya, who lived between 1165 and 1239, and who wrote about the papyrus cultivated in Palermo in the garden of the "sultan" (referring to the Norman King) (García Sánchez 2007).

1.2. Irrigated landscapes and cultivated plants in Medieval Palermo

Medieval Sicilian agriculture is only described in a few testimonies, which can be used to understand Palermo's agricultural landscape system during the period of Islamic rule. Al-Muqaddasī, born in 945 in Jerusalem, wrote a few lines in *The Best Divisions in the Knowledge of the Regions* (Vanoli 2001). However, the richest sources are the many pages written by the merchant and geographer from Upper Mesopotamia, Ibn Ḥawqal (Ibn Ḥawqal 1880-1881) in *The Face of the Earth*, written after a trip to Sicily in 972. He describes extensive agricultural development near rivers and springs, characterized by small properties and the widespread presence of irrigated crops, but containing few technological innovations.

A complete description of the Norman Palermo agricultural system and cultivated plants can be found in a text attributed to Hugo Falcando, written after the death of William II in 1189.

> «…Once the gardens are irrigated, small and short cucumbers sprout and grow, along with watermelons, which are more oblong, quite spherical melons, and pumpkins that climb

> on trellises of intertwined reeds. If you turn your gaze, then, to the various tree specimens, you will see pomegranates… And you will also see citrons… there, you will see lumias (a kind of lemon) that are good at flavoring dishes with their sourness, and oranges, which are heavy within with juice that is no less sour, but above all else serve to delight the eye with their beauty» (Falcando 1897).

The availability of irrigation water and techniques to use it efficiently made it possible to cultivate new vegetables that were already being grown in Andalusia in the 9th and 10th centuries, such as the eggplant (*Solanum melongena* L.) and the artichoke (*Cynara scolymus* L.). However, the only certain testimonies of these species in Sicily are in 1309 and 1416 (Caracausi 1983). As Ibn Ḥawqal observed as early as the 10th century, and later Falcando (12th century), many plants from the *Cucurbitaceae* family were being grown; Falcando specifically names *citruli*, *cucumeres*, *melones*, and *cucurbite*.

Citruli were certainly cucumbers (*Cucumis sativus* L.). *Cucumeres* were probably both a local variety of muskmelon (*Cucumis melo* convar. *adzhur* Greb.) – *cucummeri* in the Sicilian dialect – both the fruits of snake melon (*Cucumis melo* var. *flexuosus* (L.) Naudin) that Arab-Andalusian agronomists called *maqati* (which is what Ibn Ḥawqal called the *Cucurbitaceae* cultivated in Palermo) (Barbera 2007). The *melones* are watermelons (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) and the *cucurbite* are calabash gourds (*Lagenaria siceraria* (Molina) Standl.), which are called *zucchine da tenerumi* in Palermo and are still cultivated today as they were then, on cane support structures (Barbera 2007).

In a Mediterranean environment, the cultivation of these particular plants is a clear sign of an irrigated agricultural system, which required the development of new water management strategies.

The Palermo valley – known as the Conca d'Oro (Barbera 2012; Mandalà 2017) – was the center of these innovations brought over during the Medieval Islamic period, which would strongly influence the traditional agricultural landscape, especially agricultural water management. The introduction of new cultivated plants combined with new agronomic techniques and a new socio-economic framework were the tangible expressions of the "green revolution" in Sicily. So, what evidence and legacy has this "green revolution" left in the Palermo valley?

The Palermo valley still contains many traces of historic hydraulic infrastructure, connected to local hydrogeological characteristics, once used to tap into and manage the water table. These systems, some of which are *qanāt*s, are the clearest evidence of the kind of irrigated landscape described in sources from the Islamic era. Islamic-inherited water-management practices in suburban Palermo would continue in the Norman period, with the construction of the Favara/Maredolce (12th century), a palace facing an artificial lake with an island at the center. Here, water was also a manifestation of royal power.

2. Environmental and hydro-geological characteristics of the Palermo valley

Palermo is a lowland city with an extremely favorable geographic position. The National Hydrographic Service (Duro *et al.* 1996) reports an average annual precipitation of 644 mm for the thermo-pluviometric station of Palermo, with 73 days of rain and an average annual temperature of 18.3°C. According to the climate data trend, the area was classified by Bazan *et al.* (2015) as having a Thermomediterranean dry bioclimate with thermo-xerophilous vegetation, such as dwarf palm maquis (*Pistacio lentisci-Chamaeropetum humilis*), wild olive forest (*Ruto chalepensis-Oleetum sylvestris* subass. *euphorbietosum bivonae*) (Gianguzzi, Bazan 2019a, 2019b) and holm oak wood (*Rhamno alaterni-Quercetum ilicis* subass. *pistacietosum lentisci*). A relictual forest in the Palermo valley can still be found in the Favorita Park (Gianguzzi *et al.* 2017), located at the base of Mount Pellegrino, where there is an oak forest (*Quercus ilex* L.) characterized by laurustinus (*Viburnum tinus* L.) and other evergreen species from the Mediterranean shrubland (*Pistacia lentiscus* L., *Rhamnus alaternus* L., *Clematis cirrhosa* L., *Arbutus unedo* L., *Prasium majus* L., *Smilax aspera* L., *Asparagus acutifolius* L. and *Ruscus aculeatus* L.). An analysis of the natural plant communities of the Palermo valley has showed ecological characteristics that do not indicate a high land-suitability for agriculture. In fact, the natural vegetation is an indicator of ecological areas with poor soil that aren't fit for the ornamental or productive cultivation (Bazan *et al.* 2019; 2020). However, the labor of farmers has created the fertility necessary to maintain the agricultural system in this area through irrigation. This irrigation was made possible thanks to available underground water reservoirs formed by a vast Pleistocene calcarenite sea shelf surrounded by a double screen of high Mesozoic limestone hills that only open to the East towards the low Tyrrhenian coast (Todaro 1995, 2002). These are quite permeable formations, thanks to their high porosity (calcarenite facies), which lets them store a large volume of water collected in the phreatic zone that is then slowly released through springs and artificial catchment (Todaro 2006). In fact, this water is blocked from draining away by the prevailing large impermeable tertiary foundation, made up of hard clay (Numidic Flysch), which is more

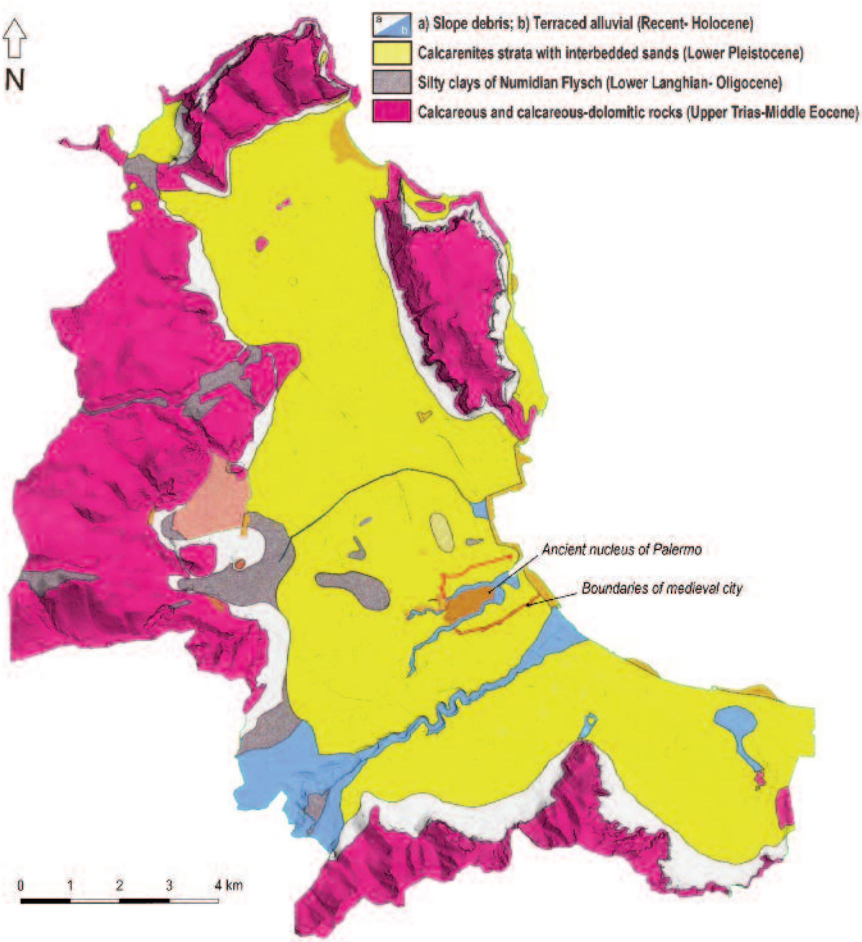

Fig. 1. Hydrogeological map of the administrative area of Palermo.

than thousands of meters wide. In these conditions, a continuous current of underground water is formed in lowland areas as a free water table, which flows slowly due to its low slope descending towards the coast to a depth that barely exceeds twenty meters.

What made this water system unique is its double feed. A first feed comes from the aquifer formed by Mesozoic limestone, a vast and deep water-reservoir whose noticeable mass flow rate is relatively unaffected by seasonal variations, and that is capable of spilling out through a series of springs located along the foothill. A second source is from the rainwater that falls directly on the soil, and is stored in the valley's Pleistocene calcarenites (fig. 1).

The presence of foothill springs has clearly been documented since the Middle Ages. In the map of Sicily represented in the *Kitāb ġarā'ib al-funūn wa-mulaḥ al-'uyūn* i.e. *The Book of Curiosities of the Sciences and Marvels for the Eyes* dated to the first few decades of the 11th century (Johns 2006), the following springs are listed as present in the Palermo valley:

1. *al-Ġirbāl*, now called *Gabriele*, located at the foot of Mount Caputo, west of the City;
2. Baida (*'Ayn al-Bayḍā*), just north of the al-Ġirbāl spring in the current Baida neighborhood;
3. *al-Fawwāra al-kabīra* (the Big Favara), the San Ciro spring at the foot of Mount Grifone that feeds the Maredolce basin, south of the city;
4. *al-Fawwāra al-ṣaġīra taḫruġu mina l- kabīra* (The Small Favara, which comes from the Big Favara) located near the Furitano Hills in Ciaculli;
5. *'Ayn al-Qādūs* (the Catuso Spring, where *catuso* refers to a terracotta pipe) located south of the city;
6. *'Ayn Abī 'Alī* (the *Abū 'Alī* Spring, perhaps named after a Sicilian governor or *walī*, Metcalfe 2017) identified with the *Aynibileli* or Ambleri spring located between the neighborhoods of Villagrazia and Falsomiele, in the south-west part of the city;
7. *'Ayn Bilāl* (*Bilāl* spring) which also can be etymologically associated to the *Aynibileli* or Ambleri spring;
8. *'Ayn al-Manī*, that might be the same as the *Ayn al-Tis'* (spring 9) that Ibn Ḥawqal mentions in *Mu'askar*;
9. *'Ayn Suġdī* (*Suġdī* spring), which is the same as the *'Ayn Abū Sa'īd* (from the commander-governor, *Abū Sa'īd Mūsá ibn Aḥmad al-Ḍayf* from the beginning of the 10th century CE, Metcalfe 2017). In the *Mu'askar*, it can probably be identified as the Danisinni springs;
10. *Al-Fisqīya* (the fountain) might be the spring in the Fiskiae district of San Martino delle Scale;
11. *'Ayn Mu'āfā* might be a synonym of *'Ayn al-Šifā'* (the Spring of health), outside the old city near the *Bāb 'Ayn šifā'* gateway.

Instead, the rainwater stored underground doesn't flow on the surface, except along the gully of the old route of the Papireto river, named *Wādī Barūṭa* or *Rūṭa* in the Arab sources (Johns 2006), which is now channeled underground – in areas where river erosion deeply carved into the calcarenite rock and hollowed out the same valley, exposing and cutting into the Numidic Flysch clay. The water from the Papireto springs could only have been used for land and crops in the lower valley basin, due to an insufficient piezometric height to arrive at higher altitudes. The same waterways that crossed the valley, the Papireto river to the North, the Kemonia river and the Oreto river (*Wādi 'Abbās 'iddat al-ṭawāḥīn min awwalihi ilā aḫirihi* i.e. "Fiume Oreto – many mills from start to finish" Johns 2006) to the South, all had drawbacks as irrigation. Their water supply wasn't continual due to their irregular hydrological regime characterized by long dry periods as well as the above-mentioned problems related to altitude, where elevated areas of the valley were unreachable by water (Todaro 2008).

However, historically, the Palermo valley's hydrology made it possible to take advantage of both the water resources on the surface (the foothill springs) as well as underground water from the water table through the use of underground gallery systems traditionally called *ingruttati* in Sicilian dialect (Todaro 2014). This term, *ingruttati*, is mentioned in documentary sources from the second half of the 19th century (Alfonso Spagna 1877; Spataro 1887). These underground galleries have made it possible to create numerous artificial springs fed by water sources that would have otherwise been difficult to exploit. With this ingenious system, underground water could be brought to the surface with only the potential energy produced by gravity and by the modest slope of the land. This resource made it possible to develop irrigated agriculture.

3. Historical hydraulic infrastructure and irrigation systems

Palermo's hydraulic resources are hidden, located in the calcarenite layers of its subsoil, and made up of a series of free flow aquifers fed directly by rainwater that falls on the valley and that contribute to the underground water currents that overflow from the rigid hydrogeologic limestone-dolomitic structure of the mountains that enclose it (Todaro 2014). These make up an enormous water reservoir, the Palermo Mountains' hydrogeological basin (Calvi *et al.* 2000), which is predominantly karstic and whose water reserves are estimated to be over $20x10^6$ square meters per year (Maniaci 1975). In addition, the Palermo valley water basin accumulates more than $2x10^6$ square meters per year.

The underground water of the city and its valley were used for irrigation as well as for the domestic needs of some urban areas, through a complex network of tunnels through which the water arrived at the surface, flowing via gravity from the water table towards the numerous artificial springs.

The systems of galleries used to access the groundwater were called "*ingruttati*" (*in grotta* or in caves) in written documentation and in the local Palermo dialect because they were made from underground tunnels

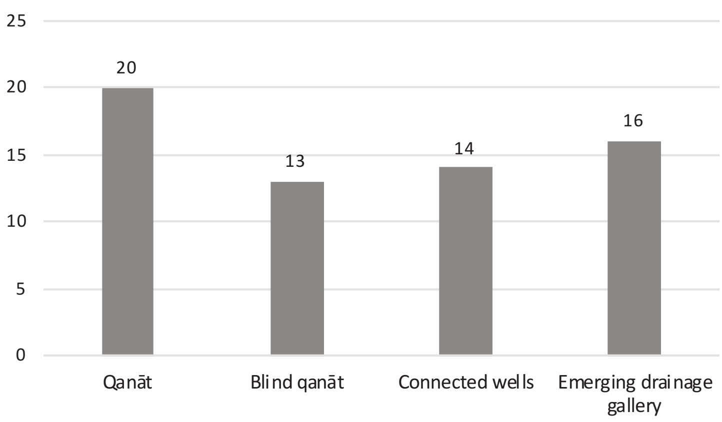

Fig. 2. Types of *ingruttati* water systems.

(Todaro 2014). The *ingruttati* were dug almost horizontally into the Pleistocene calcarenite shelf of the Palermo valley until they hit the water table. For the purposes of this study, they have been categorized into four groups, according to their shape and hydraulic characteristics: 1) *qanāt*s; 2) blind *qanāt*s; 3) connected wells; 4) emerging drainage galleries (fig. 2). Isolated wells with blind tunnels at their bottom have not been included in this study. Currently, 63 *ingruttati* (table 1, fig. 3) have been identified in the Palermo valley that belong to these four categories and that were built in different historical periods. It should be noted that based on the documentation and the research in progress, it is not possible to date the construction period of the individual underground infrastructures with certainty. However, the first mention of effective use should not to be misunderstood with the real origin of these underground structures, which were probably often used for some time before they were documented (table 2, fig. 4). Furthermore, it is possible that some structures, especially those with a later date, might have been built in an earlier period. We can only be certain of the construction period in a few cases, and these are structures built between the 16th and the 19th century CE (n. 4 Via Castelforte ai Colli; n. 29 Gesuitico alto di Case Micciulla; n. 25 Acqua nuova di Benenati, Via Altarello di Baida; n. 55 Villa Bonano, via Cassaro Bonanno, Ciaculli).

The distribution of the systems for capturing and distributing underground water is located in 6 macro-areas (fig. 3): 1) Mezzomonreale-Cuba; 2) Piana dei Colli-Piano Gallo; 3) Cruillas-Malaspina; 4) S. Ciro-Maredolce; 5) Ciaculli; 6) Villagrazia.

On the whole, the explored or surveyed "*ingruttati* (only 25 out of 63) (table 3) exceed a total length of 20,323 meters, mostly made up of *qanāt*s (fig. 5).

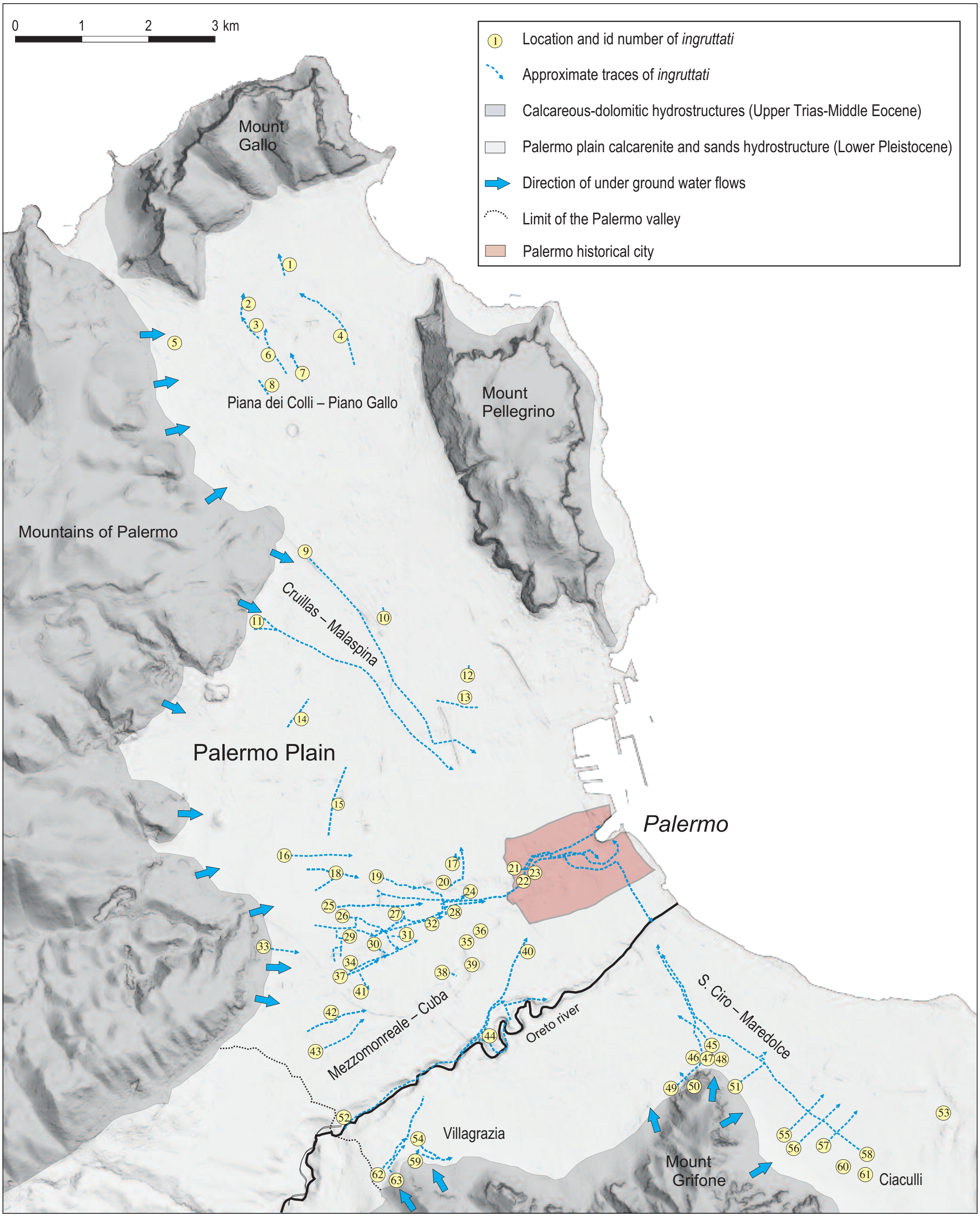

Fig. 3. Chronology of the first known use of *ingruttati* water systems.

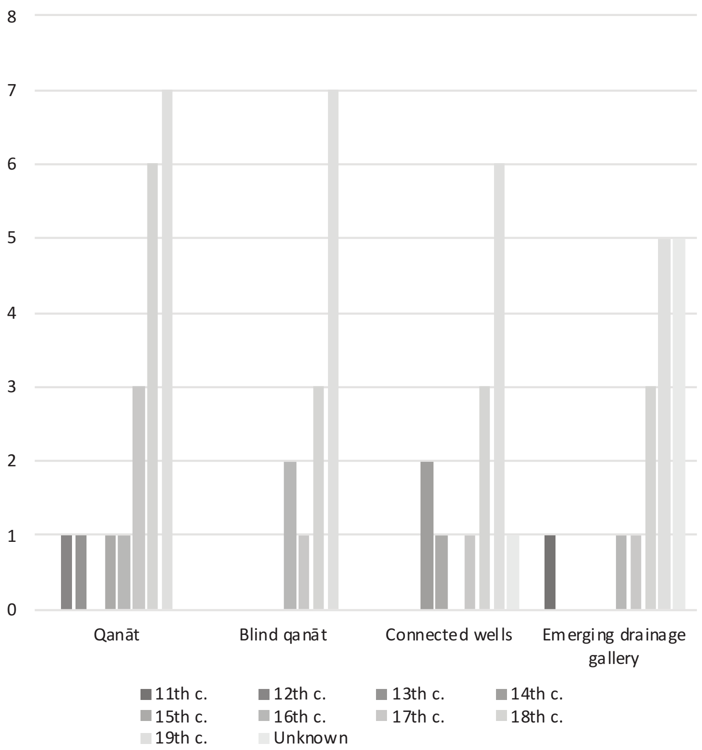

Fig. 4. Map of the location and path of *ingruttati* water systems in the Palermo valley.

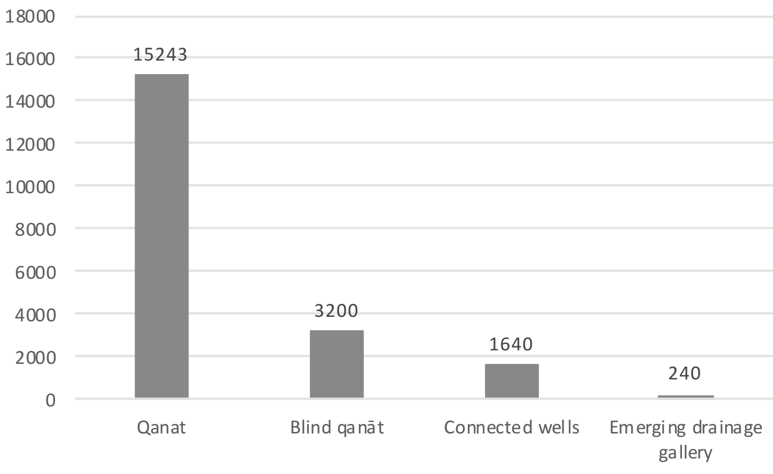

Fig. 5. Approximative lengths [m] of *ingruttati* water systems.

Historical name or current location	Type of water systems	Chronology of first known use	Approx. lengths [m]	MapID
Scibene, Altarello di Baida.	Qanāt	12th c.	735	26
Danisinni - Via Cappuccini.	Qanāt	13th c.	1130	24
Sicchiaria, Due Teste d'acqua - Quattro Camere.	Qanāt	15th c.	700	19
Gesuitico alto di Case Micciulla.	Qanāt	Early 16th c. (°)	1000	29
Corso Calatafimi basso.	Qanāt	17th c.	–	30
Florio -Trasselli, Corso Calatafimi.	Qanāt	17th c.	–	34
Florio-Airoldi, (Alliata-Saponara) - Corso Calatafimi.	Qanāt	17th c.	550	37
Via San Nicola ai Colli.	Qanāt	18th c.	900	6
Daniele - Fondo Uddo, Margifaraci.	Qanāt	18th c.	–	16
Cappuccini-Olivuzza.	Qanāt	18th c.	650	20
Gesuitico basso alla Vignicella.	Qanāt	1722 (°)	750	27
Santonocito - Via Pindemonte-Giardino del Boccone del Povero.	Qanāt	1780 (°)	560	28
Acqua nuova di Benenati, Bova -Via Altarello di Baida.	Qanāt	1789 (°)	735	25
Via Castelforte ai Colli.	Qanāt	1853 (°)	1353	4
Bova (ex Amato), Cruillas-Villa Trabia.	Qanāt	19th c.	2000	9
De Maio, Cruillas-Villa Isnello (Santantimo).	Qanāt	19th c.	2000	11
Tornabene - Via Gaetano La Loggia.	Qanāt	19th c.	780	32
Villa Maurigi - Villagrazia di Palermo.	Qanāt	19th c.	1400	54
Floridia - Conte Federico,Roccella.	Qanāt	19th c.	–	56
Urso a Ciaculli.	Qanāt	19th c.	–	57
Cuba soprana di Villa Napoli.	Blind qanāt	XVI sec	–	31
Villa Tasca (Camastra).	Blind qanāt	XVI sec	–	41
Via Partanna Mondello - Cortile Sessa.	Blind qanāt	17th c.	–	1
Scalea II ai Colli.	Blind qanāt	18th c.	320	2
Scalea I ai Colli.	Blind qanāt	18th c.	280	3
Baglio Mercadante-La Gumina ai Colli.	Blind qanāt	18th c.	–	7
Villa Bonano - via Cassaro Bonanno (Ciaculli).	Blind qanāt	1880 (°)	2000	55
Via Maio (Pagliarelli).	Blind qanāt	19th c.	–	42
Via Palmerino (Camastra).	Blind qanāt	19th c.	–	43
Maredolce - La Favara - Brancaccio-San Ciro.	Blind qanāt	19th c.	–	45
Spagnuolo (Villa Gallo)- Brancaccio-Maredolce.	Blind qanāt	19th c.	–	51
Via Conte Federico (Brancaccio-Maredolce).	Blind qanāt	19th c.	–	58
Naselli-Gela, via Villagrazia di Palermo.	Blind qanāt	19th c.	600	62
Pozzo a gradoni di Villa Briuccia-Barbera.	Connected wells (Step-wells)	14th c.	–	10
Pozzo a gradoni Piazza Edison - Via della Libertà.	Connected wells (Step-wells)	14th c.	–	12

Historical name or current location	Type of water systems	Chronology of first known use	Approx. lengths [m]	MapID
Palazzo Zisa.	Connected wells	15th c.	80	17
Villa Sperlinga.	Connected wells	17th c.	–	13
Villa Raffo ai Colli.	Connected wells	18th c.	130	8
Torre Principe di Aci, Fossa della Garofala.	Connected wells	18th c.	130	36
Villa Forni, Fossa della Garofala.	Connected wells	18th c.	100	38
Pozzo Molone.	Connected wells	19th c.	–	61
Via Casalini (Uditore).	Connected wells	19th c.	–	14
Villa Turrisi, Passo di Rigano.	Connected wells	19th c.	1200	15
Pozzo "Macchina Vecchia", Fossa della Garofala.	Connected wells	19th c.	–	35
Pozzo Liguorini, Fossa della Garofala.	Connected wells	19th c.	–	39
Pozzo Alliata.	Connected wells	19th c.	–	60
Pozzo a gradoni di Villa Eleonora, Tommaso Natale	Connected wells (Step-wells)	unknown	–	5
Favara piccola (*Fawwarah al-seghira, Ayn al-Magnunah)* alle Balate di Ciaculli.	Emerging drainage gallery	11th c.	–	53
Aynbileli-Ambleri a Villa Naselli.	Emerging drainage gallery	1554	–	63
Casa Scozzari, piazza Casuzze, Altarello di Baida.	Emerging drainage gallery	17th c.	–	18
Campofranco-Guccia, Complesso del Gabriele.	Emerging drainage gallery	18th c.	–	33
Ciaccio-Martines, Oreto river-Pagliarelli, Via G.Roccella-via Porcelli.	Emerging drainage gallery	18th c.	–	40
Ferreri, Oreto river, Santo Spirito-Piano Bonriposo, chiesa della Guadagna.	Emerging drainage gallery	18th c.	–	44
Conti-Florio-via Brancaccio.	Emerging drainage gallery	19th c.	–	46
Conti-Lauriano - Porta Termini.	Emerging drainage gallery	19th c.	–	48
Furceri - via Brasca, San Giovanni dei Lebrosi.	Emerging drainage gallery	19th c.	–	49
Bonanno-Corrao (Tortorici) - Via Brasca.	Emerging drainage gallery	19th c.	–	50
Acqua Migliore (ex S.Chiara) - via Parco, c.da Carruba.	Emerging drainage gallery	19th c.	–	52
Papireto - al Macello, piazza Papireto.	Emerging drainage gallery	Unknown	–	21
Papireto al Castello, Largo S. Rosalia.	Emerging drainage gallery	Unknown	–	22
Papireto- alla Dogana, piazza Papireto.	Emerging drainage gallery	Unknown	–	23
Corso della Scomunica.	Emerging drainage gallery	Unknown	–	47
Gristina, Villagrazia di Palermo.	Emerging drainage gallery	Unknown	240	59

Table 1. List of historical water systems (*ingruttati*) of Palermo valley [(°): known date].

Chronology of first known use	Qanāt	Blind qanāt	Connected wells	Emerging drainage gallery	Total
11th c.	–	–	–	1	**1**
12th c.	1	–	–	–	**1**
13th c.	1	–	–	–	**1**
14th c.	–	–	2		**2**
15th c.	1	–	1	–	**2**
16th c.	1	2	–	1	**4**
17th c.	3	1	1	1	**6**
18th c.	6	3	3	3	**15**
19th c.	7	7	6	5	**25**
Unknown	–	–	1	5	**5**
Total	**20**	**13**	**14**	**16**	**63**

Table 2. Distribution of water system types for historical period.

	Approximate lengths (m)
Qanāt	15243
Blind qanāt	3200
Connected wells	1640
Emerging drainage gallery	240
Total	**20323**

Table 3. Known lengths of water system types.

*3.1. Qanāt*s

The *qanāt* uses passive design to extract water from the subsoil, and was particularly used in large valleys. It consists of a simple emerging drainage gallery that allows the groundwater to flow to the soil surface via gravity, thus creating an artificial spring.

A tunnel is connected to serial access shafts – called *puzzi di annittari* in a 19th century map (ASN-Archivio Storico Napoli-A.P., Piante (Palermo), cartella IX, n.1, 1840) or *puzzi di luci, sboccaturi* – used, first, to dig underground (for ventilation and the removal of debris) and then for maintenance during the tunnel's active use (Todaro in press). The gallery carries out two distinct hydro-geological functions: 1) to capture and syphon water from the water table (the shorter tract of the gallery); 2) to transport the water flow (canal) to the outlet (the longer tract) (fig. 6a).

Regarding depth, *qanāt*s were excavated in covered trenches if they were superficial (fig. 8e), and with a blind bottom or natural tunnels if they were deep (fig. 8a). The covered tunnels were built with calcarenite

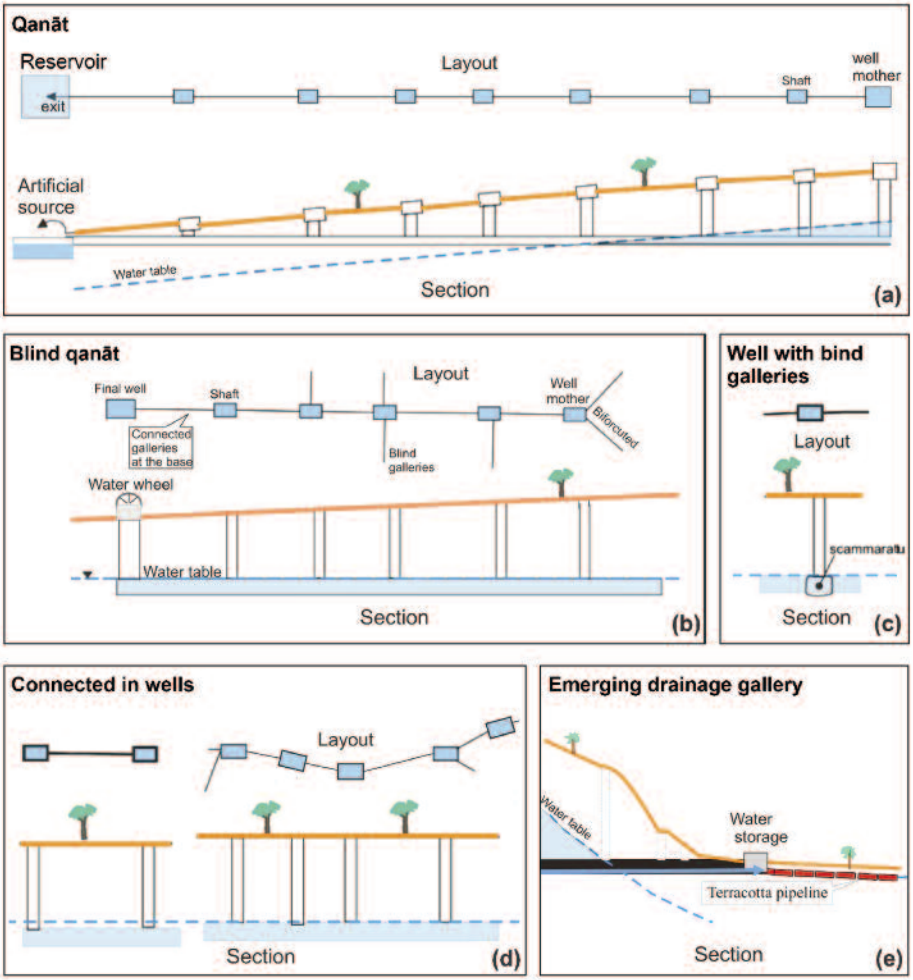

Fig. 6. Technical-hydraulic typologies of traditional *ingruttati* water systems.

ashlars or slabs (fig. 8d), and their design varied according to the tunnels' maximum depth and the water pressure they were meant to handle.

20 *qanāt*s have been identified in the Palermo valley. They are most concentrated west of the city (fig. 7a), in areas that range from 500-2,000 m a.s.l. and are often articulated in several secondary draining branches and appendages at various levels, usually not more than 20 m deep. It seems that the oldest *qanāt*s in this group are the Danisinni (fig. 8a, n. 24 in fig. 3) and Scibene (fig. 8b, n. 26 in fig. 3) tunnels, dating back to at least the Medieval era. Mills along the Papireto valley that are documented in primary sources from the beginning of the 14th century

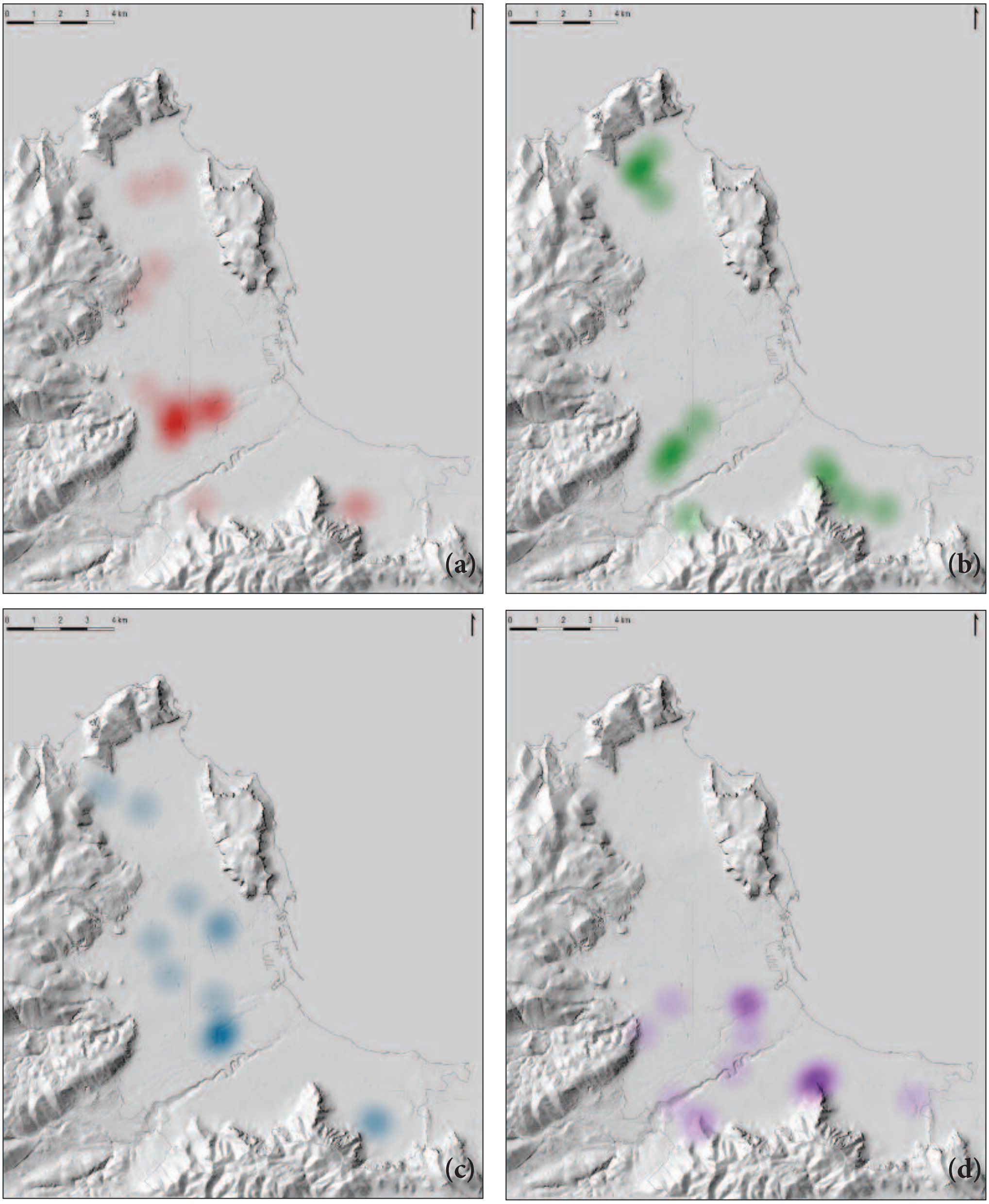

Fig. 7. Density analysis maps of water system types in the Palermo valley: a) *qanāt*s; b) blind *qanāt*s; c) connected wells; d) emerging drainage galleries.

Fig. 8. *Qanāt*s and wells in Palermo: a) Danisinni *qanāt*; b) Scibene *qanāt*, with a dry-stone reinforcement wall; c) *Senia* well (Gesuitico basso *senia* at the Vignicella *qanāt*); d) Corso Calatafimi basso *qanāt*. Roof covering and retaining wall in large calcarenite blocks; e) Maurigi *qanāt*, excavation in a trench covered with large clamped blocks of calcarenite with roof contrasting "buttonhole" shafts ("furnace mouth"); f) Well-shaft of the Cuba Soprana.

(Bresc 2001) could only have been fed by the Danisinni *qanāt* due to its piezometric head, a water flow that was able to provide the necessary kinetic energy to the mill's paddle-wheel. Furthermore, this *qanāt* was probably already active during the 14th century. A historical topographic map from the second half of the 19th century (fig. 9) shows the path of the Danisinni *qanāt* as well as its water outlet (39 m a.s.l.), located 7 m higher than a lower natural spring (32 m a.s.l.) that is only hypothetically associable to the *Ayn Abū Sa'īd* mentioned in a 11th century source (Jones 2006). Furthermore, the Danisinni *qanāt*, canalized in a *sàia* (see below, section 3.5) to run the medieval mills, is not connected to this natural spring along the Papireto river (dried up today), because it is too low to provide the necessary water energy to run these hydraulic machines.

The Scibene *qanāt* served its namesake, the 12th century Norman castle, which used the water to feed its *iwān* (fountain room), which was probably connected to a fishery (Spatrisano 1982).

Other *qanāt*s could have been recorded in later periods. In the Micciulla estate (macro-area Mezzomoreale-Cuba), the Gesuitico alto *qanāt* (n. 29 in fig. 3), built at the beginning of the 16th century by the nobleman Don Gerardo Alliata, is laid out over three depth levels and with various spring producing branches that still achieve notable water flow rates that can exceed 30 liter per second. This technology continued to be used for agriculture up until the end of the 19th century.

3.2. Blind qanāts

The only difference between blind *qanāt*s and other emerging catch galleries such as simple *qanāt*s, is their final outlet into small wells. In this case, the water was extracted by water-wheel systems, the *senia* (see below, section 3.5), or more recently by hydraulic pumps (fig. 6b). The underground tracts of the structures we studied range from 250 to 2,000 m in length (varying according to the size of the estate) and are located in areas characterized by a very low slope, where the water table was not very deep (about 10 m). 13 galleries of this type (see blind *qanāt* in table 1) have been found in various parts of Palermo and in particular in Mezzomonreale-Cuba, Piana dei Colli-Piano Gallo, San Ciro-Maredolce and Ciaculli (fig. 7b). The first recorded use was at the beginning of the 16th century, but it is possible that some of them were built during previous centuries. For example, the Cuba Soprana site at Villa Napoli (n. 31 in fig. 3) was supplied by a blind *qanāt* (fig. 8f), so it is possible to propose two hypotheses. The first one is that this water infrastructure was built for the Norman palace, probably to supply a water basin, and then repurposed for the later estate in the 16th century. The

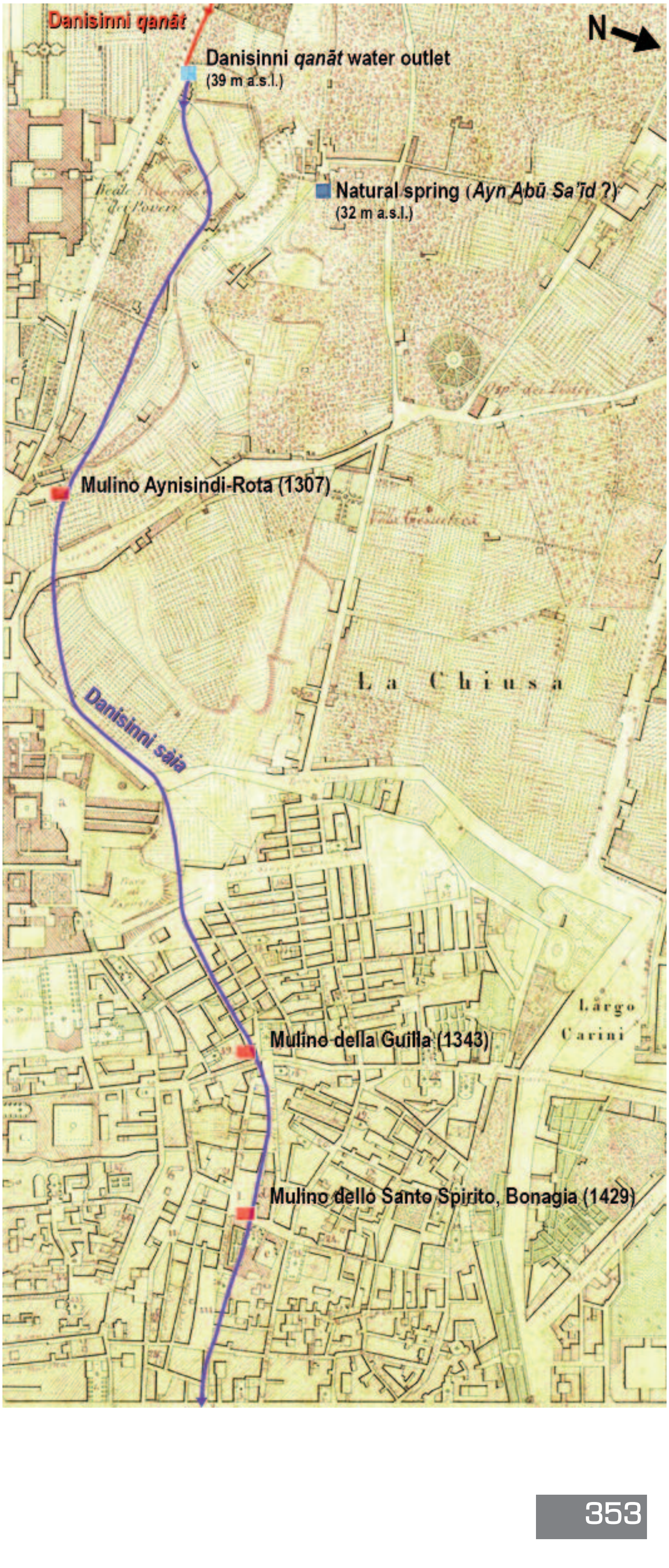

Fig. 9. Danisinni water system: the natural spring along the Papireto river, hypothetically the medieval *Ayn Abū Sa'īd* (dark blue square); the path of Danisinni *qanāt* (red line) and its related water outlet (blue square); reconstruction of the canal (*sàia*) (blue line), masonry no longer existing today whose presence was derived from the hill's contour lines, which provided water energy to medieval mills (red squares) in the Papireto valley (Base map: topographic map, scale 1:5000, of Italian Military Geographic Institute, 1863; cartella n. 88, inv. n. 9028 documento n. 17 CRICD-Palermo).

second hypothesis is that the tunnels may have been built from scratch when the more recent villa was built.

The explored tunnels (only 4 out of 13), have been estimated to be about 3,200 m long in total. 2,000 m are made up of the Villa Bonanno *qanāt* (n. 55 in fig. 3), which was built in 1880 and is a testament to the continued relevance of this technology, which had a second boom in the 19th century with the advent of the first mechanical pumping systems.

3.3. Connected wells

Although lesser known, there were other kinds of underground tunnels related to the water supply aside from the *qanāt*s. In Palermo, the underground well and quarry diggers – called *piccunieri* in 19th century sources (Traina 1868) – were able to improve the efficiency and the flow rate of wells built in tunnels that connected multiple wells of varying distances, called *pozzi allaccianti* by Ferdinando Alfonso Spagna (1877). Sometimes these had two short scissor-shaped appendages at the end (fig. 6d). In one of these wells (the main well), which is believed to have collected the run-off water from the underground system, a *senia* was inserted, in order to withdraw a continual and greater supply of water.

Furthermore, at the beginning of the 19th century, with the arrival of the Gattaux metal water-wheel from France, which substituted the previous animal-powered wooden *senia*s, the water table was exploited even more by digging deeper wells (20-30 m in respect to 10-15 m). Thus, new and deeper phreatic zones were intercepted that had previously been unexplored, supplying both a greater quantity of water and increasing the flow rate to exceed 5 liters per second. At the same time, larger areas could be irrigated, making citrus cultivation possible (Todaro 2014).

Today, 14 connected wells have been identified that are dated as early as the 15th century. These water collection systems are distributed throughout the Palermo valley, with the highest concentration in the macro-area of Mezzomonreale – Cuba (fig. 7c).

This category also includes particular types of stepped wells, such as the structure called "Pozzo a gradoni Piazza Edison" (n. 12 in fig. 3), which were probably for community use, and allowed users to go directly down to the water level at the bottom (fig. 10). From a typological point of view, this type of stepped well vaguely recalls those present in other regions, such as the more sophisticated medieval stepped wells found in India in the Jaipur region (Livingston, Beach 2002).

Another widespread practice in Palermo wells was that of digging out small blind tunnels at the base, in order to increase a tunnel's drainage (fig. 6c).

Fig. 10. Step-well of Edison square, along via Libertà in Palermo.

3.4. Emerging drainage galleries

First used in ancient mining, and primarily widespread in hill and foothill areas, these galleries are the primordial device used to intercept and collect the underground water that they cross, in order to improve the flow rate and the efficiency of natural springs. They are made up of a simple gallery or trench with a shallow enough slope so as to allow water to flow freely towards the downstream outlet (fig. 6e). Usually of modest length and without serial wells, they reached the irrigation or drinking outlets via open canals (called *saje* in Sicilian dialect) or pressurized closed pipes (called *catusati* in Sicilian dialect), if going uphill. It is interesting to note that the structure identified in Ciaculli (n. 53 in fig. 3) belongs in this category, which is associable with the historic spring, the "small Favara". This spring is documented in the Oxford map (Johns 2006), dated around 1020, with the Arabic name *al-Fawwāra al-ṣaġīra.* Due to the hydro-geological characteristics of the area, the presence of a "natural" spring in this site is impossible. Furthermore, the spring identified in the documents from the 11th century probably refers to a water point collected through a drainage tunnel. The spring is still active, even though it is abandoned, and its water is used to irrigate vegetable patches in the southern part of the Palermo valley through a network of primary and secondary canals respectively called *saje* and *cunnutti,* in Sicilian dialect.

A total of 16 drainage galleries distributed in the southern part of the Palermo valley have been identified (fig. 7d).

Another type of underground tunnels, assimilable to the emerging drainage galleries, is represented by small drainage galleries, called *gammitte* (in Sicilian dialect, *ġammīṭ* in Arabic see Ruffino, Sottile 2015), used for drying up wetlands (*margi* in Sicilian dialect, *marǧ* in Arabic see

Ruffino, Sottile 2015). These little drainage galleries come out in springs used by farmers to obtain a small quantity of drinking water (Todaro 2002).

3.5. Senia/Noria *hydraulic machines and traditional irrigation systems*

The tunnel system (*ingruttati*) was used to exploit underground water in different ways, but principally to irrigate crops.

Large square water tanks, called *gebbie* in Sicilian dialect (from the Arabic word *ǧābiyah* i.e. low, sturdy masonry tank), were placed at the outlet of the *qanāt*s. Although these *gebbie* fed by the *qanāt*s maintained the same low and squat masonry design as those fed by *senie*, they were much larger since the water flow rate was much higher. The last remaining relic of these water tanks is in the historic estates of the S. Leonardo and Vignicella cloister (Mezzomonreale – Cuba area); although smaller today, it was originally a 24 m per side square with 2 m tall walls that could contain over 1,500 m^3 of water. When *qanāt*s ended in a well – i.e. blind *qanāt*s – water was drawn to the surface through a hydraulic machine, a *senia* system (Barbera 2007).

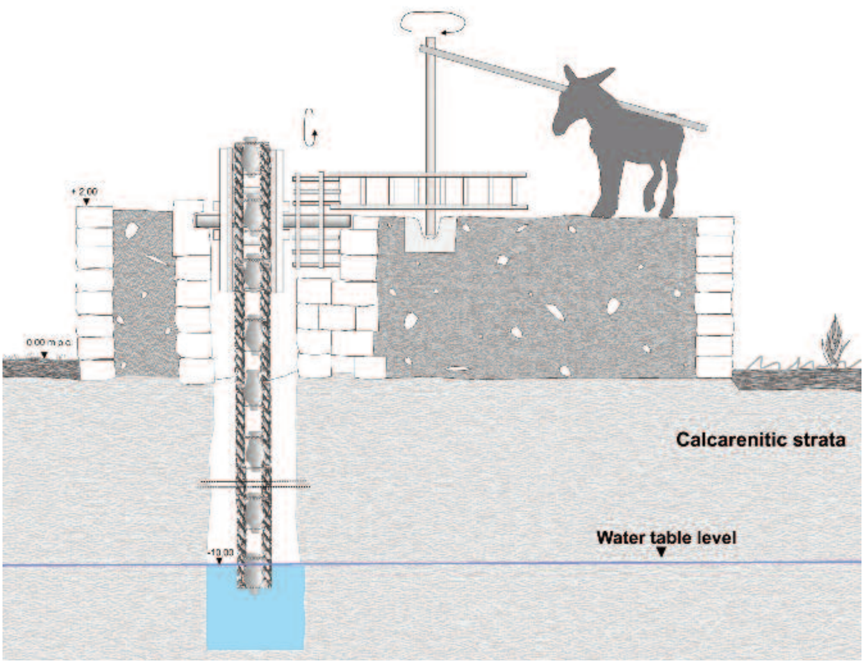

Fig. 11. Diagram of how a traditional animal-powered *senia* works.

In Sicily, the term *senia* has sometimes been used as a synonym for *noria*. The *noria* (*nā'ūra* in Arabic) usually refers to a large wheel that is moved directly by the river current that lifts the water up to the aqueduct. The *senia* (*sāniya* in Arabic) is a gear wheel moved through animal labor that makes it possible to irrigate small fields by drawing water from rectangular wells (fig. 8c) and accumulating it in tanks (*gebbia*). These machines are quite widespread in Sicily and have been compared to Egyptian, Syrian, and probably Andalusian models, which together make up the Maghreb model (Bazzana 1994). The spread of the *noria* in the Palermo valley is testified to by Ibn Ḥawqal (Ibn Ḥawqal 1880-1881): "the majority of waterways…are used to irrigate gardens through *noria*s".

However, animal-powered *senia*s were probably widespread and used to collect underground water from wells (fig. 12). In fact, in the aforementioned description of Palermo by Hugo Falcando (late 12th century), we find a detailed explanation of this *senia* system of hydraulic machines that was so widespread in the Middle-East and in North-Africa (Barbera 2007): "you can see the wheels turning in the wells filling the nearby tanks from which the water flows towards individual farms" (Falcando 1897).

No whole hydraulic machines from the Medieval period have been found in Sicily. Instead, their existence during the Medieval era is documented by the discovery of some of their components: *senia/noria* pots, clay containers (jars or buckets) used in these machines to hoist water from a well, found in the archeological stratigraphy from late 9th to 12th centuries (Arcifa 2010; Arcifa, Bagnera 2018) in urban excavations in Palermo such as in the site of the Castello-San Pietro (Arcifa, Bagnera 2014) quarter, the church of Santa Maria degli Angeli alla Gancia (Ardizzone *et al.* 2014) and at Maredolce-La Favara (Canzonieri Vassallo 2014).

In a 19th c. agronomical text, Alfonso Spagna (1877) describes the *senia* irrigation system that remained in use in the Sicilian agricultural landscape up until the widespread diffusion of mechanized agriculture and hydraulic steam-powered pumps during the 20th century (Barbera 2007).

The *senia* described by Alfonso Spagna was made up of a 1.5 m diameter wheel, positioned vertically in the well, and formed by two opposing faces; it worked through a transition gear made up of two cogged wheels (the smaller one transfers movement to the larger one), manipulated by a lever via a harness usually attached to a donkey. The animal's movement in a circle turned the wheel and the chain pump, made up of rope woven from Mauritania grass (*Ampelodesmos mauritanicus*). The rope length varied according to the well depth and held wooden or clay vessels that went from the bottom of the well to the surface, where they poured out their contents into a tank where the water was partitioned

Fig. 12. Elements of traditional Sicilian irrigation: a) *gebbia*; b) *saia*; c) *risittaculo*; d) *furra*; e) *vattali*; f) *casedda*.

and carried through canals to the crops. The *senia* wheels were built of oak (presumably downy oak).

The water was carried over land leveled with great skill so as to irrigate the soil without damaging it or creating excess humidity. This irrigation method is still used in Sicilian traditional citrus farming (Barbera 2007, Barbera 2015b) (fig. 12) with a lexicon that continues to hark back to the Islamic legacy (Caracausi 1983; Pizzuto Antinoro 2002). Water flowed out from a spring (*favara* in Sicilian; *fawwāra* in Arabic) or was drawn by a waterwheel (*senia* in Sicilian; *sāniya* in Arabic) placed on a raised embankment so that the water would spill into a large tank (*gebbia* in Sicilian; *ğābiyah* in Arabic, fig. 12a). After being poured into a *gibbiuni* (which means small *gebbia* in Sicilian) that would make it possible to ration it, it would be carried along masonry canals (*sàia* in Sicilian, *sāqiya* in Arabic, fig. 12b) and terracotta pipes (*catuso* in Sicilian; *qadūs* in Arabic) shaped like overlapping truncated cones that made the pressurized transport of water possible so that it could reach uphill land at higher elevations. The water flow is distributed in secondary channels (*sàie*) though a small receptacle (*risittaculo* in Sicilian, fig. 12c) and then in small earthen canals (*furra* in Sicilian, fig. 12d). Finally, the water reached the watering basins (*casedde* in Sicilian, fig. 12f) around the trees that are divided by low earthen berms called *vattali* or *wattali* in Sicilian dialect (fig. 12e). Water flow is measured in *zappe* (*sabba* in Arabic), which in the Palermo valley is equal to 13.3 liters per second (Pizzuto Antinoro 2002), subdivided into four *zarbi* or *darbi* (*darb* in Arabic).

Senie are documented in Palermo from the end of the 19th century until the beginning of the 20th century by *cadastre* maps, where small plots are drawn as small round parcels showing the "*giro di senia*", or the circular path of the animal around the well, delimitating a fiscal property (D'Angelo, Todaro 2003).

4. Water, kingship and agriculture during the Middle Ages: Maredolce-La Favara as a palimpsest

Irrigation techniques strongly influenced the Sicilian landscape (Barbera 2015a) in both rural as well as suburban areas, especially during the Norman era when they played a key role in the formation of royal palaces and gardens (Tronzo 2000).

For the geographer and traveler al-Idrīsī in 1139, Palermo "abounds with fruit trees [...] and within the circle of the walls there is a jubilee of orchards, such magnificence of villas and so much flowing fresh water, brought from the mountains in canals" (al-Idrīsī 1966). For Ibn Ğubayr, who visited Palermo between the end of 1184 and 1185, "proud amongst its squares and valleys that are all a garden [...] The palaces of the King encircle the throat of the city like jewels on a full-chested damsel" (Ibn Jubayr 1880-1881). This is the city of the *Viridarium Genoard* (from the Arabic *Jannat al-arḍ*, or earthly paradise), whose essential landscape characteristics can be seen in a miniature from 1195 in *Liber ad honorem Augusti* by Pietro da Eboli. Within that splendid park, the Zisa, Cuba, Cuba Soprana, and the Scibene palaces were built during the second half of the 12th century.

Chronologically, the Genoard comes after the Favara, which was also called Maredolce, and is the oldest of Palermo's Norman Parks (Bellafiore 1996). The term *fawwāra* – which means a jet of water or bubbling spring in Arabic– is a very common hydronym in Sicily (Scotoni 1979). In fact, historic documentation from the Islamic period (the Oxford map and Ibn Ḥawqal) identifies two springs, the Big Favara (*al-Fawwāra al-kabīra*) and the Little Favara (*al-Fawwāra al-ṣaġīra*). The area had been settled long before Maredolce/Favara was built during the 12th century (fig. 13), because of its proximity to the Big Favara, an important spring located at the feet of Mount Grifone, and its location along a main access route into the city from the South. In fact, recent archeological investigations (Canzonieri, Vassallo 2014; Vassallo 2018), have shown that the site has been occupied since the 3rd-2th century BC. The compact and solid building from the Islamic period was built on what was possibly a Roman farm. These may be the relics of the Ǧa'far *Qaṣr* (castello, *castrum*) belonging to the Emir Ǧa'far (997-1019), documented by Ibn Ǧubayr in 1184-1185. The Norman King Roger II (first half of the 12th century) radically changed the look and functionality of the place, thus carrying out one of the first and most important hydrological renovations of the Palermo valley. Spring water was conveyed into a large basin. Through earthworks, the lake basin was better regulated in order to avoid uncontrolled flooding and a dam was built out of large ashlars covered in impermeable pink plaster on the eastern side, where more water accumulated due to the natural slope (Todaro 2015) (fig. 14).

The grade level is about one meter from the soil level, set into the calcarenite substrate that makes up the rocky outcropping geological formation. The bed-rock was modeled at different heights in order to adequately anchor the base of the dam into the compact calcarenite substrate below the alteration zone.

The dimensions of the dam varied both in height and in width in order to adapt to the profile of the substrate and the hydraulic thrust. The central section of the dam is the largest, with an average width of

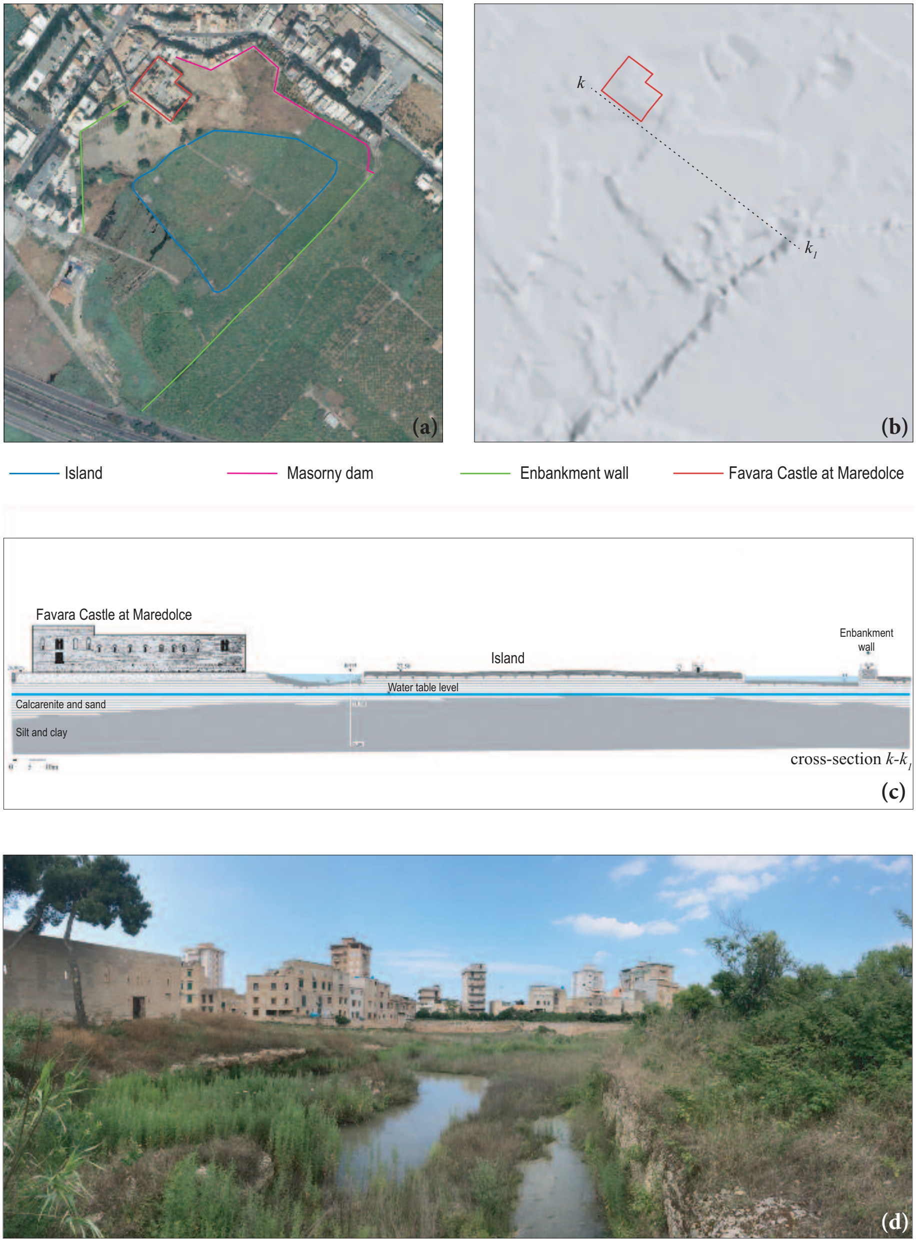

Fig. 13. The Favara-Maredoce estate: a) aerial photo image with relevant historical features; b) Lidar-based DTM; c) cross profile of artificial lake and island; d) current photo of the lake (to the left of the palace, the island on the right) (GIS images dataset: http://www.sitr.regione.sicilia.it).

Fig. 14. Masonry dam of the Favara-Maredoce artificial lake.

5.50 m at the base, 4.50 m at the top, and a height of 5.00 m; the lateral facades are smaller, varying in height from 3.20 to 2.30 m, with a width of 2.20 m. The bottom of the lake was evened out in steps whose height gradually reduced towards the front of the dam. This solution would have reduced the water head and, consequently, the hydraulic thrust on the dam itself. The surviving banks are those that close the southern face of the artificial lake, constructed with the left-over material from the excavation carried out by Sicilian-Arabic labor in the 12th century. The banks are formed by retaining walls in calcarenite stone for their entire height, which are filled in and firmly set on a foundation of Pleistocene calcarenite. The top of the embankment is quite wide, varying between 3.20 m and 4.80 m, and still allows vehicles to cross over it on a country road. Its maximum height is about 4 m; considering the depth of the lake bottom it seems that the water level would only have neared that height in periods of intense precipitation. However, considering the hydraulic potential of the Favara spring and the morphology of the place, the lake probably wouldn't have overflowed.

The reservoir extends from the spring to the dam wall, and occupies an area of about 20 hectares. Inside it, there was a 3.4 hectare large island created by Roger II. A pre-existing calcarenite outcropping shelf was shaped with pick-axes, and the profile and walls were lined with plastered masonry (figs. 13, 14). On the northern side of the lake, a historic Arabic building is also built on calcarenite outcropping. Under Roger II, it was greatly enlarged and modified so as to be worthy for its royal occupant.

The design and construction of the Maredolce lake is an important hydraulic engineering project regarding dam building and agricultural land improvement that involved a considerable commitment of time and money, necessary to carry out the significant excavations and earthworks that moved an estimated 10,000 m^3 of soil. The non-uniform depth of the excavations, which cut down 2-4 m down from the original soil height in steps until breaking into the phreatic zone in a few points, made up the lower limit of the excavations. At the center of the excavated depression, vertical walls ran along the edge of the triangular islet at the center of the basin (fig. 13 a,b), loosely shaped like Sicily as represented in the map of al-Idrīsī (Tito Rojo 2018), geographer at the court of Roger II (al-Idrīsī 1966). Furthermore, a mighty wall was built downstream, which acted as a dam in the closing position of the original depression, along with two long lateral walled banks. Some of the same calcarenite excavation material were used to infill the dam and the double-walled banks. The dam façade walls were built with large ashlars made from homogenous and compact stone, coming from an unidentified outside quarry.

The lake made up a large irrigation water reservoir, supplied by *noria*s and canals that transported or partitioned it. The reservoir was also used as a fishery. In the poem by ʻAbd ar-Raḥmān al-Iṭrābanišī (Amari 1854-1872) – living at the time of Roger II – the first verse alludes to a double lake or sea (*baḥr*), according to the various different translations. Regarding this mention of the "double seas", José Tito Rojo (Tito Rojo 2018) makes the interesting proposal that it might be describing the purposeful design of an "infinity pool" effect meant to create visual continuity between the lake and the Tyrrhenian Sea. During the centuries of Norman and Swabian rule, Maredolce would be a place of agricultural experimentation and would amaze visitors from the North – as exemplified by the words of Hugo Falcando (Falcando 1897) – with its rich biodiversity and use of new agronomic technology (Barbera 2015a).

5. Discussion and conclusion

The primary documents and materials discussed above are important indicators of the development of an irrigated landscape in the Palermo valley, starting from the Islamic occupation of Sicily during the High Middle Ages. The environmental and geological characteristics of the area around the city of Palermo are fundamental starting points for historically understanding the adoption of certain water-capture and management infrastructures. Although Palermo's landscape had few water sources on the surface, its subsoil had an enormous potential and stored water capacity.

The construction of ducts to intercept the water table fundamentally contributed both to the development of agricultural practices as well as to providing the city with water over the centuries.

The spread of *qanāt* technology throughout the western Mediterranean is evidence of that "revolutionary" wave in agricultural practices introduced into regions under Muslim rule has been discussed in the literature (Decker 2009). Although this article's purpose is not to participate in this debate, data on medieval and post-medieval Palermo may offer some interesting points for reflection.

Regarding the dating of Palermo's *qanāt*s, it is quite problematic because of the scarcity of archival documentation and of archeological and geomorphological diagnostic elements. This is because the centuries-long anthropic use and constant geological erosion of often quite soft rocks such as sandstones, calcarenites, clays etc. have easily cancelled the characteristic signs of excavation and inscriptions.

Thus, the system of *ingruttati* can be chronologically positioned within the wide chronological arc between the Medieval and post-Medieval era. If we widen our gaze to include other parts of Sicily, however, it is possible to recognize underground hydraulic channels that come far before the Medieval period (for the origin and spread of *qanāt*s in the pre-Islamic era, see Charbonnier, Hopper 2018).

For example, the identification and the study of the ancient underground aqueducts in the Greek cities of Agrigento and Syracuse (Crouch 2001; Bouffier 2001), considered by some researchers to be technologically similar to the Persian *qanāt* system, has made the period of their introduction onto the Island uncertain. It is certainly possible to make some non-simplistic correlations between *qanāt* technology and the hydraulic underground infrastructure of the Classical Era, considering how the *qanāt* hydraulically functions in respect to the hydro-geological and geo-morphologic particularities of the investigated area.

In the Valley of the Temples, Agrigento, the "Faiace conduits" or "hypogea" of Kolymbethra (Todaro 2009), are essentially a discontinuous network of 27 independent drainage tunnels that collect and convey runoff water and filter groundwater to create artificial springs at their downstream outlets, along the bed of the Hypsas river. These investigated tunnels don't use *qanāt* methods; they don't totally take advantage of the shallow slope of the valley (Quaternary marine shelfs and high alluvial plateaus), or of the "mother well" at the outlet, which is also in the lowlands. The many service-wells, which in part have survived, opened within the ancient urban center of Akragas, making a capillary water supply available to inhabitants. Instead, the valley outlets were prevalently used for irrigation.

Syracuse, instead, contains what are known as the Galermi, Paradiso, Tremilia and Ninfeo "aqueducts". Except for the Galermi (Bouffier *et al.* 2018), which draws directly from the surface waters of the Bottigliera stream, a tributary of the Anapo, these "aqueducts" are made up of drainage galleries that capture underground water from the water table like the *qanāt* systems. However, they clearly differ from *qanāt*s in structure and function due to the specific geomorphological conditions and the hydrogeological and tectonic structure of the territory in which they are inserted. In fact, they are not found in lowlands, but are formed exclusively from the Hyblaean permeable-limestone, hilly highlands that are isolated by a series of faults and fractures that create high and low structural dislocations in the sub-soil without hydrological continuity and thus are not suitable for the construction of unified *qanāt* systems. These are only tunnels and vent wells, built in a workmanlike manner to efficiently drain, collect and transport the waters flowing in contact with the waterproof base to the valley outlets (artificial springs), made up of tertiary vulcanite.

Therefore, underground water management isn't an invention produced by the "green revolution" of the Islamic period. Nonetheless, at least for the Sicilian and specifically Palermo region analyzed here, the specific introduction of *qanāt* technology seems to refer to at least the Medieval age with a further development, or introduction of a "return" from Spain, starting in the $16^{th}/17^{th}$ century.

The *qanāt*s only became widespread starting in the 16^{th} century, in the Spanish period, with the greatest presence in the valley of Mezzomonreale. The high Jesuit *qanāt* located in the Micciulla district (Altarello di Baida) was built in the early 1500s by Don Gerardo Alliata, Knight of Malta (fig. 15).

With our current knowledge of the hydraulic tunnel systems, it is only possible to hypothesize a Medieval origin – between the 12^{th} and 13^{th} century – for the Scibene and Danisinni *qanāt*s. Instead, the small Favara (*al-Fawwāra al-ṣaġīra*) can only be hypothesized to date back to at least at the beginning of the 11^{th} century, based on in what's called the Oxford map (Johns 2006), where drainage tunnels allow water to be collected in a lowland zone that isn't suitable for the presence of a natural spring.

The Islamic presence in Sicily resulted in the capillarity and spread of irrigated crops and the exploitation of water. Although not completely

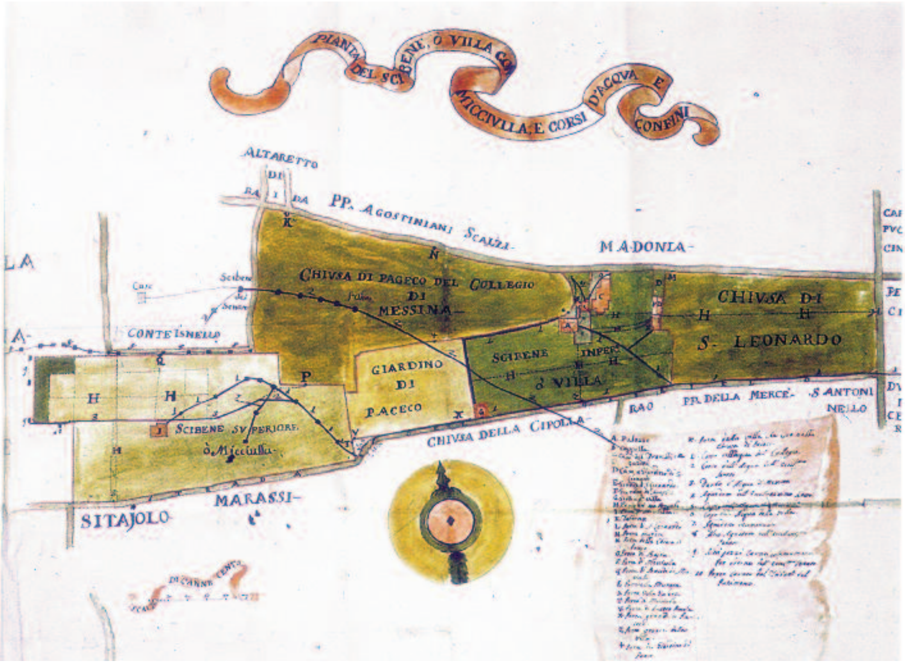

Fig. 15. Historical map (1722) of the Gesuitico alto and Scibene *qanāts* (Palermo State Archive, Case ex-Gesuitiche, serie B, vol. 644).

"revolutionary", these developments were highly innovative. In the following centuries of Norman domination, Islamic water management heritage remained and was exploited by the new kings as a characterizing demonstration of power in their palaces located around the edge of the city of Palermo. Research on the hydraulic archeology and history of the medieval irrigated landscapes of Sicily are certainly not as developed as, for example, those carried out for Al-Andalus (Cressier 1989; Malpica Cuello 1995; Barceló, Kirchner, Navarro 1996; Glick, Kirchner 2000; Martín Civantos 2011; Rotolo 2014; Kirchner 2019). However, the systematic survey and classification of traditional water systems (*ingruttati*) is an important starting point for future holistic and interdisciplinary research regarding the interpretation of water management and historic irrigated landscapes in Sicily and throughout the wider Mediterranean area.

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