DOI 10.7343/as-2024-774

ACQUE SOTTERRANEE
Italian Journal of Groundwater
journal homepage: https://www.acquesotterranee.net/

Initiative of EuroGeoSurveys' Urban Geology and Water Resources Expert Groups

Special Issue:
Groundwater in the cities of Europe

Hydrogeological and historical aspects of the water supply of Benevento town since Roman times

Aspetti idrogeologici e storici dell'approvvigionamento idrico della citta' di Benevento sin dall'eta' romana

Libera ESPOSITO[a], Michele GINOLFI[a] , Guido LEONE[a], Francesco FIORILLO[a]

[a] Department of Science and Technology, Università degli Studi del Sannio, Benevento, Italia

e-mail: *libera.esposito@unisannio.it; guido.leone93@gmail.com; francesco.fiorillo@unisannio.it;* e-mail : *m.ginolfi@studenti.unisannio.it*

ARTICLE INFO

Ricevuto/*Received*: 29 April 2024
Accettato/*Accepted*: 9 September 2024
Pubblicato online/*Published online*:
30 September 2024

Handling Editor:
Emma Petrella

Citation:
Esposito, E., Ginolfi, M., Leone, G., Fiorillo, F., (2024). Hydrogeological and historical aspects of the water supply of Benevento town since the Roman age
Acque Sotterranee - *Italian Journal of Groundwater*, 13(3), 145 - 156
https://doi.org/10.7343/as-2024-774

Correspondence to:
Michele Ginolfi :
m.ginolfi@studenti.unisannio.it

Keywords: : *ancient aqueduct, karst spring, historical supply, Benevento.*

Parole chiave: acquedotto antico, sorgente carsica, approvvigionamento storico, Benevento.

Riassunto

La ricerca analizza l'evoluzione storica dei sistemi di approvvigionamento idrico della città di Benevento (Italia meridionale) nel corso dei secoli. In particolare, il lavoro si concentra sui tre principali periodi storici della città, ovvero il periodo Romano, Longobardo e Papale, oltre che sull'attuale sistema di approvvigionamento idrico e su quello in programma per il prossimo futuro. Nel corso delle varie epoche, la quantità e la qualità delle forniture idriche sono cambiate molte volte e ciò ha probabilmente influito sulla crescita e sul benessere della città. La migliore fornitura idrica ha caratterizzato l'epoca Romana, durante la quale sono state captate importanti sorgenti carsiche che hanno alimentato la città per secoli; in questo periodo si è anche verificata la maggiore espansione demografica della città. Il periodo più depresso coincide probabilmente con quello Papale, durante il quale la città risultava isolata dal contesto, essendo un'enclave dello stato pontificio. In tale lungo periodo, le forniture idriche provenienti da fonti esterne risultavano vulnerabili e comunque difficili da manutenere. La città sfruttava principalmente le acque locali (fiume e piccole sorgenti), normalmente di bassa qualità. Solo dopo l'unificazione d'Italia, e anche dopo la Seconda Guerra Mondiale, l'approvvigionamento idrico è notevolmente migliorato, con nuovi acquedotti provenienti da acquiferi carsici. Attualmente, la gestione dell'approvvigionamento idrico di Benevento è ancora oggetto di discussione. In futuro, il rifornimento idrico sarà garantito dall'invaso della diga di Campolattaro, lungo il Fiume Tammaro. La conoscenza dell'evoluzione storica dell'approvvigionamento della città di Benevento rappresenta un presupposto necessario al fine di analizzare consapevolmente la futura pianificazione e gestione della risorsa idrica

Abstract

The research analyses the historical evolution of the water supply systems of the city of Benevento (southern Italy) during centuries. We focused on three main historical periods, namely the Roman, Lombard and Papal times, and the recent-present times. During this long historical time, the water supply amount and quality have changed many times, and this has probably affected the well-being and growth of the city. The best water quality characterized the Roman times, when large karst springs were tapped, feeding the town for centuries. In this period, the town experienced the largest population expansion. On the other hand, the most depressed period was the Papal times, coinciding with the isolation of the city, as it was an enclave of the Pontifical State. During this period, the water supply from external sources was not guaranteed and therefore it primarily derived from the local, low-quality water resources. Only after the unification of Italy, and also after the Second World War, the water supply systems have been improved, and new aqueducts have brought again high-quality waters to Benevento coming from karst aquifers. Nowadays, the drinking water management of Benevento is still a matter of debate. In the near future, the water from a dam-reservoir (Campolattaro dam, Tammaro River) will be exploited to guarantee the water needs of the city, and water-supply systems will undergo further changes . The knowledge about the historical evolution of the water supply of Benevento represents an essential requirement for consciously analyzing the future planning and management of water resources.

Introduction

The development and growth of societies are strictly connected to water availability, both in term of quality and quantity. Since the ancient times, important societies have populated the areas of the central-southern Apennine (Italy), a sector of the Italian Peninsula characterized by significant surface water and groundwater resources, the latter are stored mainly in karst and porous/alluvial aquifers. Karst aquifers hosted in carbonate massifs naturally provide large quantities of high-quality water. On the other hand, porous aquifers characterize intermontane and vast coastal plains, and are mainly hosted in alluvial Quaternary deposits.

The specific hydrogeological, topographic and climate features of this Campania-Latium region represented key factors for the growth of important settlements and cities, which developed advanced hydraulic works to ensure the continuous availability of good-quality waters. In particular, given the topographic position of karst springs, water can be transferred for long distances by gravity via aqueducts, connecting the karst spring to urban areas.

The most relevant ancient example is probably the city of Rome, built along the Tiber River, initially representing the primary source that guaranteed the water needs. However, the Romans soon understood the importance of springs in mountain areas and built, as is well known, ingenious aqueducts to have higher-quality water, favoring the economic and demographic growth of the cities and, therefore, of the empire. The towns near Rome were interested by constructions of long aqueducts as occurred initially in the Latium and Campanian regions, and in the Mediterranean area later. In central-southern Italy, these aqueducts have worked for centuries, until recent historical times in some cases. In other cases, these aqueducts were destroyed after the fall of the Roman Empire. The political instability that characterized Italy until its unification in 1861 did not provide the conditions for planning the building of new and long aqueduct systems.

Even in Rome, the city's water supply system from Acqua Marcia springs was restored only after the unification of Italy. The Naples Aqueduct was built in 1888, which conveyed water from Serino springs toward the city, as in Roman times.

Other main and strategic aqueducts were projected and built from the beginning of the twentieth century. In particular, the Apulian aqueduct was built to bring water from the Caposele karst spring first, and then from Cassano Irpino springs, to Apulia, solving one of the chronic problems of this region and favoring its economic development.

This study describes the historical evolution of the water supply of Benevento (southern Italy) since the Roman period and discusses the different types of water resources used, highlighting the incredible change regarding the water supply of the town. This problem still needs to be solved completely, and further important changes are expected in the near future.

Perhaps it is superfluous to underline that a high-quality and sufficient water supply is fundamental for the development of communities, without which the conditions for the economic and social growths always appear threatened.

Nowadays, the management of water resources, and in particular their redistribution and uses, is a hot topic due to increasing urbanization, economic development, and climate changes. Of course, any decision on the water supply, should firstly come from the knowledge of the hydrology and hydrogeology of a wide area, and then from technical and economic considerations, inside a broad context that considers many factors; thus, final political choices should be guided by avoiding prejudices and partisan interests.

The example of Benevento highlights the complexity of this topic. It represents a case-study in this field, thanks to its millenarian history that has seen the succession of different historical periods and societies (Samnite, Roman, Lombard, Papal, Post-unification of Italy, Current status), accompanied by changes in the water supply strategies during each transformation.

The aim of this study is the reconstruction of the historical evolution of water supplies of city the of Benevento, from the Roman times until nowadays, with a focus on the future of the water resource management accounting social and environmental problems

Study area

The city of Benevento is located at the confluence between the Calore and Sabato Rivers, in an area characterized by hilly slopes that degrade toward the alluvial plain near the river network.

Geologically, alluvial deposits outcrop in the area, constituted by different sedimentary cycles from Early Pleistocene to Holocene, covering a marine substratum, made by argillaceous sequences. Other geological details can be found in Amato et al. (2017) and Senatore et al. (2019).

The alluvial aquifer of Benevento Plain (about 30 Km^2) is mainly constituted of Quaternary deposits related to the dynamics of Calore and Sabato Rivers. The heterogeneity of these deposits (in terms of lithology and grain size) gives rise to a complex groundwater circulation, relying on "multiple superimposed layers" interacting with one another at a large scale (Celico et al., 1998; Esposito et al., 2005a). Moreover, the aquifer-river interaction with the river stage strongly influences groundwater flow, representing the primary driver of groundwater circulation (Leone et al., 2024). Since 1960s, this aquifer was exploited by several pumping wells for drinking purposes to feed the town.

Except for the alluvial aquifer of Benevento Plain, there are no other significant water resources near the city, and, consequently, a large part of the water supply came, and still comes, from karst massifs, such as those of Terminio-Tuoro, Taburno-Camposauro and Matese Mountains (Fig. 1; Celico, 1978; Fiorillo et al., 2015). Karst massifs are constituted by high-permeability limestone and limestone-dolostone sequences of Triassic-Miocene age, having a thickness of 2500-3000 m, and are bounded by less permeable marine argillaceous complexes (Paleocene) and flysch sequences (Miocene).

Fig. 1 - (a) Map of the Italian Peninsula and (b) of the western Campania region. Red rectangles bound the areas shown in Figures 2 and 6.

Fig. 1 - (a) Carta della penisola italiana e della Campania occidentale. I rettangoli rossi delimitano le aree mostrate nelle Figure 2 e 6.

Karst aquifers feed powerful basal springs, which have had great relevance for Benevento, as well as for other ancient cities. More specifically, the Serino springs (Acquaro-Pelosi and Urciuoli springs) are the major outlets of Terminio karst massif (Civita, 1969a; Celico, 1978; Esposito, 2001; Fiorillo et al., 2018), with an overall mean discharge of 2.25 m^3/s; during Roman times these springs were tapped to supply Benevento (Urciuoli springs) and other cities of Neapolitan area (Aquaro-Pelosi springs). Other springs of the Terminio karst massif, the powerful Cassano springs (mean discharge of 2.65 m^3/s), fed Calore River and sustain river discharge during dry periods; these springs have been tapped since the 1960s, and mainly feed the Pugliese Aqueduct .

The Matese karst massif is characterized by several basal spring groups, mainly located on the southern and northern sides. The first group is that of Piedimonte Matese (Torano and Maretto springs), with an overall mean annual discharge of about 3 m^3/s. On the northern side, there is the Boiano group (Maiella, Pietrecadute and Riofreddo springs); it has an overall discharge of 2.80 m^3/s (Civita, 1969b) and is also known as Biferno springs, as it is located at the head of Biferno River. All these springs are tapped by Campano Aqueduct to feed mainly the Neapolitan area and by Molisano Aqueduct to feed the Campobasso province. A minor amount of Boiano group spring discharge is conveyed toward Benevento city.

Another important spring group along the southern side of the Matese massif is that of Grassano-Telese Terme (Fiorillo et al., 2019), where the relative fresh water is only partially exploited.

Finally, the Taburno-Camposauro karst massif supplies many minor springs, some of which were exploited to feed Benevento city in the past.

Main historical periods

The city's strategic position, especially during the Roman period, the favorable climate conditions, and the geomorphological features of the plain have allowed different civilizations to develop here.

Some archaeological remains, dated Neolithic (8th century B.D.), were found in the city centre (Vari Square), testifying to the first human settlement in the area (Amato et al., 2017).

The city's history is intimately linked to Samnites, which built the first organized and defendable settlement in the area (IV Century B.D.; Torelli, 2002). In 268 B.D., after the Roman and Samnite wars, Benevento became a Roman colony located at the crossroads of Appia and Minucia Roads (the future Appia Traiana Road; Iasiello, 2007). During Roman times, the city reached its maximum growth (Rotili, 1958), as testified by several remains and hundreds of epigraphic inscriptions (Caruso, 2013). The prosperity of the city was guaranteed by its position located near the Appia Road and near the confluence between the Sabato and Calore Rivers. This last condition provided the water supplies needed for agricultural and drinking purposes.

After the fall of the Roman Empire (476 A.D.) and the Gothic Wars (490 A.D.), Lombards, led by King Zottone, conquered the city (570 A.D.), making it the capital of their duchy.

In 1077 A.D., after several civil wars between Salerno and Benevento (849 A.D.), and after Saracens and Normans invasions (about 1077 A.D.; Zigarelli, 1979), with the death of the last Lombard's king, Landolfo VI, the papal domination of the city started (Borgia, 1763). De facto, Benevento City became an enclave of the Papal State inside the Kingdom of

Two Sicilies (Zigarelli, 1979). During this long period, the city has undergone several alternating facts (De Antonellis, 2008), becoming a possession of the Swabian house. Fief of the Papal State, the city was governed by a rector first and a governor then. In 1688, there was a period of equilibrium and serenity due to the Cardinal Vincenzo Maria Orsini government, next Pope Benedetto XIII. He really loved the city and, especially after the 1688 and 1702 earthquakes, funded several public and reconstruction works. This domination lasted until 1860, in consequence of the Italian Independence Wars.

After the occupation by Napoleon's soldiers (in 1806), the domination of the city came back to the Papal State (in 1815) and ended with the unification of Italy in 1861. Thus, the papal period of the town lasting for about eight centuries..

Therefore, Roman, Lombard, and Papal times represent the three main historical period of the town. There were periods of expansion and retirement of city walls that affected the urbanistic framework of the city. From the primitive Roman nucleus, constituted by a castrum romano and a part outside the city walls (Borgia, 1763-1769; Mazarini, 1823; Rende, 2004), the city expanded during the Lombard period. During the IX and X centuries, city's walls expanded following the left side of the Calore River; the expansion then reached the right side of the Sabato River. Still today, this part represents the shape of the city. During Papal times, no expansion and/or modification of the city's urbanistic framework occurred, but several churches and historical monuments were built (De Lucia, 1930; Zazo, 1980). Finally, after World War II and the destruction of a great part of the city, there was an uncontrolled expansion of the city until the 1970s. These historical phases have caused a complex evolution of aqueduct systems until they reached the aqueduct scheme that currently supplies the city. This complexity results in difficulties in supplying and managing water resources.

Benevento's historic water supply

Historical information about the three periods considered in the study has been collected. Many documents, among which there are notarial transcriptions, deeds, papal bulls, and epigraphic transcriptions, were consulted. These documents were found at the State Archives of Benevento Province and at the Provincial Library of Benevento; the Cultural Association Benevento Longobarda has also been contacted. Moreover, some archaeological sites have been directly inspected.

Roman times

During Roman times, the Sannitico Aqueduct fed Benevento (Fig. 2). Long about 32.5 km and with an average slope of 5 ‰, this aqueduct was built in I century A.D. (Tolle Kasteinbein, 1993) and primarily picked up the Urciuoli spring discharge (caput aquae), located in Cesinali municipality (near Avellino city). As shown by Figure 2, it followed the path of the Sabato River, crossing the municipalities of Atripalda (ancient Abellinum), Prata di Principato Ultra (some remains were found in Parata del Molino locality), Altavilla Irpina, and Chianche (Cristilli, 2006; De Feo et al., 2009).

Another minor spring, the Fonte dei Formosi spring, and located near Altavilla Irpina village, also supplied the aqueduct but with negligible discharge compared with the Serino springs.

The ending of this aqueduct system was represented by a reservoir in Castellum Aquae, whose remains are currently located under Rocca dei Rettori castle (Preziosi, 2001; Fig. 3). From this reservoir, it branched off an underground urban aqueduct network that supplied several parts of ancient Benevento town, including several thermal facilities, whose location is shown in Figure 4. In XVIII and XIX centuries, the remains of this network were found during the reconstruction of some buildings following the 1702 earthquake and are still visible along Avellino Street (De Nicastro, 1719; Isernia,

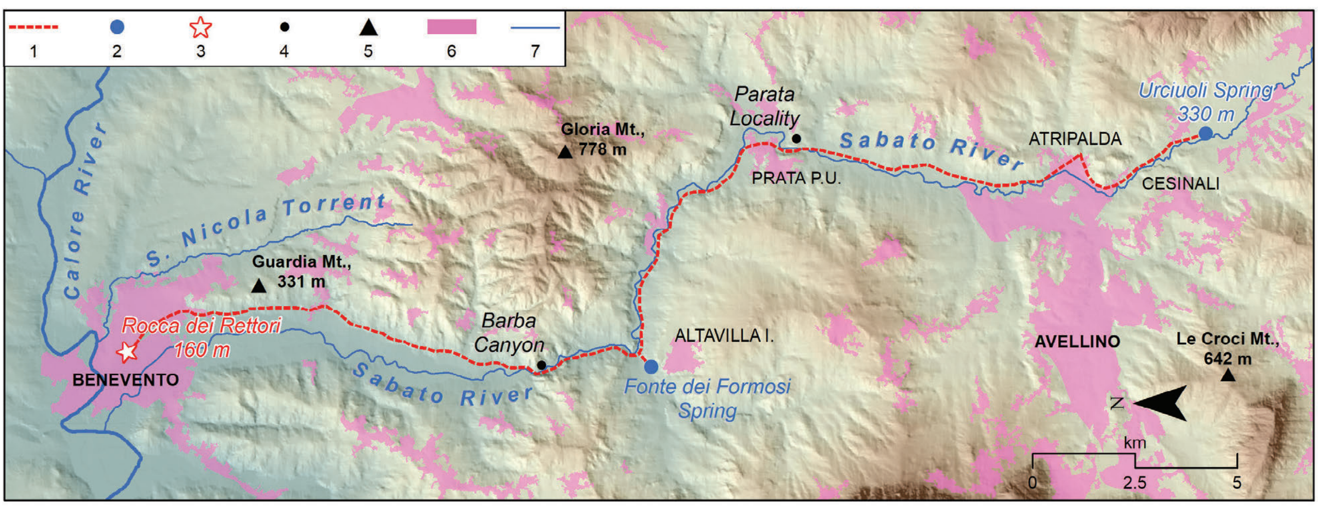

Fig. 2 - Map showing the path of the Roman Aqueduct (I Century A.C.) conveying waters of the Urciuoli karst spring to Benevento city. Legend: 1) Hypothesized Aqueduct path; 2) Main springs; 3) Castellum Aquae (Rocca dei Rettori); 4) Main toponyms; 5) Mountain peak; 6) Towns; 7) River network.

Fig. 2 - Carta del tracciato dell'Acquedotto Romano (I secolo d.C.) che convogliava le acque della sorgente carsica Urciuoli verso la città di Benevento. Legenda: 1) Percorso dell'acquedotto ipotizzato; 2) Principali sorgenti; 3) Castellum Aquae (Rocca dei Rettori); 4) Principali toponimi; 5) Vette; 6) Città; 7) Reticolo fluviale.

1895; Zazo, 1977; Zazo, 1980; Fig. 3c). During the first half of II century A.D., the Roman aqueduct represented the main water supply for several thermal facilities built into the town, such as the thermal complex of San Cristiano Street (Isernia, 1895; Rotili, 1986), Thermae Commodiane located in the underground of Cardinale Pacca square and in Posillipo Street, and the thermae located in Episcopio Street (Rotili, 1986; Fig. 4). The remains of these thermal facilities, located in city walls, are still partially visible (Fig. 5a).

Despite several injuries (Joannowski, 1983; Cristilli, 2006) and maintenance interventions, among which the reconstruction of the channel during the IV century (Rea, 1978; Pescatori Colucci, 1996), the Sannitico Aqueduct was still functioning until VIII-XI century A.D. Next, following several Lombard civil wars and natural catastrophizes (mainly floods of Sabato River, landslides, and seismic events), Roman

Fig. 3 - Sannitico Aqueduct (I century B.D.): a) beginning of the aqueduct tunnel near the Urciuoli Spring of the Serino group (Caput Aquae); b) ruins located along Avellino Street in Benevento city; c) the opus reticulatum highlights the main channel remain under Rocca dei Rettori building; d) detail of the main channel inside Rocca dei Rettori building.

Fig. 3 - Acquedotto Sannitico (I secolo d.C.): a) inizio del tunnel dell'acquedotto vicino la sorgente Urciuoli del gruppo di Serino (Caput Aquae); b) resti ubicati lungo Via Avellino in Benevento; c) l'opus reticolatum indica i resti del canale principali sotto l'edificio della Rocca dei Rettori; d) dettaglio del canale principale all'interno dell'edificio della Rocca dei Rettori.

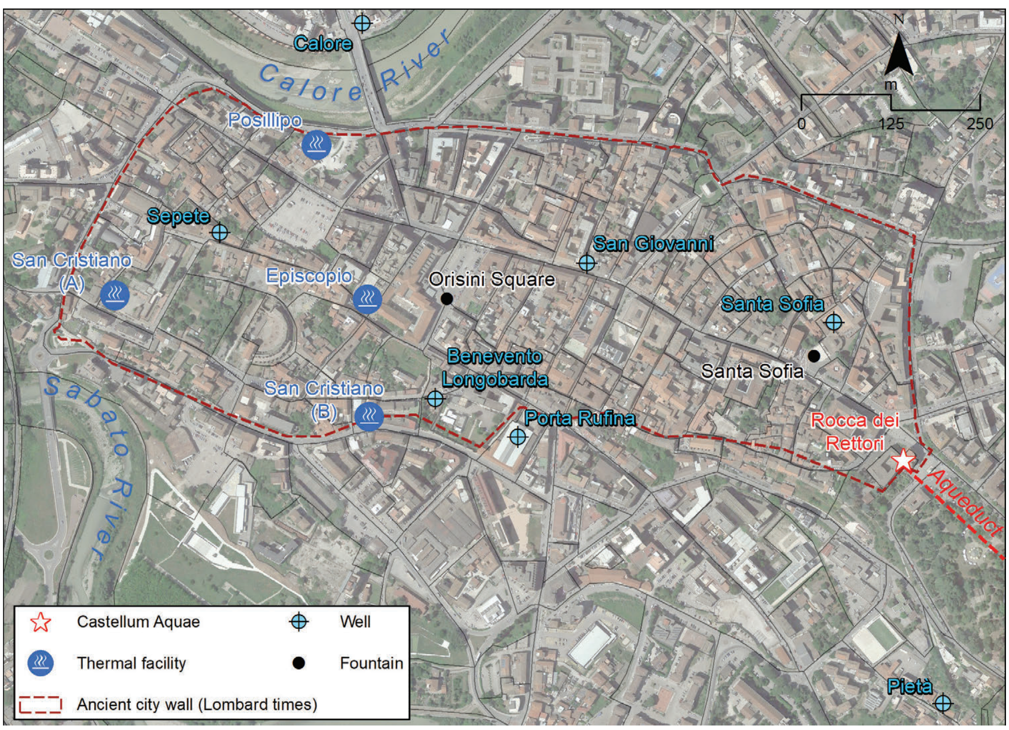

Fig. 4 - Map of Benevento showing sites of interest, including the arrival of the Roman aqueduct and thermal facilities, Lombard wells, and Orsinian fountains. Site names were taken from local elements (streets, rivers, monuments, etc.). The Lombard city wall was drawn based on a topographic map by Carlo Antonini (about 1780).

Fig. 4 - Carta della città di Benevento che mostra l'ubicazione dei siti di interesse, quali l'arrivo dell'acquedotto e le strutture termali di epoca Romana, i pozzi Longobardi e le fontane Orsiniane. I nomi dei siti si riferiscono a elementi locali (strade, fiumi, monumenti, etc.). Il perimetro delle mura longobarde è stato tracciato sulla base di una carta topografica di Carlo Antonini (1780 circa).

aqueduct was destroyed (Peduto, 1992). Consequently, the Urciuoli spring was no longer tapped and fed the Sabato River. Several centuries later, at the end of the XIX century, both Serino spring groups (Acquaro-Pelosi and Urciuoli) were re-tapped by Serino Aqueduct to supply the metropolitan area of Naples by a gravity tunnel joined to a pressure conduct (Fiorillo et al., 2007).

Lombard times and Middle Ages

During the VI century, Lombards conquered Benevento city and primarily occupied the highest part of the town, (Fragnito & Grella, 2023). Consequently, strategic human settlements near Sabato River were abandoned, and the area was exploited for agricultural (farming, grazing) and productive purposes (Tomay, 2009).

The Roman aqueduct still guaranteed water supply and fed the thermal facilities located in the city center. During barbarian invasions, the Roman aqueduct was wholly destroyed; then, in the IX Century, King Radelchi funded its reconstruction (De Feo et al., 2009). Water coming from the aqueduct was still employed to feed the thermal facilities (Fig. 5a) and was integrated by several sources, including groundwater from wells drilled in the plain (having depths ranging from 8 to 12 meters), a few cisterns catching rainfall water, Calore River, and some minor springs located near the city (among them there was Fontana Fabbricata spring; De Lucia, 1930; Zazo, 1980). Following the destruction of the Roman aqueduct, the city's water supplies were assured only by these latter sources. Two examples are represented by the remains of three wells belonging to this period: the first was realized entirely into a Roman capital and located in the Cloister of Santa Sofia Church (XII century); the other two wells, realized with some Roman rests and reached a depth of several meters, were used for water supply of a ceramic factory (Fig. 5b). These latter are still present in Triggio District, addressed by the headquarter of the Cultural Association Benevento Longobarda (Fig. 4)

Papal times

After the Middle Ages, Benevento City underwent further phases of rebuilding and reshaping, especially after destructive earthquakes and floods.

Until the XVI century, there were five public wells (De Lucia, 1930), known as Porta Rufina well (near the public marketplace, now Mercato square; Fig. 5c), Pietà well (in front of the chapel of the same name), San Giovanni fuori Port'Aurea well (in front of Commenda di Malta church), Calore well (near Saint Onofrio's Church, break down in 1927) and Sépare or Sepete well (near the Orphanage of San Filippo Neri). Furthermore, some private wells provided water to the population (Bencardino, 1991), while part of the productive activities (such as mills, factories, etc.) employed the waters of Sabato and Calore Rivers (Isernia, 1895; Bencardino, 1991; Del Prete, 2009). Some centuries later, in the XX century, mills were replaced by the Santa Barbara hydroelectric power plant that exploited the Sabato river flow energy; the plant was then to acquired by the Rummo factory and later dismissed (Del Prete, 2009).

In 1598, Architect Valente de Valenti drafted a project to uplift the Sabato River's water flow for local supplies. In 1599, however, this project was set aside in favor of another project realized by Engineer Carlo Sorrentino, which involved the tapping of the Monte della Guardia springs, located in the hilly zone 1 km south of the city.

During the XVIII century, after the 1702 earthquake, cardinal Vincenzo Maria Orsini, future Pope Benedetto XIII, funded the design and construction of the new aqueduct of Benevento, known as Orsinian Aqueduct (Gambardella,

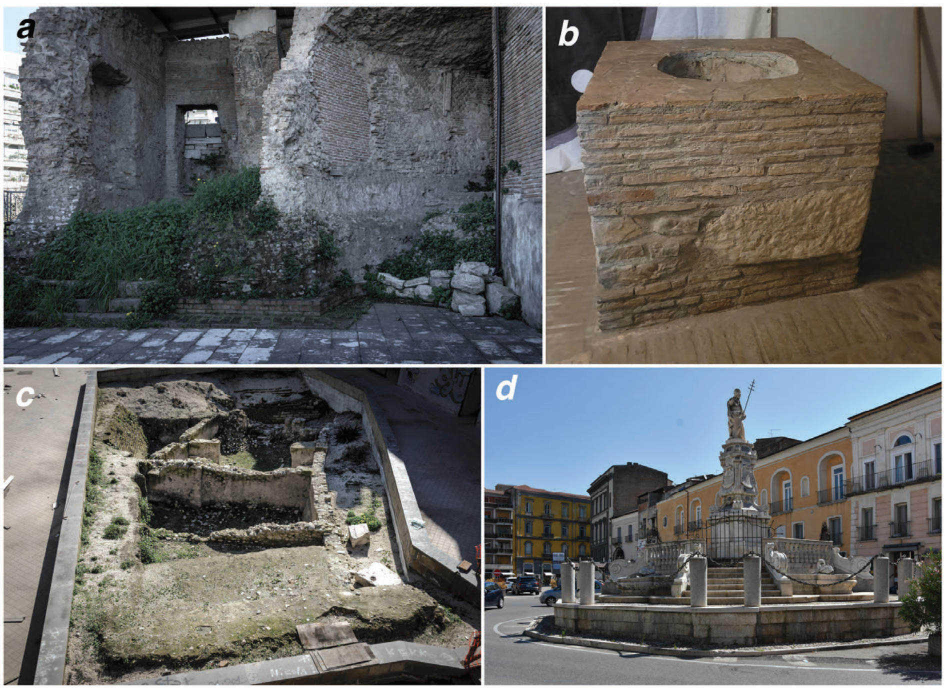

Fig. 5 - (a) Remains of Roman Thermae facilities in Posillipo Road; (b) Lombard well in headquarters of Benevento Longobarda Association; (c) Public well supplying Benevento city during Papal times located in the actual Mercato Plaza; (d) Fountain in Orsini square fed (papal times) by the Orsinian Aqueduct

Fig. 5 - (a) Resti dell'edifcio delle Terme Romane in via Posillipo; (b) Pozzo Longobardo nella sede dell'Associazione Benevento Longobarda; (c) Pozzo pubblico che riforniva Benevento durante l'epoca Papale ubicato nell'attuale Piazza Mercato; (d) Fontana in Piazza Orsini alimentata (periodo papale) dall'Acquedotto Orsiniano.

1979; Pezone, 2008). In 1705, Carlo Buratti resumed the project about tapping Monte della Guardia springs by an underground tunnel.

In addition, other primary water sources, already found by Engineer Sorrentino a century earlier, were represented by some little springs located in the low permeability deposits, which are all extinct except three. These latter are Fontana Fabbricata, Fontana del Cantaro, and Fontana Sorici springs; probably, the first two, having a discharge lower than 1 L/s, are those actually located in Torrecuso and Pietrelcina municipalities, respectively (Esposito et al., 2005b).

In 1711, the aqueduct building ended and the first public fountain, located in front of Cappuccini convent in S. Felice locality, was inaugurated (Pezone, 2008). The other two fountains were inaugurated in 1718 (Fig. 4); the first fountain was located inside the city walls, near S. Sofia's Church (Pezone, 2008), while the second was located in Orsini Plaza (Zazo, 1980), near Saint Bartolomeo's Church (De Lucia, 1930; Fig. 5d).

In 1719, with the realization of the fourth fountain in Fragola District, the Orsinian Aqueduct fed the lower part of the city (S. Domenico, S. Vittorino, Carmelitani, S. Antonio, Badia di S. Sofia, Collegio dei Gesuiti, Vescovato and Palazzo Apostolico districts) and, consequently, the whole city had a water supply (Zazo, 1980). In 1740, the aqueduct was partially dismissed because of the maintenance costs. In subsequent years, new water sources to the aqueduct system were added; however, they could not supply the growing water demand of the city (Zazo, 1980; Del Prete, 2009). Several years later the aqueduct was finally completely dismissed.

Moreover, to supplement the Orsinian aqueduct in the city's water supplies, another water source was found: a tunnel, realized in clay materials, that picked up the water flow of Torrente San Nicola was realized. This hydraulic infrastructure was still functioning until the early XX century when it was dismissed in favor of new supplies from the Cautano Aqueduct (Fig. 6).

From the unification of Italy to today

Until the fascist dictatorship, the city of Benevento underwent a series of urbanistic interventions, among them there was the recovery of the town's aqueduct systems (Bencardino, 1991).

During 1930s the Orsinian Aqueduct was renovated and re-used with the tapping of some new springs (Zazo, 1980), including the Sorienza, Spezzacarafa, Mensareina, Abazia, Sambuco, and Gamberi springs (Cautano springs in Fig. 6), which also provided the water supply to several small neighboring towns (Civita et al., 1970; Civita et al., 1971). They are located in Prata Valley (Fig. 6), between Taburno and Camposauro reliefs, and have a discharge ranging from 50 to 80 L/s. The aqueduct network followed the path of the current Vitulanese road and finally joined the Orsinian aqueduct. This aqueduct system was still functioning at the

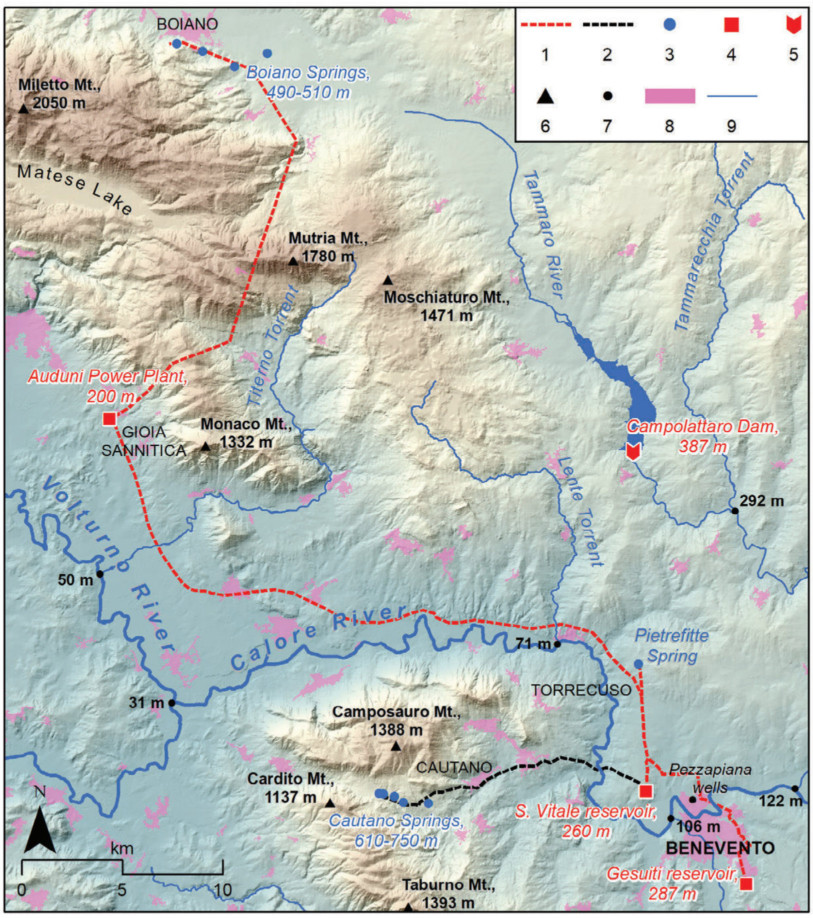

Fig. 6 - Map showing the path of the XX Century (Cautano Aqueduct) and present aqueduct (Biferno Aqueduct). Legend: 1) Biferno Aqueduct; 2) Cautano Aqueduct; 3) Main springs feeding aqueduct systems; 4) Main aqueduct facilities; 5) Dam; 6) Mountain peak; 7) Elevation points; 8) Towns; 9) River network.

Fig. 6 - Carta che mostra l'andamento dei sistemi acquedottistici del XX secolo (Acquedotto di Cautano) ed attuale (Acquedotto del Biferno). Legenda: 1) Acquedotto del Biferno; 2) Acquedotto di Cautano; 3) Principali sorgenti che alimentano i sistemi acquedottistici; 4) Principali infrastrutture acquedottistiche; 5) Diga; 6) Vetta; 7) Punti quotati; 8) Città; 9) Reticolo fluviale.

beginning of the 1980s, when it was definitively dismissed. Successively, new and modern aqueduct systems were built.

Nowadays, the city of Benevento has a complex aqueduct scheme, and the water supply involves a city division into three different areas.

The main water source is represented by water coming from Campano Aqueduct (Fig. 6). In particular, the discharge of Biferno karst springs is conveyed through a tunnel crossing the eastern sector of Matese Mountain toward the Gioia Sannitica hydraulic divider, located in Auduni district (EIC,2021; Leone et al., 2023). Then, karst groundwater is transported through a conduit crossing the Volturno and Calore Valleys and reaches the highest zones of Benevento city (Capodimonte district, Cancelleria district, city center, Avellino street, etc.). The overall discharge is 0.2 m^3/s. The lowest zones of the town, as Triggio, Ferrovia, and Libertà districts, are fed by groundwater pumped by the two wells located in thePezzapiana district alluvial aquifer, a part of the wider Benevento alluvial plain aquifer. The maximum pumping discharge is about 0.12 m^3/s. A recent study by Leone et al. (2024) highlighted the hydraulic connection between the Calore River and alluvial aquifers in this area. The cross-section in Figure 7 shows the groundwater flow in the Pezzapiana district with the localization of drinking wells and the monitoring piezometer. The local groundwater flow has a strict connection with river Calore; water is abstracted by pumping as well (Leone et al. 2024). Therefore, Pezzapiana district's wells could be susceptible to contamination, eventually due to surface water contamination or local sources.

Discussion and Conclusion

The historical and urbanistic evolution of Benevento showed how the city's water supply has represented a complex and articulated issue (Tab. 1).

Romans first solved this problem by tapping the Urciuoli spring (Preziosi, 2001). The water from this spring was conveyed toward the city via the Sannitico Aqueduct. Given its karst nature and its hydraulic mechanism characterized by ascendent flow (Fiorillo et al., 2018), this spring had to ensure a large amount of high-quality water to Benevento inhabitants.

Figure 3d shows a view of the aqueduct channel in Rocca dei Rettori castle. The original channel has a maximum width of about 0.54 m and a height ≥ 0.84 m. The channel is filled by a layered deposit, mostly made by precipitation of calcium carbonate and debris. Calcium carbonate is directly precipitated from the flowing water, considering the karst origin and the calcium bicarbonate nature of the Urciuoli spring. Generally, this type of deposit characterizes the transport and storage elements of ancient hydraulic works sourced from karst environments (Keenan-Jones et al., 2022; Sürmelihindi & Passchier 2023).

It forms below the water level, and, as shown in Figure 3d, its overall thickness is not uniform as it decreases upward. The layers are almost parallel, and the materials at the channel wall are the oldest. The maximum height reached by the deposition level is about 0.65 m from the channel floor, despite the uppermost and thinnest part of the deposit having been eroded over time. This deposition level should provide the maximum water flow height throughout the original channel at the beginning of the precipitation-sedimentation process. In particular, aqueduct discharge can be obtained by Manning's equation (Chow et al., 1988) based on channel features. Approximating the original channel section to a rectangle, the discharge Q is related to flow height h_f by:

$$Q = \frac{R\left(h_f\right)^{2/3} \cdot S^{1/2}}{n} A\left(h_f\right)$$

where $R(h_f)$ is the hydraulic radius and $A(h_f)$ is the flow section, both function of h_f, S is the bed slope, and n is Manning's roughness coefficient. Figure 8 illustrates the relationships between flow height and aqueduct discharge for different values of coefficient n. The box plot provides the discharge data distribution for the Urciuoli spring, characterized by a mean μ = 1.27 m^3/s (1934-2019 period), with a standard deviation σ = 0.2 m^3/s. Assuming a maximum water flow level of 0.65 m, with a coefficient n between 0.01-0.015 (Chow, 1959), the maximum aqueduct discharge ranges from 0.58 to 0.86 m^3/s. Assuming the past and recent spring discharge regimes are similar, this amount would be guaranteed also during extreme hydrological drought which affected the Urciuoli spring ($Q < \mu - 2\sigma$), and only a part of the total spring discharge was conveyed toward Benevento. However, water leaks along the aqueduct path cannot be ruled out, and probably the whole spring discharge was tapped. Under such hypothesis, more than 50% of the water tapped

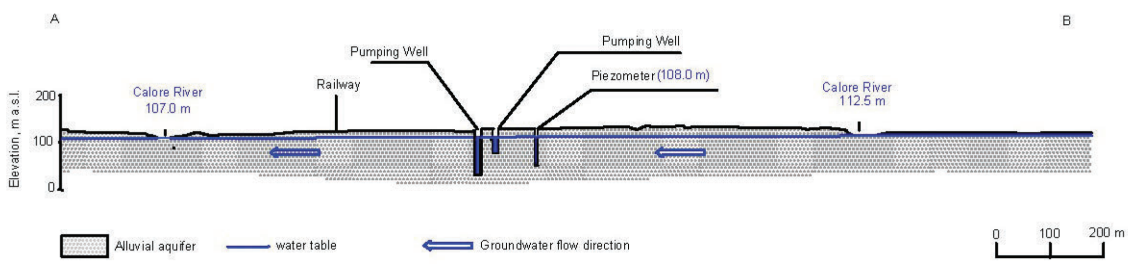

Fig. 7 - Hydrogeological cross-section of Pezzapiana industrial area of Benevento, with the localization of wells and monitoring piezometer (water level refer to February 2023).

Fig. 7 - Sezione idrogeologica dell'area industriale di Pezzapiana di Benevento, con l'ubicazione dei pozzi e del piezometro (livello falda riferito a Febbraio 2023).

Tab. 1 - Main Historical periods, number of inhabitants and water supplies of Benevento city. References: 1-Up to 250,000 following Collarile (2023); 2-Galanti (1789); 3-ISTAT (1960); 4-ISTAT (2023); 5-Inferred by the Authors; 6- Estimated by hydraulic considerations; 7-Data from Civita et al. (1971); 8-Data provided by GESESA Aqueduct Company; 9-Data from Technical Report of the Project of the Potabilization of Campolattaro Dam.

Tab. 1 - Principali periodi storici, numero di abitanti e approvvigionamento idrico della città di Benevento. Riferimenti: 1-Fino a 250,000 ipotizzato da Collarile (2023); 2-Galanti (1789); 3-ISTAT (1960); 4-ISTAT (2023); 5-Ipotizzati dagli Autori; 6-Stima da considerazioni idrauliche; 7-Dati da Civita et al. (1971); 8-Dati forniti dall'Azienda acquedottistica GESESA; 9-Dati reperiti dalla relazione tecnica del Progetto di Potabilizzazione della Diga di Campolattaro.

Historical period	Number of inhabitants (maximum)	Water source	Main distribution system	Estimated water quality at the source H, high M, medium L, low P, poor	Minimum estimated water amount (dry period)
Roman Times (I Century A.D. – V A.D.)	60,000?[1]	Karst springs, Serino (Picentini Mts.)	Sannitico Aqueduct	H	Up to 500 L/s[6]
Lombard Times (VI-XI Century)	10,000	Karst springs, Serino (Picentini Mts.)	Sannitico Aqueduct, until VIII Century	H	?
		Alluvial aquifer, Benevento	local wells and cisterns	L	-
Papal Times (XI-1860)	14,000[2]	Local springs, Monteguardia-Benevento	Orsinian Aqueduct	M	0 L/s
		Alluvial aquifer, Benevento	local wells	L	-
		Water river, Benevento	hydraulic derivation (channels)	P	-
Post-unification of Italy (1860-1950s)	40,000[3]	Karst springs, Cautano (Camposauro Mt.)	Cautano Aqueduct	H	50 L/s[7]
Current status (since 1960s)	60,000[4]	Karst springs, Boiano (Matese Mt.)	Biferno Aqueduct	H	178 L/s[8]
		Local springs, Pietrefitte-Torrecuso	local aqueduct	M	3.2 L/s[8]
		Alluvial aquifer, Benevento	local wells, Pezzapiana locality	L	120 L/s[8]
Near future	50,000[5]	Dam water, Campolattaro	Aqueduct under construction	L	362 L/s[9]

was lost during the path, but a minimum approximately of 0.5 m^3/sec, seemed guaranteed to the city also during droughts.

The deposit accumulation has caused the narrowing of the flow section and an increase of the wall roughness. This suggests a decrease in the aqueduct discharge, probably due to the abandonment and degradation of the hydraulic work rather than natural factors.

The analysis highlights that the Urciuoli karst spring has probably been the largest and best-quality water supply of the city since today. It is particularly interesting to note that the amount of karst groundwater feeding Benevento during Roman times was probably higher than today, considering that the Biferno aqueduct and Pezzapiana wells provide about 0.2 m^3/s and 0.1 m^3/s, respectively.

This suggests that during the Roman times the maximum number of inhabitants could be compared with the current or more, according to extraordinary public infrastructures left by Roman as the amphitheater (Galasso, 1999), the theater (Meomartini, 1889), the thermal sites already described and so on, but this is a difficult topic which merits specific analyses outside the scope of our study.

After the destruction of the Roman aqueduct, during the Lombards (partially) and Papal periods, the city was supplied by poor-quality waters from several wells and other sources located inside and close to the city bulk. In any case, these sources were inadequate to satisfy the water demand of the population. Indeed, during the XVI Century, citizens of Benevento protested against the Spanish viceroyalty about the tapping project of Serino springs for the supply of the Neapolitan area because these springs fed the Sabato River and their possible exploitation led to a decrease of the river flow (Zazo, 1980). It must be stressed that we did not find any documents about an agreement between the Benevento enclave and the Kingdom of the Two Sicilies on the city's water supplies. Considering this condition of geographic and geopolitical insulation, it can be reasonably hypothesized that the main water supplies of Benevento were represented only by sources that fell inside the city territory or outside and near the city walls (Zigarelli, 1979). Following the unification of Italy, the city of Benevento was involved in the local context, ending his isolation. Then, several regional aqueduct systems,

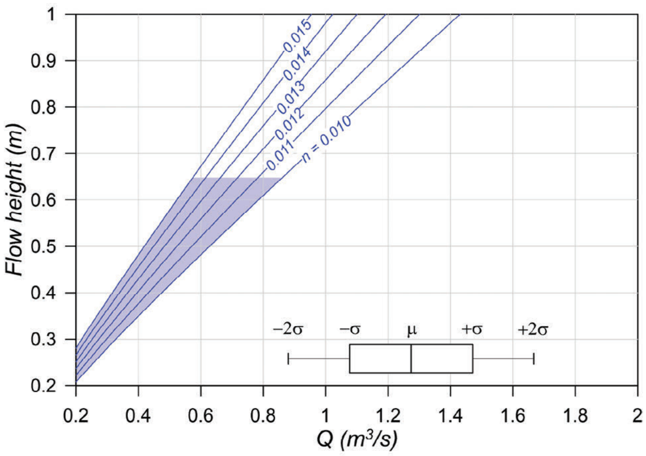

Fig. 8 - Relationship between Sannitico aqueduct discharge, Q, and water flow height (h_f) estimated by Manning's equation for different values of roughness coefficient n. The dark blue area represents the aqueduct discharge for a maximum flow height of 0.65 m. The box plot provides the distribution of discharge data of the Urciuoli karst spring (period 1934-2019; μ is the mean and σ the standard deviation).

Fig. 6 - Relazioni tra la portata dell'acquedotto Sannitico, Q, e l'altezza del flusso (h_f) stimate utilizzando la formula di Manning per differenti valori del coefficiente di scabrezza n. L'area blu rappresenta i valori di portata per un'altezza del flusso pari a 0.65 m. Il box plot descrive la distribuzione dei dati di portata della sorgente Urciuoli (periodo 1934-2019, μ è la media e σ la deviazione standard).

such as the Serino Aqueduct (1880s), Pugliese Aqueduct (1910s), Alto Calore Aqueduct (1930s), Campano Aqueduct (1950s), and so on, were built.

In this framework, water supply of Benevento city is granted by both Campano Aqueduct and GESESA Aqueduct Company (Fig. 6 and 7).

Anyway, the water supply of Benevento city is going to change entirely again in the future when the infrastructural work (purifier and hydraulic distribution works) of the Campolattaro dam is completed; however, these works are only financially supported by the Campania Region authority but not still beginning. The Campolattaro dam is an earth dam located in a middle-upper part of the Tammaro River, built in the first half of the 90s, with a reservoir of $156 \cdot 106$ m^3 and a catchment area of 253 km^2 (Magliulo et al., 2021). When the aqueduct system will be completed, a new water source will supply Benevento City , never used in the past: the water of the Tammaro River. The advantage of this supply lies in the definitive independence on extra-regional water, as the Biferno springs are disputed by both the Naples urban area and Molise region, and should guarantee more stable water supplies during droughts. However, the quality of the dam water reservoir cannot be compared with that of karst springs. In this term, the advantage of this further changing of water supplies of Benevento is controversial.

The evolution and the future perspectives on the water supply of Benevento City show the precise requirement for drinking water and the difficulties related to the provision and management of water sources. In a framework of limited water resources, also related to climate change and groundwater pollution, water supply became an essential issue in city life. Therefore, sustainable management of ground and superficial waters is desirable, considering local water sources and applying serious management and protection policies of water sources. These latter should be linked to a sort of "adaption" of human activities in the local environmental setting, minimizing the anthropic impact and protecting the water sources from quantitative and qualitative degradation.

Acknowledgments

Authors are grateful to State Archives of Benevento Province, to Provincial Library of Benevento and to Cultural Association Benevento Longobarda for their support in literature researches. Special thanks have to be given to GESESA Aqueduct Company and Benevento municipality which provided technical data of current aqueduct systems, and Benevento province allowing surveys of Roman aqueduct ruins.

Competing interest

The authors declare no competing interests.

Author contributions

L.E. and F.F. carried out the bibliographical research, conceptualized and supervised the study; M.G., carried out field surveys and contributed to bibliographical research; G.L. contributed to field surveys, drawn GIS maps and took care image presentation.

All authors have read and agreed to the final version of the manuscript.

Additional information

DOI: https://doi.org/10.7343/as-2024-774

Reprint and permission information are available writing to acquesotterranee@anipapozzi.it

Publisher's note Associazione Acque Sotterranee remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

REFERENCES

Amato, V., Ciarcia, S., Rossi, A. & Santoriello, A. (2017) The urban geoarchaeology of Benevento, Southern Italy: evaluating archeological potential. Geoarchaeology, 2018; 33, 100-111. https://doi.org/10.1002/gea.21658

Bencardino, F. (1991) Benevento funzioni urbane e trasformazioni sociali tra XI e XX secolo *"Benevento urban functions and transformations societies between the 11th and 20th centuries"*. Edizioni Scientifiche Italiane.

Borgia, S. (1763) Memorie istoriche della pontificia città di Benevento. Roma *"Historical memories of the pontifical city of Benevento"*.

Borgia, S. (1763-1769) Memorie istoriche della pontificia città di Benevento dal secolo VIII al secolo XVIII divise in tre parti, raccolte ed illustrate da Stefano Borgia. Referendario dell'una, l'altra Segnatura, governatore della medesima *"Historical memoirs of the pontifical city of Benevento from the 8th century to the 18th century divided into three parts, collected and illustrated by Stefano Borgia. Referendary of one, the other Signature, governor of the same"*. Roma, dalle Stamperie del Salomoni.

Caruso, P. (2013) Antiqua Beneventana. La storia della Città romana attraverso la documentazione epigrafica *"Antiqua Beneventana. The history of the Roman city through epigraphic documentation"*. Edizioni "La Provincia Sannita".

Celico, P. (1978) Schema Idrogeologico dell'Appennino carbonatico Centro-Meridionale *"Hydrogeological scheme of the carbonate Apennines Central-Southern."*. Memorie e Note Istituto di Geologia Applicata, Napoli, Italy. Vol. 14, pp. 1-43.

Celico, P., Conte, F., Di Santo, A., Luise, G. & Piscopo, V. (1998) L'acquifero alluvionale della Piana di Benevento (Campania): un tipico esempio di serbatoio naturale di compenso a rischio inquinamento *"The alluvial aquifer of the Benevento Plain (Campania): a typical example of a natural reservoir of compensation at risk pollution"*. Quaderni di Geologia Applicata.

Chow V.T., Maidment D.R. & Mays L.W. (1988) Applied Hydrology, McGraw-Hil, New York.

Chow, V. T. (1959) Open-channel Hydraulics. McGraw-Hill, New York.

Civita, M. (1969a) Idrogeologia del Massiccio del Terminio-Tuoro (Campania) *"Hydrogeology of the Terminio-Tuoro Massif (Campania)"*. Memorie e Note Istituto Geologia Applicata: Napoli, Italy. Vol. 11, pp. 5-102.

Civita, M. (1969b) Valutazione analitica delle riserve in acque sotterranee alimentanti alcune tra le principali sorgenti del massiccio del Matese (Italia meridionale) *"Analytical evaluation of groundwater reserves feeding some of the main springs of the massif Matese (southern Italy)"*. Memorie della Società dei Naturalisti in Napoli, 78, 133-163.

Civita, M., De Masi, R., de Riso, R. & Vallario, A. (1970) Possibilità di rinvenimento di nuove fonti di approvvigionamento idrico nella media valle dell'Isclero e nella bassa valle del Calore (Campania) *"Possibility of finding new sources of water supply in the middle Isclero valley and in the lower Calore valley (Campania)"*. Estratto da Geologia Tecnica, rivista bimestrale tecnica e informativa, n. 6.

Civita, M., de Riso, R., Vallario, A. & De Masi, R. (1971) Idrogeologia del massiccio del Taburno-Camposauro *"Hydrogeology of the Taburno-Camposauro massif"*. Mem. Soc. Geol. It., 10, 65-120.

Collarile, M. (2023) Iside signora di Benevento *"Isis lady of Benevento"*. Edizioni Iorio.

Cristilli, A. (2006) L'acquedotto Romano di Pratola Serra (Avellino) *"The Roman aqueduct of Pratola Serra (Avellino)"*. Rendiconti dell'Accademia di Archeologia, Lettere e Belle Arti, Vol. LXXXIII, 2004-2005, p. 187

De Antonellis, G. (2008) Storia di Benevento *"History of Benevento"*. Benevento, Realtà Sannita.

De Feo, G., Malvano, C., De Gisi, S. & De Biase, O. (2009) The ancient aqueduct from Serino to Beneventum, in southern Italy: A Technical and Historical Approach. Proceedings CD of 2nd IWA International Symposium on Water and Wastewater Technologies in Ancient Technologies, Bari, Italy,

De Lucia, S. (1930) Fra Vincenzo Maria Orsini e le sue opere sociali *"Fra Vincenzo Maria Orsini and his social works"*. Samnium, Anno III, VIII, n. 2-3, 24-44.

De Nicastro, G. (1719) Memorie istoriche intorno alla corona regale usata dai serenissimi prencipi di Benevento longobarda *"Historical memories around the royal crown used by the most serene princes of Lombard Benevento"*, ms. [Benvento 1719], in Scritture di Storia Beneventana, Benevento, Biblioteca arcivescovile F. Pacca, fondo manoscritti, Storia di Benevento, ms. 7.

Del Prete, R. (2009) La città e i suoi fiumi. Il cammino delle acque beneventane nella storia della sua comunità (sec. XVII-XX) *"The city and its rivers. The path of the waters Benevento in the history of its community (17th-20th centuries)"*. Edizioni Il Chiostro.

Ente Idrico Campano (2021) Relazione Piano d'Ambito Regionale ai sensi dell'art. 149 del D.Lgs. 152/2006 e ss.mm.ii. ed art. 16 della L.R. Campania 15/2015 *"Regional Area Plan Report pursuant to art. 149 of Legislative Decree 152/2006 and subsequent amendments. and art. 16 of the L.R. Campania 15/2015"*. https://www.enteidricocampano.it/download/relazione-piano-dambito-regionale/

Esposito L. (2001) Delimitation "reasoned" of the areas of safeguard of the sources of the Serino (Avellino-Italy). Geologia Tecnica e Ambientale, 1/2001. [in Italian]

Esposito, L., Bruno, R., De Paola, P.A. & Aquino, S. (2005a) Hydrogeology and vulnerability of the alluvial aquifer of the Benevento Plain (Campania). Geologia Tecnica e Ambientale.

Esposito, L., Celico, P., Guadagno, F.M., Aquino, S. & De Paola, P. (2005b). Hydrogeology of Sannio. L'Acqua.

Fiorillo F., Petitta M., Preziosi E., Rusi S., Esposito L. & Tallini M. (2015) Long-term trend and fluctuations of karst spring discharge in a Mediterranean area (central-southern Italy). Environ Earth Sci 74, 153-172. https://doi.org/10.1007/s12665-014-3946-6

Fiorillo, F., Esposito, L. & Guadagno, F.M. (2007) Analyses and forecast of water resources in an ultra-centenarian spring discharges series from Serino (Southern Italy). Journal of Hydrology 336, 125-138.

Fiorillo, F., Esposito, L., Testa, G., Ciarcia, S. & Pagnozzi, M. (2018). The Upwelling Water Flux Feeding Springs: Hydrogeological and Hydraulic Features. In Water, 10, 501. https://doi.org/10.3390/w10040501

Fiorillo F., Leone G., Pagnozzi M., Catani V., Testa G. & Esposito L. (2019) The upwelling groundwater flow in the karst area of Grassano-Telese springs (southern Italy). Water, 11(5). https://doi.org/10.3390/w11050872.

Fragnito, A. & Grella, V.A. (2023) Il Ducato Longobardo di Benevento *"The Lombard Duchy of Benevento"*. Dall'Origo Gentis alla Divisio Ducatus. Delta 3 Edizioni.

Galanti, G.M. (1789) Della descrizione geografica e politica delle Sicilie *"Of the geographical and political description of Sicilies."*. Tomo Terzo. Presso i Soci del Gabinetto Letterario. Napoli.

Galasso, G. (1999) The Benevento amphitheater reappears. Archeo, n. 11, 14-15.

Galli, E. (1909) Cautano aqueduct for the city of Benevento: 5th project supplementary. Unpublished Technical Report

Gambardella, A. (1979) Architettura e committenza nello Stato Pontificio tra barocco e rococò *"Architecture and commissioning in the State Pontifical between Baroque and Rococo"*. Un amministratore illuminato: Giuseppe Renato Imperiali, Napoli, 1979.

Iasiello, I.M. (2007) Samnium: assetti e trasformazioni di una provincia tardoantica *"Samnium: structures and transformations of a province late antique"*. Edipuglia, p. 59.

Isernia, E. (1895) Istoria della città di Benevento, dalla sua origine fino al 1894 *"History of the city of Benevento, from its origins until 1894"*. Vol. 1-3. Benevento. Stabilimento Tipografico A. D'Alessandro e Figlio.

ISTAT (2023) Bilancio demografico mensile anno 2023 (dati provvisori) *"Monthly demographic balance for the year 2023 (provisional data)"*, su demo.istat.it, ISTAT, 18 dicembre 2023. URL consultato il 22 dicembre 2023.

Johannowsky, W. (1983) L'attività archeologica nella provincia di Salerno, Avellino e Benevento *"Archaeological activity in the province of Salerno, Avellino and Benevento"*. Pratola Serra. Atti del XXII Convegno di Studi sulla Magna Grecia, Taranto, p. 437.

Keenan-Jones, D., Motta, D., Garcia, M.H., Sivaguru, M., Perillo, M., Shosted, R.K., Fouke, B.W. (2022) Travertine crystal growth ripples record the hydraulic history of ancient Rome's Anio Novus aqueduct. Sicentific Reports, 12. https://doi.org/10.1038/s41598-022-05158-2

Leone, G., Catani, V., Pagnozzi, M., Ginolfi, M., Testa, L., Esposito, L. & Fiorillo, F. (2023) Hydrological features of Matese Karst Massif, focused on endorheic areas, dolines and hydroelectric exploitation. Journal of Maps, Vol. 19, 1. https://doi.org/10.1080/17445647.2022.2144497

Leone, G., Ginolfi, M., Esposito, L. & Fiorillo, F. (2024) Relationships between River and Groundwater Flow in an Alluvial Plain by Time Series Analysis and Numerical Modeling. Water Resources Management. https://doi.org/10.1007/s11269-024-03795-y

Magliulo, P., Bozzi, F., Leone, G., Fiorillo, F., Leone, N., Russo, F., & Valente, A. (2021) Channel adjustments over 140 years in response to extreme floods and land-use changing, Tammaro River, southern Italy. Geomorphology, 383, 107715. https://doi.org/10.1016/j-geomorph.2021.107715.

Mazarini, L. (1823) Mappa originale della città di Benevento *"Original map of the city of Benevento"*. Roma. Archivio di Stato.

Meomartini, A. (1889) The monuments and works of art of the city of Benevento. de Martini typography, Benevento."

Nobile, G. (1876) La conduttura dell'acqua potabile per la Città di Benevento *"The drinking water pipeline for the City of Benevento"*.

Parise, M., Marangella, A., Maranò, P., Sammarco, M. & Sannicola, G. (2013) Collecting transporting and storing water in karst settings of southern Italy: some lessons learned froma ancienti hydraulic systems. Water Science & technology, water supply, 13 (3). DOI: https://doi.org/10.2166/ws.2013.014

Peduto, A. (1992) S. Giovanni di Pratola Serra. Archeologia e storia nel ducato longobardo di Benevento *"S. Giovanni di Pratola Serra. Archeology and history in Lombard duchy of Benevento"*. Salerno.

Pescatori Colucci, G. (1996) L'acquedotto di Serino: Fontis Augustei Aquaeductus *"The Serino aqueduct: Fontis Augustei Aquaeductus"*. Storia Illustrata di Avellino e dell'Irpinia, I, Pratola Serra, 129-142.

Pezone, M.G. (2008) Carlo Buratti. Architettura tardo Barocca tra Roma e Napoli *"Carlo Buratti. Late Baroque architecture Rome and Naples"*. Alinea. Firenze 2008, 217-221.

Preziosi, G. (2001) L'acquedotto di Serino nella storia del territorio *"The Serino aqueduct in the history of the area"*. Atti del Convegno di Studi San Gemini, 18-20 ottobre 2000 Abbazia di San Niccolò.

Rea, R. (1978) L'acquedotto augusteo di Serino, Roma (tesi di laurea non pubblicata) *"The Augustan aqueduct of Serino, Rome (degree thesis not published)"*.

Rende, P. (20004) Storia ed Urbanistica della Benevento romana e medievale attraverso l'uso della fotografia aerea *"History and Urban Planning of Roman Benevento e medieval through the use of aerial photography"*. La Provincia KR, 21/2004.

Rotili, M. (1958) Benevento e la provincia sannitica *" "Benevento and the Samnite province"*. Roma.

Rotili, M. (1986) Benevento romana e longobarda *"Roman and Lombard Benevento"*. L'immagine urbana, Napoli-Ercolano, 91-62.

Senatore, M.R., Boscaino, M. & Pinto, F. (2019) The Quaternary geology of the Benevento urban area (southern Italy) for seismic microzonation purposes. Italian Journal of Geoscience, 138:66–87. https://doi.org/10.3301/IJG.2018.27

Sürmelihindi, G. & Passchier, C. (2023) Writ in water-Unwritten histories obtained from carbonate deposits in ancient water systems. Geoarchaeology, 39, 63–88. DOI: 10.1002/gea.21980

Tolle Kasteinbein, R. (1993) L'archeologia dell'acqua: la cultura idraulica del mondo classico *"The archeology of water: culture hydraulics of the classical world"*. Longanesi Ed., Milan.

Tomay, L. (2009) Benevento longobarda: dinamiche insediative e processi di trasformazione *"Lombard Benevento: settlement dynamics and transformation processes"*. In G. D'Henry & C. Lambert (Eds.), il popolo dei longobardi meridionali (576-1076): Testimonianze storiche e monumentali (pp. 119-151). Salerno: Gruppo Archeologico Salernitano.

Torelli, M.R. (2002) Benevento romana, Roma *"Roman Benevento, Roma"*. L'Erma di Bretschneider.

Zazo, A. (1977) L'acquedotto del Serino e una vertenza fra Napoli e Benevento nel XVI secolo *"The Serino aqueduct and a dispute between Naples and Benevento in the 16th century"*. Samnium, Anno L, n. 3-4, 124-133.

Zazo, A. (1980) L'acquedotto settecentesco di Benevento e le rimostranze dell'architetto romano Carlo Buratti *"The eighteenth-century aqueduct of Benevento and the grievances by the Roman architect Carlo Buratti"*, Samnium, Anno LIII, 1980, 137-151.

Zigarelli, D.M. (1979) Storia di Benevento *"History of Benevento"*. Bologna