

# 20 Years of the project “The map of ancient underground aqueducts in Italy”, and future perspectives

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## Abstract

The Project “The Map of Ancient Underground Aqueducts in Italy”, was launched in 2003 by the Commission on Artificial Cavities of the Italian Speleological Society (SSI). The main aim of the project is the collection of all available data about underground waterworks in Italy, from both direct explorations and bibliographic information, in order to implement a detailed inventory of these unique works of historical and hydraulic engineering importance. All the data have been stored in digital spreadsheets implemented in Microsoft Excel, obeying to two spatial and temporal minimum requirements for considering a feature as suitable for its inclusion in the database: a minimum length of 400 m and a construction time no more recent than the XVIII Century CE. The last updates of the database were presented at the International Congress of Speleology in Artificial Cavities “Hypogea2015”, held in Rome on March 2015, with 140 records populating it. A retrospective analysis of the information stored in the database, and the recent advances in the information technology applied to the management and public dissemination of georeferenced data, have suggested the need of some changes to both the criteria for populating the database and its structure. The minimum length for inclusion in the database diminishes from 400 m to 200 m, with the aim of making this repository more dynamic and inclusive, also for hydraulic works of minor length but of particular significance or of local importance. The minimum age is postponed to the XIX Century CE, for including waterworks dating at the beginning of the technological era, but still constructed without the help of construction machineries. Information associated to waterworks will include hydraulic and water chemical data (if available), for re-considering these features not only as a valuable cultural and environmental heritage, but as facility managements that could still work as sustainable water supply systems. Given the intrinsic geospatial nature of the descriptive attributes associated to these features, the data structure will be converted from an alphanumeric database to a geodatabase, implemented in the freeware Qgis, presently the most used open-source GIS software. Excel spreadsheets will be transformed in an attribute table associated to spatial entities representing the aqueducts, using topologies (points, lines, polygons) that will allow to perform effective spatial queries for getting information from the geodatabase. Particular care will be taken in the transformation from the graphic to the geographic space of maps and schemes associated to the datasheets. We will promote research agreements with universities and public research agencies, which will be involved under the general coordination of SSI in the implementation of the ancient underground aqueducts’ geodatabase and its dissemination to both stakeholders (cavers, academic and public administrations) and the general public.

*Keywords:* Artificial cavities, cultural heritage, geodatabase, GIS, hydraulic works, water resources.

## Introduction

Since ancient time, the availability of water has been mandatory for the settlement of stably inhabited areas. This prompted the National Commission on Artificial Cavities of the Italian Speleological Society (SSI), given the remarkable amount of ancient hydraulic works sited in Italy, to start in the year 2003 the Project “The Map of Ancient Underground Aqueducts in Italy”.

Ancient aqueducts, often well preserved or still in operation nowadays, are not only valuable archaeological records of historical engineering techniques but, in some cases, they presently are, or could be in the next future after modest interventions, parts of state-of-

the-art water supply systems commonly used (Mays, 2010; Angelakis *et al.*, 2016; Valipour *et al.*, 2020).

The main aims of the project consist in creating and feeding a detailed repository of the ancient aqueducts in Italy, and of their related literature, encouraging new studies and explorations, promoting their safeguard and possible sustainable exploitation.

Due to the huge number of ancient hydraulic works in Italy, two minimum requirements were selected for the initial population of the database: a construction time not younger than the XVIII Century CE and an overall length not lower than 400 m.

About the time requirement, three different periods were adopted for their classification: i) Greek – Roman age (until the 6<sup>th</sup> century CE); ii) Byzantine – Mediae-

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val age (7<sup>th</sup> – 14<sup>th</sup> century CE); iii) Renaissance – Modern age (15<sup>th</sup> – 18<sup>th</sup> century CE).

A specific data sheet was created for resuming the main descriptive data of the classified ancient aqueducts, subdivided in three sections: 1) General data, including name, location, length, availability of plans and sections, present state of the structure and possible interventions needed for its re-use, reference bibliography; 2) Technical data, including hydro-geological information and the utilization history of the aqueducts; 3) Personal data, reporting contact details of the compiler.

First results of the project were published in a special issue of the journal *Opera Ipogea* in 2007 (Parise, 2007a, 2007b), followed by several titles about advances of both repository and related literature list (Parise, 2009, 2012; Parise *et al.*, 2009, 2013a, 2013b, 2015).

In the present paper we first present the state of the

art of the project, followed by indications about its future perspectives and advances, and related criticalities, with a specific focus on possible changes of the minimum requirements for introducing new items in the database, its transformation in a geodatabase implemented in a GIS environment, and some suggestions about the involvement of other entities in its future developments.

### State of the art of the project

A critical revision of the database, previously containing about 140 entries (Parise *et al.*, 2015), led to the withdrawal of some of them, which cannot be considered properly as aqueducts. Following the revision, the database contains now 123 records, about two third of which (82) located in central-southern Italy regions: 60 in Lazio, 12 in Apulia and 10 in Campania (fig. 1a).

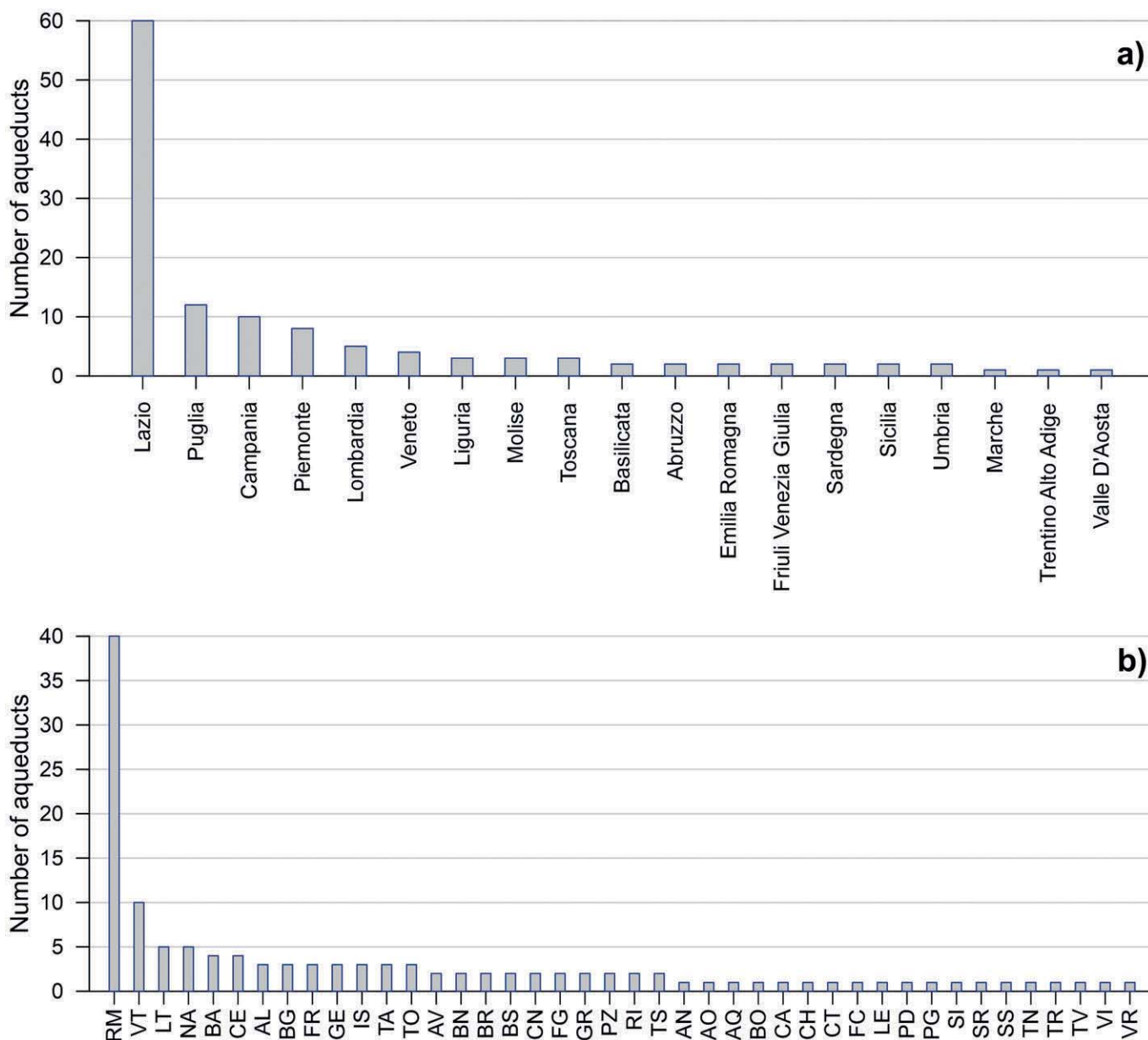


Fig. 1 – Bar chart illustrating the number of old aqueducts of Italy grouped for regions (a) and provinces (b) (graphics P. Madonia).

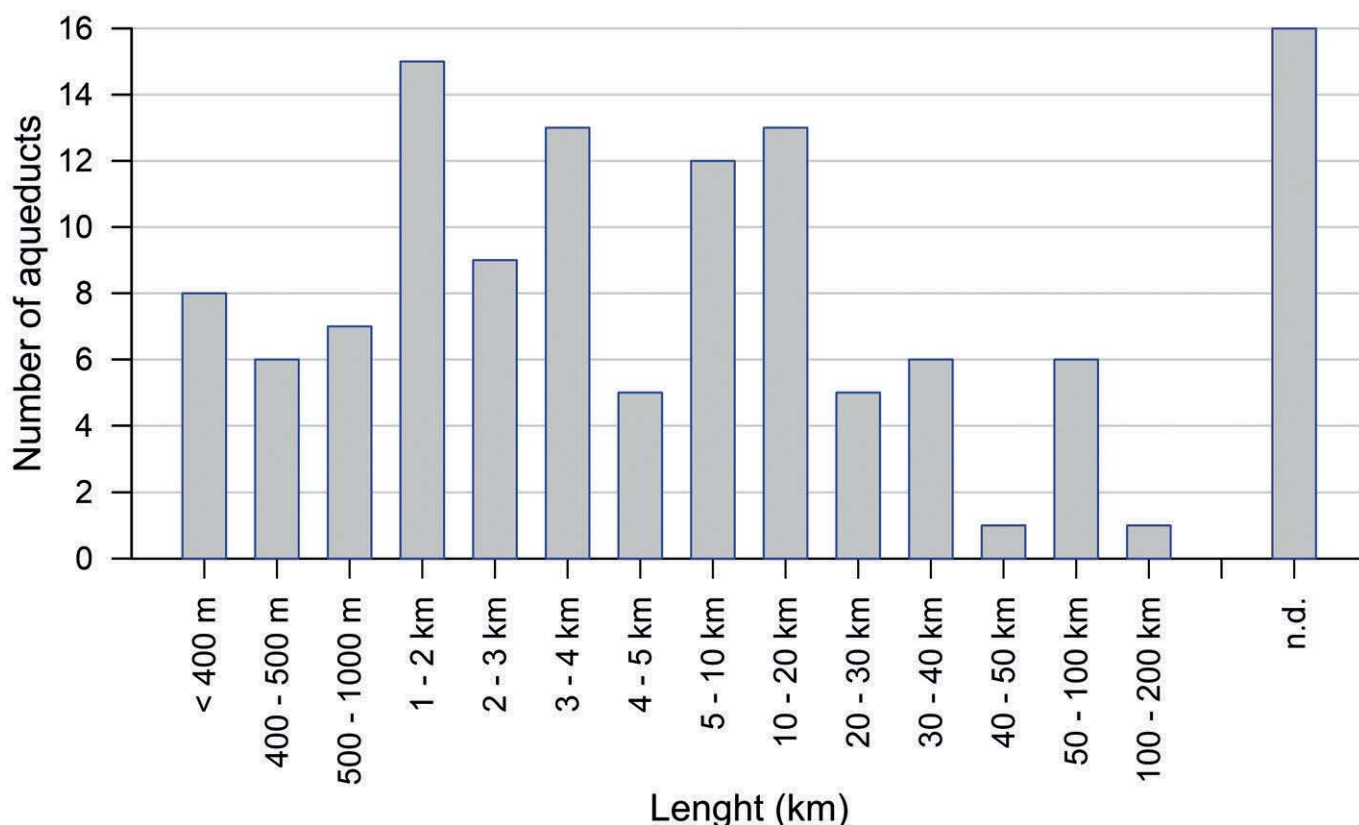


Fig. 2 – Histogram reporting the frequency of old aqueducts of Italy for length classes; n.d. is not determined (graphics P. Madonia).

The other 41 are distributed all over Italy, with only one region (Calabria) where no features are reported. Two aqueducts are trans-regional: the Montemilone aqueduct, running through Apulia and Basilicata, and the Libarna aqueduct, between Liguria and Piemonte. The subdivision by provinces is illustrated in fig. 1b: half of them is concentrated in the provinces of Roma (40), Viterbo (10), Latina (5) and Napoli (5).

About lengths (fig. 2), most of the aqueducts exhibit values comprised between 1 and 20 km, 8 have lengths <400 m, the minimum requirement below which only features of particular interest are considered, and 7 are longer than 50 km, with one feature exceeding 100 km: the Claudio aqueduct in Campania, running through the provinces of Avellino and Napoli for 170 km. For 16 of them, no information about length is contained in the related forms.

About 80% of the classified ancient water works date at the Greek–Roman period (fig.3), followed by aqueducts built during the Renaissance–Modern age (about 17%); only few features (1.6%) were realized in the intermediate Byzantine–Mediaeval period.

As expected, information about the lithological nature of both the water sources feeding the aqueducts and the terrains they cross is much more fragmentary and incomplete (fig. 4): less than a half of the entries contains this information. Volcanic rocks and carbonates, here including limestones, dolostones and travertines, show similar percentages and include the majority of the aqueducts (50–60%). Alluvial deposits, conglomerates, sandstones and flysch characterize the rest of the features. It is worth to note the difference in the percentages of mixed lithologies between source areas and paths, equal to 2.4 and 8.9, respectively: while

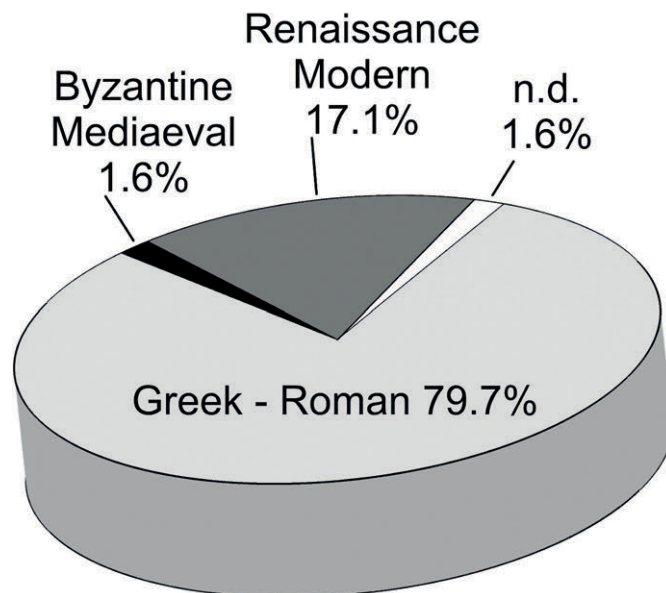


Fig. 3 – Pie chart reporting the relative distribution (%) for ages of the old aqueducts of Italy; n.d. is not determined (graphics P. Madonia).

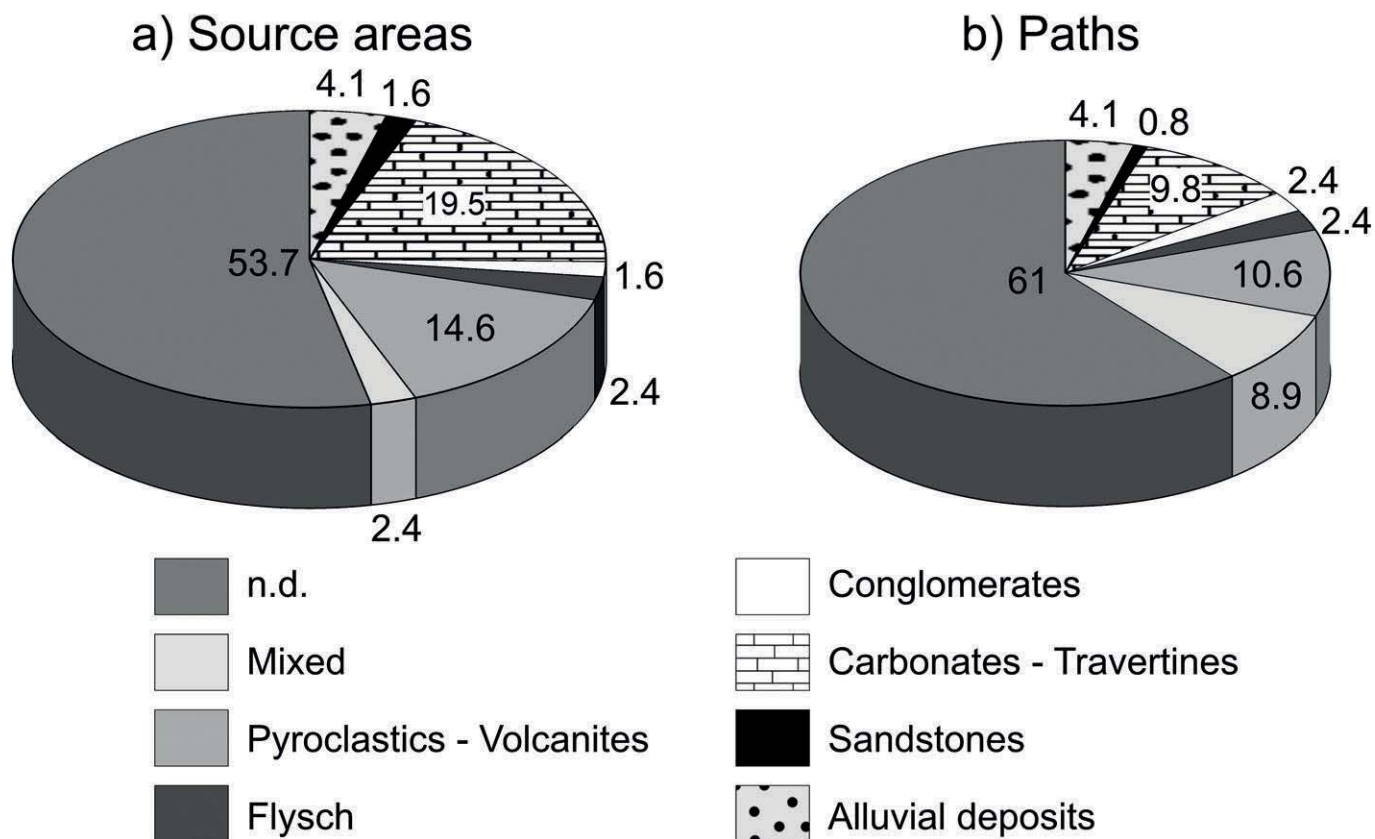


Fig. 4 – Pie charts illustrating the relative distribution (%) for lithological character of the source areas (a) and paths (b) of the old aqueducts of Italy; n.d. is not determined (graphics P. Madonia).

source areas have a limited areal extension, the higher is the overall length of an aqueduct, the higher the probability of crossing terrains of different geological nature, thus justifying the observed differences in the reported percentages.

### Future perspectives and criticalities

The analysis of the data presently contained in the old aqueducts database of Italy suggests some changes to be possibly introduced, for both maintaining the vitality of the project and valorising the intrinsic geographic nature of most of the information here contained. Although in an initial phase it was necessary introducing a minimum length (400 m) for listing an aqueduct in the database, due to the huge number of these features present in Italy, this requirement could represent now, in a more mature phase, an obstacle for its future development. A possible solution is halving the length requirement, from 400 to 200 m, but leaving researchers and explorers of the underground environment free of proposing the cataloguing of any features of particular interest, aside of its length. Special cases could encompass aqueducts located in regions scarcely represented in the database, built adopting peculiar construction techniques, located in particular geological settings, of high historic relevance or presently exploited for important anthropic uses.

Another change could concern the minimum age requirements: it could be expanded to the 1930s, providing that they were built without the use of construction machineries. A 4<sup>th</sup> age could be thus introduced, referred as the “Early technological age (1800–1939)”.

Last but not least, the transformation from a classical alphanumeric database to a geodatabase represents the main possible evolution of the project. Given the intrinsic geospatial nature of the descriptive attributes associated to these features, the data structure could be converted to a geodatabase in the ESRI shapefile format, considered as a standard for geographical information accepted worldwide. Such a data structure should be managed with a freeware like Qgis, presently the most used open-source GIS software. Excel spreadsheets will be transformed in an attribute table associated to spatial entities representing the aqueducts, using topologies (points, lines, polygons) that will allow to perform effective spatial queries for getting information from the geodatabase, as well as generating new information by overlying the old aqueducts’ maps with other thematic cartographic products.

Looking at the informative content of the old aqueduct records, only few fields, as name or age, are not of geospatial nature. All the others, as regions, provinces, cities related to a waterwork, as well as its length, geological nature, and so on, can be borrowed from other maps or auto calculated within the digitizing

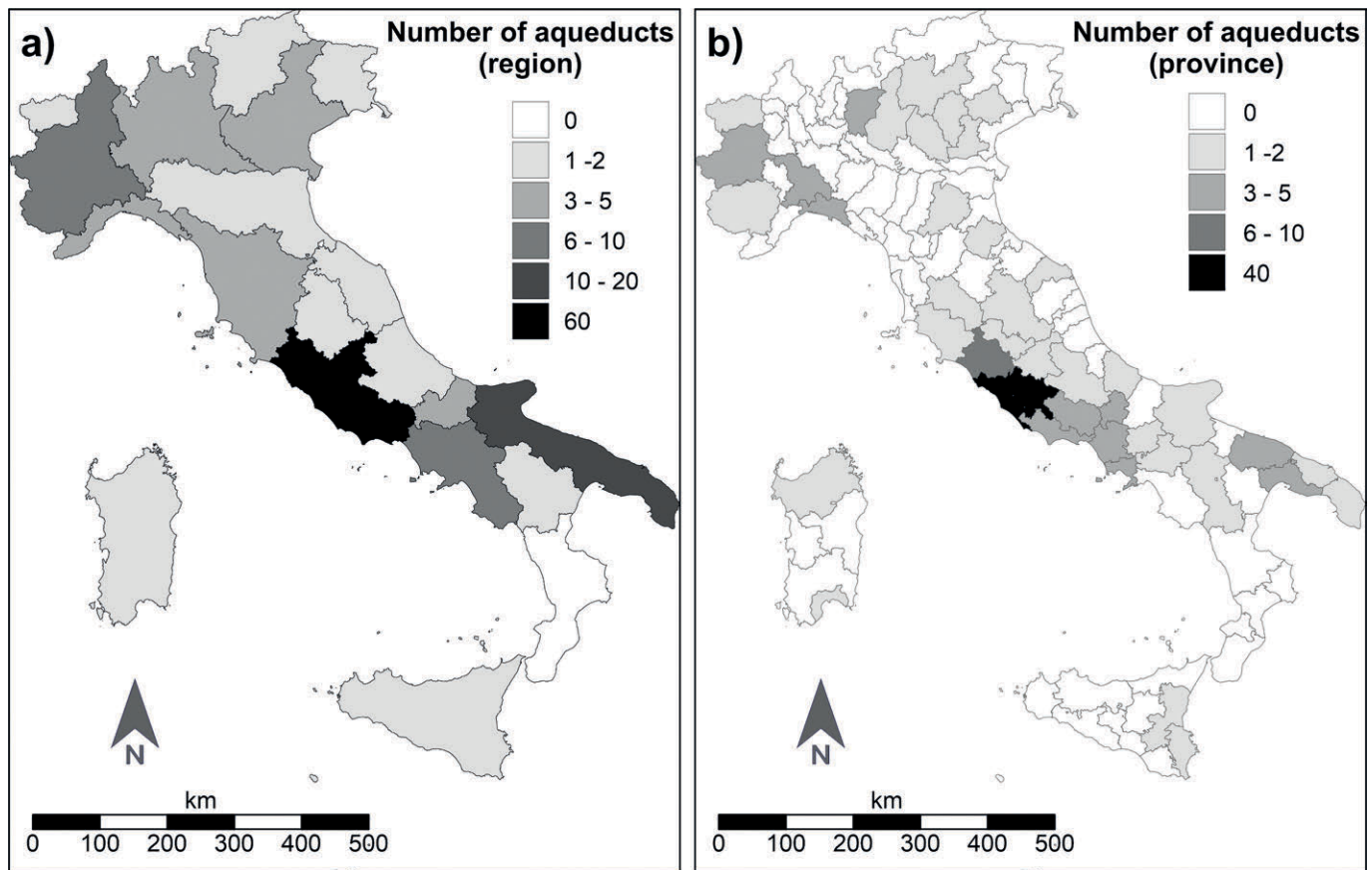


Fig. 5 – Maps illustrating the number of old aqueducts of Italy grouped for regions (a) and provinces (b). Region and province boundaries are from the Italian Institute for Statistics (ISTAT) (graphics P. Madonia).

process (length). A basic example is the distribution for regions and provinces, given by classical graphs in fig. 1, and here reposed as thematic maps based on the ISTAT shapefiles containing their boundaries (fig. 5). It is evident that associating a modulus (the number of features) to its geographic location and shape (georeferenced polygons representing regions and provinces) improves the readability and the informative content itself. It is worth to note the effect of the spatial resolution on data representation: if the number of aqueducts is associated to region boundaries, the whole Italy, with the exception of Calabria, seems hosting these features (fig. 5a). If the same parameter is associated to more spatially resolved entities, as province boundaries (fig. 5b), the depicted scenery reveals the clustering of features in preferential areas, driven by factors as local orographic and geologi-

cal settings, geographic distribution of ancient settlements or, more simply, the location of active artificial cavity research groups, which preferentially explore sites close to them.

Particular care should be taken in the transformation from the graphic to the geographic space of maps and schemes associated to the datasheets, because georeferencing errors will result in critical issues when overlying with other thematic maps, from which erroneous information will be retrieved.

Finally, research agreements with universities and public research agencies, which could be involved under the general coordination of SSI, could boost the implementation of the ancient underground aqueducts' geodatabase and its dissemination to both specific stakeholders (cavers, academic and public administrations) and the general public.

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