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The survey of Italian springs by the National Hydrographic Service, a forgotten database. Structuring and analysis of a dataset of Campania springs (southern Italy)

Il censimento delle sorgenti italiane del Servizio Idrografico, un database dimenticato. Strutturazione e analisi del dataset delle sorgenti della Campania (Italia meridionale)

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Riassunto

L'analisi delle risorse idriche sotterranee è un aspetto particolarmente significativo per lo sviluppo economico, sociale ed ambientale del territorio nazionale. Ciò è particolarmente importante per la Campania che, sebbene caratterizzata dai sistemi acquiferi più rilevanti dell'Italia meridionale, soffre di criticità connesse al progressivo incremento della domanda ed alle variazioni climatiche a varie scale temporali. In tale contesto, la carenza di dati riguardanti il censimento delle sorgenti, anche minori, e di misure storiche di portata rappresenta il principale limite ad una più ampia caratterizzazione idrogeologica del territorio. L'unica fonte di dati storici riguardante il censimento e la misura delle portate delle sorgenti sistematici è rappresentata dalla Pubblicazione N. 14 del Servizio Idrografico del Ministero dei Lavori Pubblici "Le sorgenti italiane. Elenco e descrizione", pubblicata in volumi distinti per ciascun compartimento e riferita a rilievi effettuati tra gli anni 1920s e 1940s del secolo scorso. Tuttavia, tale fonte è stata finora poco utilizzata negli studi idrogeologici regionali.

Nel presente lavoro è stato effettuato, per la Campania, uno studio comparativo tra i dati delle sorgenti della Pubblicazione N. 14 e quelli derivati da campagne di misura, eseguite tra gli anni 1960s e 1980s del secolo scorso dalla Cassa per il Mezzogiorno sulle principali sorgenti (Progetto Speciale 26). Le informazioni disponibili per ciascuna sorgente sono state validate attraverso un controllo incrociato tra le fonti, basato su un confronto tra le coordinate ed un'analisi statistica dei parametri caratterizzanti. Il nuovo dataset ha consentito di ampliare l'analisi idrogeologica regionale con un numero più ampio di sorgenti, comprensivo anche di quelle minori. I risultati ottenuti evidenziano la Pubblicazione N. 14 del Servizio Idrografico come un'importante fonte di dati da non trascurare, soprattutto nel contesto di scarsità di dati storici, dalla quale sono possibili analisi idrogeologiche regionali e di evoluzione temporale nonché l'identificazione di risorse idriche integrative.

Abstract

The analysis of groundwater resources is a particularly significant aspect of the economic, social and environmental development of the national territory. This is particularly relevant for the Campania region which, although characterized by the most significant aquifer systems of southern Italy, suffers from critical issues related to the progressive increase in demand and climatic variability at different time scales. In this framework, the lack of data concerning the survey of springs, including the minor ones, and of historical discharge measurements represents the main limitation to a more comprehensive regional hydrogeological characterization. The only source of historical data regarding the systematic and comprehensive survey of springs and discharge measurement is the Publication No. 14 of the National Hydrographic Service of the Ministry of Public Works "The Italian springs. List and description" reporting measures made between the 1920s and 1940s which was published in distinct volumes for each compartment. Despite its potential relevance, this source has so far been little used in regional hydrogeological studies.

In this paper, a comparative analysis among data of springs derived from the Publication No. 14 and from measurement campaigns made by the Cassa per il Mezzogiorno (Special Project 26), between the 1960s and 1980s for main springs, was carried out for the Campania region. The information available from each source was validated through a cross-check, by means of a comparison of coordinates and a statistical analysis of the characterizing parameters. The new dataset allowed to expand the hydrogeological regional characterization with a higher number of springs, including the minor ones. The results obtained recognize the Publication No. 14 of the National Hydrographic Service as an important source of data to not be overlooked, especially in a condition of historical data shortage, by which can be both carried out regional hydrogeological and temporal analyses as well as identified integrative groundwater resources.

Introduction

In many hydrogeological environments, management of groundwater resources is to be based on reliable hydrological historical data and time series comprising precipitations, spring discharges and piezometric levels. Specifically, in hilly and mountainous areas, not provided by wells, the regime of groundwater circulation is understandable only by springs surveys and discharge measurements. Although spatial distribution of aquifer characteristics such as hydraulic conductivity might be unavailable, temporal variations in springs discharge (Mangin 1974; Leonardi et al. 1996; Angelini 1997; Manga 1999) and temperature (Bundschuh 1993) can be used to characterize groundwater systems. Different tools are known in literature for the analysis of spring discharge regime and groundwater flow in aquifers. Numerical models, which represent one of most important predictive tools, were specifically developed in porous aquifers being their applicability not always feasible in karst aquifers due to the discontinuity and heterogeneity of the medium (Scanlon et al. 2003). Nevertheless, several empirical and statistical methods, such as input-output models, spectral analysis (Mangin 1974) and time series analysis (Ford and Williams 1989) were proposed to characterize and simulate variability of spring discharge.

Consequently, a comprehensive survey of springs, even including the minor ones, provided with occasional or systematic discharge measurements, is fundamental for the hydrogeological characterization of a region as well as for prospecting temporal evolution of hydrogeological systems. In Italy, the only systematic and comprehensive survey of springs was carried out in the first decades of the last century (1920s – 1940s), by the National Hydrographic Service of the Ministry of Public Works (Servizio Idrografico del Consiglio Superiore dei Lavori Pubblici), a technical government agency, and published in the Publication No. 14 "The Italian springs. List and description" consisting in a series of volumes, for each regional compartment. The survey of springs started at the beginning of 1920s with the purpose of collecting data by means of simple but systematic methods based on field surveys, measurements and writing of technical reports. After this initial comprehensive survey, only between 1960s and 1980s there were carried out other surveys and measurement campaigns. These were limited to the major springs because aimed at their tapping for the supplying of regional aqueduct systems. Therefore, wide-ranging information on springs and long-lasting time series are currently lacking in Italy, except for very few cases (De Vita et al. 2012). This issue appears even more relevant if considering the current need to assess effects of climate changes on groundwater regime and to identify integrative groundwater resources involving minor springs not tapped yet.

In such a framework, the retrieval of the first and comprehensive survey of springs published by the National Hydrographic Service represents a valuable possibility to be not disregarded. So far, this spring database has not been considered in regional studies due to the not easy usage of data contained in Publication No. 14, which is available in printed and digitally scanned versions only. Moreover, the disregarding of this database has been partly due also to the alleged unreliability of the outdated methods of measurements.

In this paper, we propose the possible use of spring data of Publication No. 14 by a validation based on the comparison with data collected by more recent surveys carried out between 1960s and 1980s. The study area chosen is the Campania region (southern Italy), which is characterized by a high availability of groundwater resources. After the validation, data of Publication No. 14 were used for a comprehensive statistical analysis of hydrogeological features of principal regional hydrostratigraphic units. Hereinafter we name the two datasets A and B, respectively.

Geological and hydrogeological settings of the Campania region

The Campania region, extending over about 14,000 km^2, comprises a complex geological and hydrogeological framework resulting from geodynamic events related to the formation of the southern Apennines, whose structure is characterized by the compressive tectonic superposition of several thrust sheets made up of sedimentary series existing in the Tethys paleo-ocean from Mesozoic to Cenozoic. These were formed by deep basin terrigenous series and shallow-water carbonate platform series (Vitale and Ciarcia 2018). After the formation, during the Pliocene and Quaternary, the Apennine Chain was dissected by Quaternary extensional tectonic phases, which formed the semi-graben structures along the Tyrrhenian side. In the same period an intense back-arc volcanic activity began with Vulture, Roccamonfina, Ischia Island, Phlaegraean Fields and Somma-Vesuvius volcanic centres.

According to the geological and structural complexity of the Campania region, four principal hydrogeological domains can be identified (De Vita et al. 2018; Tufano et al. 2020), which can be listed below considering their decreasing relevance in supplying regional aqueduct systems: (a) Mesozoic-Cenozoic carbonate platform series, (b) Pliocene-Quaternary alluvial and epiclastic deposits, (c) Quaternary volcanic deposits and (d) Paleogene-Neogene terrigenous series.

The (a) group consists of limestone and subordinately dolomite aquifers, which are characterized by high and medium permeability grade respectively and host the most important groundwater regional aquifers. Moreover, they form the highest mountain ranges of the region. Knowledge about hydrogeological behavior of these aquifers in southern Italy has strongly advanced between the 1960s and 1980s due to the Special Projects 26 and 29, carried out by the Cassa per il Mezzogiorno (Celico 1983), a governmental agency in charge of economical developing of the territory by the design and construction of new infrastructures and aqueduct systems. The key hydrogeological aspects of this conceptual model, different from other conceptual models found in the literature (Mangin 1974; Kiraly 1975; Drogue 1971), are: a) each aquifer hosts a groundwater body well confined by terrigenous deposits with low permeability; b) the main groundwater circulation is basal outflowing from huge basal springs (average discharge up to 5,5 m^3 s^{-1}) and/or seeping through adjoining alluvial aquifers; c) perched groundwater flow also occurs in the surficial part of carbonate aquifers, where the different thickness and hydraulic characteristics of the epikarst, as well as stratigraphic structural factors and/or the presence of karst conduits, can generate high-altitude seasonal/temporary springs, characterized by low flow (generally with an average discharge < 0,10 m^3 s^{-1}). An important role in the basal groundwater circulation is played by the tectonic structures, such as fault and thrust zones, that can behave as impervious barriers or low-flow boundaries (Celico 1983; Petrella et al. 2015; De Vita et al. 2018). The high productivity of karst aquifers is due to the high permeability of the karst rocks, the occurrence of large summit endorheic zones (Manna et al. 2013; Allocca et al. 2014) and the existence of a "soil-vegetation" surficial system, acting as a temporary water storage tank which controls groundwater recharge of the underlying carbonate aquifer.

The alluvial and epiclastic aquifers (group b), formed by clastic deposits of talus, alluvial and coastal plains, are heterogeneous and anisotropic and their permeability is due to primary porosity (De Vita et al. 2018). The peculiarity of these aquifers is the shallowness of water table which has favored the intense overexploitation by wells for agricultural and industrial uses (Coda et al. 2019; Allocca et al. 2021). The widespread cultivation practices coupled with the high anthropogenic pressure, make the (b) group highly vulnerable to pollution (Cusano et al. 2019; Fusco et al. 2020).

The volcanic hydrostratigraphic units of Campania (group c) are formed by deposits of the main eruptive centers (Roccamonfina, Ischia Island, Phlegraean Fields and Somma Vesuvius volcanoes), developed along the Thyrrhenian side during the Quaternary. The peculiar properties, including not-ordinary temperature and high concentration in CO_2, make groundwater circulating in these hydrostratigraphic units very important for their thermal uses (Celico et al.1992; Celico et al.1998).

The last group (d) consists of hydrostratigraphic units with minor hydrogeological relevance, that are formed by basin and turbidite terrigenous series, varying from sandstone to calcarenite interbedded with mudrock (De Vita et al. 2018).

The climate of the study region varies from Mediterranean type (Csa) in the coastal sector to Mediterranean mild climate (Csb) in the inland areas (Geiger 1954). Mean annual air temperatures are in the range of approximately 10–12°C in the mountainous interior, 13–15°C in the coastal areas, and 12–13°C in alluvial plains surrounded by carbonate mountains. According to the location of the Apennine chain, higher orographic precipitation occurs in the western sector, with maximum values up to 1,700–2,000 mm along the Apennine ridge itself. Eastward of the Apennine ridge, lower precipitations down to 700–900 mm are recorded because of the rain shadow effect (Allocca et al. 2014). As typical of the Mediterranean climate, on average precipitations are concentrated during autumn and winter seasons with a principal peak in November and a progressive decrease during spring season, till the minimum value in July. Snow typically occurs only during the coldest months (December-February) with a duration of its cover limited to few weeks in the highest altitudes (above 1,000 m a.s.l.).

Materials and Methods

On behalf of the Presidency of the 3rd section of the Higher Council of Public Works (Consiglio Superiore dei Lavori Pubblici), the National Hydrographic Service (Servizio Idrografico) carried out in the period across the 1920s and 1940s the systematic and comprehensive survey of springs for each compartment in which the national territory was subdivided (Fig. 1). The survey comprised all significant springs, with a minimum discharge variable from 0,1 to 0,5 l s^{-1}, depending on technical decisions made by each compartment. Results of the survey were published in the Special Publication No. 14 of the National Hydrographic Service "The Italian springs. List and description" (Servizio Idrografico 1942), issued in distinct volumes for each compartment.

The work began at the beginning of the 1920s and was executed until the 1940s by field campaigns and production of technical reports comprising altitude, discharge, temperature, geographical coordinates and other observations regarding

Fig. 1 - Compartments of the National Hydrographic Service (Ministry of Public Works) (https://www.isprambiente.gov.it/it/progetti/cartella-progetti-in-corso/acque-interne-e-marino-costiere-1/progetti-conclusi/progetto-annali/inquadramento-storico-del-monitoraggio-idro-meteografico-e-delle-relative-competenze).

Fig. 1 - Compartimenti del Servizio Idrografico Nazionale (Ministero dei Lavori Pubblici) (https://www.isprambiente.gov.it/it/progetti/cartella-progetti-in-corso/acque-interne-e-marino-costiere-1/progetti-conclusi/progetto-annali/inquadramento-storico-del-monitoraggio-idro-meteografico-e-delle-relative-competenze).

use and description of the outflow area. Data were collected with measuring instruments consisting in calibrated vessels, chronometers, altimeters, flow meters (weirs), thermometers and cameras. Field activities were carried out under the support of local municipal authorities and experts in charge of examining results of the survey and filing special reports signed by all people participating. Subsequently, technicians employed for each compartmental office developed, validated and filed field data in a final form which was published in the Special Publication No. 14. Moreover, a series of orographic maps at 1:250,000 scale reporting location of springs were included in the Publication No. 14.

We analysed data of the Naples' compartment (Fig. 1) extending over about 19,340 km² and including the whole Campania region and significant parts of Lazio, Abruzzo and Molise regions as well as Campanian island and Pontine archipelagos (Servizio Idrografico 1942). The survey activity in the Naples' compartment involved 700 municipalities, recognizing 9,538 springs with a discharge higher than 0,5 l s^{-1} and carrying out more than 10,000 discharge measurements. Specifically, in this paper a subset of 2,082 springs belonging to the Campania region was analysed. Among springs surveyed there were also several used for thermal and mineral purposes. The database of Special Publication N. 14 reports the following data for each spring: hydrographic basin, denomination, municipality, province, geographic coordinates (Gauss Boaga), discharge (l s^{-1}), altitude (m a.s.l.), temperature (°C) and information about the use.

Due to the problematic Optical Character Recognition (OCR) of the digital scanned version, related the complex graphical format, data of springs of the Campania region were manually digitized and arranged in a relational database (dataset A), subdivided into the following fields: 1) Spring ID; 2) Spring name; 3) Spring coordinates (geographic format, with reference to Monte Mario meridian); 4) Province (Tab. 1); 5) Municipality; 6) Administrative localization; 7) Altitude (m a.s.l.); 8) Discharge (l s^{-1}); 9) Temperature (°C); 10) Use.

Moreover, by the plotting of coordinates on a regional hydrogeological map (scale 1:250,000) (De Vita et al. 2018), a further field consisting in the hydrostratigraphic unit, to which each spring belongs, was added.

Tab. 1 - Springs of Campania region known by the Publication No. 14, subdivided by province.

Tab. 1 - Sorgenti della Campania note dalla pubblicazione speciale N. 14, suddivise per provincia.

Province	Number of springs
Napoli	203
Salerno	1,005
Benevento	402
Avellino	467
Caserta	5
Total	2,082

Analyses carried out for the Campania region were firstly focused on the comparison of data of the same major springs reported both in the Special Publication No. 14 (dataset A) and in successive field surveys carried out across the 1960s and 1980s by the Cassa per il Mezzogiorno (Special Project 26) (dataset B) for the design of tapping works. The latter were previously collected and validated in the framework of INTERREG IIC project (Allocca et al. 2007; De Vita et al. 2018) by an accurate check of coordinates on I.G.M.I. topographic maps 1:25,000 scale (I.G.M.I. 1996). From the intersection of the two datasets, a third comprising 115 common springs was considered for comparative analyses.

In order to verify the correct geolocalization of springs reported in the dataset A, firstly their coordinates were compared with those of datasets B by the conversion in the UTM WGS 84 reference system (Zone 33N – EPGS 32633) and the implementation of data in a GIS platform. Such a comparison appeared the most important aspect because dealing with the consequent possible use of dataset A. Finally, data of all 2,082 springs of dataset A were used to characterize comprehensively hydrostratigraphic units of the Campania region (Fig. 2).

Results

Validation of the Special Publication No. 14 dataset of springs for Campania region

The springs mutually corresponding in A and B datasets were compared with the purpose of assessing the reliability of the coordinates reported in the Special Publication No. 14 (Servizio Idrografico 1942). 115 springs, which were filtered out by their name and administrative localization, were found mutually corresponding in both datasets reconstructed for the Campania region. The error in coordinates was estimated as the planimetric distance, called planimetric error, between coordinates of springs belonging to the dataset A and those of the corresponding spring belonging to the dataset B. Planimetric error was estimated by the composition of longitude and latitude errors (Fig. 3).

Results obtained by the calculation of planimetric error show a fair overlapping between springs belonging to the two datasets A and B (Fig. 3a). Specifically, both the longitude and latitude errors of the same spring belonging to two datasets are included within a range of 500-1,000 m. A frequency analysis of planimetric errors between corresponding springs of the two datasets was carried out (Fig. 3b) showing that in 31%, 47%, 68% and 82% of cases, the planimetric error is less than 200 m, 400 m, 600 m and 800 m, respectively. By this analysis, it is also possible to identify some cases with major planimetric errors (outliers) such ad for Pretalanno spring, located in Padula municipality (Salerno province) with latitude and longitude errors of – 2,783 m and – 543 m, respectively, and for Aquara spring (Avellino province), with longitude and latitude errors of 266 m and 2,437 m, respectively.

Given the analysis of the error on coordinates between datasets A and B, the association of springs of the dataset A to

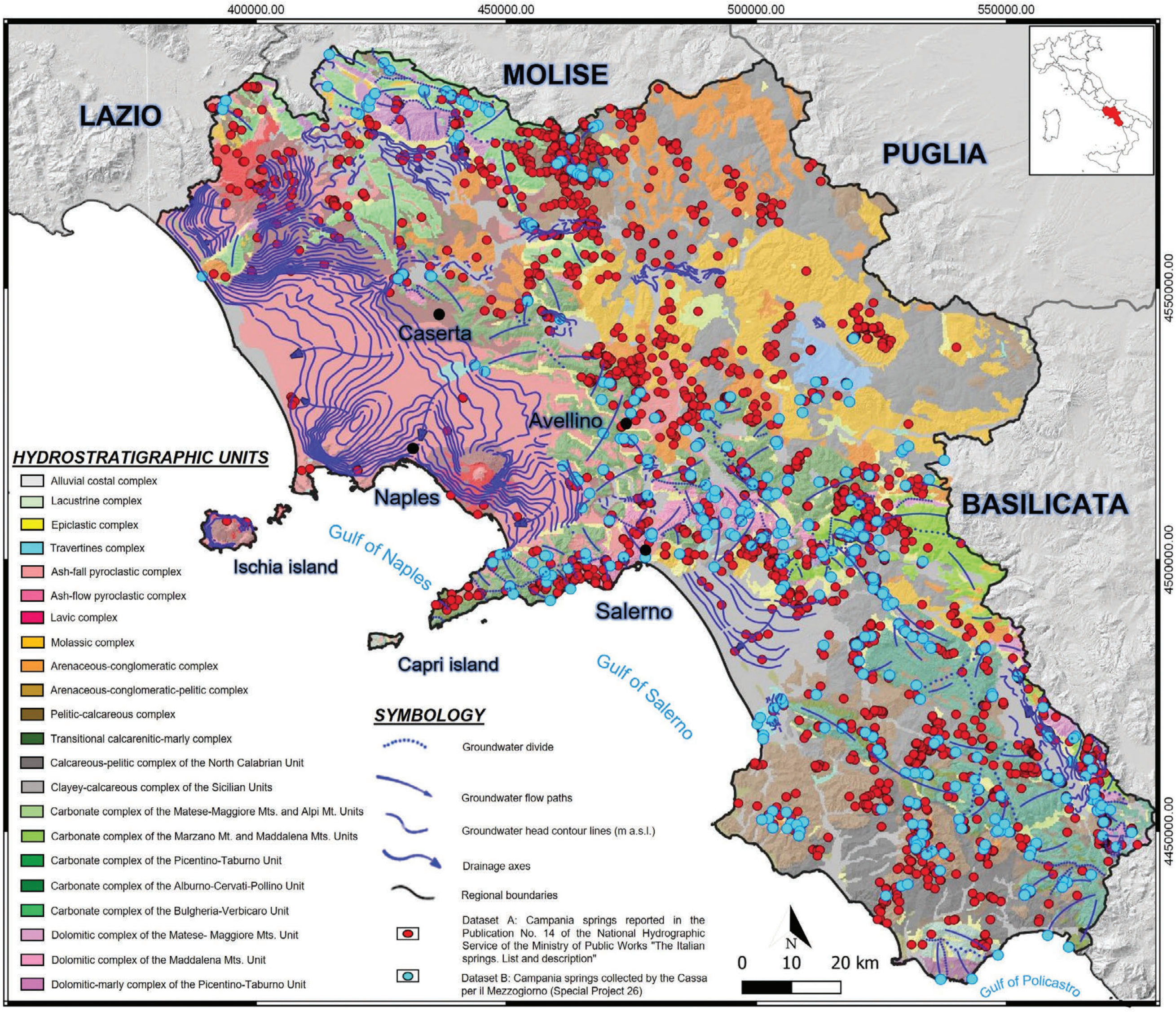

Fig. 2 - Hydrogeological map of the Campania region. Coordinate system UTM WGS 84, 33 N zone (modified from the "Hydrogeological map of continental southern Italy", De Vita et al. 2018).

Fig. 2 - Carta idrogeologica della regione Campania. Sistema di coordinate UTM WGS 84, 33N (modificata da "Mappa idrogeologica dell'Italia meridionale continentale, De Vita et al. 2018).

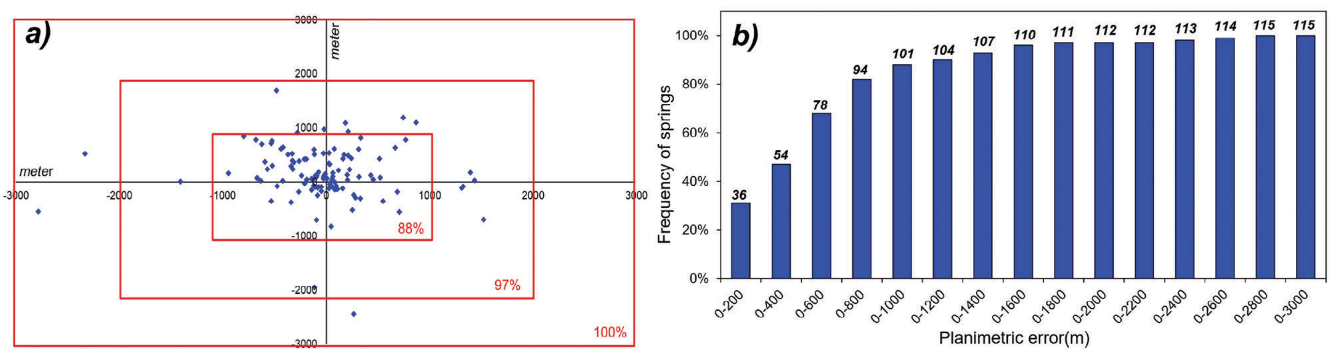

Fig. 3 - a) Scatter plot representing the longitude and latitude errors for the corresponding springs of the datasets A and B; b) Frequency histogram of planimetric error for springs belonging to the datasets A and B.

Fig. 3 - a) Grafico a dispersione dell'errore in longitudine e latitudine tra le sorgenti dei dataset A e B; b) Istogramma di frequenza dell'errore planimetrico tra le sorgenti dei dataset A e B.

the hydrostratigraphic units, from which their groundwater flow is reliant on, was carried out considering the distance between the spring location and the hydrogeological boundary separating adjoining hydrostratigraphic units. In the case this distance resulted lower than 1,000 m, the association was attributed through an analysis of coherence of spring parameters (discharge and temperature) with the hydrogeological features of the adjoining hydrostratigraphic units. However, an evaluation of these parameters was performed in all cases apparently anomalous as those represented by springs with high discharge rates occurring in hydrostratigraphic units with low permeability grade.

Regional hydrogeological analysis based on data of springs

In order to carry out a regional hydrogeological analysis based on a dataset of springs more comprehensive than that considered in previous studies, which were limited to major springs only (Allocca et al. 2007; De Vita et al. 2018), the 2,082 springs reported by the Special Publication No. 14 (Servizio Idrografico 1942) for the Campania region were associated to the hydrostratigraphic unit from which they outlet and receive groundwater flow.

For the Campania region, 12 principal hydrostratigraphic units were recognized by grouping lithostratigraphic and tectonic units with homogeneous hydrogeological features (De Vita et al. 2018), according to the concepts of aquifer (Meinzer 1923), hydrogeological complex (Civita et al. 1975) and principles of hydrogeological mapping (Maxey 1964; UNESCO and WMO 1977). Specifically, the identification of hydrostratigraphic units was carried out by respecting geometrical relationships and considering their hydrogeological features, such as type of permeability (Freeze and Cherry 1979) and permeability grade (Bureau of Reclamation 1985; Civita 1975) (Tab. 2).

Following, a brief outline of the hydrogeological knowledge of each hydrostratigraphic unit is described and associated to the number of related springs.

- Quaternary unit (ID 1): formed by alluvial-coastal Quaternary deposits, comprising 176 springs, and lacustrine deposits, with 9 springs. It is constituted by porous, heterogeneous and anisotropic aquifers, characterized by medium grade of permeability due to primary porosity. These aquifers are fed by direct recharge and seepage from the adjoining units, mainly carbonate or volcanic.
- Pliocene-Quaternary epiclastic unit (ID 2): consisting of Pliocene-Quaternary continental epiclastic deposits and characterized by a medium grade of permeability due to primary porosity. It comprises 210 springs.
- Quaternary ash-fall pyroclastic unit (ID 3): formed by thick Quaternary pyroclastic ash-fall deposits filling alluvial plains where they result interfingered with alluvial deposits. It forms aquifers with medium permeability grade due to primary porosity. It includes 80 springs.
- Quaternary ash-flow pyroclastic unit (ID 4): formed by ash-flow pyroclastic deposits which are characterized by both primary and secondary porosity due to lithification processes and cooling fracturing respectively. This unit includes 72 springs.
- Quaternary lava unit (ID 5): formed by lavas and characterized by a generally high permeability grade mainly due to fracturing caused by cooling. 8 springs were associated to it.
- Pliocene molassic unit (ID 6): formed by post-orogenic terrigenous deposits and characterized by a general medium grade of porosity due fracturing and porosity. It comprises 129 springs.
- Miocene arenaceous-conglomeratic unit (ID 7): formed by syn-orogenic coarse turbidite series reaching a medium grade of permeability due to fracturing and subordinate porosity. 136 springs were recognized belonging to it.
- Paleogene-Miocene arenaceous-calcarenite-pelitic unit (ID 8): formed by pre- and syn-orogenic fine-graded turbidite series reaching a scarce to impervious grade of permeability due to fracturing and subordinate porosity, depending on the relative abundance of mudrock component. This domain includes 285 springs.
- Paleogene transitional calcarenite-marly unit (ID 9): formed by calcarenite series interbedded with marls and belonging to Cenozoic transitional facies of carbonate platform. The grade of permeability is globally medium due chiefly to fracturing. This domain includes 74 springs.
- Cretaceous-Paleogene clayey-calcareous unit (ID 10): formed by Varicolored Clays, constituted by irregular alternation of clays, marly clays, fissured calcareous marls and calcilutites. The permeability grade is globally impervious even if reaching locally up to medium grade depending on the relative abundance of the clay component. It comprises 260 springs.
- Mesozoic limestone series unit (ID 11): formed by Mesozoic limestone to dolomitic-limestone carbonate platform series belonging to Matese-Maggiore, Mts. Picentino-Taburno, Mts. Alburno-Cervati-Pollino, Mt. Alpi, Mt. Marzano, Mts. della Maddalena and Mts. Bulgheria-Verbicaro tectonic units. It hosts the most important regional aquifers and supply the main drinkable water resources of southern Italy. It is generally characterized by a high permeability grade due to fracturing and karst. This unit comprises 520 springs.
- Mesozoic dolomite series unit (ID 12): formed by dolomite and dolomitic limestones belonging to the Mts. Matese-Maggiore, Mts. Maddalena and Mts. Picentini Taburno tectonic units. It is characterized in general by a medium permeability grade mainly due to fracturing and negligibly to karst phenomena. It comprises 121 springs.

A statistical analysis of parameters recorded, altitude (m a.s.l.), discharge (l s^{-1}) and temperature (°C), was performed by grouping springs according to the hydrostratigraphic unit from which their groundwater derives (Tab. 2). In particular,

Tab. 2 - Main hydrogeological features of the hydrostratigraphic units recognized in the Campania region (De Vita et al. 2018).

Tab. 2 - Principali caratteristiche idrogeologiche delle unità idrostratigrafiche riconosciute in Campania (De Vita et al. 2018).

ID	Hydrostratigraphic unit	Area (km^2)	Number of springs (No.)	Spatial density of springs (No./ 100 km^2)	Type of permeability			Permeability grade			
					Porosity	Fracturing	Karst	Impervious	Low	Medium	High
1	Quaternary unit	1,589	186	12	•				•	•	
2	Pliocene-Quaternary epiclastic unit	594	210	35	•				•		
3	Quaternary ash-fall pyroclastic unit	1,929	80	4	•				•	•	
4	Quaternary ash-Flow pyroclastic unit	725	72	10	•	•				•	
5	Quaternary lava unit	138	9	7		•					•
6	Pliocene molassic unit	1,114	129	12	•	•				•	
7	Miocene arenaceous-conglomeratic unit	820	136	17	•	•				•	
8	Paleogene-Miocene arenaceous calcarenitic pelitic series unit	1,209	285	24	•	•		•	•		
9	Paleogene transitional calcarenitic marly unit	100	74	74		•				•	•
10	Cretaceous-Paleogene clayey calcareous unit	2,137	260	12	•	•		•			
11	Mesozoic limestone series unit	2,519	520	21		•	•				•
12	Mesozoic dolomite series unit	477	121	25	•	•				•	

the variability of spring parameters was estimated using box plots for each hydrogeological unit and using a frequency analysis of all springs aggregated (Fig. 4).

Altitude of springs (Fig. 4 a-b) was recognized varying depending on the physiographic context characterizing each hydrogeological domain. An important differentiation in altimetric distribution of springs was observed for hydrostratigraphic units 11 and 12, belonging to the hydrogeological domain of Mesozoic-Cenozoic carbonate platform series, which are characterized by different physiographic zones, varying between high-relief landscape and flat erosional land surface on top of the massifs. In this context, basal and high-altitude springs were recognized. The first group is characterized by median value of altitude varying from 500 to 600 m a.s.l. with lower values down to few meters above sea level. Moreover, high-altitude springs (up 1,800 m a.s.l.) are generated by stratigraphic-structural factors as well as the presence of karst conduits which favor perched groundwater flow in the higher parts of carbonate aquifers. The hydrostratigraphic units 1 and 2, belonging to hydrogeological domain of Pliocene-Quaternary alluvial and clastic deposits, are characterized by springs with a range of altitude between 0 m and 1,200 m a.s.l. and median values varying from 150 to 420 m a.s.l., respectively. The altimetric variability was mainly related to different sedimentation environments varying from internal mountain to coastal areas across the Campania region. The lowest altitude range, from 0 to 900 m a.s.l., with median values ranging from 150 to 250 m a.s.l., characterize the hydrostratigraphic units 3, 4 and 5, which constitute the hydrogeological domain of Quaternary volcanic deposits occurring in the Campanian plain. Instead the Paleogene-Neogene terrigenous series, representing a separate hydrogeological domain and forming the remaining hydrostratigraphic units 6,7,8, 9 and 10, give rise to a minor mountain chains and hills of southern Italy. The lithologic heterogeneity of these deposits results in relative altitude variability of springs ranging from few m a.s.l. to 1,500 m a.s.l. with median values ranging from 420 to 600 m a.s.l.

The Fig. 4 c-d shows a relevant variability of the spring discharge parameter, better appreciable in a logarithmic scale. The hydrogeological characteristics of each domain to which springs belong, were considered key aspects to understand the different discharge values. The peculiar characteristics of hydrostratigraphic units belonging to hydrogeological domain of Mesozoic-Cenozoic carbonate platform series (ID 11 and 12) results in springs with the widest range, from median values varying from few liters per second to very high values reaching a discharge up to 3,780 l s^{-1}. This subgroup, resulting as outliers of the statistical distribution, corresponds to the major basal springs of the karst aquifers.

The Plio-Quaternary deposits domain (ID 1 and 2) is characterized by springs with median values of discharge ranging around 2 l s^{-1} but with outlier values up to 80 l s^{-1} depending on the extent of the groundwater domain and the groundwater exchange from other adjoining hydrostratigraphic units. Variable discharge values (0,2 - 20 l s^{-1}) characterize the hydrogeological domain of volcanic deposits (ID 3, 4) with median values ranging around 2 l s^{-1}. The lava hydrostratigraphic unit (ID 5) is characterized by discharge values lower than 10 l s^{-1}. The groundwater yield of Paleogene-Neogene terrigenous hydrostratigraphic units (ID 6, 7, 8, 9 and 10) was considered strictly dependent on lithologic heterogeneity due to different occurrence of mudrock component which, as for the altitude parameter, results in discharge variability. The coexistence of pelitic and calcareous units determines variable permeability grade, from impervious to medium and consequently discharge values variable from 0,5 l s^{-1} up to 20 l s^{-1}.

The groundwater temperature was evaluated strongly dependent on the altimetric distribution of springs. Regardless of outliers, which are present for all the data analyzed, groundwater temperature ranges between 5 and 15 °C (Fig. 4 e-f). The highest temperature values were recognized for the hydrogeological domain of Quaternary volcanic deposits (ID 3, 4 and 5), distributed in the lowest range of altitude.

Discussion and conclusions

The present study proposes the retrieval of the dataset of springs surveyed across 1920s and 1940s by the National Hydrographic Service of the Ministry of Public Works, published in different volumes of the Special Publication No. 14 "The Italian springs. List and description", for each compartment in which the national territory was subdivided (Fig. 1). Considering the comprehensive survey made, which took into account even minor springs with low values of discharge, down to values varying from 0,1 to 0,5 l s^{-1}, and resulted in a number of springs much higher than that of other surveys made in the following decades, this database appears inexplicably not used yet for hydrogeological studies. Specifically, this work is aimed at structuring and validating a dataset related to the Campania region in order appreciate its reliability in terms of coordinates and its applicability to hydrogeological studies.

The most crucial aspect dealing with the possible use of this database is related to the accuracy of coordinates which, among the other parameters recorded, appear the most influenced by outdated survey methods based more on the appraisal of the geolocalization on 1:25,000 topographic maps than in the application of on-purpose topographic recognitions. Results of the comparison of coordinates of springs corresponding in both datasets A and B, the latter representing a true reference because properly validated (Allocca et al. 2007; De Vita et al. 2018), show a reasonable correspondence with a median planimetric error lower than 400 m (Fig. 3).

Springs of Special Publication No. 14, grouped for each hydrostratigraphic unit to which they belong, allowed a more comprehensive regional hydrogeological analysis because including a higher number of minor springs. This is particularly relevant for hydrostratigraphic units with lower permeability grade, such as those belonging to the hydrogeological domain of Paleogene-Neogene terrigenous series characterized by several springs with low discharge rate.

Overall, results of statistical analyses of spring parameters allowed to evaluate that the distribution of data is consistent with geological and hydrogeological characteristics of the study area. The discharge values are correctly dependent on the permeability grade of the hydrostratigraphic unit from which they receive groundwater flow.

However, the present study highlighted the disappearance of minor springs, as well as changes in spring discharge during the last 60 years. These variations were considered dependent on anthropogenic forcings such as land use, groundwater overexploitation by wells located the same aquifer near the springs. Aquifer storage, type and location of springs as well as the increase of atmospheric minimum temperatures and variations of precipitation regime were considered manifold effects causing changes on quantity and quality of groundwater resources and on the hydrological cycle, in agreement with Mastrocicco et al. (2019) , Ducci and Tranfaglia (2008) and Braca et al. (2019). The influence of climate change on the characteristics of springs discharge and temperature variations, is widely accepted in the scientific community (Kurylyk et al. 2014). Therefore, the climate change and different land use practices affect not only the groundwater resources but also the surface water systems (Green et al. 2011).

A possible further application of data of the Publication No. 14 is the checking of springs by field surveys, especially the minor ones, which would allow to appraise both the effects of climate changes, by the eventual disappearance of springs or strong variation in discharge, and to identify possible integrative resources to be used, especially for local communities.

In conclusion, the results obtained show the Publication No. 14 of the National Hydrographic Service as an important source of data to not be overlooked, especially in a condition of historical data shortage, from which can be both carried out regional hydrogeological and temporal evolution analyses as well as identified integrative groundwater resources.

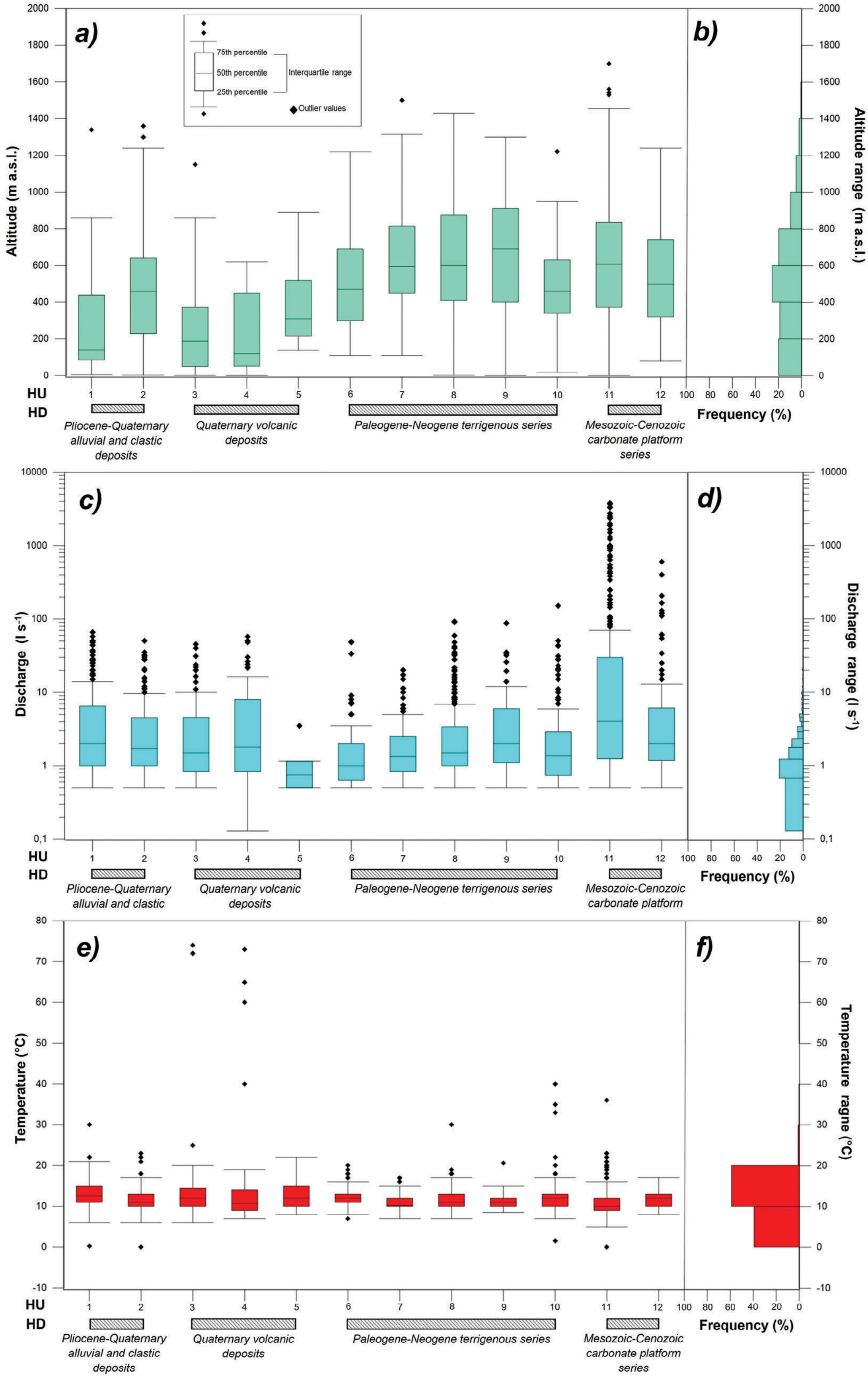

Fig. 4 - Statistical analysis of springs parameters reported in the A dataset. Key to symbol: HU: Hydrostratigraphic unit; HD: Hydrogeological domain.

Fig. 4 - Analisi statistica effettuata sui parametri delle sorgenti riportate nel dataset A. Simboli: HU: unità idrostratigrafica; HD: dominio idrogeologico.

Competing interest
The authors declare no competing interest.

Author contributions
Conceptualization, D.C., P.D.V., V.A, S.C., D.L. and M.V.; methodology, D.C., P.D.V., V.A, S.C., D.L. and M.V.; software, D.C., P.D.V., V.A, S.C., D.L. and M.V.; validation, D.C., P.D.V., V.A, S.C., D.L. and M.V.; writing-original draft preparation, D.C., P.D.V., V.A, S.C., D.L. and M.V.; writing-review and editing, D.C., P.D.V., V.A, S.C., D.L. and M.V.; visualization, D.C., P.D.V., V.A, S.C., D.L. and M.V.; supervision, D.C., P.D.V., V.A, S.C., D.L. and M.V.; project administration, D.C., P.D.V., V.A, S.C., D.L. and M.V.All authors have read and agreed to the published version of the manuscript.

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