Groundwater of Rome

F. La Vigna, R. Mazza, M. Amanti, C. Di Salvo, M. Petitta, L. Pizzino, A. Pietrosante, L. Martarelli, I. Bonfà, G. Capelli, D. Cinti, F. Ciotoli, G. Ciotoli, G. Conte, A. Del Bon, M. Dimasi, S. Falcetti, R. M. Gafà, A. Lacchini, M. Mancini, S. Martelli, L. Mastrorillo, G. M. Monti, M. Procesi, M. Roma, A. Sciarra, A. Silvi, F. Stigliano & C. Succhiarelli

To cite this article: F. La Vigna, R. Mazza, M. Amanti, C. Di Salvo, M. Petitta, L. Pizzino, A. Pietrosante, L. Martarelli, I. Bonfà, G. Capelli, D. Cinti, F. Ciotoli, G. Ciotoli, G. Conte, A. Del Bon, M. Dimasi, S. Falcetti, R. M. Gafà, A. Lacchini, M. Mancini, S. Martelli, L. Mastrorillo, G. M. Monti, M. Procesi, M. Roma, A. Sciarra, A. Silvi, F. Stigliano & C. Succhiarelli (2016): Groundwater of Rome, Journal of Maps

To link to this article: http://dx.doi.org/10.1080/17445647.2016.1158669

View supplementary material

Published online: 16 Mar 2016.

Submit your article to this journal

View related articles

View Crossmark data
Groundwater of Rome

F. La Vigna\textsuperscript{a}, R. Maza\textsuperscript{b}, M. Amanti\textsuperscript{c}, C. Di Salvo\textsuperscript{d}, M. Petitta\textsuperscript{e}, L. Pizzino\textsuperscript{f}, A. Pietrosante\textsuperscript{b}, L. Martarelli\textsuperscript{c}, I. Bonf\textsuperscript{a}, G. Capelli\textsuperscript{b}, D. Cinti\textsuperscript{f}, F. Ciotoli\textsuperscript{d}, G. Ciotoli\textsuperscript{e}, G. Conte\textsuperscript{c}, A. Del Bon\textsuperscript{f}, M. Dimasi\textsuperscript{b}, S. Falcetti\textsuperscript{c}, R. M. Ga\textsuperscript{a}, A. Lacchini\textsuperscript{d}, M. Mancini\textsuperscript{b}, S. Martelli\textsuperscript{b}, L. Mastrorillo\textsuperscript{b}, G. M. Monti\textsuperscript{c}, M. Procesi\textsuperscript{f}, M. Roma\textsuperscript{c}, A. Sciarra\textsuperscript{f}, A. Silvi\textsuperscript{c}, F. Stigliano\textsuperscript{d} and C. Succhiarelli\textsuperscript{g}

\textsuperscript{a}Department of Environmental Protection, Roma Capitale, Rome, Italy; \textsuperscript{b}Department of Science, Geology Section, Roma Tre University, Rome, Italy; \textsuperscript{c}ISPRA – Italian Geological Survey, Rome, Italy; \textsuperscript{d}CNR – Institute of Environmental Geology and Geoengineering, Monterotondo, Italy; \textsuperscript{e}Department of Earth Science, Sapienza University of Rome, Rome, Italy, \textsuperscript{f}INGV – National Geophysics and Volcanology Institute, Rome, Italy; \textsuperscript{g}Department of Urban Planning, Roma Capitale (Municipality of Rome), Rome, Italy

1. Introduction

Groundwater monitoring systems and related maps have become critical. Such maps and analysis provide a context for activities that affect what we cannot see – the water world beneath the ground. This largely invisible world is involved in many aspects of city life: water supply systems, sewage, surface water features, the health of plants and trees, flood potential and drought events. Recently, groundwater has been recognized as a cornerstone in the resilience of cities (Tanner, Mitchell, Polack, & Guenther, 2009).

Urbanization is a worldwide trend, with more than 50% of the world’s population currently living in cities, reaching 70% in Europe (UN-HABITAT, 2012). The urban water cycle is the key to integrated sustainable management (Marsalek et al., 2008) for ensuring supply of safe (good quality) water, sanitation and correct drainage systems. Moreover, human activities such as land use change, extensive withdrawals and waste water discharge may exert a strong influence on hydrogeology, sometimes stronger than climate change (Taylor et al., 2013), causing changes in the chemical-physical and quantitative status of surface and groundwater. As a consequence, urban water management poses not only scientific but also technical, socio-economic, cultural and ethical challenges (Chaminé, Afonso, & Freitas, 2014; Freitas et al., 2014, 2015). In this context, mapping groundwater and surface water resources represents a fundamental step for optimizing the urban water system and minimizing water consumption and deterioration.

Urban areas worldwide are employing different techniques for groundwater mapping. Hydrogeological maps are needed for a wide range of applications such as (see details in Chaminé, Carvalho, Teixeira, & Freitas, 2015; Margat & van der Gun, 2013): protecting groundwater resources from deterioration (Ravikumar, Venkatesharaju, Prakash, & Somashekar, 2011); defining groundwater protection zones in newly urbanized contexts (Thomsen, Sondersgssrd, & Sorensen, 2004); assessing groundwater potential (Oh, Kim, Choi, Park, & Lee, 2011); identifying groundwater vulnerability (Wolf, Eiswirth, & Hotzl, 2006); quantifying the recharge due to sewer and pipe leakage (Yang, Lerter, & Tellam, 1999); furnishing the basic information for underground infrastructure design and to perform city-scale groundwater modeling (Di Salvo, Moscatelli, Mazza, Capelli, & Cavinato, 2014; La Vigna, Demiray, & Mazza, 2013; La Vigna, Hill, Rossetto, & Mazza, 2016) and the historical evolution of urban groundwater systems (Chaminé et al., 2014; Freitas et al., 2014).

In the city of Rome, most drinking water supplies derive from springs located far from the city, and is delivered to the population through the aqueduct network (Bono & Boni, 1996). Even if, currently, there are not specific issues related to water quantity, the Rome municipality is dealing with many groundwater-related problems. Some example are: pollution (Ellis, 1999),...
relationships between poor quality streams and aquifers (La Vigna, Ciadamidaro, Mazza, & Mancini, 2010), natural background levels of dissolved elements and compounds (La Vigna, Bonfà, & Martelli, 2014), differential settlements in stream valleys (Raspa et al., 2008), subsidence and salinization (Manca, Capelli, La Vigna, Mazza, & Pascarella, 2014; Manca, Capelli, & Tuccimei, 2015) as well as groundwater flooding. The Hydrogeological Map of Rome (Main Map) constitutes a first important step for future development of surveys and research aimed at solving such problems.

The new Hydrogeological Map of Rome (Main Map) has been prepared with the intention of incorporating the findings of previous studies concerning the hydrogeological setting of the city, with special attention paid to the reconstruction of piezometric levels, based on field data (La Vigna et al., 2016).

Previous hydrogeological maps of the city do not cover the total extent of the municipality (Capelli, Mazza, & Taviani, 2008; Corazza & Lombardi, 2005; La Vigna, Capelli, & Mazza, 2008) or were drawn only using literature data (Succhiarelli & D’ottavio, 2008) or use now-outdated sources (Ventriglia, 1971, 1990, 2002). For these reasons, this map aims to become the new groundwater benchmark for Rome.

2. Hydrogeological conceptual model

The hydrogeological conceptual model and the groundwater circulation in the Rome municipality are driven by: (1) the local morpho-stratigraphic and structural setting, which is dominated by two main middle-late Quaternary volcanic complexes, the Sabatini Mts to the North West and the Alban Hills South East of the city, and by several NW–SE and N–S trending horsts and grabens that dissect Plio-Pleistocene marine and continental sedimentary sequences underneath the volcanic cover; (2) the relationship of groundwater exchange between the hydrogeological units; (3) the two main rivers flowing in the study area, the Tiber and Aniene River (Capelli et al., 2008) and (4) the proximity to the Tyrrenian Sea coast. The groundwater circulation is in fact directed mainly from the volcanic relief toward the base level of the Tiber and Aniene rivers and the Tyrrenian Sea. The hydrogeological boundaries and the groundwater directions of the main aquifers depend on the position of the horsts and grabens, as well as on the different permeabilities which characterize the main hydrogeological complexes.

Conceptually, the groundwater circulation is represented by four aquifers, three of which overlap. Iso-potential lines in the map highlight that groundwater flowpaths are similar to those of surface water, so that the hydrological and hydrogeological basins are quite similar.

In areas of higher elevation (i.e. the flanks of Alban Hills – Southern and Southeastern sector), the overlapped aquifers can be well defined and distinguished, whereas at lower elevations, the aquifers tend to merge into one single aquifer. This is consistent with the depositional architecture of a typical stratovolcano, as the Alban Hills Volcano is, characterized by the thinning and wedging out of the formations at the periphery of the complex.

The identified aquifers are bounded at the base by a very low-permeability bedrock, formed by a basal clayey–sandy complex (Monte Vaticano, Monte delle Piche and the lowermost levels of Monte Mario formations) acting as an aquiclude (see ‘Top surface of the basal aquiclude’ on the Map). The top of the aquiclude is strongly irregular due to the complexity of the morpho-structural setting and to the network of river incisions predating the emplacement of volcanic units. On the Map, two main incisions are shown: the first is the Middle Pleistocene NW–SE trending depression called the Paleotiber Graben, located in the northern and eastern sectors of the city; the second corresponds to the Tiber River valley incision, etched during the last low stand of sea level (Wurmian age).

For more details on the hydrogeological setting of Rome, see also the works of La Vigna, Mazza, Pietrosante, Martarelli, and Di Salvo (2015) and Mazza et al. (2016).

3. Methodology

With regard to both the plain view cartography and cross sections, the Geological Map of Rome Municipality, 1:50,000 scale (Funicelli, Giordano, & Mattei, 2008), has been hydrogeologically revisited. This choice was driven by the fact that the 2008 geological map represents the most recent and complete geological product, based on CARG (Italian Geological Cartography Project) data. The choice of this geological basis implicitly required the adoption of the IGM (Military Geographic Institute) topographic map (1:50,000 scale). This topographic product can be considered outdated for the area of Rome. Indeed, it does not match in detail the relief and the actual urban fabric, especially in peripheral sectors and in active quarry areas. The resulting mismatches became evident in the preparation of the hydrogeological cross sections. All groundwater levels were instead referred to the most available detailed topographic map (scale 1:5000).

The piezometric data were collected during a survey which took place between July 2014 and May 2015. The investigation was performed relying on the Groundwater Monitoring Network of Rome which is currently made up of 101 measuring points (wells and piezometers). This widespread hydrogeological survey included also private wells and/or piezometers located on the right bank of the Tiber River and the monitoring
network of the Castel Porziano Presidential Estate (Banzato et al., 2013). In order to reconstruct the potentiometric surface and piezometric lines, the Numerical and Quantitative Hydrogeology Laboratory of Roma TRE University (LinQ) database was also used. This database consists of more than 5000 records related to wells and springs in the area of Rome. This repository has been populated since the early 1990s with the data coming from different hydrogeological studies conducted in Rome and the surrounding area.

Groundwater physical–chemical characterization (i.e. temperature, electric conductivity, pH and pCO₂ measurements) as well as alkalinity were performed onsite by means of portable meters and titration with hydrochloric acid, respectively. A pump powered by a battery or a bailer, where needed, were used to collect water samples. Moreover, T, pH and alkalinity were used to compute partial pressure of dissolved CO₂ (pCO₂).

Thermometric, rainfall and hydrometric gauging data were provided by the Regional Civil Protection Agency of Latium Region for the period 1984–2014. Only data belonging to the period 1994–2014 were selected on the basis of their time continuity and working periods of the gauging stations.

Riparian spring data (linear springs on the map) have been plotted querying the LinQ database. Information about locations of springs and related data (if available) comes from the LinQ database, from surveys conducted by INGV, and from the Geological Map of Rome (Funiciello et al., 2008).

The WGS84 datum is adopted, and the metric coordinates reported close to the vertices framing the study area refer to the UTM 33N projection zone.

The hydrogeological symbols used on the map take up the recommendations reported in the Italian Official Guidelines for hydrogeological survey and representation (Mari, Motteran, Scalise, Terribili, & Zattini, 1995) and in later experimental tests and proposals of implementation (Roma & Vitale, 2008; Tarragoni, Martarelli, Pierdominici, Roma, & Boni, 2011), which aim to provide an immediate understanding and readability of the hydrogeological items.

The lithologies of the geological map were grouped in hydrogeological complexes by considering their relative permeability and their importance according to groundwater circulation. The area symbols for their representation adopts red to orange shades for complexes characterized by relative permeability ranging from high to intermediate values, while greenish to grayish shades correspond to scarce to very low relative permeability complexes. The lightest or darkest shades of color have been selected for each complex in order to highlight the minor or major extent, of the related outcropping areas, respectively. Patterns overlaying the areal symbols have been also used to show the lithological features of the high and intermediate relative permeability complexes.

The water table contours were obtained manually resorting to a triangulation method. The variability of elevations, the existence of areas with extensive anthropogenic modification and the presence of riparian springs made automatic interpolation inappropriate. In order to avoid the outcropping of the water table above the ground surface, the digital elevation model (DEM) of the equipotential surface of each aquifer has been compared with the most recent and detailed DEM of the topographic surface of the area. This comparison succeeds in highlighting some discrepancies and making the water table reconstruction more representative. Contour intervals are denser where the water table gradient is lower, as in the coastal area.

A particular symbology has been adopted for natural and anthropogenic features related to the same

Figure 1. Hydrogeological map excerpt (zoom 1.5x). Riparian springs (linear springs on the (Main Map)), fed by different superposed aquifers, assume the color of the related source aquifers.
identified aquifer: both point and linear elements have
been associated, according to their features, to one of
the four identified aquifers using different colors. The
excerpt of the map in Figure 1 shows how springs,
water table and wells have been symbolized for differ-
ent aquifers.

Riparian springs are reported along water courses
adopting the same criterion. Therefore, a water course
section intersecting riparian springs which are fed by
different aquifers is represented with the different col-
ors corresponding to the aquifers. Thus, the same line
feature is characterized by a different color from the
starting point where the spring begins to contribute
to the stream discharge by a different aquifer.

Four hydrogeological cross sections have been pro-
duced along the lines of the corresponding geological
sections shown on the Geological Map of Rome Munici-
pality (Funiciello et al., 2008). The previous C–C′ cross
section has been extended toward the Tyrrhenian coast-
line by a further stretch oriented from north to south.

The hydrogeological sections contain 16 out of the
17 hydrogeological complexes identified in this study,
as well as a separate gravel layer located at the bottom
of the alluvial and the lacustrine deposit complex and
within the S. Cecilia formation complex.

The geo-database built to produce the map encom-
passes different shape files. It will be integrated into a
specifically built GIS, whose architecture is being tested
(Martarelli et al., 2015).

4. Discussion and concluding remarks

The Hydrogeological Map of Rome (Main Map) has
been designed to lend itself easy to use by experts, pub-
lic administrations and stakeholders.

In some parts of the map there are overlapping
information layers. For example, in the Alban Hills sec-
tor (Southern and Southeastern part of Rome Munici-
pal Territory) three superposed piezometric surfaces
are mapped together with the related flowpath arrows,
the monitoring points and other themes.

A special method of piezometric representation has
been developed in the areas where piezometric con-
tours of superposed aquifers merge into one. It is evi-
dent that, although differently represented by colors,
in the above-mentioned areas, the isolines of equal
elevation should join, or conversely, should separate,
due to vertical and lateral heterogeneity. However,
since the merge (or separation) of two flow paths
occurs in large undefined areas, a dotted line was
adopted to symbolize the shallower water table contour
where it separates from the deeper ones (Figure 2). This
technique makes it possible to represent the typical
groundwater flow of stratovolcanoes, where superim-
posed aquifers, flowing radially towards lower elevations, merge into a single one, due to stratigraphic
forcing. With this map, the City of Rome has in place
the ability to manage groundwater at a larger strategic
context. Demands for water wells, contaminant distri-
bution and transport, the effect of groundwater devel-
opment on saltwater intrusion or the integrity of
infrastructure can be now considered in an objective
manner that can bring parties in dispute to a common
scientific understanding. This in turn will facilitate
appropriate planning and infrastructure development
in order to confront climate-related problems from
occurring as well.

One possible future development concerning ground-
water mapping in Rome could be to collect and map
information about groundwater circulation in anthropo-
genic deposits (such as urban fill), likely hosting small
discontinuous aquifers. Such deposits are difficult
to map in detail at the chosen scale of the Hydrogeologi-
cal Map because of their irregular shape and thickness
(from several meters to several decameters). In fact,
despite the availability of specific maps of anthropogenic

Figure 2. Hydrogeological map excerpt (zoom 1.5×). Piezometry splitting (30 m a.s.l.).
deposits in Rome (in particular in the downtown area) at various scales and produced with different techniques (Ciotoli et al. 2015; Corazza & Marra, 1995; Ventriglia, 1971), a comprehensive map (or survey) of the entire municipal territory is still lacking, which may be useful for groundwater characterization, especially for shallow contamination issues.

Another possible objective for the future could be to map all area affected by groundwater flooding to understand the flow dynamics in detail, especially in the lowland and underground heritage sites.

Software
All data processing and spatial analysis regarding the map were performed by GIS software (Arc GIS 10). The final editing aimed to obtain high-quality files for cartographic press and graphics has been achieved by using vector graphics software (Adobe Illustrator CS6) coupled with a specific cartography plugin for the shape file geographic information management (Map Publisher 9.2).

Disclosure statement
No potential conflict of interest was reported by the authors.

ORCID
F. La Vigna ORCID
http://orcid.org/0000-0003-2727-2017
G. Ciotoli ORCID
http://orcid.org/0000-0002-9496-3021

References
Banzato, F., Caschetto, M., Lacchini, A., Marinelli, V., Mastrorillo, L., & Sbarbati, C. (2013). Recharge and groundwater flow of the coastal aquifer of Castelporziano Presidential Estate (Rome, Italy). Rendiconti della Società Geologica Italiana, 24, 22–24.
Bono, P., & Boni, C. (1996). Water supply of Rome in antiquity and today. Environmental Geology, 27(2), 126–134. doi:10.1007/BF01061685
Capelli, G., Mazza, R., & Taviani, S. (2008). Carta Idrogeologica dell’area di Roma [Hydrogeological Map of the Area of Rome]. Memorie Descrittive della Carta Geologica d’Italia, 80, Roma – ISSN-0242.
Chaminé, H. I., Afonso, M. J., & Freitas, L. (2014). From historical hydrogeological inventories, through GIS mapping to problem solving in urban groundwater systems. European Geologist. Journal of the European Federation of Geologists, 38, 33–39.
Chaminé, H. I., Carvalho, J. M., Teixeira, I., & Freitas, L. (2015). Role of hydrogeological mapping in groundwater practice: back to basics. European Geologist. Journal of the European Federation of Geologists, 40, 34–42.
Ciotoli, G., Stigliano, F., Mancini, M., Marconi, F., Moscatelli, M., & Cavinato, G. P. (2015). Geostatistical interpolators for the estimation of the geometry of anthropogenic deposits in Rome (Italy) and related physical-mechanical characterization with implications on geohazard assessment. Environmental Earth Sciences, 74, 2635–2658. doi:10.1007/s12665-015-4284-z
Corazza, A., & Lombardi, L. (1995). Idrogeologia dell’area del centro storico di Roma [Hydrogeology of the downtown of Rome]. Memorie Descrittive della Carta Geologica d’Italia, 50.
Corazza, A., & Marra, F. (1995). Carta dello spessore dei terreni di riporto [Anthropogenic deposits’ thickness map]. Memorie Descrittive della Carta Geologica d’Italia, 50.
Di Salvo, C., Moscatelli, M., Mazza, R., Capelli, G., & Cavinato, G. P. (2014). Evaluating groundwater resource of an urban alluvial area through the development of a numerical model. Environmental Earth Sciences, 72, 2279–2299. doi:10.1007/s12665-014-3138-4
Ellis, B. (1999). Impacts of urban growth on surface water and groundwater quality. IAHS no. 259, IAHS, Wallingford, 437 pp.
Freitas, L., Afonso, M. J., Devy-Vareta, N., Marques, J. M., Gomes, A., & Chaminé, H. I. (2014). Coupling hydrotoponomy and GIS cartography: A case study of hydrohistorical issues in urban groundwater systems, Porto, NW Portugal. Geographical Research, 52(2), 182–197. doi:10.1111/1745-5871.12051
Freitas, L., Pereira, A. J. S. C., Afonso, M. J., & Chaminé, H. I. (2015). Urban groundwater mapping techniques: Importance on urban water cycle. Proceedings of the Congreso Internacional del Agua-Termalismo y Calidad de Vida. Ourense, Spain: Campus de Aouga.
Funicelli, R., Giordano, G., & Mattei, M. (Eds.). (2008). Carta geologica di Roma. Memorie Descrittive della Carta Geologica d’Italia, 80, Roma – ISSN-0242.
La Vigna, F., Bonfà, I., & Martelli, S. (2014). La determinazione dei valori di fondo naturale ed antropico nelle acque sotterranee dei grandi agglomerati urbani [Anthropogenic and natural background levels in groundwater of large cities]. Acque Sotterranee – Italian Journal of Groundwater, 3(136), doi:10.7343/AS-074-14-0100
La Vigna, F., Capelli, G., & Mazza, R. (2008). Carta Idrogeologica del Settore Terminale del Bacino del Fiume Aniene [Hydrogeological Map of the Lower Aniene River Basin]. In R. Funicelli, G. Giordano, & M. Mattei (Eds.), Memorie Descrittive della Carta Geologica d’Italia, 80, Roma – ISSN-0242.
La Vigna, F., Ciadamidaro, S., Mazza, R., & Mancini, L. (2010). Water quality and relationship between superficial and ground water in Rome (Aniene River basin, central Italy). Environmental Earth Sciences, 60(6). doi:10.1007/s12665-009-0267-2
La Vigna, F., Demiray, Z., & Mazza, R. (2013). Exploring the use of alternative groundwater models to understand the hydrogeological flow processes in an alluvial context (Tiber River, Rome – Italy). Environmental Earth Sciences, 71(3). doi:10.1007/s12665-013-2515-8
La Vigna, F., Hill, M. C., Rossetto, R., & Mazza, R. (2016). Parameterization, sensitivity analysis, and inversion: An investigation using groundwater modeling of the surface-mined Tivoli-Guidonia basin (Metropolitan City of Rome – Italy). Hydrogeology Journal. doi:10.1007/s10040-016-1393-z
La Vigna, F., Mazza, R., Amanti, M., Di Salvo, C., Petitta, M., & Pizzino, L. (2016). The synthesis of decades of groundwater knowledge: The new Hydrogeological Map of Rome. Acque Sotterranee – Italian Journal of Groundwater, 4(142), 9–17. doi:10.7343/AS-128-15-0155
La Vigna, F., Mazza, R., Pietrosante, A., Martarelli, L., & Di Salvo, C. (2015). Unità Idrogeologiche del territorio romano e modello concettuale di circolazione [Hydrogeological units of roman area and groundwater
conceptual model]. In F. La Vigna, & R. Mazza (Ed.), *Carta Idrogeologica di Roma* [Hydrogeological Map of Rome] Scala/Scale 1:50,000. Roma Capitale.

Manca, F., Capelli, G., La Vigna, F., Mazza, R., & Pascarella, A. (2014). Wind-induced salt-wedge intrusion in the Tiber river mouth (Rome-Central Italy). *Environmental Earth Sciences*, 72, 1083–1095. doi:10.1007/s12665-013-3024-5

Manca, F., Capelli, G., & Tuccimei, P. (2015). Sea salt aerosol groundwater salinization in the Litorale Romano natural reserve (Rome, Central Italy). *Environmental Earth Sciences*, 73, 4179–4190. doi:10.1007/s12665-014-3704-9

Margat, J., & van der Gun, J. (2013). *Groundwater around the world: A geographic synopsis*. Boca Raton, FL: CRC Press.

Mari, G. M., Motteran, G., Scalise, A. R., Terribili, D., & Zattini, N. (1995). *Carta Idrogeologica d’Italia – 1:50.000. Guida al rilevamento e alla rappresentazione*. *Quaderni del Servizio Geologico d’Italia*, Serie III, 5, IPZS, Roma.

Marsalek, J., Jimenez-Cisneros, B., Karamouz, M., Malmoquist, P. A., Goldenfum, J., & Chocat, B. (2008). *Urban water cycle processes and interactions*. UNESCO-HP Urban water series. Leiden: Taylor and Francis.

Martarelli, L., Roma, M., Scalise, A. R., Ventura, R., Battaglini, L., Carta, R., & Lettieri, M. T. (2015, September 13–18). The hydrogeological geodatabase by the Geological Survey of Italy. 42 International Congress AQUA 2015, Rome.

Mazza, R., La Vigna, F., Capelli, G., Dimasi, M., Mancini, M., & Mastrorillo, L. (2016). Hydrogeology of the area of Pohang City, Korea. *Journal of Hydrology*, 399, 158–172. doi:10.1016/j.jhydrol.2010.12.027

Raspa, G., Moscatelli, M., Stigliano, F., Patera, A., Marconi, F., Folle, D., ... Coimbra Leite Costa, J. F. (2008). Geotechnical characterization of the upper Pleistocene–Holocene alluvial deposits of Roma (Italy) by means of multivariate geostatistics: Cross-validation results. *Engineering Geology*. doi:10.1016/j.enggeo.2008.06.007

Ravikumar, P., Venkatesharaju, K., Prakash, K. L., & Somashekar, R. K. (2011). Geochemistry of groundwater and groundwater prospects evaluation, Anekal Taluk, Bangalore Urban District, Karnataka, India. *Environmental Monitoring Assessment*, 179, 93–112. doi:10.1007/s10661-010-1721-z

Roma, M., & Vitale, V. (2008). Strumenti e metodologie informative per l’idrogeologia: dai dati alla rappresentazione cartografica. In A. R. Scalis e L. Martarelli (Eds.), Studi sperimentali finalizzati alla cartografia idrogeologica. *Memorie Descrittive della Carta Geologica d’Italia*, 81, 47–58.

Sacchiarelli, C., & D’ottavio, D. (2008). *Carta idrogeologica del territorio comunale, scala 1:50,000, 1 foglio, scala 1:20,000, 11 fogli. Comune di Roma, Dipartimento VI – Politiche della Programmazione e Pianificazione del Territorio – Roma Capitale.*

Tanner, T., Mitchell, T., Polack, E., & Guenther, B. (2009). Urban governance for adaptation: Assessing climate change resilience in ten Asian cities (IDS Working Papers). doi:10.1111/j.2040-0209.2009.00315_2.x

Tarragoni, C., Martarelli, L., Pierdominici, S., Roma, M., & Boni, C. F. (2011). A proposal for compiling quantitative hydrogeological maps. *Rendiconti Online della Società Geologica Italiana*, 14, 75–85. doi:10.3301/ROL.2011.07

Taylor, R., Scanlon, B., Doll, P., Rodell, M., Van Beek, R., Wada, Y., ... Treidel, H. (2013). Groundwater and climate change. *Nature Climate Change*, 3, 322–329.

Thomsen, R., Sondergssrd, V. H., & Sorensen, K. I. (2004). Hydrological mapping as a basis for establishing site-specific groundwater protection zones in Denmark. *Hydrogeology Journal*, 12, 550–562. doi:10.1007/s10040-004-0345-1

UN-Habitat. (2012). *State of the world’s cities 2012/2013: Prosperity of cities. United Nations Human Settlements Programme, World Urban Forum edition.*

Ventriglia, U. (1971). *La Geologia della Città di Roma*. Amm. Prov. di Roma.

Ventriglia, U. (1990). *Idrgeologia della Provincia di Roma*. Provincia di Roma. Ass. LL.PP. Viab. E Trasp., Roma.

Ventriglia, U. (2002). *Geologia del territorio del Comune di Roma*. Amm. Prov. Di Roma, Servizio Geologico, Difesa del Suolo, Roma.

Wolf, L., Eiswirth, M., & Hotzl, H. (2006). Assessing sewer–groundwater interaction at the city scale based on individual sewer defects and marker species distributions. *Environmental Geology*, 49(849), 857. doi:10.1007/s00254-006-0180-x

Yang, Y., Lerner, D. N., Barrett, M. H., & Tellam, J. H. (1999). Quantification of groundwater recharge in the city of Nottingham, UK. *Environmental Geology*, 38(3), 183–198.