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HYDROGEOLOGICAL FEATURES OF THE MONTEVERDE HILL EASTERN SLOPE (ROME URBAN AREA, ITALY)

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EXTENDED ABSTRACT

Il presente studio è finalizzato alla definizione dell'assetto idrogeologico del versante sudorientale della collina di Monteverde, nel centro urbano di Roma (Italia). Le informazioni sull'evoluzione della circolazione idrica sotterranea nella suddetta area di limitata estensione potranno contribuire alla prevenzione degli effetti d'infiltrazioni idriche nei livelli interrati di alcuni fabbricati con una futura realizzazione di un efficace sistema di drenaggio delle acque sotterranee. L'area di studio è attualmente soggetta ad una potenziale residua pericolosità per instabilità di versante dovuta sia alle caratteristiche intrinseche dei terreni sia allo sviluppo urbano, avvenuto dall'inizio del XX secolo.

L'area di studio ricade in un'unità idrogeologica costituita da depositi sedimentari continentali e pre-vulcanici, in cui sono comprese le formazioni ghiaioso-sabbioso-limose di Ponte Galeria e Monte Mario. Quest'unità ha un complesso deflusso idrico sotterraneo che localmente si raccorda con i livelli piezometrici del Fiume Tevere. Per quanto riguarda il quadro meteoclimatico, la precipitazione media annua è di 728 mm. Inoltre, le medie mensili di precipitazione mostrano che i mesi più piovosi sono ottobre (100 mm) e novembre (109 mm), mentre il mese più secco è luglio (15 mm). L'analisi degli eventi piovosi evidenzia che, dal 1951 al 2015, l'indice d'intensità di pioggia ha una fase ascendente. Le precipitazioni intense o di lunga durata non sono relazionate ad aumenti dei livelli piezometrici locali, probabilmente per la presenza di diffuse superfici cementate e asfaltate ed in considerazione del fatto che i suddetti eventi contribuiscono prevalentemente al ruscellamento superficiale. L'analisi dei trend della temperatura dell'aria evidenzia un incremento dei valori medi, massimi e minimi.

L'assetto idrostratigrafico locale è stato definito (dall'alto verso il basso) come segue: 1) terreni di riporto, eterogenei, a volte saturi alla base, conducibilità idraulica 10^{-4}-10^{-5} cm/s; 2) sabbie giallo-ocra e ghiaie eterometriche con clasti calcarei, localmente sature alla base se in contatto con terreni poco permeabili, conducibilità idraulica 10^{-4} cm/s; 3) intercalazioni di argille beige e/o grigie e sabbie limoso-argillose beige, localmente sature, conducibilità idraulica 10^{-4}-10^{-6} cm/s per le sabbie e 10^{-7} cm/s per le argille; 4) argille grigie con intercalazioni di sabbie argillose grigie, a volte umide e plastiche.

I dati piezometrici distribuiti nello spazio non hanno consentito di definire un modello concettuale locale unitario. Comunque, dopo una valutazione di dettaglio, è stato possibile distinguere almeno due aree con differenti caratteristiche. La diversità più evidente riguarda la risposta dell'incremento dei livelli piezometrici nel tempo, probabilmente dovuta ad una diversa tipologia dei processi di ricarica dei livelli/lenti prevalentemente sabbiosi che ospitano le acque sotterranee. Nonostante l'eterogeneità spaziale e la variazione temporale delle condizioni di flusso idrico sotterraneo, i dati stratigrafici e idrogeologici raccolti hanno permesso di ricostruire, attraverso l'elaborazione di alcune sezioni verticali interpretative, l'assetto idrogeologico e idrostrutturale locale: 1) sono presenti vari corpi acquiferi a differenti quote e con differenti livelli piezometrici di riferimento nella Formazione di Monte Mario (spessore circa 1-3 m) e nei terreni di riporto (spessore circa 1-6 m), sospesi su depositi limoso-sabbioso-argillosi; 2) la paratia di pali realizzata nella parte più bassa di Via Saffi lungo Via Dall'Ongaro costituisce una barriera (semi)permeabile per il flusso idrico sotterraneo e induce livelli piezometrici con quote di 47-55 m s.l.m. nel settore a monte e di 24-39 m s.l.m. in quello a valle della paratia; 3) si sono riscontrati livelli piezometrici ancor meno elevati (circa 13-15 m s.l.m.) andando verso i depositi alluvionali del Fiume Tevere; 4) alcune sorgenti locali alimentate dalle acque presenti nei terreni di riporto sono state rilevate alla base del versante in Via Sterbini, in corrispondenza di Via Dall'Ongaro ed in prossimità della parte inferiore della scalea di Via Bassi.

Le analisi chimiche degli elementi maggiori delle acque hanno permesso di classificarle come bicarbonate, anche se, rispetto ai contenuti in cationi, sono state evidenziate differenze tra le acque del locale acquedotto, alcaline con relativa abbondanza di K, e quelle delle sorgenti dell'area di studio, alcaline con prevalente Ca. La presenza di ingenti perdite idriche dalla rete acquedottistica sembra quindi da potersi escludere. Le acque prelevate dai piezometri, invece, mostrano valori distribuiti in un più ampio intervallo rispetto a quelli delle acque sorgive, in accordo con un probabile arricchimento in molti degli elementi chimici analizzati durante il percorso di deflusso sotterraneo verso i livelli/lenti acquiferi locali. Un tentativo di valutazione del bilancio idrogeologico, considerando la sola area di ricarica locale di circa 5-10 km^2, ha portato alla valutazione di un deficit d'infiltrazione efficace (circa -400 mm/a). Questo induce a considerare un contributo di acque sotterranee provenienti da acquiferi contigui e da aree di ricarica situate nei limitrofi rilevi vulcanici.

ABSTRACT

The study area is located in the Monteverde Hill, urban area of the Rome City (Italy). Gravelly-sandy-silty geological formations outcrop in it.

The aim of the present study was to outline the local groundwater circulation for contributing to accomplish a drainage system for preventing water infiltration in building basements.

Local hydrogeological setting is very fragmented. The stratigraphical, hydrogeological, hydrochemical and piezometric data evidenced the presence of deep saturated sandy levels/lenses, saturated covering excavation soils and shallow mostly unsaturated gravelly/sandy horizons.

The main recharge processes of groundwater-bearing bodies are due to direct infiltration from surrounding recharge areas and lateral drainage towards sandy lenses/levels. Two main sectors displaying different reference piezometric heads (about 47-55 in up-hill sector and 24-39 m a.s.l. in down-hill) were evidenced, due to presence of a soil retaining wall acting as a (semi)permeable divide in the middle of the study area. A further lower piezometric head interval (about 13-15 m a.s.l.) was at the base of the slope. All waters may be classified as bicarbonate waters.

Strong or long-lasting rainfall did not evidently affected groundwater heads, likely because of diffuse cemented/asphalted paved surfaces.

The hydrogeological budget evaluation of the study area suggested groundwater contributions from adjacent aquifers.

Keywords: *hydrogeology, groundwater monitoring, urban groundwater, Rome (Italy)*

INTRODUCTION

The study area is located in the city center of Rome (Italy), along the southeastern slope of the Monteverde Hill (Fig. 1), between Saffi and Bassi Streets, facing Nievo Square (Fig. 2) along the well known Trastevere Boulevard. This slope sector was in the past prone to landslide processes, the most remarkable in 1963 (e.g., Corazza *et alii*, 2002; Amanti & Catalano, 2011) and nowadays, after a general stabilization of the slope carried out during 1984-85, only a minor residual landslide hazard is expected (e.g., Corazza *et alii*, 2002; Amanti & Catalano, 2011). The main causes of this situation are connected to the local lithostratigraphical and hydrogeological features and to the sprawl of urban settlements realized from the beginning of the XX Century.

The aim of the present study was (i) to carry out a summary of the previous hydrogeological knowledge, (ii) to define the local groundwater circulation features and to provide the outlines of their evolution with time, (iii) to investigate by direct surveys the effects on groundwater infiltration at basement and ground levels of some buildings and on residual slope instability. The latter aspect and the related geotechnical investigations will be the subject of a further dedicated paper. The study of this little study area was carried out as a contribution to the realization of a more efficient drainage system for preventing water infiltrations at the cited building basement level.

Groundwater monitoring surveys in urban areas are critical issues for defining (i) the interactions between urban hydrogeology features and existing infrastructure and buildings and, consequently, (ii) the activities that have to be actuated for a sustainable management of many city life risks related to, among others, landslides, subsidence, flood and drought events, water supply and sewage requirements. Then, in the last decades, the awareness to specific approach for hydrogeological surveys aimed at defining pollution, protection, management, sustainability, recharge and climate change aspects related to urban groundwater was developed (e.g., Foster *et alii,* 1993; Chilton, 1999; Barrett, 2004; Zaadnoordijk *et alii*, 2004; Zhang *et alii*, 2004; Foster, 2009; Vazquez-Suñe *et alii,* 2010; Shirmer *et alii,* 2013). The aim was to face the frequent difficulties to interpret meaningfully the obtained data on urban groundwater, mainly due to large spatial heterogeneity and temporal fluctuations of flow conditions.

Comprehensive studies on geological setting and groundwater circulation of Roman area are available from the beginning of XX Century (e.g., De Angelis D'Ossat, 1905; Fossa Mancini, 1922; Frosini, 1931). At that time, the study area was depicted as a suburban-rural district with subordinate groundwater resources connected to local short flow pathways and cropping out as small springs used for rural purposes. The local urban sprawl during the following years led the necessity of the realization of more in-depth studies (e.g., Lombardi, 1966; Albani *et alii,,* 1973; Corazza *et alii,,* 1989; Ventriglia, 1990; Corazza & Lombardi, 1995; Corazza *et alii,,* 2002; Ventriglia, 2002; Capelli *et alii,,* 2008; La Vigna & Mazza, 2015; La Vigna *et alii,* 2015; La Vigna *et alii,* 2016).

As a result, in the last years hydrogeological studies on the investigated area were mainly aimed to contribute to the characterization of some landslide and groundwater related hazard assessment and risk mitigation (e.g., Leone, 1986; Sciotti, 1986; Amanti *et alii,* 1995; Corazza *et alii,* 2002; Amanti *et alii,* 2008; Amanti & Catalano, 2011). Also the hydrogeological surveys carried out during the present research contributed to that by the employment of opportune selected conventional methodologies of study (in particular by a meteoclimatic, piezometric and hydrochemical approach) to the Monteverde Hill urban area case study.

MATERIALS AND METHODS

Geological, hydrogeological and geomorphological settings

The study area is located in the lower part of the Gianicolo Hill, in the ancient quarter of Monteverde. The elevation of the area is between 30 and 70 m a.s.l. and it is about 400 meters far-away from the right bank of the Tiber River. The southwestern

Roman region lithostratigraphical outline and the study area and surroundings hydrogeological map are both sketched in Fig. 1.

Four main hydrogeological units may be distinguished in the Roman area (e.g., Capelli *et alii*, 2008; La Vigna *et alii*, 2015; La Vigna *et alii*, 2016). They are, from bottom to top (Fig. 1):

- the pre-volcanic and continental sedimentary deposit hydrogeological unit (corresponding to the lower part of the sedimentary/volcanic lithostratigraphical unit; Lower-Middle Pleistocene);
- the Sabatini Mts and Alban Hills hydrogeological units, composed of volcanic deposits (corresponding to the upper part of the sedimentary/volcanic lithostratigraphical units; Middle-Upper Pleistocene);
- the recent and actual alluvial deposit hydrogeological unit (alluvial lithostratigraphical unit; Upper Pleistocene-Holocene);
- the Tiber river delta hydrogeological unit, constituted of alluvial deposits (Tiber river delta and heterogeneous clastic lithostratigraphical unit, not occurring in the study area; Upper Pleistocene-Holocene).

The basal aquiclude and low permeability deposits (lowest part of the sedimentary/volcanic lithostratigraphical unit; Lower-Upper Pliocene to Lower Pleistocene) are mainly represented by gray/beige clay and fine sand of the Monte Vaticano Formation (Gelasian *p.p.*-Zanclean *p.p.*; marine environment; Amanti & Catalano, 2011) and of the lower part of the Monte Mario Formation (Santernian *p.p.*; transitional environment) and generally constitutes the hilly relief outline (Corazza *et alii*, 2002) and the top surface of the basal aquiclude. Other medium-low permeability deposits are mainly represented by gravelly-sandy-silty or sandy-clayey anthropogenic excavation soils (Amanti & Catalano, 2011; not distinguished in Fig. 1).

The pre-volcanic and continental sedimentary deposit hydrogeological unit incorporates the upper part of the Monte Mario and the Ponte Galeria formations (Capelli & Mazza, 2005; Capelli *et alii*, 2008; La Vigna *et alii*, 2015; La Vigna *et alii*, 2016). This unit shows a complex groundwater flow that locally joins up with the Tiber River piezometric heads and, at an extended

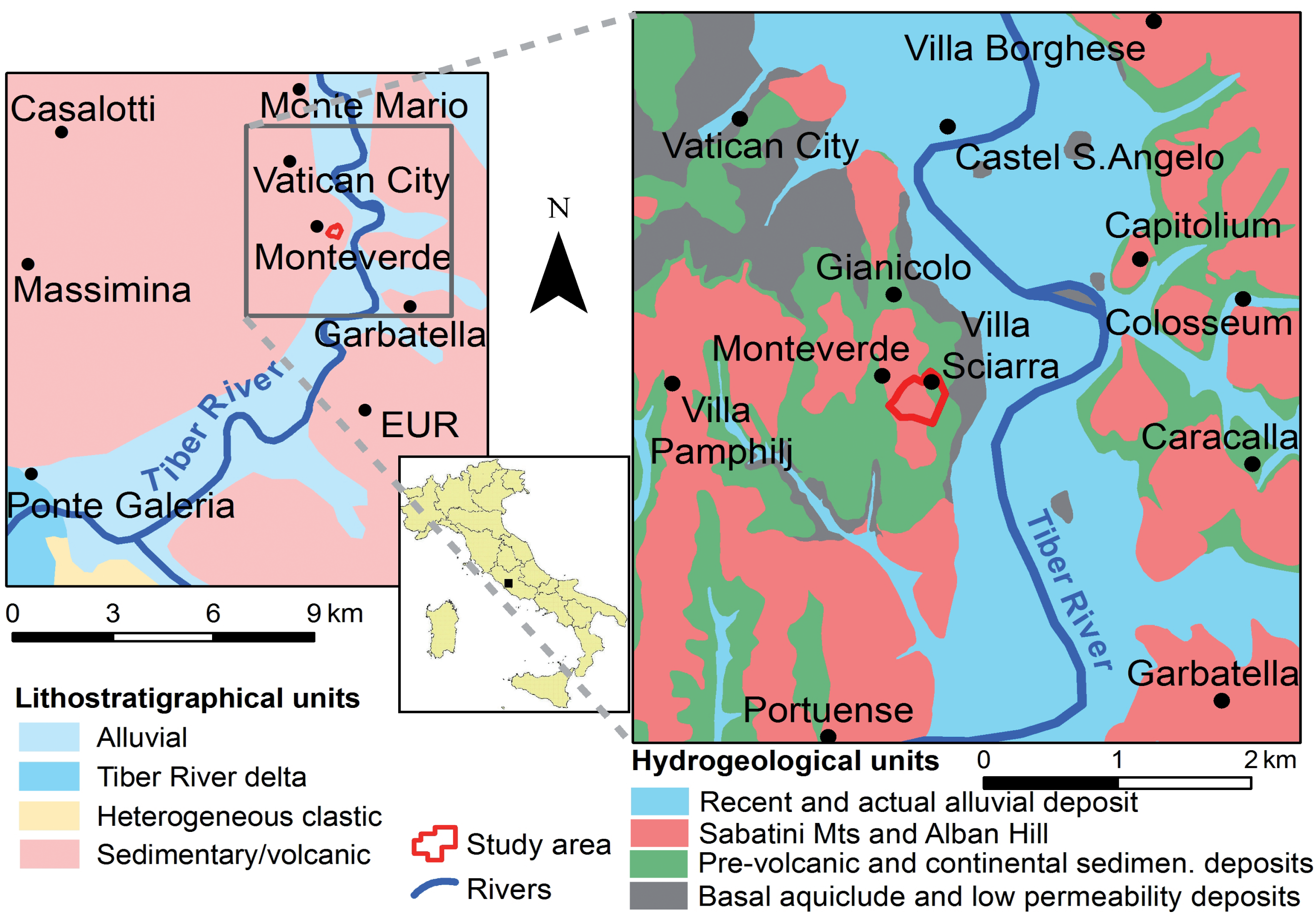

Fig. 1 - Broadly sketch maps of the lithostratigraphical units of the southwestern Roman area (left) and of the hydrogeological units of the study area and surroundings (right). The study area location (black box) in the Italian territory context is also shown

scenario, with the Aniene River and the Tyrrhenian Sea. The upper part of the Monte Mario Formation is composed of sand with sandstone and bioclastic (panchina) intercalations of transitional brackish environment (Lower Pliocene; Santernian p.p.; Amanti & Catalano, 2011) in unconformity contact on the former clays and may reach more than 15 m of thickness (Corazza *et alii*, 2002). The Ponte Galeria Formation is constituted of beach gravel and quartz sand of transgressive environment (Monte Ciocci Unit; Lower-Middle Pleistocene; Amanti & Catalano, 2011) and shows a thickness of less than 10 m (Corazza *et alii*, 2002).

According to the investigations by Leone (1986), two probable aquifers have been delineated in the Monteverde hill area. The first one is hosted in covering formations constituted of excavation soils where during abundant rainfall the identification of an aquifer is probable. But, due to its high permeability and slope of bedrock, the aquifer drains toward downslope and dries in little time. The second one is hosted in the sandy horizons ascribed to the Monte Mario Formation (hydraulic conductivity between $7.8 \cdot 10^{-5}$ and $8.6 \cdot 10^{-6}$ cm/s; Leone, 1986) overlaying the Pliocene impermeable clayey formation ($2 \cdot 10^{-8}$ cm/s; Leone, 1986). This perennial aquifer feeds little springs now mostly disappeared because of the reduction of their recharge areas by urban sprawl or since they were covered by excavation soil layers. Therefore, the recharge areas of this aquifer are actually out of the study area and some water infiltrates from the overlaying detritic aquifers (Corazza *et alii*, 2002).

A recent hydrogeological map of the isopotential surface of the local groundwater has been reported by Provincia di Roma (2006). A water delivery toward Nievo Square, along Trastevere Boulevard, converging to a spring behind the Sterbini Street soil retaining wall, has been evidenced. It was recognized that, in this SW sector of the slope, relatively high amount of groundwater are hosted within the excavation soils filling up an ancient paleovalley. This groundwater flow causes water infiltrations in basements and garages of some buildings in contact with these soils.

As a whole, most recent investigations, including those from the present study, assessed that the local hydrogeological setting is very complex and fragmented and a clear delineation of aquifer thickness and heads still needs a better definition in detail.

As concerns the main anthropogenic land modifications, they

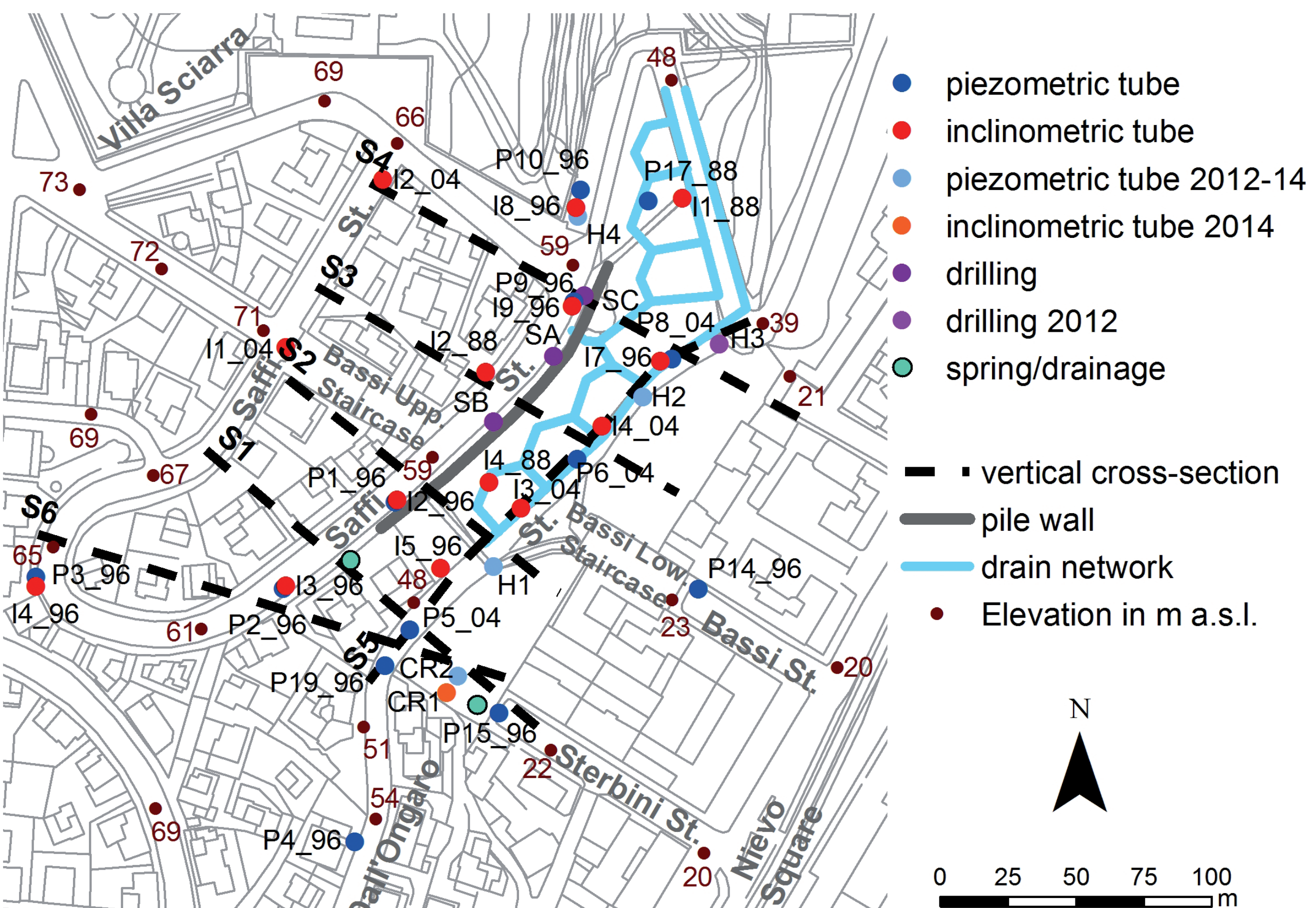

Fig. 2 - Sketch map of the study area showing control point, vertical cross-section and previously realized stability and draining work locations

are due to the urban sprawl occurred in the study area from the beginning of XX century (Leone, 1986). Urbanization process leads to realization of excavations, leveling and artificial soil overloads. Landslides in the study area are documented just from the beginning of XX century and in 1963 there was the most harmful event which caused damages to soil retaining walls, road network and sewers (e.g., Leone, 1986; Amanti & Catalano, 2011). As a whole, in the study area, landslides are mainly related to slope reshaping works, soil overloads and surface and groundwater flows and they happened after huge rainfall periods (Leone, 1986). Many consolidation works were realized with time. The most important was the construction of a pile retaining wall and a groundwater draining system between Saffi and Dall'Ongaro streets in 1984-1985 (Amanti & Catalano, 2011). The stabilization of the Saffi Street high-slope area was obtained by that work. In any case, an inclinometric survey actuated from 2005 to 2009 evidenced that small residual superficial landslide movements generally connected to rainfall events are still active in the down-slope area (Amanti & Catalano 2011).

Meteoclimatic data

Geomorphological evolution, hydrogeological characteristics and slope stability also depend on geological and climatic features. Therefore, the meteoclimatic outline of the metropolitan area of Rome was reconstructed.

Meteoclimatic data were collected from the Hydrological Annals of the Lazio Region (Regione Lazio - U.I.M., 2015). Among others, two available pluviometric stations have been selected for the characterization of the study area: 1) Rosolino Pilo (in the Monteverde Hill, very close to the study area, about 0.5 km); 2) Collegio Romano (in the Rome downtown, about 2-2.5 km). The second one has been selected due to completeness and length of time series (monthly data from 1921 to December 2015; daily records from 1951 to 2015). In any case, as a general consideration, the local meteoclimatic gauging stations display similar occurrence time of rainfall events, which differs one another only as concerns relative peak intensities.

For detecting trends in the time series, tests of significance with the widely used non-parametric method of Mann-Kendall (MK; Kendall *et alii*, 1983; Sneyers, 1990) were conducted. In MK test the null hypothesis, H_0, is that the time series does not contain a significant trend; this test is applicable to the detection of a monotonic trend of a time series with no seasonal or other cycle (Von Storch, 1995; Zhang *et alii*, 2001). Finally, for estimating the linear trend slope (the rate change), the Sen's method (Sen, 1968) was applied.

Rainfall time distribution is important for activation of landslide processes and then rainfall event analysis was conducted. The ETCCDI (Expert Team on Climate Change Detection and Indices of the CCL/CLIVAR Working Group on Climate Change Detection; www.clivar.org) indexes were used to describe the extremes of temperature and precipitation in respect of frequency, intensity and duration. In particular, regarding precipitation, the following indices were considered:

- rainfall intensity index (SDII), representing the ratio of annual cumulated precipitation to the number of days with rainfall≥1mm;
- R10 index, expressing the number of heavy precipitation (≥10 mm) days;
- R20 index, expressing the number of very heavy precipitation (≥20 mm) days.

The first index gives information on the evolution of extreme precipitation; the last two, being defined by a fixed threshold value, describe the intensity variation of the phenomena that may trigger any landslides.

With respect to the annual temperature data, they are available from the Collegio Romano thermometric station.

Piezometric and hydrochemical data

Preliminary field surveys have been carried out in order to find the available monitoring points (piezometer and inclinometer tubes) realized in the study area during previous investigations (about 35 points in total; Fig. 2).

The reactivation of the existing piezometers, some of which about 20 years old, was opportunely considered since there was availability, from scientific papers and/or from technical documents, of information concerning year of completion, original depth of the piezometers and stratigraphical log description. A monograph for each piezometer was compiled. Special attention was paid to any permanent or temporary obstructions eventually occurred and to assessment of their conservation status in order to evaluate their reliability for readings.

Four drillings (three of which equipped with a open slotted tube piezometer) and two drillings (one of which equipped with a open slotted tube piezometer) (Fig. 2) were executed in November 2012 and in November 2014, respectively, in order to verify the hydrostratigraphical still unclear features in some specific locations.

The data collected by a following long term monitoring activity have been organized as a hydrogeological database and migrated to a GIS, in order to support graphic and mapping elaborations. The whole of stratigraphical and hydrogeological data has allowed the reconstruction of the local hydrogeological asset and the realization of 2D interpretative cross-sections of the study area. Some geological elements (e.g., tectonic elements) have not been considered in detail for the hydrogeological models realization, since most of them have a subordinate role with respect to the groundwater flow circulation at the study area scale.

In situ hydrochemical analyses (temperature, electrical conductivity and pH) of waters were conducted on samples collected at several points. Furthermore, major element analyses of different typology of waters from selected control points of the study area have been conducted in February 2013.

RESULTS

Meteoclimatic outline

The annual average rainfall is 728.4 mm. The over time change of the annual cumulated rainfall (Fig. 3) has been put in relation to both the average and the 10th order moving average contours. The oscillation around the average shows variable periods and, particularly from '80s to 2000, the annual cumulated precipitation remained below average value; then, from 2010 has risen again above the average line.

The average monthly rainfall data (reference period 1951-2015) shows that the wettest months are October (100.4 mm) and November (109.0 mm), while the driest month is July with 15.2 mm.

The trend analysis conducted by the MK test on data collected from 1921 to 2015 at the Collegio Romano Station, does not show a significant trend, with the exception of July, which shows a positive slightly significant trend.

From 1951 to 2015, the rainfall intensity index SDII (Fig. 4) oscillates around the mean and in recent years displays an ascending phase.

The R10 index trend (Fig. 5a) shows in recent years an increase in intense events, while the very intense events (R20) do not record a sharp increase (Fig. 5b).

With respect to air temperatures, trend analysis highlights a significant increase in average, maximum and minimum values. In particular, maximum temperature trends are significant in January, March, June, August and November, while minimum ones are in February, May, June and August. The temperature anomaly trend (expressed as deviation from 1951-2015 mean value; Fig. 6) has been compared to the annual average temperature: until the beginning of the '80s, values are below average but from the second half of 90's values are constantly increasing.

Piezometric monitoring activities

Groundwater level variations have been compared with rainfall amounts registered in the same period (last 4 years) in order to verify a possible correlation between them. Specifically, the Pearson correlation coefficient between cumulated rainfall at Collegio Romano control station and piezometric head variations have very low (-0.05 to 0.18; piezometers P6_04, P3_96, P5_04b and P19_96) to low values (0.33 to 0.55; H2, P10_96a, CR1, P5_04a, H4, H1 and P9_96a), thus indicating the two parameters are not directly correlated.

Stratigraphical information on drillings at control point locations from previous studies in the investigation area were collected and as well discussed in order to match groundwater level and local geological context.

DATA COLLECTED FROM EXISTING CONTROL POINTS

A first evaluation of the reliability of the control points

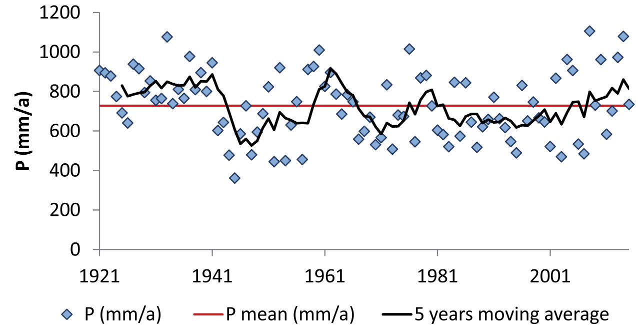

Fig. 3 - Annual mean rainfall (P) in relation to the average (red line) and the 5 years moving average curve (black polyline). Reference period 1921-2015

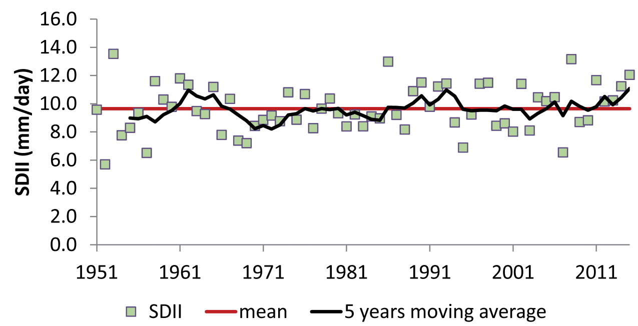

Fig. 4 - Rainfall intensity index (SDII) trend. Reference period 1951-2015

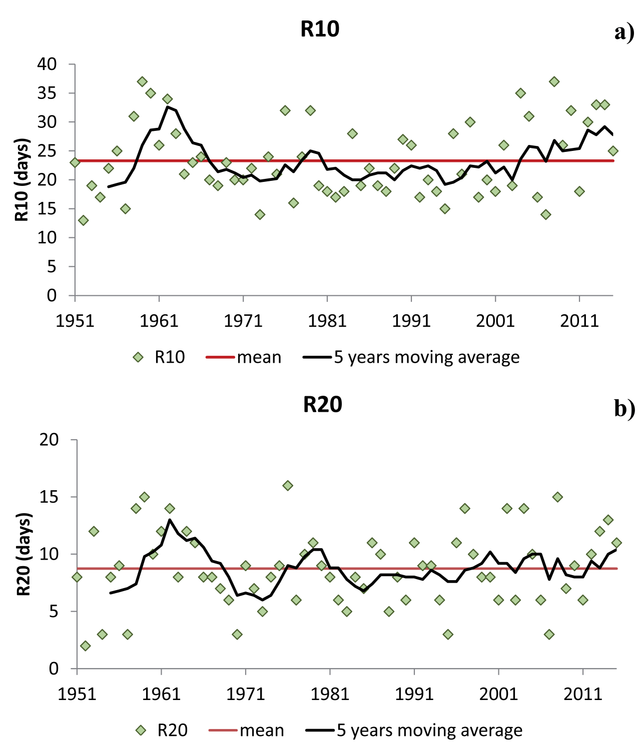

Fig. 5 - R10 index (a) and R20 index (b) trends. Reference period 1951-2015

realized during previous studies was done after the field surveys conducted till March 2012. The water level variations at the inclinometer tubes and in one piezometer (P8_04) did not evidence relations neither with adjacent control points nor with rainfall amounts and therefore they were excluded from the next monitoring surveys. Then, the monitoring activities continued in the remaining 15 piezometers.

A second verification of the control point reliability was done at the end of December 2012 and leads to the exclusion of some Casagrande piezometers which displayed significant different water levels between the two corresponding tubes (P9_96b, P4_96a, P5_04b).

The water level data of the control points recognized as reliable were finally validated (Tab. 1) and then they were ready

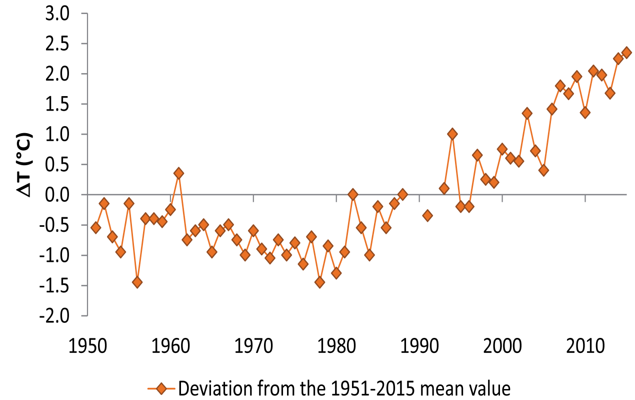

Fig. 6 - Annual temperature anomaly trend. Reference period 1951-2015

Piezometer ID	P3_96	P5_04a	P5_04b	P6_04	P9_96a	P10_96a	P19_96	H1	H2	H4	CR1
Ground level elevation (m a.s.l.)	64.88	48.44	48.44	42.45	58.95	61	48.44	47	42	61	40.27
Total depth (m)	16.4	15.5	20.8	14.2	11.5	12.5	14.8	14.0	21.0	13.0	9.0
Typology C = Casagrande OT = Open slotted tube	C	OT	C	C	C	C	OT	OT	OT	OT	OT
29/05/2012	52.65	38.65	34.88	31.74	48.66	-	38.63	-	-	-	-
12/06/2012	52.64	38.50	34.85	32.80	48.43	-	38.60	-	-	-	-
06/07/2012	52.56	38.44	34.79	30.96	48.17	-	38.56	-	-	-	-
18/07/2012	52.99	38.43	34.78	30.85	48.11	-	38.56	-	-	-	-
31/07/2012	53.78	38.78	34.95	30.82	47.99	-	38.91	-	-	-	-
07/09/2012	54.24	39.24	35.24	30.95	48.16	-	39.35	-	-	-	-
21/09/2012	54.28	39.23	35.22	30.92	48.45	-	39.34	-	-	-	-
05/10/2012	54.36	39.25	35.27	31.11	48.32	-	39.33	-	-	-	-
18/10/2012	54.40	39.26	35.28	31.30	48.49	-	39.34	-	-	-	-
30/10/2012	54.47	39.26	35.33	31.15	48.64	-	39.36	-	-	-	-
16/11/2012	54.50	39.28	35.44	31.03	48.37	51.00	39.38	34.35	24.09	-	-
27/11/2012	54.36	39.16	35.34	30.93	48.21	50.87	39.36	34.35	23.88	49.72	-
13/12/2012	54.40	39.16	33.45	31.17	48.53	51.01	39.31	34.51	25.26	49.81	-
04/01/2013	54.44	39.19	35.34	29.60	48.21	50.92	39.30	34.66	25.16	49.72	-
25/01/2013	54.50	39.25	33.64	31.24	48.39	51.02	39.38	34.76	25.61	49.78	-
20/05/2013	54.70	39.27	35.55	31.27	48.30	51.25	39.45	34.81	25.80	50.06	-
18/07/2013	53.90	39.26	35.59	31.07	48.30	51.04	39.42	34.52	25.33	49.89	-
17/10/2013	52.70	38.74	35.31	30.88	48.28	50.93	38.80	34.11	24.80	49.82	-
06/02/2014	53.67	39.06	35.68	31.80	49.13	51.83	39.15	36.01	27.22	50.54	-
30/04/2014	52.77	38.83	33.66	31.41	48.33	50.98	38.87	34.72	26.21	49.89	-
01/08/2014	52.64	37.57	33.74	31.08	48.57	50.94	38.75	34.28	25.22	49.82	-
21/10/2014	52.59	38.64	35.26	30.88	48.33	50.81	38.64	34.03	24.68	49.71	33.85
11/02/2015	52.65	38.50	35.54	31.36	48.80	51.03	38.79	34.90	25.82	49.89	33.90
23/04/2015	52.62	38.50	35.51	31.67	48.22	51.00	38.75	34.77	26.02	49.82	33.87
02/09/2015	52.49	38.46	35.22	30.80	47.95	50.70	38.61	33.79	24.18	49.62	33.80
27/11/2015	51.60	38.61	35.35	31.84	48.26	50.60	38.62	34.78	24.74	49.74	33.87
max	54.70	39.28	35.58	32.80	48.80	51.83	39.45	36.01	27.22	50.54	33.90
min	51.60	37.57	33.45	29.60	47.95	50.60	38.56	33.79	23.88	49.62	33.80
max-min	3.10	1.71	2.13	3.20	0.85	1.23	0.89	2.22	3.34	0.92	0.10

Tab. 1 - Representative groundwater level elevation (m a.s.l.) in previous reliable and new control points (data from May 2012 to recent were selected).

Name of Formation	Summary description	Reference thickness (m)	Reference depth of saturated levels (m from ground level)
Excavation soil	Silty-sandy soil with heterogeneous embeddings	3÷9	6÷9
Ponte Galeria Formation	Yellow-orange silty sand/gravel locally cemented	0÷7	
Monte Mario Formation	Ochre silty sand with sandy-silty intercalated layers	5÷14	11÷12 13÷14 20÷21
Monte Vaticano Formation	Gray silty clay with sandy intercalated layers	at least 2÷11	

Tab. 2 - Summary of the lithostratigraphical succession inferred from drilling information obtained during present work (boreholes H1, H2, H4 and CR1) in the study area

to be compared with rainfall data.

DATA COLLECTED FROM NEW CONTROL POINTS

The information coming from new drillings (H1, H2, H4 and CR1; Tab. 1 and Tab. 2) is mainly consistent with previous one and allowed to have a direct view of the subsoil lithostratigraphical succession, confirming the presence of saturated sandy levels/lenses and excavation soils with limited seasonal head excursion in the deeper levels and mostly unsaturated gravelly/sandy upper horizons.

Hydrochemical investigations

Table 3 shows the results of in situ hydrochemical analyses,

Control point	Cropping out elevation (m a.s.l.)	Date	Electrical conductivity (µS/cm)	pH	Temperature (°C)
Fountain in the upper side of Bassi Staircase	-	30/09/2011	567	7.56	15.1
		13/12/2012	619	7.72	11.4
		12/02/2013	637	6.55	11.4
Monumental fountain at Garibaldi Street, down side San Pietro in Montorio monastery	-	10/11/2011	581	7.65	12.9
Tap water at 30 Dall'Ongaro Street building	-	12/02/2013	628	7.22	10.5
Tap water at a flat of 30 Dall'Ongaro Street	-	12/02/2013	628	6.90	12.7
Spring at Sterbini Street	28	30/09/2011	748	7.84	18.1
		21/11/2011	760	7.94	14.5
		18/04/2012	756	8.42	17.9
		18/10/2012	811	8.40	18.0
		13/12/2012	783	8.49	14.2
		12/02/2013	773	7.22	14.7
Draining water at 30 Dall'Ongaro Street basement	45	12/02/2013	1022	7.35	13.0
Groundwater at Ponziano Catacomb (Poerio Street)	52	12/02/2013	638	6.80	16.9
Cropping out water at Santuario Siriaco (Dandolo Str.)	45	12/02/2013	955	6.88	11.0
Water capture at VillaSciarra, Dandolo Street entrance	45	12/02/2013	890	6.50	15.8
Draining water at the base of Saffi Street retaining wall	-	10/11/2011	656	8.15	19.3
Piezometer P5_04 (open slotted tube, Dall'Ongaro Str.)	-	21/09/2012	834	7.41	18.0
		13/12/2012	781	7.53	15.9
		12/02/2013	541	6.70	14.5
Piezometer H1 (open slotted tube, Dall'Ongaro Str.)	-	13/12/2012	822	7.90	16.3
		12/02/2013	1112	6.70	13.5
Piezometer H2 (open slotted tube, Dall'Ongaro Str.)	-	13/12/2012	770	10.50	15.6
		12/02/2013	354	9.60	15.8
Piezometer H4 (open slotted tube, Saffi Street)	-	13/12/2012	938	7.49	15.7
		12/02/2013	888	6.50	16.8
Inclinometer tube I1_88 (Saffi Street)	-	13/12/2012	319	7.85	15.1
		12/02/2013	282	7.20	15.0
Inclinometer tube I1_96 (Saffi Street)	-	13/12/2012	477	7.09	16.9
Inclinometer tube I8_96 (Saffi Street)	-	13/12/2012	537	7.70	15.1
Inclinometer tube I4_04 (Dall'Ongaro Street)	-	13/12/2012	265	8.39	16.4
Inclinometer tube I7_96 (Dall'Ongaro Street)	-	13/12/2012	187	8.50	15.5

Tab. 3 - In situ hydrochemical data of waters from study area and adjacent sectors) while Table 4 displays the results of major element contents of different typology of waters from selected control points of the study area (tap waters from public network at buildings and fountains were analyzed in order to have elements for excluding leakage of these waters towards local groundwater). They are in general agreement with the previous information and evidence some feature in detail.

DISCUSSION

Lithostratigraphic and hydrostratigraphical successions

Subsoil lithological information from drillings realized in the investigated area during the present (Tab. 2) and previous studies have been used for the reconstruction of the local lithostratigraphical succession. This information has been compared, discussed and then simplified for outlining lithostratigraphical models suitable for hydrostratigraphical purposes. Then, four main hydrostratigraphical units have been defined (from top to bottom):

- excavation soil, heterogeneous, only locally saturated, hydraulic conductivity 10^{-4}-10^{-5} cm/s (e.g., Leone, 1986; this paper), intermediate-low relative permeability degree (not distinguished in Fig. 1);
- sand, including yellow-ochre sand and heterometric gravel with calcareous clasts, locally saturated at the base contact with less permeable deposits (silty±sandy ochre/beige clay), hydraulic conductivity 10^{-4} cm/s (e.g., Leone, 1986; this paper), intermediate relative permeability degree (Ponte Galeria Formation p.p. and Monte Mario Formation p.p.; pre-volcanic and continental sedimentary deposit of Fig. 1);
- sand and clay intercalations, composed of beige/gray clay with beige silty-clayey sand, up to about 1 m of thickness, locally saturated, hydraulic conductivity 10^{-4}-10^{-6} cm/s for sands and 10^{-7} cm/s for clays (e.g., Leone, 1986; this paper), low relative permeability degree (Monte Mario Formation *p.p.*; upper part of basal aquiclude and low permeability deposits of Fig. 1);
- clay, constituted of gray clay with gray clayey sand intercalations, sometimes wet and plastic, very low relative permeability degree (Monte Vaticano Formation p.p.; lower part of basal aquiclude and low permeability deposits of Fig. 1).

Piezometric heads

The collected groundwater levels allow the identification of a seasonal high-level situation during February-March and a low-level one in September-November, even if not all control points closely fit with them in extent and time. The groundwater level annual variations are generally within 1.2 m (excluding some piezometers showing 1.7-3.3 m of variation).

It is possible to stress that correlation between groundwater level variations and rainfall distribution with time is very slight

Control point	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl
Piezometer H1 (open slotted tube, Dall'Ongaro Street)	101	28.7	73.3	20.8	486	bdl	83.0	67.3
Piezometer H2 (open slotted tube, Dall'Ongaro Street)	23	bdl	24.1	19.9	87	34.2	32.8	19.2
Piezometer H4 (open slotted tube, Saffi Street)	125	22.6	44.5	7.3	414	bdl	50.4	45.8
Piezometer P5_04 (open slotted tube, Dall'Ongaro Street)	50	6.1	16.3	17.1	270	bdl	11.6	13.9
Inclinometer I1_88 (Saffi Street)	34	2.6	13.8	15.5	110	bdl	9.8	13.8
Spring at Sterbini Street	112	16.7	33.7	8.0	391	bdl	39.1	29.0
Draining waters at 30 Dall'Ongaro Street basement	114	17.8	46.4	11.1	407	5.0	54.2	66.9
Water capture (VillaSciarra, Dandolo Street entrance)	127	19.1	40.1	18.6	458	bdl	53.0	44.1
Groundwater at Ponziano Catacombs (Poerio Street)	73	17.7	31.8	15.3	304	bdl	44.7	30.0
Public fountain at the upper side of Bassi Staircase	107	20.3	5.8	1.2	404	bdl	21.9	8.0
Tap water at 30 Dall'Ongaro Street building	104	19.5	5.2	1.9	397	bdl	18.2	6.7

Tab. 4 - Major element contents of waters from the study area (contents in ppm; samples collected on 12th February 2013; bdl= below detection limit)

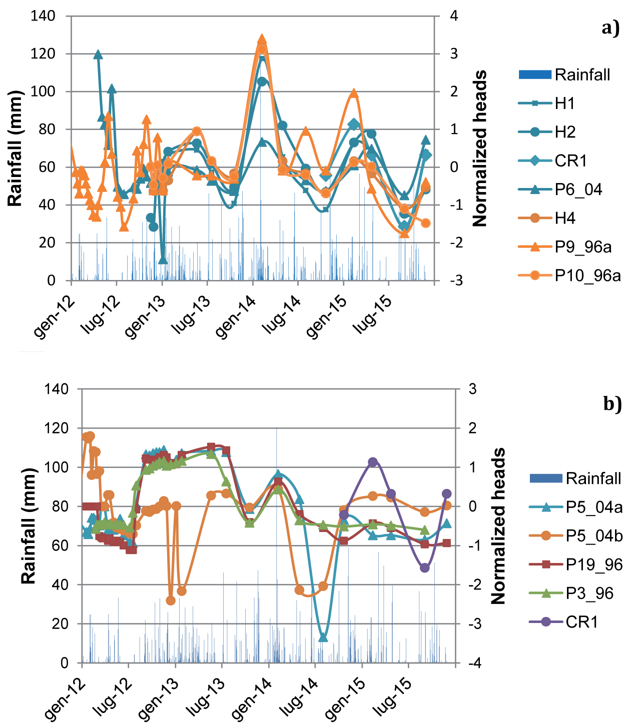

Fig. 7 - First (7a, upper plot; blue and orange colors refers to the two location sector defined) and second (7b, lower plot) piezometer groups distinguished after comparison among groundwater level data (January 2012 to recent) standardized to mean values collected at selected control points

Date	Duration (days)	Total rainfall (mm)	Max rainfall in one day (mm)
31/01-05/02/2012	6	77	25
13-14/04/2012	2	42	25
21-22/05/2012	2	51	33
02-05/09/2012	4	52	22
12-15/10/2012	4	47	31
28/11-02/12/2012	4	81	26
13-17/01/2013	5	55	33
06-07/02/2013	2	32	28
06-08/07/2013	3	52	46
21/07/2013	1	22	22
25-28/08/2013	4	69	42
29-30/09/2013	2	29	28
02-05/11/2013	4	62	33
15/11/2103	1	25	25
18-24/11/2013	7	144	47
02-06/01/2014	5	27	23
29/01-12/02/2014	15	250	120
19-20/04/2014	2	32	32
02-03/05/2014	2	36	27
14-19/06/2014	6	117	46
01-04/10/2014	4	52	37
06-07/11/2014	2	103	59
29/11-07/12/2014	9	75	24
29/01-07/02/2015	10	91	23
04-06/03/2015	2	70	57
25/03/2015	1	50	50
27-29/04/2015	3	71	40
10-11/08/2015	2	41	37
19/08/2015	1	26	26
04-05/09/2015	2	46	26
09-10/10/2015	2	55	51

Tab. 5 - Strong (>20 mm) or long-lasting rainfall data (January 2012-November 2015) from Rosolino Pilo meteoclimatic control station

and delayed or even not evident (e.g., P5_04a, P19_96 and P3_96 piezometers: Fig. 7b). It is also evident that strong or long-lasting rainfall (Fig. 7 and Tab. 5) did not evidently caused increasing of groundwater levels. The relatively small distance from likely recharge areas (Villa Sciarra, Gianicolo and/or Villa Doria-Pamphilj; e.g. Corazza *et alii*, 2002) is not consistent with the previously observed long time response delay, which is likely induced by direct sewing of meteoric waters and occurrence of cropping out of intermediate-low permeability soils. Furthermore, the presence of diffuse cemented and asphalted paved ground surfaces and the soon saturation of soil after these strong events generally trigger high runoff amounts.

The survey of groundwater level variations with time has allowed the understanding of the local hydraulic head field and the related differences with time and space were discussed. The relative scattered differences of piezometric heads also among quite adjacent control points throughout the study area outline a complex groundwater flow situation. This was confirmed by the evident both horizontally and vertically hydraulic conductivity spatial variations observed during previous and recent geognostic drilling activities.

Furthermore, sand layers are in general at least partially saturated and a marked piezometric lowering between high and low seasonal levels has been evidenced in the NE sector of Dall'Ongaro Street, likely due to drying effect of groundwater draining network (Fig. 2) realized during 1980s, which induces a soon decreasing of piezometric heads.

The former evidences are consistent with the complex hydrogeological scenario suggested by many Authors (e.g., Provincia di Roma, 2006; Succhiarelli & D'Ottavio 2008; Capelli *et alii*, 2008; La Vigna *et alii*, 2015) likely due to occurrence of distinct levels/lenses saturated in various extents and then having different hydraulic heads, as revealed by the present study. Then, the reconstruction of a unitary aquifer in the study area by some Authors, though generally at smaller mapping scales (e.g., Ventriglia, 1990; Provincia di Roma, 2006; Capelli *et alii*, 2008; La Vigna & Mazza, 2015; Mazza *et alii*, 2015; La Vigna *et alii*, 2016), was not adopted in this work and the assumption of a unitary conceptual model for the variation of groundwater levels was not possible. In addition, the results obtained after the recently executed geognostic drillings show that these detached levels/lenses have a general geometrical asset dipping towards the lower part of the slope and, in any case, they are distributed in discrete reference elevation ranges.

In any case, in order to perform a better evaluation of the piezometric head variations with both time and space at the control points, the collected groundwater level data were standardized to mean values (Conte *et alii*, 2011) and plotted for comparison (Figs. 7a and 7b). After a detailed comparison of the head variations of the different control points and also considering stratigraphical data, the delineation of at least two piezometer groups showing different patterns was achieved.

The most significant differences between the two groups regard the amount of positive groundwater head variations with time, probably due to different recharge process typology at the groundwater-bearing body level.

The first group (Fig. 7a) is located within an area spreading from the base of the ancient perimeter wall of Villa Sciarra (P9_96a; P10_96a and H4; Fig. 2) to the zone adjacent to the pile retaining wall along Saffi/Dall'Ongaro streets (H1, H2, P6_04 and CR1; Fig. 2). The very vicinity and same hydrostratigraphical situation of P10_96a and H4 suggest further similar features (and then affinity) in their plots. The piezometers in this group reach some sandy lenses at 10-18 m of depth from the ground level (52 to 48 and 35 to 25 m a.s.l. of elevation in the two zones, respectively; thickness from about 1 to 4 m). They are located close to the Villa Sciarra urban park, representing a probable local recharge area, and the pile retaining wall probably acts as a (semi)permeable barrier, reducing groundwater recharge transfer from this area and inducing groundwater level differentiation between the two zones. A small contribution to recharge might be from direct infiltration within the small green zone surrounding Dall'Ongaro Street, just in the middle of the study area. The most probable recharge process in these zones consists in direct infiltration from the recharge areas and then in lateral drainage towards the sandy lenses/levels.

The second group (Fig. 7b) is at west with respect to the same pile retaining wall (P5_04a, P5_04b, P19_96 and P3_96; Fig. 2). These control points reach the unconfined aquifer hosted in an excavation soil cover filling up a paleostreambed and have relatively stable groundwater heads at 9-11 m of depth from ground level (52 to 34 m a.s.l. of elevation; thickness from about 3 to 9 m). The most probable origin of groundwater recharge in this sector is partially from direct zenithal recharge within the cited small green zone but also from groundwater lateral connections with a local relatively deep aquifer occurring beneath the Monteverde Hill. This aquifer is generally hosted in the sandy/gravelly terrains of both the upper part of the Monte Mario Formation and the lower part of the Ponte Galeria Formation and gives rise to cropping out of local minor springs and to flooding of some catacombs and other ancient excavated sites beneath the study area. Due to location and groundwater level values, the recently drilled CR1 piezometer might probably represent and interface situation between the two piezometer groups.

A further group of two piezometers (P14_96 and P15_96; Fig. 2), located towards Nievo Square, at the down end of the SE slope of the Monteverde Hill, both reaching the Monte Vaticano clayey formation, are not likely related to the study area groundwater flow, but reveal a hydraulic transfer towards the alluvial deposits of Tiber River (Fig. 1).

Aquifer layer succession outline

The local hydrostructural conceptual model has been discussed and delineated in two-dimensional vertical hydrogeological cross-sections (Fig. 2) arranged in both transversal and longitudinal directions with respect to the slope orientation. The conceptual model of the aquifer layer succession (e.g., Fig. 8) is as follows:

- various aquifer layers (thickness about 1-3 m) occur at different elevations and with different reference piezometric levels within the Monte Mario Formation;
- the former layers and the aquifer hosted in excavation soils are perched on sandy-silty-clayey deposits at the intermediate and basal stratigraphical levels of the succession (Monte Mario Formation *p.p.*; Monte Vaticano Formation) that may be at least partially saturated;
- a saturated zone with piezometric level lowering towards the alluvial deposits of Tiber River (reference isopotential levels about 13-15 m a.s.l.) occurs in correspondence of the control points P14_96 and P15_96 near Sterbini Street, at the base of the Monteverde Hill southeastern slope;
- local aquifer outcroppings have only been observed at the beginning of the slope area at the end of Sterbini Street (spring and water infiltrations at the ground floors of the adjacent buildings), in correspondence of Dall'Ongaro Street level (infiltrations at the Dall'Ongaro Street basements) and next to the low side of the Bassi Staircase (spring now convoyed in sewers; not in Fig. 8). The perennial spring of Sterbini Street, in the SE sector of the study area (Fig. 8), is fed by the saturated zone (thickness about 1-6 m) hosted in excavation soils filling up a paleostreambed with NW to SE trend.

Hints on hydrochemical features

After major elements chemical analyses, all waters may be classified (Piper, 1944) as bicarbonate waters, even if, regarding cation contents, differences between pipeline waters, alkaline with relative abundance of K, and spring waters (spring at Sterbini Street, drained water at 30 Dall'Ongaro Street basement, Villa Sciarra water capture and Ponziano Catacomb site), alkaline earth with prevailing Ca, are evident. These two typologies of waters show also differences based on electrical conductivity (EC; pipeline waters 567-637 μS/cm; local springs 638-1022 μS/cm; Tab. 3), representing the only remarkable hydrochemical parameter among the others in the analyzed list. Furthermore, taking into consideration the Schoeller (1958) diagram (Fig. 9), the scarce affinity between local groundwater and tap water from public network is confirmed and allowed estimating that the assumption of considerable contribution to groundwater from supplying pipeline leakage is not consistent. This is also in agreement with the evidence that the study area may be actually considered only a minor landslide hazard prone area. It is also apparent that characteristic line patterns of water from piezometers and spring waters shows only general similar features, likely due to the differences in groundwater pathway toward each sampled lens/level.

Water samples from piezometers display broader value ranges of major element content (Ca, Mg, Na, K, Cl, SO_4, HCO_3; Tab. 4 and Fig. 9) and of EC (354-1112 µS/cm; Tab. 3) with respect to spring waters, though showing some affinity with them. This was not fully expected but is in agreement with the likely different chemical element concentration enrichment occurred throughout the relatively complex local groundwater flowing pathway network. Water from inclinometer tubes (187-537 µS/cm; Tab. 3) has contrarily relatively lower EC values, probably due to inlet of low electrical conductivity rainfall water. This latter issue is in agreement with the decision to do not consider the inclinometer tubes for hydrogeological issues.

The Schoeller characteristic patterns of groundwater analyzed for present work have been compared (Fig. 9) with patterns of a number of groundwater analyses from the Rome urban area (Corazza & Lombardi, 1995; Pizzino *et alii*, 2015).

As a whole, even if these issues deserve more detailed and specialized studies (e.g., minor and trace chemical element and stable isotope analyses of groundwater), with respect to Corazza & Lombardi (1995) conclusions, it may be stressed that: 1) spring waters from Monteverde Hill local aquifer are akin to waters circulating through Paleotiber gravels and excavation soils, which may be hydraulically interconnected; 2) groundwater from H1, H2 and H4 piezometers, really positioned within sand levels/lenses of Monte Mario formation, accordingly display some affinity to Monte Mario Formation groundwater. Furthermore, groundwater from present work shows a poor geochemical affinity to those from Tiber River alluvial deposits.

Finally, the range of major element contents obtained by Pizzino *et alii* (2015) on Rome urban area samples, excluding mineralized and coastal aquifer related waters, is in agreement with the corresponding values of local groundwater from the present study.

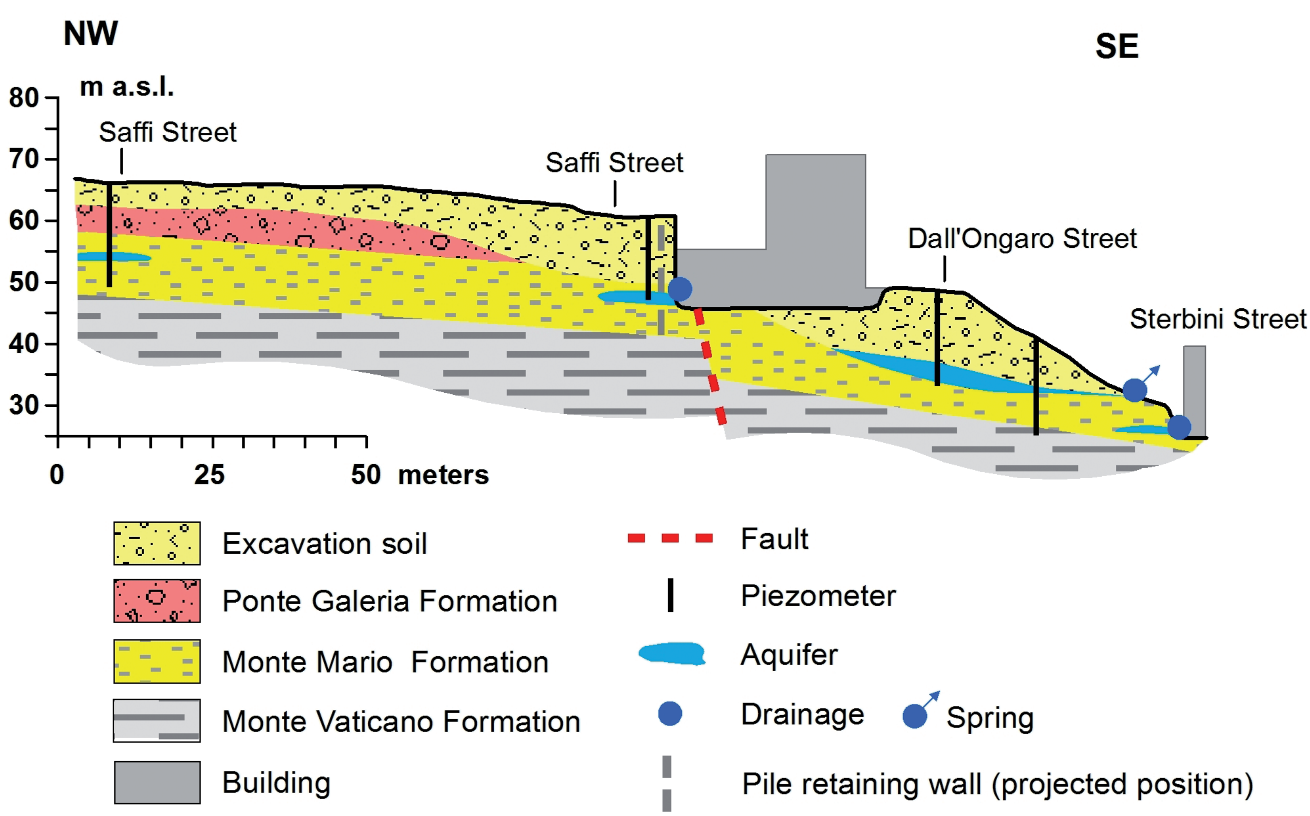

Fig. 8 - Hydrostratigraphical cross-section S6 in Fig. 2 (NW-SE orientation, with transversal arrangement with respect to slope trend)

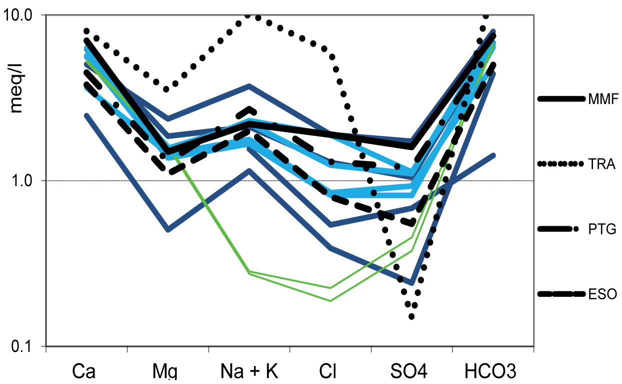

Fig. 9 - Schoeller (1958) diagram of analyzed waters from the study area. Dark blue lines: piezometers (H1, H2, H4 and P5_04); light blue lines: springs (spring at Sterbini Street; water draining at 30 Dall'Ongaro Street basement; groundwater at the Ponziano Catacombs; water capture at Villa Sciarra, Dandolo Street entrance); green lines: tap water (Dall'Ongaro Street building, public fountain at upper side of Bassi Staircase). Black lines show reference trends (Corazza & Lombardi, 2002) for groundwater within: sands and gravels of Monte Mario Formation (MMF); basal gravels of Tiber River alluvial deposits (TRA); Paleotiber gravels (PTG); excavation soils (ESO)

Hydrogeological budget outline

Due to lacking of exhaustive quantitative estimation of some elements regarding delimitation of aquifers and definition of surface and groundwater flows and exchanges, the knowledge of the complex aquifer system of the Rome urban area (e.g., Capelli *et alii*, 2008) is not fully available. In addition, the real dimensions of the recharge areas, likely represented by Villa Sciarra, Gianicolo and, partly, Villa Doria-Pamphilj park areas (e.g. Corazza *et alii*, 2002; Fig. 1), are not well known and there are still uncertainty on actual position of local hydrogeological boundaries. Furthermore, the study area represents as a whole a sector featured by hydraulic transfer from the Monteverde Hill to the Tiber River alluvial deposits. Then, a realistic attempt of realizing any issue about the evaluation of the elements involved in the local hydrogeological budget has not been fully achieved.

In any case, some considerations about local hydrogeological budget will be here proposed, even if they are based on strong generalizations. The relevant elements for the local hydrogeological budget evaluation are: i) rainfall, estimated in about 728 mm/a in the study area; ii) real evapotranspiration, calculated in about 615 mm/a using the Turc (1955) method, according to a mean annual temperature of about 16°C (Conte *et alii*, 2015); iii) runoff, evaluated as a percentage of the rainfall amount in similar situation (urban areas with high cemented and asphalted paved ground surface; at least 70-75% of P) and corresponding to 550-600 mm/a; iiii) spring outlet, which is very low (<5-10 l/s, about 15-30 mm/a). As a whole, considering the hydrogeological budget formula (I=P-ET-R±U) and a likely recharge area of about 5-10 km^2, the infiltration rate balance is apparently negative (approximately -400 mm/a, about -0.125 m^3/s) and it means that not all groundwater resources within the study area are from rainfall infiltrated just through the recharge area. Then, groundwater contributions from adjacent aquifers (likely hosted in sandy horizons of the Monte Mario Formation) probably reach the study area through underground flowpaths. Furthermore, also due to the actual medium-low hydraulic potentiality of the deepest horizons, it is possible that these latter are concerned, in turn, with seepage recharge coming from surrounding aquifers, probably located in Sabatini and Alban Hills volcanic reliefs.

CONCLUSIONS

The aim of the present study was to define the local groundwater circulation features and to provide indications about its evolution with time and its possible effects on groundwater infiltration at the basement of some buildings. The study of such little aquifers was carried out as a contribution to a suitable future realization of a more efficient groundwater drainage system.

The study area shows a complex groundwater flow that locally joins up with the Tiber River piezometric heads. Local aquifer outcroppings have been observed.

Rainfall event analysis evidenced that, from 1951 to 2015, the rainfall intensity index in recent years displays an ascending phase. With respect to air temperatures, trend analysis highlights a significant increase in average, maximum and minimum values. It was highlighted that strong or long-lasting rainfall did not evidently caused increasing of groundwater levels, likely because of the presence of diffuse cemented and asphalted paved ground surfaces and also considering that these strong events both trigger high runoff amounts.

All waters may be classified as bicarbonate waters, even if there are evident differences between pipeline waters, alkaline with relative abundance of K, and local groundwater, alkaline earth with prevailing Ca. Waters from the various saturated lenses/levels show quite difference in chemical element concentration, in agreement with the diverse enrichment likely occurred during groundwater flow throughout the relatively complex local hydraulic pathway network.

The assumed local conceptual model of groundwater flow is not unitary and it was possible to distinguish at least two areas showing significant differences regarding the amount of positive groundwater head variations with time, probably due to different recharge process typology at the groundwater-bearing body level. Furthermore, the inferred hydrostructural model of the study area is here reported: i) various aquifer layers occur at different elevations and with different reference piezometric levels within the Monte Mario Formation (thickness about

1-3 m) and excavation soils (thickness about 1-6 m), probably perched on sandy-silty-clayey deposits; ii) the soil retaining pile wall in the down side of Saffi Street along Dall'Ongaro Street acts as a (semi)permeable divide for the groundwater flow network (piezometric level are 47-55 m a.s.l. in the upper and 24-39 m a.s.l.in the lower side of the wall); iii) a further lowering in the piezometric levels towards the alluvial deposits of Tiber River (about 13-15 m a.s.l.) was found.

Seepage recharge toward study area groundwater resources was revealed and it comes from adjacent aquifers and from recharge areas likely located in the surrounding volcanic reliefs.

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