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Preliminary identification of areas suitable for Sustainable Drainage Systems and Managed Aquifer Recharge to mitigate stormwater flooding phenomena in Rome (Italy)

Identificazione preliminare delle aree idonee per i Sistemi di Drenaggio Sostenibile (SuDS) e le tecniche di Ricarica in condizioni controllate degli Acquiferi (MAR), per mitigare i fenomeni di allagamento dovuti a precipitazioni intense nella Città di Roma (Italia)

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Riassunto

Questo articolo propone una metodologia di indagine preliminare e su larga scala per identificare le aree idonee ad approfondimenti di studio per l'applicazione di Sistemi di Drenaggio Sostenibile e le tecniche di Ricarica in Condizioni controllate degli acquiferi, che hanno lo scopo di incrementare la capacità naturale dell'acqua di infiltrarsi nel terreno, e il cui successo dipende fortemente dalle caratteristiche idrogeologiche e morfologiche di un'area.

L'area di studio è la città di Roma dove l'obiettivo dell'applicazione di queste tecniche è quello di mitigare problematiche relative al surplus di acqua piovana che, in caso di eventi di precipitazione estremi, fatica ad infiltrarsi nel terreno, sovraccarica i sistemi di drenaggio, spesso sottodimensionati rispetto agli attuali regimi, e allaga lo spazio urbano.

Il metodo proposto si avvale di analisi spaziali GIS dei dati di permeabilità delle litologie affioranti, del modello di elevazione del terreno e dei livelli piezometrici negli acquiferi.

Per identificare le aree idonee, sono state individuate quelle aree caratterizzate da un'elevata permeabilità ed una soggiacenza della falda che conferisce all'acquifero una capacità volumetrica tale da essere potenzialmente in grado di immagazzinare maggiori quantità d'acqua, senza innescare problemi associati alla risalita della falda.

I dati sono stati suddivisi in classi ed indicizzati per essere confrontati e combinati. In seguito, il risultato finale è stato confrontato con le segnalazioni di allagamenti urbani per comprendere dove la necessità di smaltire più acqua piovana corrisponda a zone potenzialmente favorevoli.

I risultati dell'analisi effettuata mostrano che le condizioni favorevoli per applicare tali tecniche nella città di Roma siano abbastanza diffuse. L'ambiente geologico della città è caratterizzato da litologie permeabili con un effettivo potenziale di infiltrazione che permetterebbe all'acqua piovana di infiltrarsi nel sottosuolo e raggiungere la prima falda acquifera disponibile.

Abstract

This paper proposes a preliminary and large-scale survey methodology to identify areas suitable for in-depth analysis for the application of Sustainable Drainage Systems and Managed Aquifer Recharge.

These techniques are frequently applied to increase the natural infiltration capacity of water into the ground and their effectiveness depends on the local hydrogeological and morphological characteristics.

The study area is the city of Rome where the aim is to mitigate the problems related to rainwater which, in case of extreme events, struggles to infiltrate into the ground, overloads the undersized drainage systems, and floods the urban space.The proposed method involves GIS geospatial analysis of the permeability of outcropping lithologies, the digital elevation model, and the piezometric levels of the aquifers.

To identify the suitable zones, areas characterised by high permeability and a piezometric level that would confer a volumetric capacity to possibly store even large quantities of water, without triggering possible problems of water table rise, were identified. Data were divided into classes and indexed to compare and overlap them. Furthermore, the final result was compared with the urban flooding phenomena and the soil permeability map of Rome.

The results of the performed analysis show that the preliminary suitable conditions to apply SuDS and MAR in Rome are widespread. The geological setting of the city is characterised by permeable lithologies in many places with an effective infiltration potential that would allow rainwater to infiltrate the subsoil and reach the first available aquifer.

Introduction

Integrated water resource management is an extremely important aspect of the Sustainable Development Goals (UN General Assembly 2015) and this is still more crucial for cities (Schaffer and Vollmer 2010; La Vigna 2022).

The rapid and global expansion of urban areas and the occurrence of more frequent extreme weather phenomena are bringing up many water-related problems in cities globally (Marlow et al. 2013). The widespread use of "grey infrastructures" (i.e. made of concrete and asphalt) created impermeable urban surfaces which, not being able to absorb water, often cause flooding (Nguyen et al. 2019). In fact, in nature, the territory is characterized by streams, rivers, water surfaces, woods, and plants through which water is free to follow its natural cycle, while the natural hydrological cycle in cities is strongly altered (Howard et al. 2015).

Artificial drainage systems in cities are in general failing in their functions mainly due to non-stationary climate and rapid urbanization increase (Yazdanfar and Sharma 2015); they have been often designed for rainfall regimes different from the current ones and for those that will be in the future, and therefore today they are often inadequate, thus constituting examples of maladaptation (Shipper 2020; Nie et al 2009, Eckart et al 2012; Pedersen et al. 2012; Huong and Pathirana 2013). In recent decades, attention has focused on reducing flooding (Fletcher et al. 2015), focusing on the processes that may increase the infiltration capacity of rainwater in cities (Nguyen et al. 2019).

Moreover, the current model of centralised urban drainages with a single drainage outlet has been considered inappropriate due to constraints associated with climate change and cities' growth (Brown et al. 2009).

In recent years has been observed an over-exploitation of water resources and reusing of urban stormwater can provide an alternative water supply to reduce pressure on existing water supply systems (Dillon et al. 2019; Dillon et al. 2014). Usually, rainwater that converts to runoff is discharged as wastewater, rather than being absorbed into the soil; if drained into the soil it could reach groundwater reserves to conserve water or be reused as local water resources for many uses (Saleh et al 2019); moreover, discharging stormwater as wastewater implies some additional cascading effects such that locally the water cycle is disrupted with potential water shortages, the urban drainage system becomes overloaded, and treating rainwater (in the wastewater treatment plants WWTP) the same way as wastewater is costly (Mitchell 2002).

Where the location and the local hydrogeological setting are suitable, an alternative approach to managing stormwater might involve practices increasing the natural recharge, both by intentional actions such as Managed Aquifer Recharge (MAR), both by non-intentional as Sustainable Drainage Systems (SuDS) as part of wider integrated water management strategies (Saleh et al 2019; Humberto et al 2018; Kretschmer 2017: Pavelic et al 2012).

Managed Aquifer Recharge (MAR) is meant a set of techniques involving artificially introducing and storing water into the ground to supplement groundwater stocks (Saleh et al. 2019; Sprenger et al 2017; Stefan and Ansems 2018).

The (MAR) techniques are applied for the mitigation and resolution of several problems, such as to improve drinking water quality (Stuyfzand and Hartog 2017; Shammi et al. 2019), to mitigate negative geological effects due to the lowering of the piezometric level of the aquifer (i.e. subsidence, Herrera et al. 2021), the intrusion of salt water in coastal areas (Masciopinto 2013; Sallwey et al. 2019), flooding and problems related to rainwater (Dillon et al. 2009). Sustainable drainage systems (SuDS) are those practices that help runoff water Infiltrate the soil simply by using or improving the natural permeability of the soil (Scholz 2015). SuDS are ideal for reducing city runoff and, therefore, it is possible to plan a SuDS/MAR scheme in an urban context (Saleh et al 2019) with excellent expected results. These techniques are widely and successfully applied in Australian cities such as Adelaide (Dillon et al. 2002) and Melbourne (Dillon et al. 2010; Mudd et al. 2004). Even if the groundwater is not used for water production, urban aquifers are thus a potential storage location for stormwater, reducing surface runoff from sealed areas (Göbel et al. 2004).

Internationally, various studies propose different GIS criteria and various methods to delineate suitable sites for MAR and SuDS application (Hussaini et al 2022; Hayat et al 2021; Fathi et al 2020; Kazakis 2018; Aghazadeh et al. 2019; Dearden et al. 2013; Warwick et al. 2013). The MAR and SuDS siting approach for the city of Rome (Italy), proposed in this work, is similar to that defined by Warwick et al. (2013) where hydrogeological properties and water table depth play the predominant factors in the analysis.

The city of Rome has been chosen as a test case since it is characterised by the following issues and properties:

- flooding phenomenon due to strong rainwater events and exacerbated by the lack of an efficient sewerage system (La Vigna et al. 2015);
- overexploitation of the volcanic aquifers located in the Eastern sector of Rome (Mazza and Mastrorillo 2013);
- a complete dataset of geological and hydrogeological information is available at the city scale (La Vigna et al. 2016).

The main aim of this work is thus to evaluate the areas potentially suitable for Sustainable Drainage Systems and Managed Aquifer Recharge to mitigate stormwater flooding phenomena in the whole city of Rome (Italy). Moreover, the comparison of these areas potentially suitable for these techniques, with data regarding the floods and the imperviousness of the city, indicates the places that most would need such interventions to mitigate and prevent the cited issues.

Materials and Methods

Site description

Rome is one of the largest European cities for surface extension (1285 Km^2) and where in the last twenty years between 800 mm and 950 mm of rain annually fall (Conte et al 2015).

The geology of Rome is characterised by heterogeneous lithologies resulting from a long series of evolutionary phases. The most recent evolution of the study area, starting from 4 Ma, initiated by climatic and eustatic oscillations which, in association with the tectonic activity, determined a progressive transition from a marine sedimentary environment – with the Marls of the Monte Vaticano Formation, Grey Sands, Yellow Sands and Farneto silts of the Monte Mario Formation (Cosentino et al. 2008), clays and sandy clays of the Monte delle Piche Formation - to a deltaic environment - with the Ponte Galeria Formation - and 'Paleo Tiber' fluvial environment - with the Santa Cecilia Formation (Parotto 2008). After this phase, the fluvial-lacustrine environment, and the fluvial environment - with the Tiber River system - became predominant. Following the last glaciation stage, the sea level considerably dropped, triggering fluvial incision by the watercourses, thus causing the oldest sediments to outcrop (Parotto 2008).

The result of all these processes is an almost flat geomorphology in the central area of the city along the Tiber alluvial valley, where the urban centre develops, reaching higher altitudes in the surrounding hills and the in NW and SE peripheral sectors. The geology of Rome is strongly influenced by the presence of volcanic deposits and structures as well, coming from different volcanoes located in this sector of Italy: the Sabatini Mts and the Colli Albani volcanoes (Funiciello et al. 2008).

From a general hydrogeological point of view, different aquifer levels have been identified in the Rome City area (Mazza et al. 2015) overlapping each other. A regional aquifer affects the whole territory in a rather continuous way and it flows both into the recent alluvial aquifers along valleys, both into a multilayer aquifer system inside the volcanic deposits (La Vigna et al. 2016). The groundwater circulation starts from the more peripheral and elevated sectors of the city area joining in the central city area in correspondence with the main rivers (Tevere and Aniene) (Fig. 1, Mazza et al. 2015) and to the sea along the coast in the western sector (not visible in the main scheme); according to La Vigna (2022), Rome is thus a city that can be hydrogeologically identified as a Volcanic Groundwater City (VGC) but also a Coastal Groundwater City (CGC).

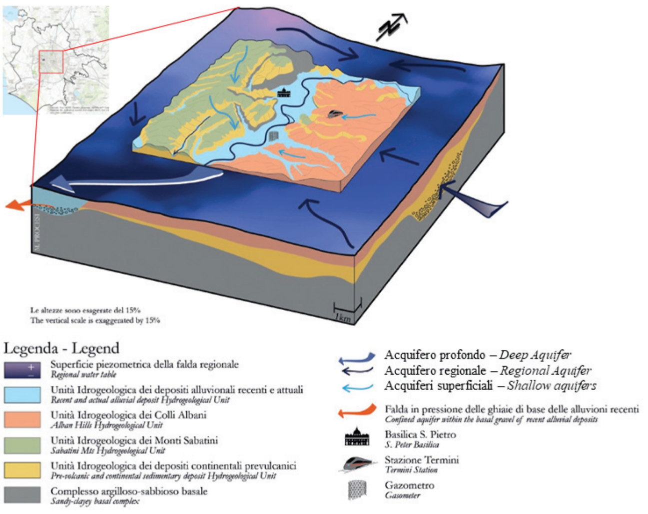

Fig. 1 - Hydrogeological conceptual model of Rome, modified from Mazza et al (2015).

Fig. 1 - Modello concettuale idrogeologico dell'area di Roma, modificato da Mazza et al (2015).

Starting hypothesis

To preliminary identify the suitable areas for the SuDS and MAR techniques, a reference conceptual scenario was hypothesised (Fig. 2), which represents the optimal hydrogeological configuration for the purpose and reflects the general suitability characteristics of the sites to identify. This optimal configuration is determined by a permeable hydrogeological complex that is vertically continuous from the surface until the base of the aquifer; the water table that is at such distance that it is not extremely deep (which increases the probability of vertical anisotropies), nor too shallow (increasing the probability of emerging from the ground level when recharged).

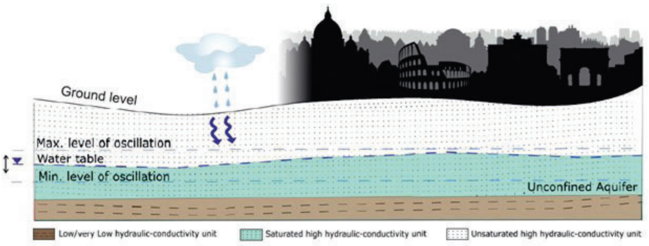

Fig. 2 - Reference conceptual suitability scenario.

Fig. 2 - Scenario concettuale di idoneità di riferimento.

According to this ideal conceptual model, those areas of the city that reflect the best configuration must be characterised by:

- a good permeability (hydraulic conductivity) of the shallow and deep lithologies;
- an aquifer capable both of providing a good volumetric capacity, and a water table with an appropriate distance from the surface.

This scenario shows how, to allow rainwater to easily recharge the aquifer, unconfined conditions and the outcrop of high hydraulic conductivity lithologies are required; these two conditions are the necessary for the best performance of SuDS and MAR techniques.

The key aspects are:

- the water table should not be too shallow as any enhanced level increase could cause a negative interaction with the urban fabric and the storage capacity would not be enough

- on the other hand, areas characterised by too deep aquifers could be considered unsuitable as well, for a greater possibility of vertical aquifer heterogeneity, especially in a context characterized by volcanic deposits as well.

The aquifer must therefore ensure a storage capacity capable of accommodating enough water, and the consequent water table rise should not affect the topsoil layers.

Once the eligibility criteria described above were established, the parameters for the preliminary identification of suitable areas were also determined.

Methods

The geospatial procedures used to classify, index, and overlap data have been implemented using version 3.16 of the QGis software using WGS84/UTM as the reference system (QGIS Development Team 2020).

The flowchart of the methodology used to perform the siting analysis is shown in Fig. 3.

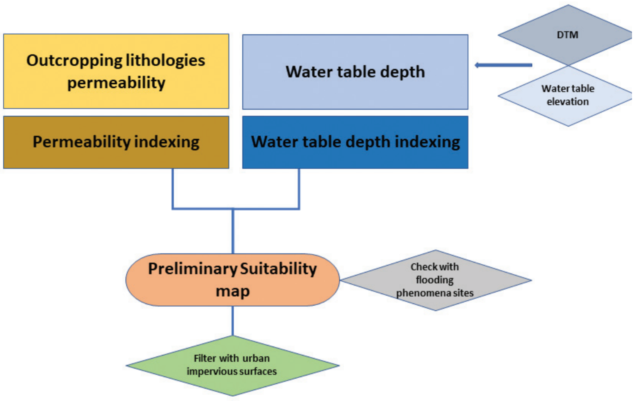

Fig. 3 - Flowchart of the performed siting analysis.

Fig. 3 - Diagramma di flusso dell'analisi spaziale di potenziale idoneità dei siti.

The first considered parameter is the permeability (hereafter when referred to "permeability" is intended as the capacity of the rocks or soils to transmit and drain water) of the outcropping lithologies, obtained using the subsoil permeability map of Rome from D'Antona et al (2022) based on the Geological map of Rome (Funiciello et al. 2008) and obtained following the ISPRA's methodology defined for the Permeability Map of Italy (Gafà et al. 2019).

The second parameter involved in the methodology is the water table depth which was calculated as the difference between the terrain elevation and the piezometric level of the "first available aquifer".

The terrain elevation model used is the TINITALY DEM raster file (Tarquini et al. 2007) with a 10 m resolution. The piezometric elevation data referring to the shallow aquifer were extrapolated as a vector file from the Hydrogeological map of Rome at 1:50.000 scale (La Vigna and Mazza 2015) and the work of Clausi et al. (2019).

According to the need to refer only to the first available aquifer from the surface, where piezometric isolines at different altitudes overlap (Fig.4), those isolines representing the deeper layers have been excluded (Fig.5).

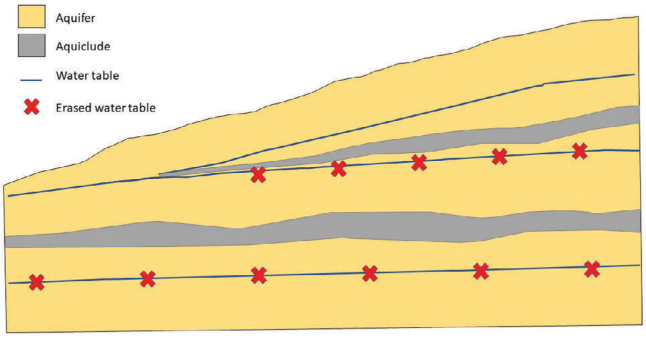

Fig. 4 - Identification of the water level to be considered in the calculation.

Fig. 4 - Identificazione della prima falda utile da valutare nel calcolo.

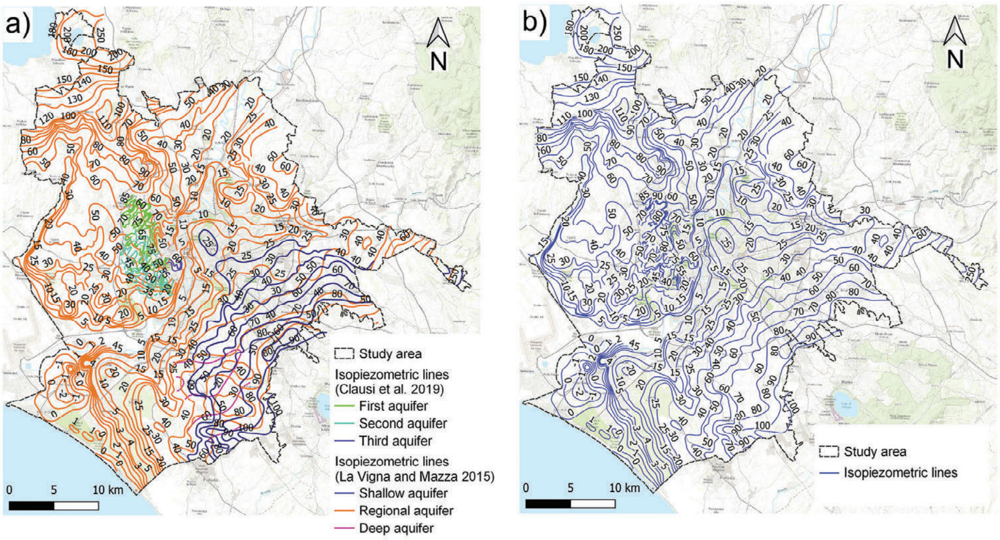

Fig. 5 - a) Piezometric lines extracted from Clausi et al. (2019) (first/second/third is referred to the aquifers available from ground level) and from the Hydrogeological Map of Rome (La Vigna and Mazza 2015). b) The same piezometric lines after removing those referring to deeper aquifers.

Fig. 5 - a) Linee isopiezometriche estratte da Clausi et al. (2019) (primo/secondo/terzo sono gli acquiferi a partire dal livello del suolo) e dalla Carta Idrogeologica di Roma (La Vigna e Mazza 2015). b) Le stesse curve dopo aver rimosso quelle delle falde più profonde.

The piezometric levels of the shallow aquifers were interpolated through 'TIN' interpolation to create a raster file (Fig. 6); this raster file was subtracted from the DEM to obtain a raster with the depth to the water table.

The used GIS tool was the "Raster Calculator" and it has been used as follows:

Water table depth = Terrain elevation model – Piezometric elevation

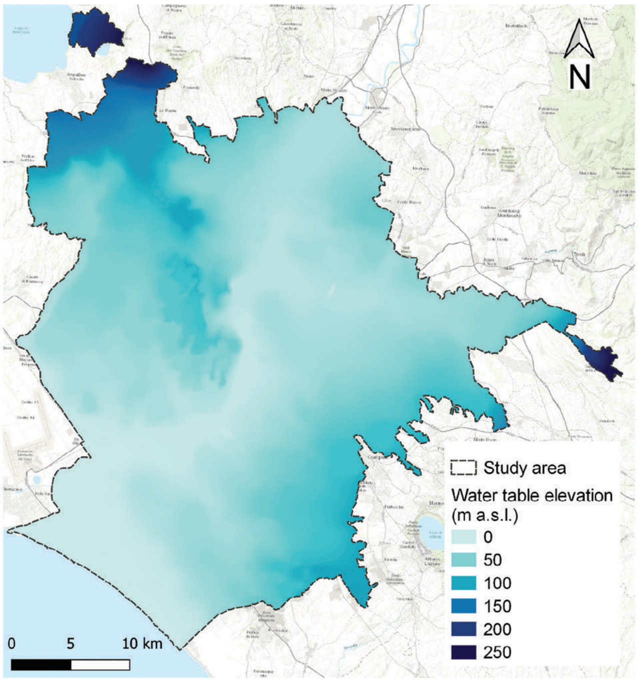

Fig. 6 - Water table elevation raster resulting from TIN interpolation.

Fig. 6 - Raster delle quote piezometriche ottenuto dalla interpolazione TIN.

Indexing and classification

The subsoil permeability map and the water table depth map were classified and indexed. The higher index values were assigned to those classes representing the best conditions of rock permeability and water table depth more compatible with the referring scenario (Fig. 2).

Regarding the subsoil permeability map, five classes have been identified, according to the different permeability classes; 5 indexes were assigned to these classes, with values from 0, referring to the class with lower permeability, to 4, for class with higher permeability.

Concerning the map of the water table depth, six classes were identified, based on the depth range. The lowest values (0 and 1) were assigned both to very shallow and too deep-water table zones, respectively; that's because those conditions are non-conforming with the reference suitability scenario. In fact, in the very shallow water table zones, groundwater floods are possibly linked to groundwater oscillation.

In the case of too deep-water table zones (referred to the available depth range in the study area), the higher the depth of piezometric level and the higher the probability to have geological anisotropies and permeability variations which could slow down and/or deviate effective infiltration towards the saturated zone.

Higher values were assigned to intermediate water table depth classes (referred to the available depth range in the study area), and the highest indices, 4 and 5, were respectively assigned to value classes 11-20m and 21-30m, considered the best compromise between good volumetric capacity and water table depth, with the prerequisites of the conceptual reference scenario of Fig. 2.

In Tab.1 a synthesis of the classes and assigned indexes are reported. Using these indexes, the permeability and water table maps were combined and rasterized.

Tab. 1 - Summary of the classified and indexed subsoil Permeability Map and Water Table Depth Map values.

Tab. 1 - Riepilogo dei valori di classificazione ed indicizzazione assegnati alle mappe di Permeabilità del sottosuolo e di Soggiacenza.

Permeability Map Class	Index
Very Low	0
Low	1
Intermediate	2
High	3
Very high	4
Water Table Depth Map Class (m)	**Index**
≤3	0
3-10	2
10-20	4
20-30	5
30-40	3
>40	1

Overlay

The preliminary selection of the suitable areas, based on these two indicators, was conducted using the "Raster Calculator" tool, which allowed the calculation to obtain the overlay of the two layers, using the following function:

(Indexed Subsoil Permeability Map + Indexed Water Table Depth Map) / 2

The output raster shows those areas having conditions more comparable to the referring scenario (Fig. 2) and those that are more different. It has been chosen to not use weights for any parameter in the calculation, in order to reduce subjectivity in the analysis.

Results

One of the main results of the study is the Indexed Subsoil Permeability Map (Fig. 7b), obtained by indexing the Subsoil Permeability Map from D'Antona et al. (2022) (Fig. 7a), showing the five identified permeability classes (from light to dark colors as permeability increases), and the relative indexing; the five indices and the highest values (3-4) correspond to the areas characterised by the higher permeable outcropping lithologies in the area.

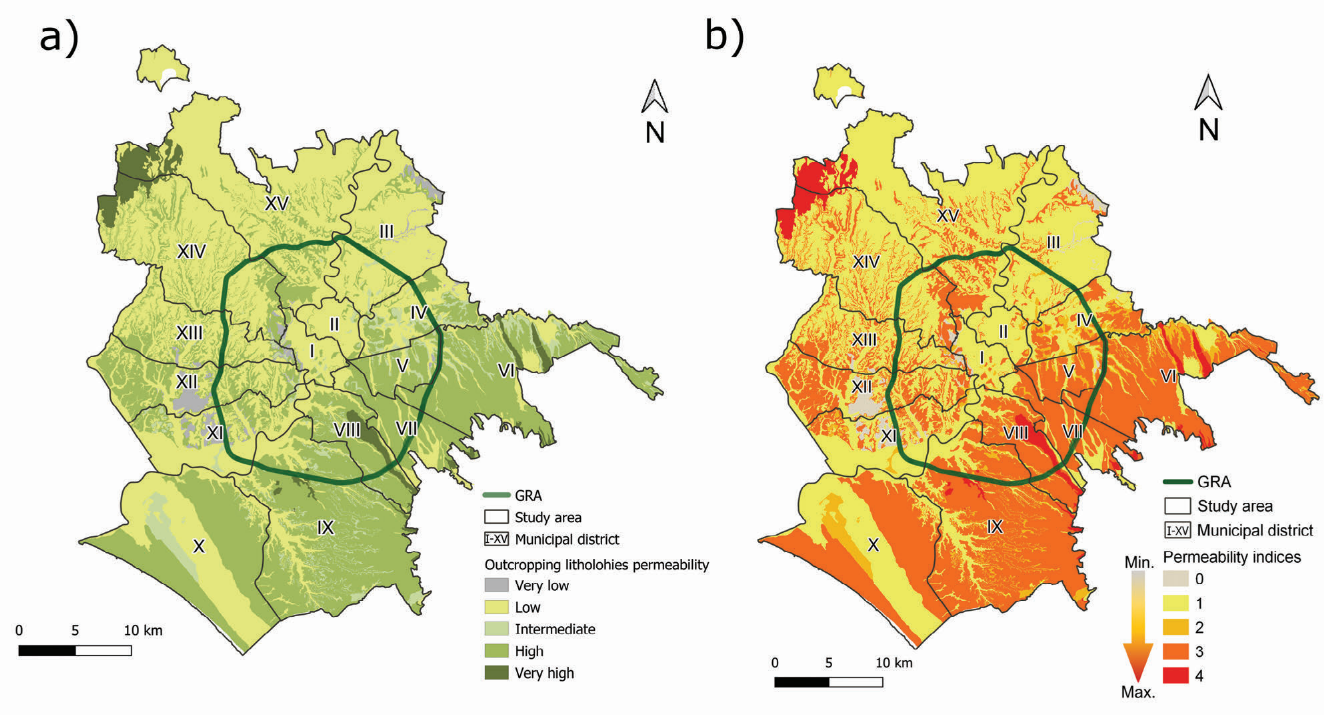

Fig. 7 - a) Subsoil permeability map; b) Permeability Indices Map.

Fig. 7 - a) Mappa della permeabilità del sottosuolo; b) Mappa degli Indici di Permeabilità.

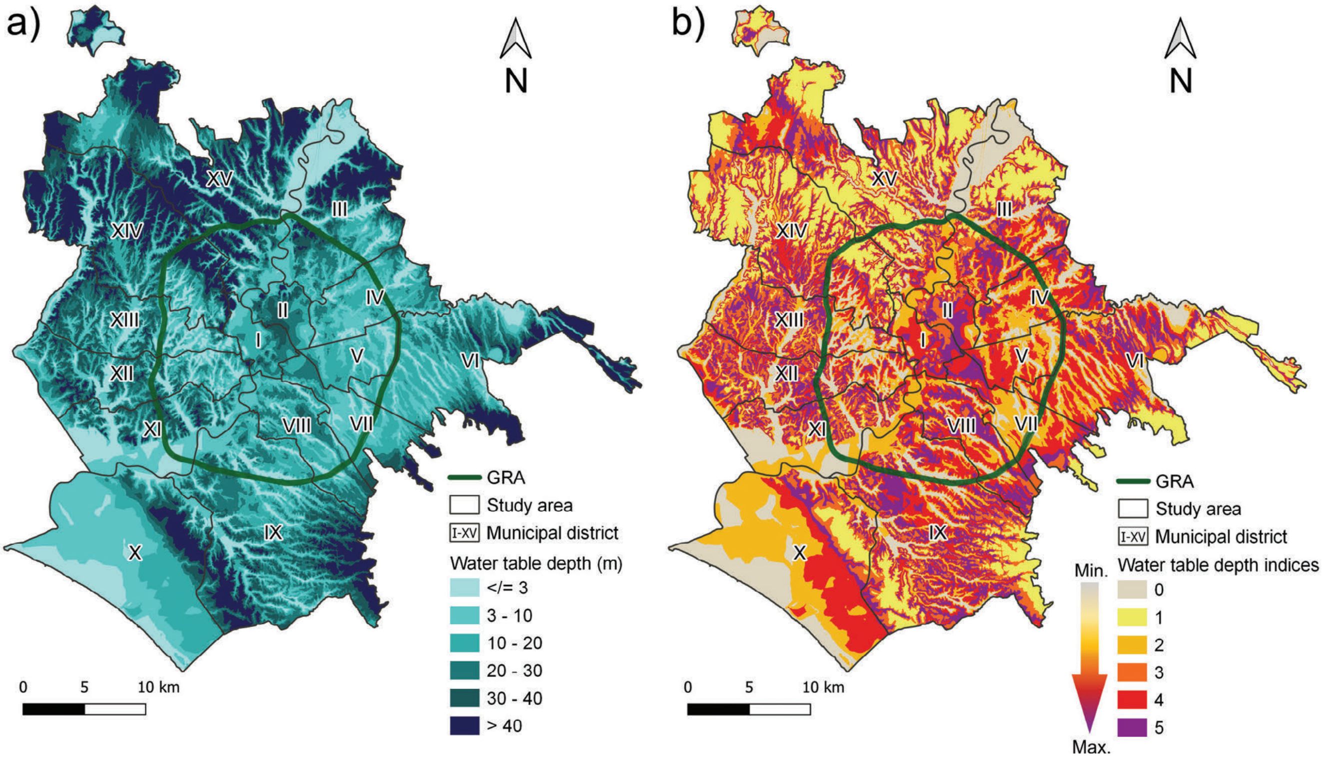

Fig. 8 - a) Water Table Depth Map; b) Water Table Depth Indices Map.

Fig. 8 - a) Carta della Soggiacenza; b) Carta degli Indici di Soggiacenza

Another important result is the "water table" depth map (Fig. 8a) and the relative indexed map (Fig. 8b): in the first, the color scale shows how, as the darkness of blue increases, the depth of the water table increases; the second shows the indexing result. In the Water Table Depth Indices Map, the highest values (4-5) correspond to those areas characterised by a water table located at the optimal intermediate depths (compared with the referring scenario).

The main result of the study is the preliminary map of suitability for effective infiltration of Rome, obtained after combining the Permeability Indices Map and the Water Table Depth Indices Map (Fig. 9), the highest indices (4-5) correspond to those areas that, in this preliminary step were considered as more suitable in the city of Rome.

The map shows different zones with the following features:

- zones with an index between '0-1' are considered unsuitable or not suitable enough, as the water tables occur from near-surface (</=3 m) and due to very low permeable outcropping lithologies;
- zones with an index between '1-2' correspond to areas not suitable enough, as insufficient suitable permeability conditions are combined with unsuitable water table depth conditions, and vice versa. Among them, are those areas in which the levels of permeability are not so high and/or also associated with an extremely shallow or extremely deep water table;
- zones with an index between '2-3' are related to areas defined as fairly suitable, e.g. those areas characterised by high permeability values and shallow or deep water table, or areas in which the water table has an optimal depth according to the selected criterion, but not very high permeability;
- zones associated with an interval between '3-4' or '4-5' indexes are those considered as suitable or extremely suitable, as permeability (high – very high) and water table depth (between 11-20 m and 21-30 m) conditions are optimal.

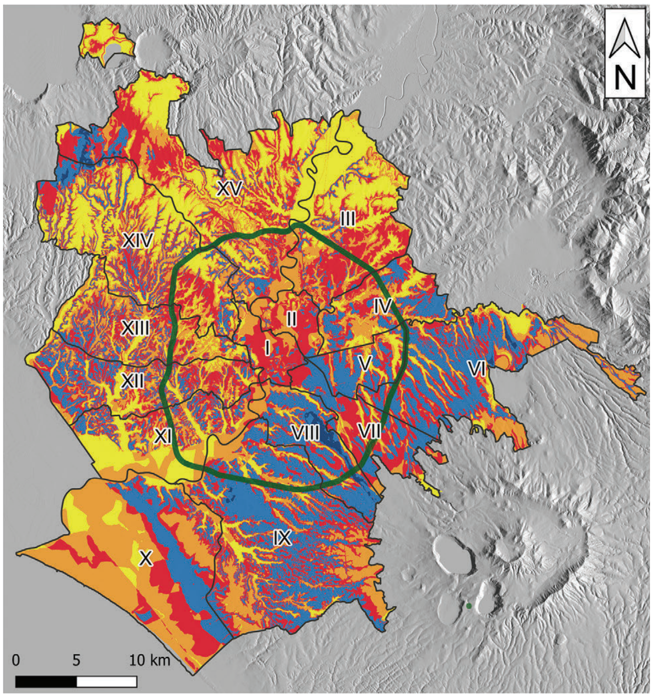

Fig. 9 - Preliminary map of suitability for effective infiltration of Rome. GRA stands for Grande Raccordo Anulare (orbital motorway that encircles the city).

Fig. 9 - Mappa preliminare di idoneità all'infiltrazione efficace di Roma. L'acronimo GRA indica l'autostrada del Grande Raccordo Anulare.

Discussions

The results of the performed analysis show how the preliminary suitable conditions to apply SuDS and MAR in the city of Rome are widespread; the geological setting of the city is characterised in many places by permeable lithologies with an effective infiltration potential that would allow rainwater to infiltrate the subsoil and reach the first available aquifer. The southern and southeastern zones of the city present a greater concentration of suitable conditions. This is due to the nature of the geological units of these sectors which are characterised by very permeable volcanic deposits.

Just to have an example of the potential of the presented analysis, a comparison between the sites affected by flooding events on the occasion of heavy rains in Rome (more than 3100 events reported/registered between 2013 and 2019), and the map obtained has been performed (Fig. 10) together with

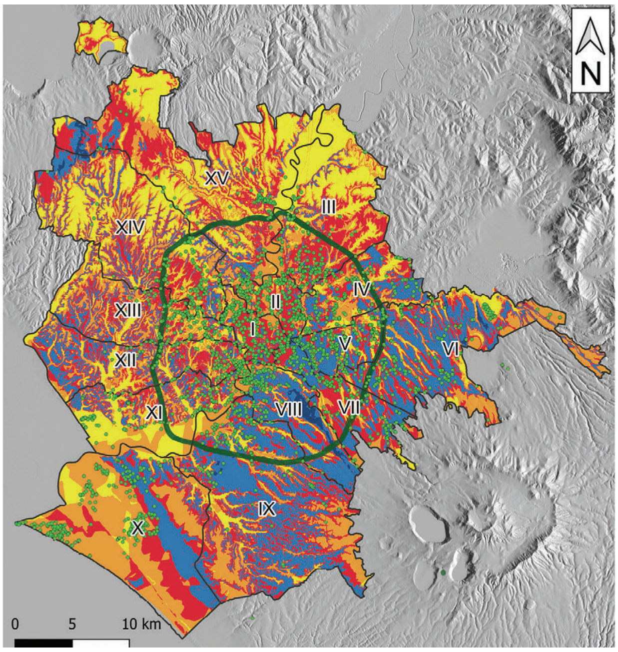

Fig. 10 - Flooding phenomena and the identified suitable areas.

Fig. 10 - Fenomeni di allagamento e aree idonee individuate.

a graph where the number of phenomena for every class is highlighted (Fig. 11). It is observed that about 45% of those areas characterised by flooding phenomena (Civil Protection of Rome - personal communication, unpublished data) corresponds to suitable areas (High and Very High Classes) in the obtained map, thus SuDS and MAR techniques could be extremely effective in these locations and in general for Rome.

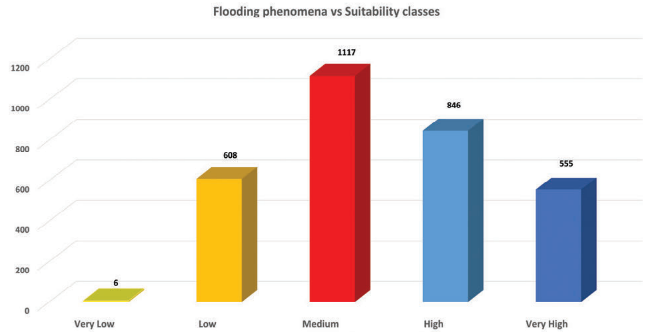

Fig. 11 - Number of flooding phenomena vs the identified suitable areas.

Fig. 11 - Numero dei fenomeni di allagamento rispetto alle aree idonee individuate.

Finally, the suitable map was compared with the impervious zones of Rome (D'Antona et al., 2022), to understand which areas with high soil sealing overlap suitable zones; in these zones it is strongly suggested to de-seal the surface and enhance the effective infiltration towards the subsoil (Fig. 12).

Therefore, even if Rome municipality is not characterised by high percentages of impervious surfaces (23, 5%, Munafò 2022), if compared with other large cities, the natural local water cycle is affected by the presence of grey infrastructures as well.

The obtained results suggested that many places in Rome are potentially suitable for the application of SuDS/MAR techniques which could contribute to mitigating runoff water and promoting its infiltration into the aquifers. Where these characteristics overlap with flood prone-areas, these places should be first analysed in depth to verify their effective local suitability.

It could be also convenient to evaluate the possibility of impervious anthropic surface removal in several localized points, where suitable conditions exist below, for example by increasing the areas assigned to flowerbeds, parks, and gardens (Minixhofer and Stangl 2021). At the same time, suitable areas corresponding to existing green spaces, would not require intervention, however, they would still be used to promote the protection and development of the territory and green spaces in the city. Moreover, in this context, in a possible further study step, concave areas should also be identified through landscape studies, to be selected as areas where the confluence of runoff waters can be poured out, and consequently easily accumulated to facilitate the infiltration.

Considering the ongoing climate change and the increase in the intensity and frequency of exceptional precipitation

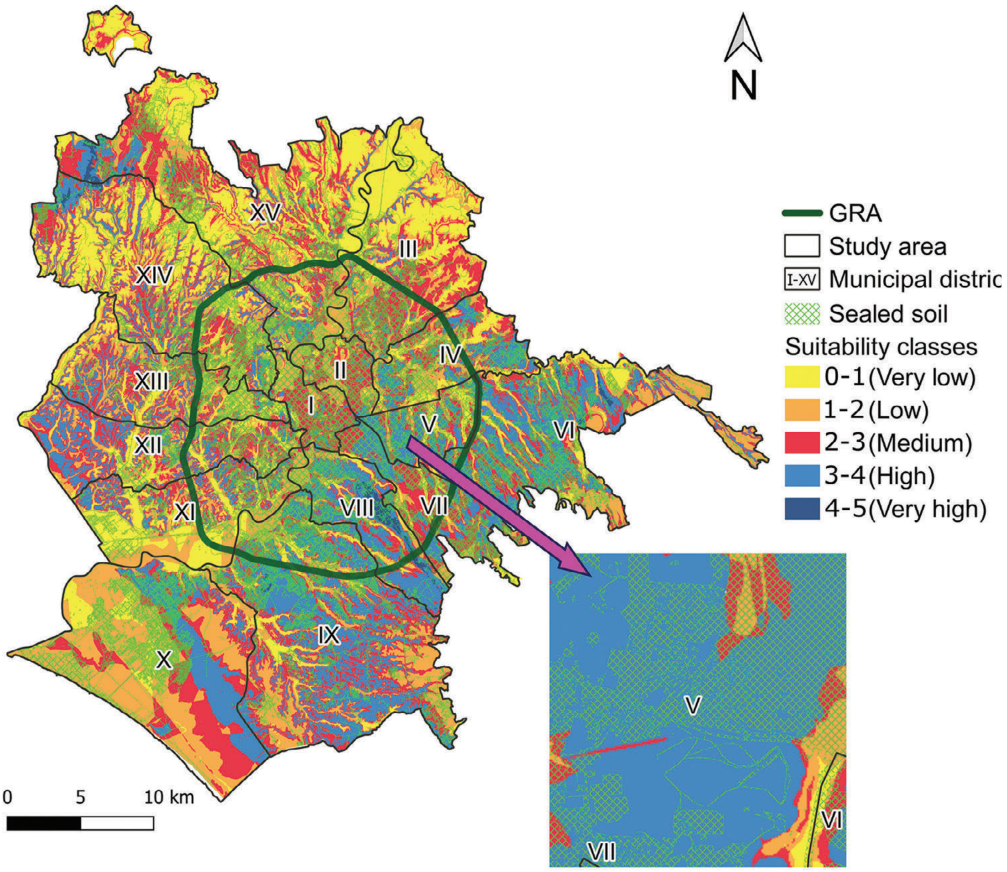

Fig. 12 - Extension of the impermeable surface sealing the suitable areas of the substrate.

Fig. 12 - Estensione della superficie impermeabile che sigilla le aree idonee del substrato

events (Brönnimann et al. 2018; Asadieh and Krakauer 2015), adaptation strategies are needed to mitigate the runoff flow rates and the pressure on urban drainage systems, which are expected to increase in the future. SuDS techniques could considerably help also the city of Rome in the future to solve the drainage system issues that were observed in the last years.

Furthermore, the application of SuDS in particular hydrogeologically suitable places, can also have the function of a MAR system; facilitating stormwater infiltration can substantially contribute to a huge recharge of local groundwater resources which should not be underestimated.

Increasing the local groundwater resources in urbanized contexts would allow, as presented in the introduction section, (e.g.):

- to dilute the pollutant load of the local aquifers by decreasing the pressure of urban pollutants (Stuyfzand and Hartog 2017; Shammi et al. 2019);
- to be able to rely on alternative sources of supply for secondary uses (Göbel et al. 2004), such as irrigation of green areas, street washing, and fire-fighting services.

Conclusions

The performed analysis presented in this work, at this stage, should be considered as a first general overview of the entire administrative area of Rome and those areas identified in this work as most suitable and covering about 470 km^2 in extension (125 Km^2 very high suitability; 345 Km^2 high suitability) should be more thoroughly investigated. The research could be integrated with additional surveys and on-site evaluation, such as the vertical permeability gradient, given by the analysis of local hydrogeological complexes, and also a slope analysis in order to identify possible concave areas inside the most suitable sectors. Only site-specific investigations will allow identifying, among the areas with higher general suitability, those characterised by constant favorable vertical permeability from the ground surface to the saturated zone and assess the real volumetric aquifer capacity.

The selected areas shall be analysed in comparison with territorial planning rules, to check the feasibility of the application of these techniques, and to also discard those places that, even if technically suitable, are not, from an administrative or binding point of view.

In conclusion, the results presented in this work could be used for Rome's land management and provides the current territorial planning system with an innovative general hydrogeological point of view.

The Preliminary map of suitability for effective infiltration of Rome could be used for sustainable management of those water resources (stormwater), which are normally seen as an issue in a city, but that indeed constitute possible resources, to store when they are abundant, as in the autumn and winter, and to be withdrawn when needed, as in summer and spring.

The cited techniques for stormwater flood mitigation are solutions having a very low impact on the environment and a high reduction of the social and economic impacts of these events.

SuDS development promotes green areas, reduction of imperviousness, reduction of floods, and the increase of water infiltration; therefore, implementing the enhanced rainfall infiltration and contributing to the increase of local groundwater recharge.

Finally, this article is proposing a spatial and quantitative investigation method to identify areas with hydrogeological and geomorphological characteristics suitable for the application of SuDS and MAR techniques; in these areas, where allowed by territorial and administrative planning, natural conditions could be restored and/or re-naturalised to improve the absorbing capacity of the urban surface.

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Competing interest

The authors declare no competing interest.

Author contributions

A. Lentini, E. Meddi, GIS elaborations. A. Lentini, F. La Vigna, E. Meddi manuscript writing. J.P. Galve and C. Papiccio collaboration in process validation and manuscript editing. C. Papiccio, F. La Vigna and A. Lentini coordination of activities.

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Additional information

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