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METHODS, TOOLS AND BEST PRACTICES

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Soil *de-sealing* for cities' adaptation to climate change

Planning of priority interventions in urban public space

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Abstract
It is well known that extreme heat waves or weather events combined with the increased soil consumption and sealing processes are significantly affecting urban systems especially the most exposed and vulnerable. These urban challenges call for specific mitigation and adaptation actions; soil de-sealing (i.e., the removal of the impermeable surfaces for increasing green areas and restoring soil ecosystem functions) may be one of the possible solutions. However, this urban practice, to have meaningful outcomes, would need widespread and systematic application in urban areas that can be pursued only if supported by innovative programming and planning tools based on the construction of in-depth knowledge frameworks on the permeability and vulnerability of urban soils.
In this regard, the paper aims to outline a methodological approach, supported by GIS technology, to map in detail urban public soils and identify priority areas to be de-paved. In particular, the method assesses the permeability of public land in relation to hydraulic and heat island hazard exposure of potentially vulnerable urban systems. The methodological approach is applied to a pilot case in the city of Parma to test its potential and limitations, with the goal of creating a replicable procedure.

Keywords
Climate change; Urban planning; Adaptive measures; De-sealing; Public space.

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1. Introduction

The climate-regulating functions of the soil resource have long been known; however, data confirm that the slowdown in soil consumption has, in fact, ended moving further away from the European goals of ‘no net land take’ by 2050 (European Commission, 2011). Almost 98,000 km^2 (2.23% of the total NUTS3 area) of sealed soil was detected by the European monitoring programme ‘Copernicus’ in 2018 (Copernicus Land Monitoring Service, n.d.). More than 3,000 km^2 have been added to the count since 2012 (European Environment Agency, 2021). Urban growth, with the consequent transformations of agricultural and natural areas and a significant loss of biodiversity (Agenzia Europea dell’Ambiente, 2019), in Italy has achieved an average consumption of 77 km^2 per year reaching 7.13%, higher than the EU average of 4.2% (Munafò, 2022).

The trend of increased high air temperatures is growing as well. Temperatures in Europe are rising faster than the global average. Copernicus Climate Change data report that over the past ten years, the average annual temperature is 1.94 to 2.01°C warmer than in the 19th century (Simmons et al., 2017). In the main Italian cities, the average annual temperature has shown an increasing trend since 1971. In 2020, the average temperature is +16.3°C, an increase of 0.3°C over the corresponding average value for the decade 2006-2015 (Istat, 2022). Heavy rainfall events also increase, leading to higher flood risk. Urban layout with buildings, streets, and squares significantly affects the heat island phenomenon (European Commission, 2012), as well as the ability of urban soils to drain or retain water.

In the process of adapting to climate change, the European Union promoted the Covenant of Mayors (2008), an initiative that led many cities to sign a pact and draw up a specific Sustainable Energy and Climate Action Plan (SECAP), a planning tool that identifies mitigation and adaptation actions starting from a rigorous assessment of possible urban risks. Different risk levels derive from the combination of the probability of certain phenomena occurring (such as floods and heat waves), with the exposure and vulnerability of urban systems (World Health Organization, 2002). The increased awareness of the impacts of climate change on cities is also reflected in urban planning, as some local governments have recently complemented their urban plans with Climate Change Adaptation Plans (Pietrapertosa et al., 2018; Zucaro & Morosini, 2018). EU also funded projects, such as Urban GreenUP, to develop, apply and validate a methodology for implementing nature-based solutions (NBSs) in urban planning tools (Urban GreenUP, n.d.), to provide for new green infrastructures.

Studies carried out by several countries in the urban planning field and the good practices implemented by cities, show how this topic has become central in the debate on spatial planning (Oliveira et al., 2018; Zucaro & Morosini, 2018; Rota et al., 2019; Tardieu et al., 2021; Ventura et al., 2021; Pellicelli et al., 2022), with an increased awareness on environmental and social issues (Apreda, 2016). For these reasons, strong relationships must be established between the shape of cities and climate change adaptation strategies (Gerundo, 2018). By restoring nature to the city, proposing NBSs and permeable materials, there is an overall improvement in soil ecosystem services, as they help cool city temperatures, better manage water drainage, increase biodiversity, improve air quality and generate well-being (Dessì et al., 2016; Lehmann, 2019; Cortinovis et al., 2022). Urban regeneration, in addition to limiting soil consumption by recovering obsolete and/or degraded urban fabric, can also activate soil *de-sealing* interventions, i.e., the removal of the surface impermeable layer, to increase the permeability of soils, their ecological performance and their capacity to provide ecosystem services (Science for Environment Policy, 2016; Maienza et al., 2021; Garda, 2022). Various international de-sealing experiences are emerging in recent years, through associations and foundations, with the common aim of promoting urban regreening to adapt to climate challenges (Depave, s.d.; Stobbelaar et al., 2021). Indeed de-sealing practices contribute to microclimatic comfort (by increasing soil evapotranspiration resulting in a decrease in temperature and air cooling) and to the management of water runoff during heavy and prolonged rainfall (due to the increased capacity of permeable green areas to absorb and filter water), thus improving urban quality and increasing the quality of life for the urban population (Directorate General for Environment - European Commission, 2012; Dessì et al., 2016; Garda, 2020; De Noia et al., 2022). Therefore, in the context of urban adaptation policies, an effective approach of spatial planning tools should address both effects of climate change by identifying a scale of intervention priorities, mapping both areas subject to the heat island phenomenon and those at risk of flooding (Musco & Fregolent, 2014, p. 93). The overlapping of high levels of criticality outlines a priority for intervention. Soil sealing, and the consequent choice of areas to be de-sealed, is, therefore, one of the key points to be addressed to measure the sustainable development of the city; but it is not always easy to find areas available and suitable to the purpose.

For instance, in the digital mapping of the 'Berlin Environmental Atlas', factors such as ownership, technical evaluation, technical effort, and feasibility in terms of time are considered as evaluation criteria for defining the priority levels of intervention of potential areas to be de-sealed[1]. Instead, in the 'SOS4life' project these areas were traced among those already classified for urban regeneration by the current urban plans of the participating cities, supplemented with areas that due to their degradation and poor environmental quality could provide for de-sealing actions (SOS4LIFE, 2018).

The paper aims to illustrate a practical method to map impermeable soils in public space and to analyse the priority areas for de-sealing interventions. The methodological approach, supported by GIS (Geographical Information System), aims at mapping non-permeable surfaces, identifying operable/transformable ones and interfacing them with hydraulic and heat island hazard maps to highlight potential intervention priorities. Indeed, de-sealing actions on public open spaces may have varying degrees of priority but should have immediate operability for the city government. A GIS database has been built with the double purpose of mapping impermeable/permeable surfaces and public space uses.

The contribution stems from a collaboration with the Municipality of Parma (Italy) interested in acquiring a tool to adequately respond to the new urban planning requirements of the Emilia-Romagna regional law no. 24/2017[2]. The study aims to support the public administration in the construction of a cognitive and analytical framework, and it is experimented on a residential neighbourhood in Parma to test its applicability.

The following chapters discuss in detail the methodology and lessons learnt from the case study. Section 2 develops a literature review on the relationship between urban planning and soil regulation and assessment, developing insight into the analysis of permeability in urban areas, also identifying indices used to assess the quality and ecological performance of urban soils. Section 3 introduces the research methodology for identifying areas to be de-paved, supported by a GIS database and the application of the method to a pilot case study. Finally, section 4 presents the results of the analysis and section 5 discusses the research outputs and sets some concluding remarks.

2. Urban planning studies on the permeability and quality of urban soils

Covering part of the land with non-draining materials (such as asphalt, concrete, etc.) for new construction means consuming soil and making it impermeable (Bencardino, 2015; Munafò, 2021). In the process of achieving zero soil consumption, envisaged in 2050 by the European Commission, some European countries have been integrating measures to limit soil consumption and compensate soil sealing into their strategic spatial planning processes (Science for Environment Policy, 2016). These are generally provided with specific environmental assessment tools on soil permeability and quality (SOS4LIFE, 2017; Juhola, 2018). These aspects will be addressed in the next sub-sections.

1 https://www.berlin.de/umweltatlas/boden/entsiegelungspotenziale/fortlaufend-aktualisiert/methode/

2 Urban Regional Law 'Regional regulations on the protection and use of land' refers to de-sealing actions, through the removal of soil sealing, as a measure to be taken to achieve a balance of soil consumption (Article 5.5) but also as an incentive measure for urban regeneration practices (Article 7).

2.1 De-sealing interventions as compensatory measures: the German cases

As early as the 1990s in Germany, the concepts of soil sealing and de-sealing were already being questioned (Mohs & Meiners, 1994). Other more recent authors remind us how significant the degree of imperviousness of this State is and the consequent considerable experience in implementing these principles of protection and conversion of sealed soil (Meyer, 2011; Adobati & Garda, 2018). For these reasons, it has been decided to discuss a few examples of German cities, taking them as a reference in the context of increasing urban soil permeability through planning tools.

Therefore, Germany left it up to the various Länder to supplement adaptation processes with specific technical and economic instruments, fiscal incentive policies and environmental compensatory measures (such as the promotion of de-sealing actions).

Following a chronological order, the city of Dresden, the capital of Saxony which was flooded in 2002 by a devastating overflow of the Elba river, has defined a long-term planning strategy that envisages a land take target limited to 40% of the total urban area; a target to be met also through a 'soil compensation account (Bodenausgleichskonto)' (Directorate General for Environment (European Commission), 2012). Any soil sealing, therefore, requires compensatory measures on an equivalent area within the urban perimeter, through de-sealing actions, renaturation, or greening. Areas for de-sealing are filed in the city's Climate Change Adaptation Plan and are chosen according to the size and value of the new area to be developed (Righini, 2016; Bundesministerium für Bildung und Forschung, n.d.).

Since 2003, the Bavarian Länder have also had suitable regulations to compensate consumption of new soil. The aim is to evaluate each future intervention through ecological account and compensation factors (Ökokonto), varying according to the soil quality and planned soil sealing. To achieve ecological compensation, each new intervention needs to be preceded by the renaturalisation of an area already listed in the 'Ökoflächenkataster' stock (Bayerisches Landesamt für Umwelt, n.d.).

The city of Stuttgart, since 2006, has implemented regulatory measures to reduce soil sealing and promote a more responsible use of soil. Two tools were used: the soil quality map and a soil index, the 'Bodenindikation', evaluating the quality and quantity of consumed soil. The compensatory measures also include de-sealing actions (beneficial for not very large sealed areas) and redevelopment of brownfield sites for which a constantly updated database has been set up (SOS4LIFE, 2017; Osservatorio del Paesaggio trentino, 2022).

No less careful about these issues is the city of Berlin, the German capital. The 'Potentials for Impervious Coverage Reduction' project is one of the proposals to remove the impermeable land cover: the aim is to obtain a dedicated database, after carrying out a specific assessment of the functions of all the land in the city that could potentially be renaturalised, by removing their impermeable topsoil. The project, therefore, provides for the creation of a cataloguing system throughout the city. In addition, it allows for a constant updating of the areas in the database, enabling even private landowners to access the platform both to obtain information on possible areas suitable for de-sealing and to enter their properties into the system (Senatsverwaltung für & Umwelt, Mobilität, Verbraucher und Klimaschutz, 2022).

2.2 Assess the performance of building interventions based on soil permeability: scores and indices

In addition to spatial regulations, many recent urban practices are based on assessing the quality of urban soils to preserve high ecological values, and eventually subject lower-quality soils to urban transformation. Different indicators have been used to define levels of soil quality, quantify the ecological performance of soils, and interact with urban transformation regulations. Environmental quality indices are considered valuable tools both for monitoring the phenomenon of soil sealing and for strategic urban-building planning aimed at proposing effective de-sealing/re-greening actions to contrast the effects of climate change (De Lotto et al., 2015, 2022).

Since 1994, Berlin's Landscape Program has included a regulation requiring a proportion of the area to be left as green space, creating an index/standard to be respected in case of new construction or redevelopment: the Biotope Area Factor (BAF) or BFF (Biotop Flächenfaktor) (Climate-ADAPT, n.d.). The BAF index is the result of a ratio between ecologically effective areas and the total surface area of the urban plot considered. The value of the ecological index varies according to the level of sealing of the open space and the characteristics of the built environment (e.g. the presence of green roofs or green walls). The city of Berlin has provided an abacus of urban surface types by associating weighting factors[3] from 0 to 1. A value of '0' corresponds to completely sealed surfaces with no green areas and therefore negative effects on water runoff and urban microclimate. A value of '1' corresponds to plots with vegetation connected to the underlying soil, providing maximum performance in terms of water absorption, biodiversity, and improvement of the urban microclimate. Intermediate values correspond to semi-permeable surfaces or materials with intermediate ecological values. Berlin's urban transformation regulations also set a target parameter for redevelopment and new construction. Urban and architectural planners are allowed to develop their projects freely, as long as the target is met, and soil permeability and the presence of greenery are guaranteed. An inner-city area of Seoul has also experienced this methodical and systematic approach applied to its territory, to assess and manage urban ecosystem services by implementation in local planning instruments (Lakes & Kim, 2012).

At the international level, other cities adopted different indices, such as Malmö in Sweden with the Green Space Factor (Malmö stad, 2021), Oslo in Norway with the Green-Blue Factor (Cortinovis & Geneletti, 2020) and Seattle in the U.S.A. with the Seattle Green Factor (Seattle Department of Construction & Inspections, n.d.).

Another example of an environmental soil quality index is the Reduced Building Impact (RIE), adopted by the city of Bolzano, in Italy. This parameter supports land use planning in case of new buildings or renovations and is used to limit soil sealing in favour of more permeable areas (Città di Bolzano, 2021). In 2004 the city approved the new numerical index (with a range from '0' to '10') to certify the environmental quality of any future urban-building intervention. Importance is given to the benefit that permeable soil gives to the environment and to the well-being of the inhabitants, improving the urban microclimate and the capturing of rainwater runoff.

Other Italian municipalities in recent years have adopted these indices of environmental quality within their urban planning tools (Di Paolo et al., 2020): e.g. the city of Segrate adopted the BAF (Città di Segrate, 2017) while the city of Bologna adopted the RIE (Comune di Bologna, n.d.). In addition, an automatic methodology called M4BAF (maps for BAF) has been tested in Pavia to assess the quality of urban transformation interventions by comparing environmental quality indicators ex-ante and ex-post. The methodology refers in particular to the BAF index and is capable of automatically associating the value of the BAF coefficient (following the abacus proposed by the city of Berlin) with each urban area based on the existing vector cartography of the city of Pavia and GIS technology (Casella et al., 2015). With the detailed digital mapping of soil permeability, M4BAF can be considered an accurate methodology, that is replicable elsewhere.

Another study carried out in the medium-sized Italian city of Padua (Peroni et al., 2018) uses the BAF index to assess the current soil quality and to simulate future transformation scenarios for a pilot neighbourhood in the city. The analysis led to the hypothesis of improved interventions in urban areas characterised by a high degree of soil sealing, e.g. by providing green roofs and quantifying their positive effects, through the BAF index calculation. Indeed, the more the index reaches a high value, through the replacements of paving materials with more permeable ones or the addition of green walls/rooftops, the more the area can absorb water flows and improve local thermal comfort.

[3] See (Senate Department for & the Environment, Urban Mobility, Consumer Protection and Climate Action, 2021) for updated values of BAF weighting factors.

The cases reported above demonstrate the effort and attention of local governments and scholars to the contemporary need of adapting to climate change in the existing city using greenery and cool materials. However, the reported experiences do not specify how the areas to be de-paved are chosen, except on the basis of their permeability characteristics, equal extent for compensation purposes (Bundesministerium für Bildung und Forschung, n.d.) or feasibility of the intervention (Senatsverwaltung für & Umwelt, Mobilität, Verbraucher und Klimaschutz, 2022). Therefore, the authors intend to address the lack of a rigorous methodology to prioritise de-sealing operations. The methodology considers not only soil ecological and environmental performance but also the different levels of hydraulic and heat island hazards affecting urban areas. The hydraulic hazard identifies the probability that very heavy or abundant rainfall, combined with the area characteristics, may contribute to causing a flood. Instead, heat island hazard is due to higher daytime temperatures and reduced cooling at night resulting in higher air pollution and higher risk for vulnerable people in urban areas (Rota & Zazzi, 2018).

3. Materials and methods

This chapter will illustrate the methodological approach, developed with the support of the Municipality of Parma, adopted for the identification of priority public urban areas to be de-sealed. It is based on the measurement of the degree of permeability of public land and the assessment of areas subject to greater hydraulic and heat island hazards. Performing with ArcGIS software, a specific database was designed to locate and quantify impermeable surfaces on which the public administration can intervene directly with depaving, greening and replacing paving materials with cooler materials to mitigate possible flooding and hot temperatures. Only public open spaces were mapped as potential areas of intervention, leaving the remaining private areas for further future investigation. However, in agreement with the urban planning office of the Municipality of Parma, undeveloped private areas of considerable size and potentially subject to redevelopment were still pointed out.

The paragraphs below will illustrate the method which consists of the following steps:

- design of a GIS database aimed at mapping and quantifying permeable and impermeable surfaces of public urban spaces; the research defines in detail the procedure for collecting and storing data on ground cover and paving materials, and supports the calculation of the BAF weighting factor, i.e., the parameter chosen for evaluating the ecological-environmental performance of soils;
- data management to extrapolate, based on the BAF coefficient, urban public areas with lower levels of permeability to point out the potentially de-sealing areas;
- spatial analysis for identifying urban areas most prone to hydraulic and heat island hazards and defining priority interventions;
- identification and description of the pilot case study (a residential neighbourhood in Parma), to adapt data collection methods to the specific urban context and test the GIS database in a concrete case;
- finally, data collection and data entry for the implementation of the GIS database.

The method described aims to become a rigorous but easily replicable model of analysis applicable to other urban contexts.

3.1 Building the GIS database

The GIS database aimed at mapping in detail permeable and impermeable surfaces within public open spaces and evaluating priorities for de-sealing interventions has been designed following two data modelling steps (Laurini, 2001): conceptual and physical. These steps lead to a simplification of the problem, which is useful for the public administration to facilitate planning and management choices of urban transformations.

Table 1 shows the structure of the conceptual data model containing the list of useful feature classes for the research. For each feature class it is specified, the data typology (vector/raster), the geometry used to indicate it graphically in the GIS, and a brief description of the main categories belonging to each feature class.

Feature class	Data type	Geometry	Description
Road areas	Vector	Polygon	Categories of public spaces classified as road areas: road sections, intersections, overlaps, roundabouts, traffic dividers, slopes, squares, unmarked parking areas, pavements and other pedestrian areas.
Parking lots	Vector	Polygon	Categories of public spaces classified as parking lots: stalls, manoeuvring areas, flowerbeds or green strips.
Green areas	Vector	Polygon	Categories of public spaces classified as green areas: equipped parks or gardens, unequipped green areas, school gardens, urban gardens, dog areas and any internal paved paths.
Buildings	Vector	Polygon	Area occupied by private and public buildings

Tab.1 Conceptual data model of the GIS database

The conceptual data model establishes that all public open spaces are to be classified into three main feature classes: road areas, parking lots and (public) green areas. Each feature class maps in detail the land cover related to the object of investigation (respectively roads, car parks, and green areas) and thus contains both permeable and impermeable surfaces.

Data on land cover and paving materials are stored for each entity in the feature classes' attribute tables. This necessarily leads to the generation of separate entities (geometries) depending on the different paving materials. For instance, if the parking spaces in a car park are made of concrete-grass paver blocks and the manoeuvring space for vehicles is asphalt, two separate geometries must be drawn, both belonging to the car park's feature class.

All the main attributes (type, material, BAF coefficient[4]…) of the drawn entities have been defined in detail in the physical data modelling stage. This step defines the list of attributes to be filled in and describes their meaning and possible inputs. Where possible, a domain is set per attribute, i.e., the set of possible input values within the attribute. Tabb.2, 3, and 4, show the physical data modelling of each feature class.

Attribute	Description	Domains
Type	Road area typology	Road section, intersection, overlap, roundabout, traffic dividers, subway, slope, square, unmarked parking areas, pedestrian areas
Shape area	Geometry area	Numeric value
Road type	Road category	Highway, road, avenue, street, alley, corner, other
Material	Paving material	Asphalt, cobblestones, concrete, soil, granite, grass, gravel, grass paving blocks, self-locking blocks, limestone, masonry, porphyry, stone tiles, other
BAF coefficient		0.0, 0.3, 0.5, 1.0
Status	Current status of the area	Existing, planned, under construction
Green status	Status of the greenery	Empty, free, cured
Green type	Green category	Cemetery, large urban park >8,000 sqm, equipped green area 5,000>8,000 sqm, equipped green area <5,000 sqm, listed green area, school gardens, slope, sports areas, uncultivated green areas, urban landscaping, urban gardens, wooded areas, other.
Transformable		Yes, no

Tab.2 Attribute table of the feature class 'Road areas'

[4] See Chapter 3.2 for the calculation of the BAF coefficient

Attribute	Description	Domains
Type	Area typology	Stalls, manoeuvring areas, flowerbeds or green strips
Shape area	Geometry area	Numeric value
Material	Paving material	Asphalt, cobblestones, concrete, soil, granite, grass, gravel, grass paving blocks, self-locking blocks, limestone, masonry, porphyry, stone tiles, other
BAF coefficient		0.0, 0.3, 0.5, 1.0
Green type	Green category	Cemetery, large urban park >8,000 sqm, equipped green area 5,000>8,000 sqm, equipped green area <5,000 sqm, listed green area, school gardens, slope, sports areas, uncultivated green areas, urban landscaping, urban gardens, wooded areas, other.
Green status	Status of the greenery	Empty, free, cured
Status	Current status of the area	Existing, planned, under construction
Transformable		Yes, no

Tab.3 Attribute table of the feature class 'Parking lots'

Attribute	Description	Domains
Type	Area typology	Green area, paved area
Shape area	Geometry area	Numeric value
Material	Paving material	Asphalt, cobblestones, concrete, soil, granite, grass, gravel, grass paving blocks, self-locking blocks, limestone, masonry, porphyry, stone tiles, other
BAF coefficient		0.0, 0.3, 0.5, 1.0
Green type	Green category	Cemetery, large urban park >8,000 sqm, equipped green area 5,000>8,000 sqm, equipped green area <5,000 sqm, listed green area, school gardens, slope, sports areas, uncultivated green areas, urban landscaping, urban gardens, wooded areas, other.
Green status	Status of the greenery	Empty, free, cured
Status	Current status of the area	Existing, planned, under construction
Transformable		Yes, no

Tab.4 Attribute table of the feature class 'Green areas'

An additional feature class of the GIS database stores information concerning buildings, their shape, public or private ownership and main uses. Filling in the descriptive attributes of this feature class is particularly useful for obtaining references on the functional aspects of the built environment.

In addition to the geometries mapping the entities, further information completes the GIS database:

- hydraulic hazard zones;
- urban heat island temperature.

The inclusion in the GIS database of these data is intended to guide the choices of future new territorial transformation interventions. The following section illustrates the spatial analysis process adopted to derive from the overlaying of these new data with permeable or impermeable public areas possible de-sealing actions aimed at improving environmental effects. By overlapping each of these feature classes with public areas, whether they are permeable or impermeable, mapped in the area of interest, it is possible to plan the actions to be taken, maximizing the environmental effects and economic costs.

In order to constantly update the GIS database, useful information can be derived from various sources.

Geographical data can be drawn from the official databases of local/regional geographic information systems; other information, on the other hand, can be gathered through direct and photo-interpretative surveys[5] or through collaboration with the urban planning office of city administrations.

3.2 Permeability Indices and Spatial Analysis

Once the GIS database has been set up and data have been collected and organized, information components (attribute tables) of the three feature classes that map public open space in detail (road area, green areas, and parking lots) are enriched with quantitative information about permeability and ecological effectiveness.
Each entity is then assigned a particular ecological-environmental performance parameter named 'BAF coefficient', related to the land cover material. This weighting factor of the BAF system, as explained in Chapter 2.2, is an ecological-environmental performance parameter that defines the ecological effectiveness of different land covers in terms of soil permeability and ecosystem functions (biodiversity, water absorption, urban microclimate control).
Table 5 lists the different paving materials of public open spaces in the pilot areaassociated with the corresponding BAF coefficient (according to the BAF system used by the city of Segrate) and the relative level of ecological performance.

Material	BAF coefficient	Level of ecological performance
Asphalt	0.0	Fully sealed surface: it is impermeable to water and has no plant growth. Zero evapotranspiration efficiency.
Cobblestones		
Concrete		
Granite		
Masonry		
Porphyry		
Stone tiles		
Gravel	0.3	Partially permeable surface: it is permeable to water and air but no plant growth.
Self-locking blocks		
Limestone		
Grass paving blocks	0.5	Semi-permeable surface: it is permeable to water and air. The possible vegetation is unconnected to soil below. Medium evapotranspiration efficiency.
Soil	1.0	Fully permeable and highly environmentally effective surface: vegetation is connected to the surrounding land and it is available for the development of flora and fauna.
Grass		

Tab.5 Abacus of materials and their ecological performance levels (Città di Segrate, 2017)

Once the BAF coefficients have been assigned to each geometry belonging to the main data classes of street area, green areas and parking lots, the GIS database is ready for data analysis. In this phase, the most impermeable or less efficient areas have been selected as potential areas for de-sealing and greening interventions.
Finally, a spatial analysis is conducted to identify urban areas most prone to hydraulic and heat island hazards, with the aim of defining different levels of priority for de-sealing and greening interventions. This last operational phase, supported by GIS geoprocessing tools, consists of studying the vulnerability of the urban

[5] The photo-interpretation process, in the research under review, was carried out in the systematic collection of information using the orthophoto 'Ortofoto CGR 2018 RGB (WMS). Ortofoto 30 cm' retrieved from the geoportal of the Emilia-Romagna region (https://geoportale.regione.emilia-romagna.it/servizi/servizi-ogc/elenco-capabilities-dei-servizi-wms/cartografia-di-base/service-29). *In situ* surveys and remote inspection from Google Earth and Google Street View applications were carried out for further detailed verifications.

system to flooding and rising temperatures in relation to the permeability of public open spaces. A higher priority for possible urban regeneration and de-sealing interventions can be assigned to public impermeable surfaces located in the surrounding areas of the main public facilities, since in case of extreme weather events, there would be a possible higher concentration of people affected. The public facilities considered in this methodology include mainly administrative and institutional facilities, school facilities and libraries, sports areas and major transport nodes such as the railway station. The most exposed area around each public facility is estimated to be around 300 m, a distance considered acceptable for pedestrian accessibility. Then, these buffer areas combined with hydraulic and heat island hazard zones, bring out urban areas with different potential levels of priority for intervention. Hydraulic and heat island hazards were chosen because they represent significant challenges in the urban environment, especially with the increasing effects of climate change. The latter phenomenon is particularly dangerous for citizens living in high-density urban areas, especially the most vulnerable ones, due to excessive temperature rises.

Regarding the planning of priority future soil de-sealing interventions, two possible planning solutions are evaluated:

- the first solution (A) combines the previously extrapolated selection of more impermeable surfaces with the high, medium, and low priority areas due to hydraulic hazard;
- the second solution (B) considers the same combination but based on the assessment of heat island hazard only.

Table 6 describes in detail the parameters used to assign the three intervention priority levels for the first solution examined, considering the BAF coefficients, the hydraulic hazard zones, and the most exposed areas. The criteria used to assign priority levels according to the heat island hazard (solution B) are expressed in Table 7, which takes up the approach of the previous one.

The results of the data analysis, performed on a pilot case study are described in detail in the following chapters.

	Hydraulic hazard					
	Rare floods		Infrequent floods		Frequent floods	
BAF coeff.	less exposed areas	most exposed areas	less exposed areas	most exposed areas	less exposed areas	most exposed areas
0.0	Medium	High	High	High	High	High
0.3	Low	Medium	Low	Medium	Medium	High
0.5	Low	Medium	Low	Medium	Low	Medium
1.0	Low	Low	Low	Low	Low	Low

Priority: Low Medium High

Tab.6 Criteria for assigning priority soil de-sealing interventions according to the hydraulic hazard

	Heat island hazard					
	27-29°C		29-31°C and 31-33°C		33+ °C	
BAF coeff.	less exposed areas	most exposed areas	less exposed areas	most exposed areas	less exposed areas	most exposed areas
0.0	Medium	High	Medium	High	Medium	High
0.3	Low	Medium	Low	Medium	Medium	High
0.5	Low	Low	Low	Medium	Low	Medium
1.0	Low	Low	Low	Low	Low	Medium

Priority: Low Medium High

Tab.7 Criteria for assigning priority soil de-sealing interventions according to the heat island hazard

3.3 Pilot case study: San Leonardo neighbourhood in Parma

The method has been applied to a significant pilot case study, the San Leonardo neighbourhood in Parma, to test its applicability and adjust data collection procedures, considering the specific urban context. The city of Parma, in accordance with regional regulations, is committed to equipping its urban plan with strategies and measures for urban compensation and adaptation to climate change, thus promoting interventions to increase the permeability of urban soils, with reference to public land which has a high degree of operability. Considering the complexity of drafting a suitable proposal, the municipal administration not only collaborated in the implementation of the methodology of this research activity but also suggested the S. Leonardo neighbourhood as a possible case study.

The neighbourhood is located in the northern, north-eastern part of the city (Fig.1). It has an extension of 444 ha and is bordered to the west by the Parma stream, to the east by the provincial road axis SP62R (Via Mantova), to the south by the Milano-Bologna railway axis and to the north partly by the northern ring road and partly by provincial road SP7. The neighbourhood is characterised by a high population density and multiethnicity, as reported by a recent document of the Statistics Office of the City of Parma (Comune di Parma, 2021). In addition, it hosts public facilities and infrastructure such as schools, sports facilities, a railway station, and a wide variety of shops.

The decision to test the methodology on this neighbourhood was guided by a few criteria. First, it is a peripheral area, therefore with fewer urban planning constraints than the historic centre. Moreover, it has a high degree of urbanisation and is located near a watercourse of the primary hydrographic network. Finally, the neighbourhood is not particularly extended, ensuring more rapid testing of the methodology proposed over here.

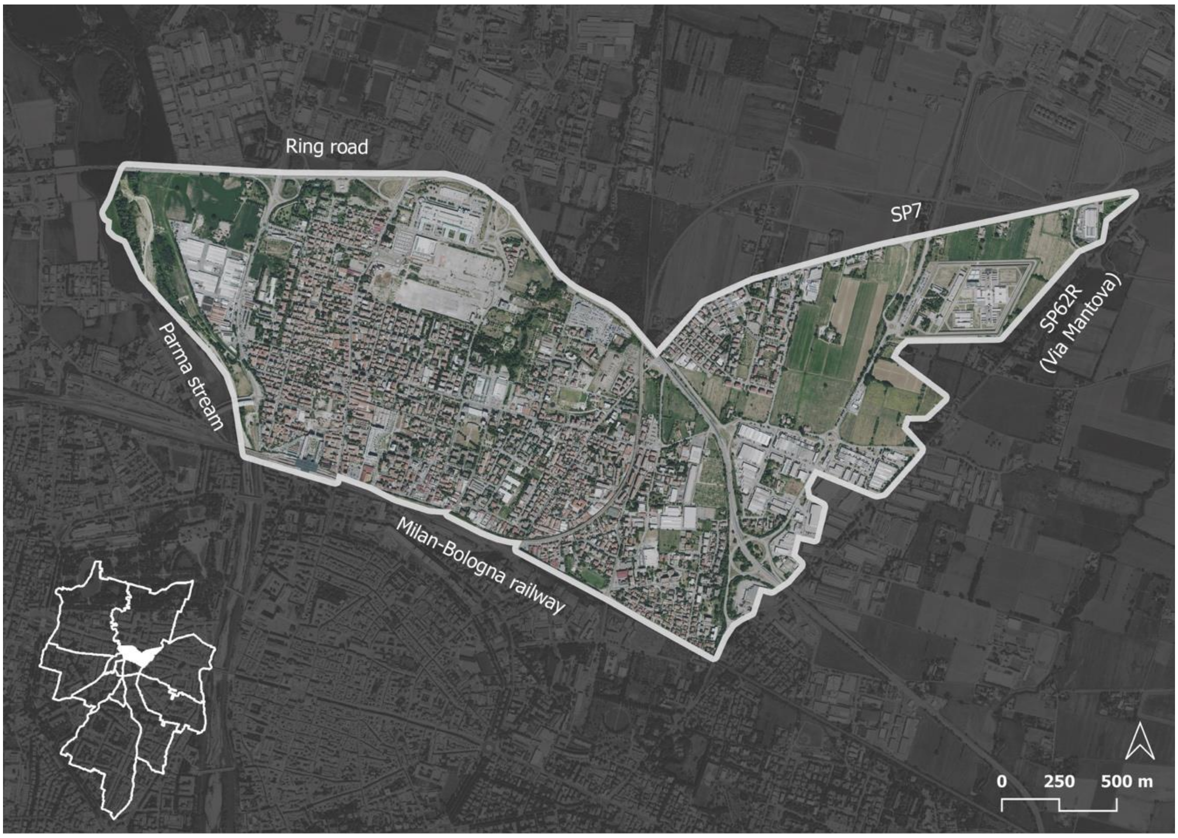

Fig.1 San Leonardo neighbourhood in Parma

3.4 Data

This phase covers all data search activities to enable the implementation and populating of the GIS database according to the data modelling described in Chapter 3.1.

In this pilot case, the data collection activity involved the consultation of existing official databases in local/regional spatial information systems, the construction of vector data through photo-interpretation and digitalisation of satellite images[6], and the collection of vector and raster maps directly from the urban planning office of the Municipality of Parma or research centres such as the Institute of Biometeorology of the National Research Council (CNR-IBIMET).

As highlighted in Tab.8, most of the cartographic data in vector format were retrieved from the Regional topographic database layers available in the geoportal of the Emilia-Romagna region. Data on the different hydraulic hazard levels were provided by the Urban Planning office, while the surface air temperature map (2015) was provided by the CNR-IBIMET (Rota, 2017). Finally, the municipal spatial information system mainly provided the necessary spatial and non-spatial information to implement the feature classes of the GIS database.

	Type	**Source**				**Editing /Updating**
	Vector (V) Raster (R)	*Municipal geoportal*	*Regional geoportal*	*Urban planning office - Municipality of Parma*	*CNR-IBIMET*	*Photo-interpretation and digitalisation of satellite images*
Base map data						
Regional topographic database	V		√			no
Pre-processed data						
Hydraulic-hazard_ER_high	V			√		no
Hydraulic-hazard_ER_medium	V			√		no
Hydraulic-hazard_ER_low	V			√		no
Surface_air_temperature_map (2015)	R				√	no
Pre-processed data						
Buildings	V	√				yes
Road_area	V	√				yes
Roundabout_material	V			√		no
Cycle_paths	V			√		yes
Green_areas	V			√		yes
Green_Work_Gen (2015)	V			√		no
Library	V			√		no
School	V			√		no
New feature classes						
Pavements	V					yes
Parking_lots	V					yes

Tab.8 Summary of data sources

[6] See note 5 for more details.

The 'Road_area' feature class served as the spatial reference for editing other feature classes of the GIS database, considering that the street area is a substantial part of the public space under investigation. Other collected data only served to retrieve qualitative attributes about the physical characteristics of public urban spaces (e.g. paving materials) to be transferred into the feature classes' attribute table.

Since the spatial and non-spatial information stored in the existing geographic data was not sufficient to provide a detailed mapping of the urban public space, several new geometries, with associated attributes, were created through photointerpretation and digitisation of satellite images. To ensure the consistency of the final GIS database, geometry validity and geometric congruence checks were performed in all feature classes, obtaining a homogeneous work base, without mistakes or data overlaps.

ArcGIS software was chosen to manage the pre-processing and data entry to ensure the compatibility and interoperability of the data provided by the Urban Planning office, which is accustomed to using this operational tool.

4. Results

The carried-out research has resulted in a cognitive framework concerning the permeable and impermeable public space of the urban fabric in the S. Leonardo neighbourhood in Parma. From the maps produced with the methodology and data described above, it is possible to highlight areas with different degrees of permeability according to the use of different surface materials within the three main open space typologies: road area, parking lots and green areas.

Fig.2 shows a detailed mapping of the different paving materials found in public space. Each colour corresponds to a different surface material. On a total of almost 134 ha of public land analysed, the quantitative analysis carried out revealed most surfaces covered by the following materials:

- asphalt (approx. 70 hectares) covers 51.96% of the total extent of public space;
- grass (approx. 55 hectares) covers 41.17% of the total extent of public space;
- grass paving blocks (approx. 3 hectares), cover 2.29% of the total extent of public space.

Asphalt mainly covers the principal road system that branches off into the urban fabric, while the greatest presence of permeable soil (grass) can be seen in the areas of the Parma stream bed, in the large green roadside areas to the north and east of the neighbourhood, and in the clearly recognisable urban parks and gardens in the middle of the neighbourhood.

Then, Fig.3 shows the BAF coefficient (i.e., the weighting factor referring to soil permeability) assigned to each surface material type according to the abacus presented in Tab.5. The graphical representation, with different colours for each coefficient value, helps to have a quick overview of the soil permeability condition.

Impermeable soil is widespread, especially in street areas and numerous public car parks, while it is only limited to some pedestrian and bicycle paths within public parks and gardens.

Partially permeable areas with intermediate ecological performance are mainly concentrated in parking lots in the northern part of the neighbourhood (since the relatively recent construction of public car parks in Parma has a considerable extension of semi-permeable paving materials and many more planted areas), and in the south, near the train station in an urban sector that has undergone recent redevelopment. However, they constitute the lowest percentage, covering only 8.22 ha out of a total of about 134 ha (Fig.4).

Through the GIS database used it was possible to find, in the study area and with reference to the three main feature classes of analysis, the presence of permeable soil equal to about 41% of the mapped surface. The remaining 59% corresponds to impermeable soil, 88% of which is classified as an asphalt area. Fig.5 shows this percentage on a graph, also adding the corresponding land extension in hectares.

Fig.2 Classification of surface materials in the public space of S. Leonardo neighbourhood

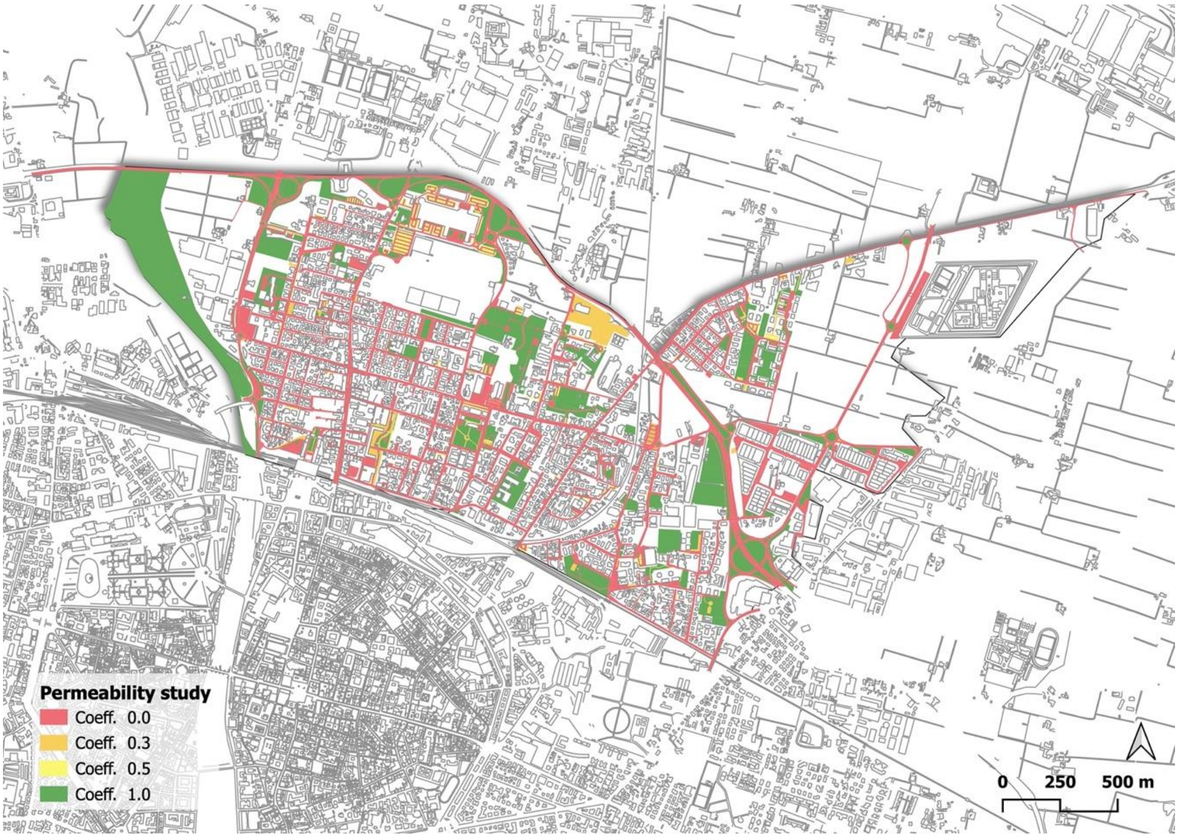

Fig.3 BAF coefficients map (permeability map) of the public space in S. Leonardo neighbourhood

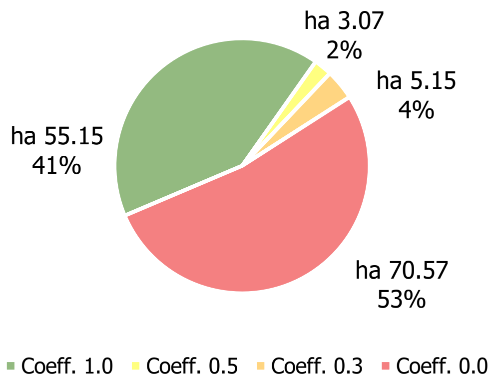

Fig.4 Quantitative analysis of soil permeability, based on the BAF coefficients, in S. Leonardo neighbourhood

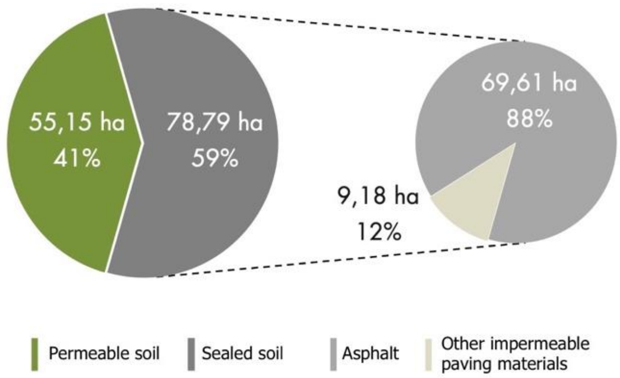

Fig.5 Quantitative analysis of impermeable public areas in S. Leonardo neighbourhood

Then, focusing on the impermeable areas only, which are in clear majority compared to the completely permeable ones, the result is a map like the one in Fig.6.

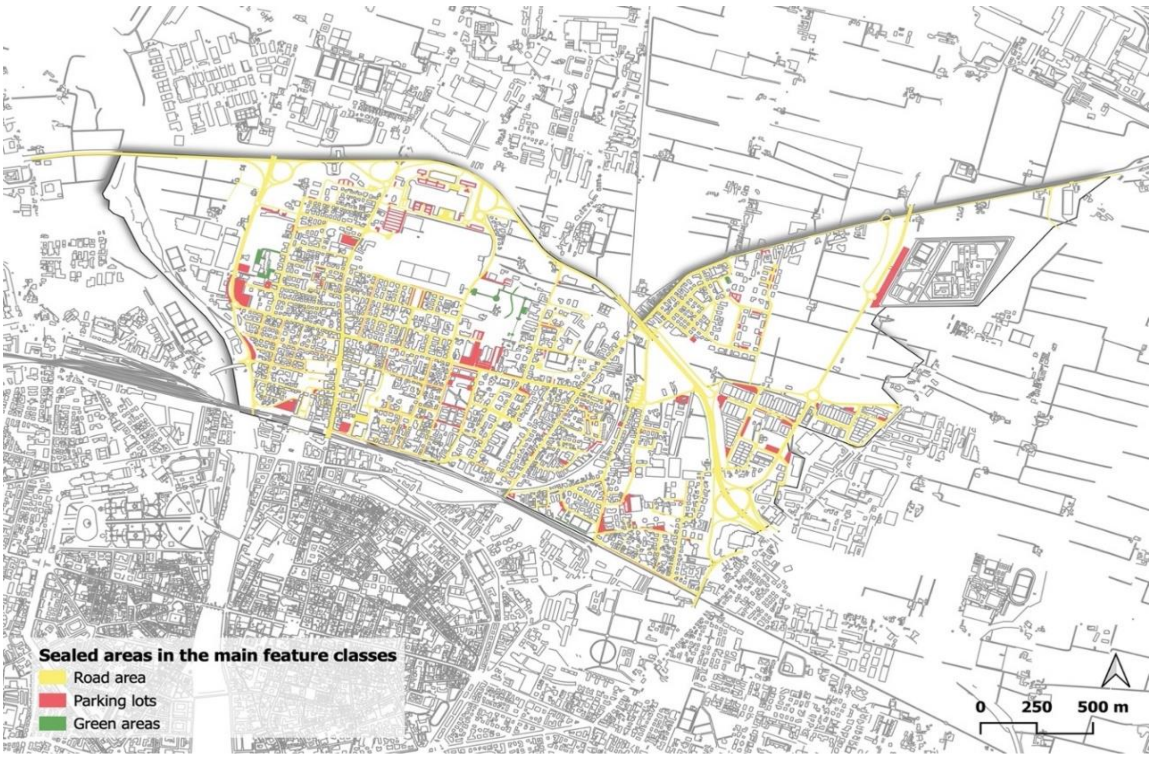

Fig.6 Location of the main feature classes' sealed areas

The areas represented have been subdivided according to the main feature classes under study and, in order of largest area occupied, we obtain:

- road areas with 57.48 ha impermeable, mostly occupied by the road network grid, equal to 73%;
- parking lots with 19.14 ha impermeable, consisting of manoeuvring areas and mainly asphalted parking spaces, equal to 24%;
- green areas with 2.17 ha considered impermeable, due to the presence within these areas of footpaths with a not fully draining surface coverage equal to 3%.

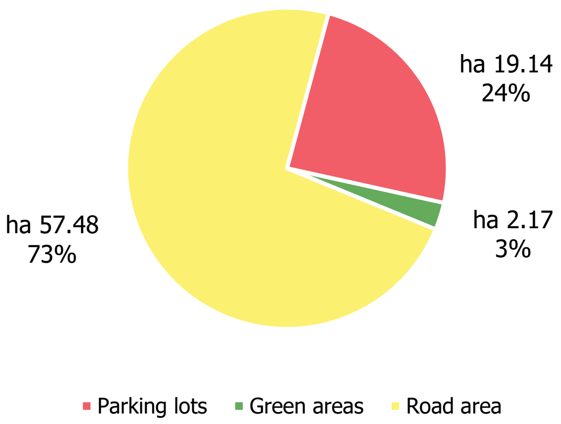

Fig.7 Graph of the sealed areas registered in the GIS database

The second phase of the analysis is aimed at identifying priority criteria for de-sealing interventions of sealed public areas in relation to areas most exposed to hydraulic and heat island hazards. Following the methodological steps described in Chapter 3.2, firstly, the main public facilities in the S. Leonardo neighbourhood have been selected (within the buildings layer of the GIS database): 1 library, 8 schools, 11 sports areas, and 1 railway station.

Then, for each public facility, a 300-meter buffer area has been generated.

In Fig.8 buffer areas have been overlaid with the hydraulic hazard map (Comune di Parma, n.d.), in which the area of flooding potential propagation is classified into three categories related to the probability of the event occurring: frequent floods, infrequent floods, and rare floods. Frequent floods mainly occur along the course of the Parma stream (with a higher probability - H); infrequent floods affect a larger area in the eastern part of the neighbourhood (medium probability - M); finally, rare floods affect urban areas in the western side of the stream (low probability - L). Public facilities buffer areas are mainly located in the medium and low hydraulic hazard zones. While the area denoted by 'H' is limited to the Parma stream bed.

Then, in Fig.9, public facilities' buffer areas have been overlaid with the surface air temperature map[7]. In this map surface air temperatures were grouped into four bands: 27-29°C, 29-31°C, 31-33°C, and over 33°C in order to have a clearer reading of the data and, consequently, easier identification of areas with different levels of criticality. A low criticality level was assigned to the 27-29°C band, medium to the 29-31°C and 31-33°C bands, and finally high to temperatures exceeding 33°C. The higher is the temperature, the higher the level of attention.

[7] CNR-IBIMET, Diurnal Land Surface Temperature (LST) detected on 23/6/2015 by ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), a NASA satellite remote sensing sensor.

Fig.8 Hydraulic hazard and most exposed urban areas

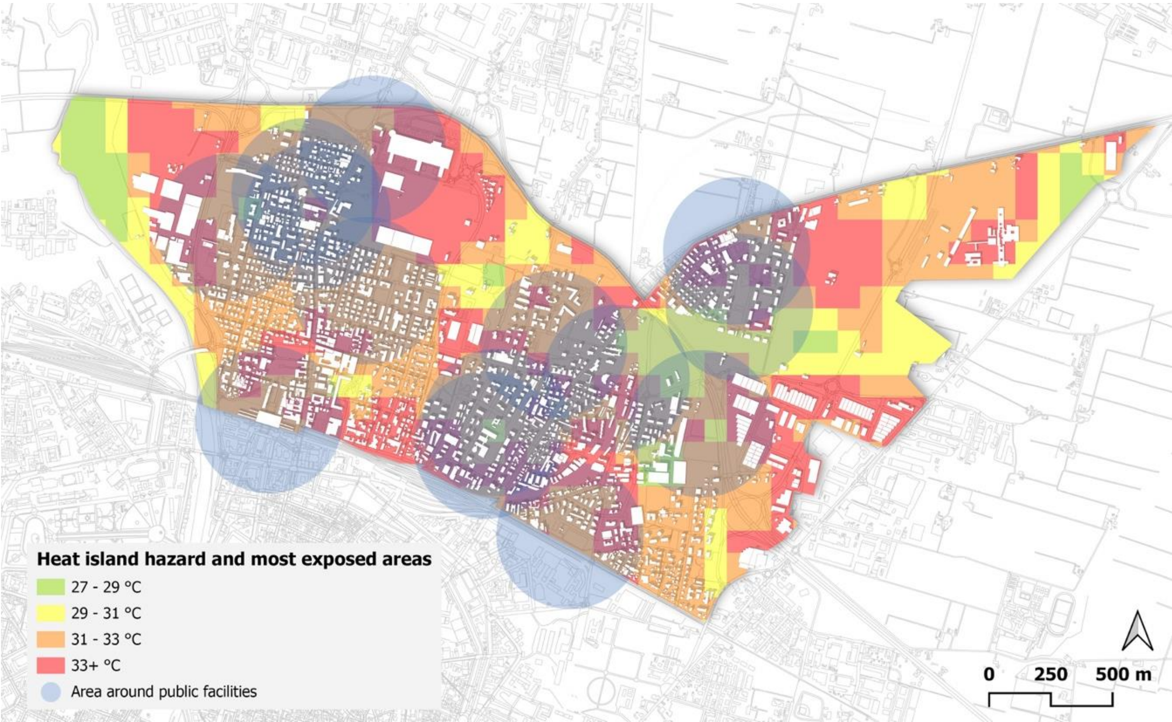

Fig.9 Heat island hazard and most exposed urban areas

The next two maps show two possible planning solutions of de-sealing intervention priorities, to adapt respectively to hydraulic hazards effects (Fig.10), by increasing the water absorption capacity of the soil, or heat island hazard effects (Fig.12), by decreasing heat absorption and release of urban space surfaces. In both maps, three priority levels have been identified: high, medium, and low. For those low-priority areas that are completely permeable, and for which there is therefore no need for de-sealing actions, greening interventions are envisaged.

It should be noted that at this stage, the data processing was carried out considering only the entities of the feature class 'Parking lots', which means that the next figures identify priority de-sealing interventions for public car parks only. The intersection between the different permeability of the parking areas and their location near one or more public facilities, as well as areas of more or less high hydraulic danger (left in greyscale in the background), led to the elaboration of solution A (Fig.10). According to these criteria, only a few high priority areas result: 2 hectares for a total area of just less than 20 hectares. The graph below (Fig.11) completes the quantitative analysis of impervious areas by priority levels of intervention. The greater concentration of public facilities in the western part of the study area, causes a higher concentration of high-priority areas within a particularly small radius. Similarly, the presence of high hydraulic hazard on the east side of the district, although distributed over a larger area.

Fig.10 Planning of priority soil de-sealing interventions: solution A

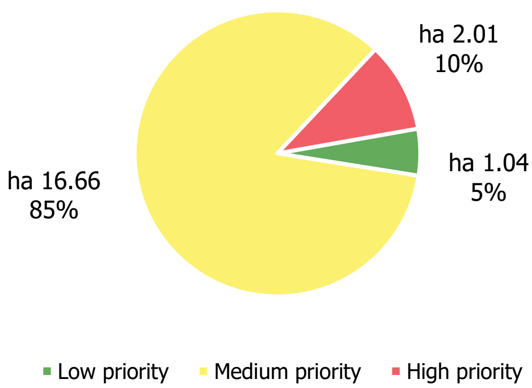

Fig.11 Quantitative analysis of the priority soil de-sealing intervention in solution A

The combination of the data on the permeability of the intervention areas and the data on the danger of the heat island (shown on a chromatic scale from black to white) led to the creation of a second scale of intervention priorities, solution B, represented in Fig.12.

The map shows how, in contrast to the previous one, the areas of high priority (H) have increased: from 2 hectares before to almost 9 hectares, following this second order of priority (Fig.13). The higher density of buildings and the lower presence of green areas, especially in the western part of the district, have led to an intensification of the heat island phenomenon, with a more uniform temperature but, at the same time, on average higher than in other areas.

Fig.12 Planning of priority soil de-sealing interventions: solution B

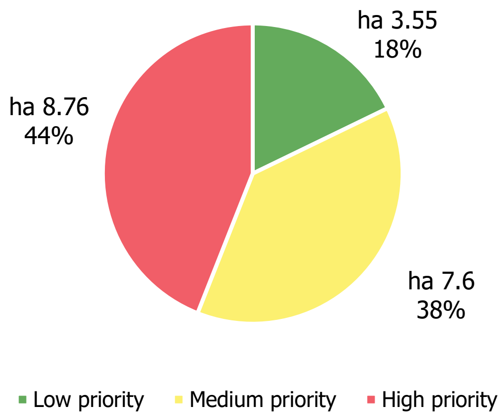

Fig.13 Quantitative analysis of the priority soil de-sealing intervention in solution B

5. Discussion and conclusion

This contribution aimed to illustrate a methodological approach, supported by GIS technology, involving detailed mapping of land cover in public space and an assessment of the location of areas to be de-sealed in relation to the identification of the most exposed urban areas. To achieve this goal, a GIS database was designed to map soil permeability in public open spaces (i.e., surface materials of road areas, parking lots, and green areas) and specific ecological-environmental coefficients were associated to the different ground cover and paving materials. Then to draw up a priority list of public urban areas that can be subjected to future de-sealing interventions, data on hydraulic and heat island hazards were added to the analysis, as well as the perimeter of potentially more exposed/vulnerable urban areas. The systematic approach was then applied to a pilot case study, the San Leonardo neighbourhood in Parma, to test its applicability. The combination of the above data with the impermeable areas belonging to the parking lots feature class led to two different intervention priority scales: solution A with reference to the hydraulic hazard, and solution B with reference to the heat island hazard. Our identification of areas for de-sealing interventions fits and builds on the experiences cited in the literature review but adds an innovative aspect to the analysis, namely the prioritisation of intervention levels based on the assessment of hazards and vulnerability of urban systems. The areas with the lowest permeability coefficient were compared with maps representing critical climatic and environmental issues affecting the city. Working with overlapping levels, it was possible to note the coexistence of various levels of criticality, thus delineating a scale of intervention priorities. Furthermore, the analysis focuses only on public space, a system that is in the immediate availability of the public administration and thus it does not require land acquisition processes. An extension of the analysis to private areas could be also considered in future applications, including privately owned areas, especially unused and/or abandoned ones. The methodology presented lends itself to the practical application in planning tools such as the strategic component of urban plans or SEAPs. Although it starts from the design of a rigorous and original database, it does not present excessive levels of complexity and furthermore is based on the use of GIS for geographical data collection and management, a well-known tool widely used in the field of town planning and in the municipal planning offices to facilitate urban transformations choices (Harris & Elmes, 1993; Yeh, 1999; Rezvani et al., 2023; Legambiente, n.d.). A database built using such an expeditious methodology is a helpful tool that can be easily updated over time by the technicians in charge according to the needs.

However, the study has limitations, such as the use of the BAF coefficient itself: it does not contemplate differences in performance between green soil and vegetated soil, so the presence of, for example, trees that help with shading, and which would therefore play a greater role in mitigation, are not considered. Thus, extending to a larger scale, a characterization refinement of morphology and permeability of virgin soils could be a prospect of improvements in this research.Some interpretation mistakes may also arise from mapping surface materials in public open space by photo-interpretation, as proposed by the methodology, as well as less precision in digitalising and quantifying areas. In addition, the onerousness of constructing and updating data by photo-interpretation (in terms of time and people in charge) can be considered the main limitation of the application to extended urban areas, which, however, can be overcome considering the possibility of introducing faster and more automated data collection that relies on aerial surveying using sensors and machine learning methods (e.g. precision aerial surveying, using remotely piloted aircraft systems – RPAS) (Naughton & McDonald, 2019; Yigitcanlar et al., 2020). These technologies, however, while very effective in collecting data in a rather autonomous manner over large expanses of land, require specific technical skills and expensive equipment. Another observation on the validity of the method concerns the choice of criteria and factors for selecting de-sealing priority areas. In the case of Parma, for example, evaluations on which areas are to be preferred for de-sealing interventions can also be based on a comparison with the city's Public Works Programme: the overlap between de-sealing priority areas and the intervention areas identified in this Programme leads to a better optimisation and management of the necessary workforce. Finally, the economic factor also influences the choice of priorities, so it is necessary to carry out appropriate checks on the costs for redevelopment and disposal of excavation soil and other materials.

About future developments, a next step would be to apply scenarios of de-sealing, to check how effective the interventions really are in the surrounding context, depending also on other factors such as topography and morphology of each studied area.

This paper could also be a starting point for local administrations that desire to implement their urban planning tools in terms of improving urban resilience, developing integration of this methodology with devices and mechanisms for calculating hydraulic invariance of urban transformation interventions.
The work done, in addition to building a GIS methodology that can potentially be replicated in other urban contexts, lays the groundwork for research development aimed at better-defining criteria and directions for the inclusion of de-sealing objectives in the strategic and regulatory component of urban regeneration planning tools. Within this development, urban planning indices and parameters will be defined for the pursuit of de-sealing objectives related to the response of urban soils to water runoff and the heat island effect. In conclusion, the contribution aims to fill that methodological gap with regard to the choice of priority areas to be de-sealed, considering both their degree of permeability and their role in adapting to strong climatic events.

Authors' contribution

The authors jointly designed and contributed to the paper. Conceptualization, M.Z., B.C. and M.C.; Data curation, M.C.; Investigation, M.C.; Validation: M.Z. and B.C.; Methodology, M.C., M.Z., and B.C.; Supervision, M.Z.; Writing—original draft, M.C. and B.C.; Writing—review and editing, B.C. and M.Z. All authors have read and agreed to the published version of the manuscript.

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Image sources

Fig.1: Authors' elaboration with data retrieved from: Geoportale Emilia-Romagna region https://geoportale.regione.emilia-romagna.it/servizi/servizi-ogc/elenco-capabilities-dei-servizi-wms/cartografia-di-base/service-29;

Fig.2: Authors' elaboration with data retrieved from: Municipal geoportal https://opendata.comune.parma.it;

Fig.3: Authors' elaboration with data retrieved from: Municipal geoportal https://opendata.comune.parma.it;

Fig.4: Authors' elaboration;

Fig.5: Authors' elaboration;

Fig.6: Authors' elaboration with data retrieved from: Municipal geoportal https://opendata.comune.parma.it;

Fig.7: Authors' elaboration;

Fig.8: Authors' elaboration with data retrieved from: Municipal geoportal https://opendata.comune.parma.it and Comune di Parma, *Rischio idrogeologico*. https://www.comune.parma.it/protezionecivile/Rischio-idrogeologico.aspx;

Fig.9: Authors' elaboration with data retrieved from: Municipal geoportal https://opendata.comune.parma.it and CNR-IBIMET, Diurnal Land Surface Temperature (LST) detected on 23/6/2015 by ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), a NASA satellite remote sensing sensor;

Fig.10: Authors' elaboration with data retrieved from: Municipal geoportal https://opendata.comune.parma.it and Comune di Parma, *Rischio idrogeologico*. https://www.comune.parma.it/protezionecivile/Rischio-idrogeologico.aspx;

Fig.11: Authors' elaboration;

Fig.12: Authors' elaboration with data retrieved from: Municipal geoportal https://opendata.comune.parma.it and CNR-IBIMET, Diurnal Land Surface Temperature (LST) detected on 23/6/2015 by ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), a NASA satellite remote sensing sensor;

Fig.13: Authors' elaboration.

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