Integrating permeable pavements into sustainable urban mobility planning

Intégrer les chaussées perméables dans la planification de la mobilité urbaine durable

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RÉSUMÉ

L'étude examine l'intégration des chaussées perméables dans la planification de la mobilité urbaine durable à Bologne, en Italie, en évaluant leurs avantages pour la gestion des eaux pluviales dans les conditions climatiques actuelles et futures. Un bassin versant résidentiel représentatif de 50 hectares, situé dans la municipalité de Bologne, a été analysé à l'aide de simulations hydrologiques et hydrauliques à long terme réalisées avec EPA SWMM. Les scénarios considérés prennent en compte la mise en œuvre de chaussées perméables sur les chemins piétons et les parkings. Un ensemble de paramètres LID calibrés à partir d'expériences en laboratoire a été appliqué au modèle. Les résultats montrent des bénéfices substantiels, avec une réduction des volumes d'eaux pluviales drainées de 40 % dans les conditions climatiques actuelles et de 38 % dans les conditions futures. Ces conclusions soutiennent le Plan de mobilité urbaine durable de Bologne, soulignant que les chaussées perméables constituent une stratégie efficace pour améliorer la capacité globale de gestion des eaux pluviales en répondant aux contraintes des zones urbaines fortement densifiées. L'étude montre comment les chaussées perméables peuvent être intégrés dans le plan de mobilité en tant que mesure d'adaptation au climat, en complétant les stratégies d'atténuation et en offrant des synergies pour guider une planification urbaine efficace.

ABSTRACT

The study investigates the integration of permeable pavements into sustainable urban mobility planning in Bologna, Italy, assessing their stormwater management benefits under current and future climate conditions. A representative 50-hectare residential catchment within Bologna municipality was analyzed through long-term hydrological-hydraulic simulations in EPA SWMM. Scenarios built consider the implementation of permeable pavements, in currently impervious areas that are not occupied by building or major roads, such as pedestrian paths and parking areas. A calibrated LID parameter set derived from laboratory experiments was applied to the model. Results indicate substantial benefits, with a drained stormwater volumes reduced by 40% under current climate and by 38% under future conditions. Findings support Bologna's Urban Plan for Sustainable Mobility, highlighting permeable pavements as an effective strategy to improve overall stormwater management capacity by addressing the constraints of highly densified urban areas. The study shows how permeable pavements can be integrated into the mobility plan as a climate-adaptation measure, complementing mitigation strategies and offering synergies to guide effective urban planning.

KEYWORDS

EPA SWMM, LID module, Permeable pavements, Stormwater management

1 INTRODUCTION

Bologna and its surrounding territory are entering a new era of urban development, guided by a renewed planning vision. The municipality is actively promoting the enhancement of green areas, recognizing the vital role of permeable soils and vegetation in supporting natural cycles, mitigating climate-related hazards, and delivering multiple co-benefits. At the same time, the city is investing in infrastructures that prioritize cycling and walking as primary modes of transport. A key component of this vision is the Urban Plan for Sustainable Mobility (UPSM), which integrates a range of strategies including the development of pedestrian areas, pedestrian-priority traffic zones, environmentally restricted traffic zones, and the widespread implementation of a 30 km/h speed limit across many areas of the city (Nuvolari-Duodo et al., 2024).

The context described above well aligns the needs for stormwater management in urban areas: the potential implementation of permeable pavements in currently impervious areas that are not occupied by building or major roads, such as pedestrian pathways and car parks, seems to meet the desire of municipality and water stakeholders. From one side, it promotes more sustainable use of public space, and on the other one, it allows infiltration of stormwater, thereby reducing the volume that must be managed at the wastewater treatment plant. The objective of the paper is to quantify the benefits in terms of stormwater volumes reduction when considering the inclusion of permeable pavements in urban areas, by taking into account the future climate contexts. This design approach aligns with the strategies of the UPSM and supports the municipality's broader goals of increasing urban resilience, improving stormwater management, and promoting more sustainable use of public space.

2 MATERIAL AND METHODS

2.1 Case study

To assess the potential benefits, a representative urban context within Bologna municipality was selected. The study area is a neighborhood covering approximately 50 ha, characterized as a densely urbanized residential area with about 11,000 inhabitants (ISTAT, 2021). Dominant land uses include residential and commercial, while green areas, both public and private, account for 22% of the total surface.

2.2 Scenarios development

Based on the characteristics of the case study and the objectives of the analysis, four scenarios were defined. Figure 1 summarizes the scenarios considered, which are structured around two main dimensions: land use and climate. The first set of scenarios is based on the current land use, while the second set explores the implementation of permeable pavements in impervious areas that are not occupied by buildings or main roads, such as pedestrian paths and car parks. In addition, incorporating green infrastructure along sidewalks can enhance the perceived safety and usability of public spaces, as promoted in USPM. Overall, the suitable areas for conversion represent 11% of the total catchment area.

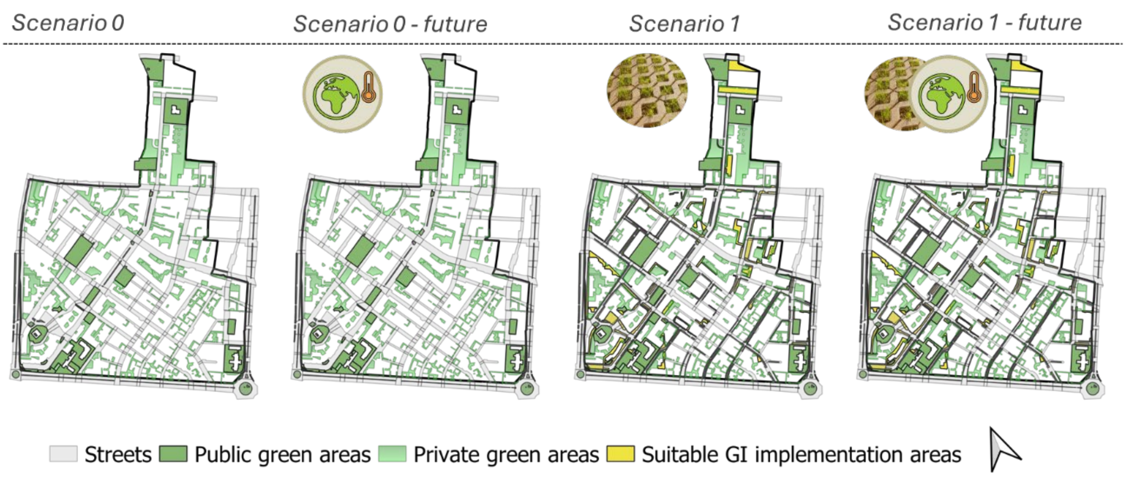

Figure 1. Description of the four scenarios developed, combining GI implementation with current and future climate conditions.

Both sets of scenarios are analyzed under current and future climate conditions. Exploring how these two policies - climate-adaptation measures such as green infrastructure and climate-mitigation strategies like the USPM, which reduce gas and pollutant emissions - interact under future climate conditions provides valuable insights for urban planning (Grafakos et al., 2019).

In detail, **Scenario 0** considers current land use under current climate conditions; **Scenario 0 – future** applies the same land use under future climate conditions. **Scenario 1** includes the implementation of permeable pavements in suitable areas, specifically in currently impervious pedestrian paths and car parks, under current climate conditions; **Scenario 1 – future** assesses the same intervention under future climate conditions.

Current climate condition has been modeled through long-term observed timeseries of precipitation (15 minutes resolution) and temperature (minimum, maximum at daily scale) for the period 2013 - 2022 registered at Bologna weather station. Future climate conditions have been modeled based on RCP8.5 and downscaled using the method proposed by (Pons et al., 2022). The period 2059 - 2068 was considered for long-term simulation.

2.3 SWMM modelling

The scenarios presented were set-up in EPA Storm Water Management Model (EPA SWMM), a dynamic hydrology-hydraulic model. The LID module in EPA SWMM allows for the simulation of the physical processes (storage, infiltration, evapotranspiration, and overflow) occurring in the individual layers of a variety of LID types (Randall et al., 2020). Similarly to the work developed by (Palla and Gnecco, 2015), the LID control module has been calibrated based on laboratory test measurements. The tests were performed in a small size laboratory test-bed realized at the University of Bologna to investigate the hydrologic response of an infiltration system under different rainfall conditions. The calibrated parameter set of the LID module was then transferred and applied to Scenario 1 and Scenario 1-future. According to the existing urban characteristics of the catchment, the potential surface availability for permeable pavement was quantified. Land cover data of the neighborhood were obtained from Open Data Bologna and satellite images. The spatial analysis resulted in the identification of the potential pervious pavement implementation surfaces, which characteristics summarized in Table 1.

Table 1. Potential surface area available for permeable pavement implementation.

	Value
Total suitable surface of pedestrian pathways and car parks [m^2]	53’743
Number of subcatchments [-]	214
Mean surface of subcatchment [m^2]	2300
Mean surface of pervious pavement in a single subcatchment [m^2]	251
Mean percentage of pervious pavement area in the catchment [%]	11 %

3 RESULTS

The results of the scenarios analysis are presented using the drained stormwater volume at the catchment outlet, located in the northern part of the catchment, as the main variable of interest, evaluated over a long-term simulation period of 10 years. Figure 2 is organized into subplots, each one addressing a specific research question, below introduced:

A) How will the drained stormwater volume change in the future if no management actions are implemented in the catchment? Under future conditions without intervention, a slight increase in the drained volume is observed compared with current land use in the current climate.

B) What are the current benefits, in terms of stormwater management, of introducing green infrastructure in the catchment? Under current conditions, the implementation of permeable pavement - discussed in the previous section - reduces the stormwater volume to be managed. The drained volume in the long period decreases by 40% from Scenario 0 to Scenario 1. This reduction not only alleviates pressure on the drainage network but also decreases the volume discharged into CSOs, thereby lowering the risk of pollution events during storm periods.

C) In the near future, what benefits could be expected if green infrastructures are implemented in the catchment? A similar benefit is expected under future conditions. In this case, the modelled drained volume in the long period decreases by 38% with the adoption of permeable pavement in the suitable areas. This indicates that green infrastructure remains effective even under changing climatic conditions, offering a resilient strategy to mitigate runoff increases and improve overall stormwater management capacity.

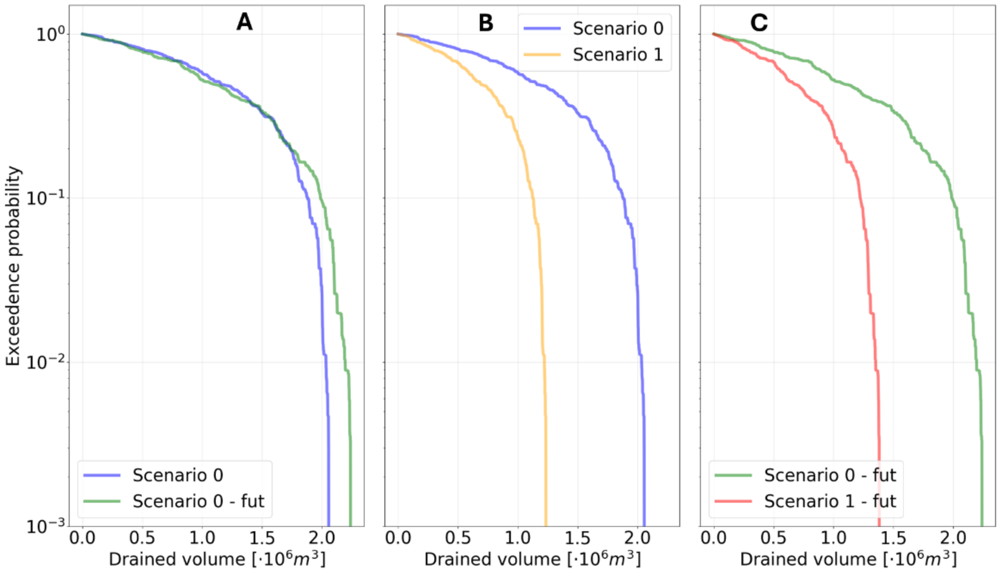

Figure 2. Drained stormwater volumes at the catchment outlet over a 10-year simulation period for each scenario, with subplots illustrating the three research questions guiding the analysis.

4 CONCLUSIONS

Reliable scenarios are developed by combining, from a modelling perspective, the use of calibrated parameter sets derived from laboratory experiments, and from an urban planning perspective, the implementation of permeable pavements in low traffic areas, where reduced vehicle speed is compatible with their structural limits. The results support the Urban Plan for Sustainable Mobility, showing that permeable pavements can significantly reduce stormwater volumes in the urban context analyzed, with benefits observed both under current (- 40%) and future (- 38%) climate conditions. A further, though not yet investigated, advantage of the application of the Urban Plan for Sustainable Mobility is the reduction of vehicle pollutant emissions associated with lower driving speed, which can directly improve the quality of stormwater runoff. The overall decrease in traffic emissions makes the Plan a practical climate mitigation strategy. Integrating climate-adaptation measures, such as green infrastructure, with the mitigation strategies promoted by the Sustainable Mobility Plan offers an opportunity to identify synergies that can support more effective urban planning.

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