SUSTAINABLE STORMWATER MANAGEMENT IN URBAN AREAS OF HIGH FLOOD RISK: DESIGN, SIMULATION AND EVALUATION OF THE APPLICATION OF NATURE-BASED SOLUTIONS IN THE CITY OF THESSALONIKI

DOI: 10.26341/issn.2241-4010-2026-6a-4-L02199

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Abstract
The present paper explores sustainable stormwater management in urban areas with high flood risk, using Thessaloniki, Greece, as a case study. The primary objective is to assess the effectiveness of Nature-based Solutions (NbS) - specifically rain gardens and permeable pavements - in mitigating surface runoff and improving urban climate resilience. The study aims to provide practical insights for integrating NbS into Mediterranean cities.

The methodology combines meteorological data analysis, spatial identification of potential intervention sites along Aristotelous Square and the development of a hydrological model using EPA SWMM software. Multiple design alternatives were simulated, reproducing the intense rainfall events of 2022 and 2023, both with and without NbS implementation. Key performance measures such as runoff volume, peak discharge and runoff coefficient were compared across the examined cases.

Results reveal a substantial reduction in surface runoff and peak flow, with the combined application of NbS achieving up to 35-45% runoff reduction in critical subcatchments. Beyond flood mitigation, NbS demonstrated co-benefits including improved water quality, enhanced urban biodiversity and increased thermal comfort through evapotranspiration.

The findings highlight the potential of NbS as cost-effective and multifunctional tools for climate adaptation. The paper concludes by emphasizing the importance of integrating NbS into urban planning policies, supported by pilot projects, long-term monitoring and public engagement to maximize environmental, social and economic benefits.

Keywords:*Flood Risk, Urban Environment, Sustainable Stormwater Management, Nature-based Solutions, Thessaloniki, Aristotelous Square, EPA SWMM software*

INTRODUCTION

Urban areas around the world are increasingly facing the combined effects of rapid urban growth, climate change and ageing stormwater management infrastructure. Mediterranean cities are particularly vulnerable due to their climatic characteristics, which include long dry periods followed by short and intense rainfall events. These conditions, intensified in recent years, have increased the frequency and the impact of urban flooding (Giorgi, 2006; Zanis et al., 2008; Diakakis et al., 2012; Evelpidou et al., 2023; National Academies of Sciences, Engineering, and Medicine, 2019).

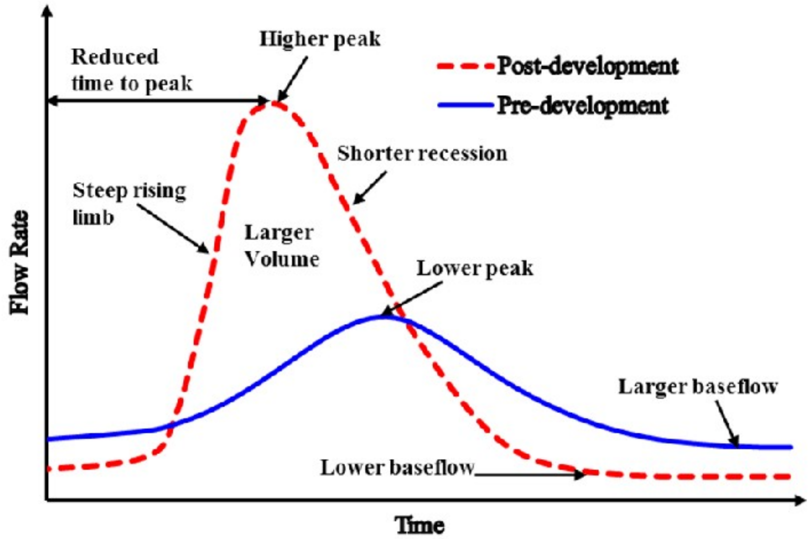

Figure 1: Schematic graph of the relative effects of urbanization on catchment hydrology (Source: Rezaei et al., 2019)

Urbanization significantly alters the natural hydrological cycle. The expansion of impervious surfaces reduces infiltration, limits groundwater recharge and increases surface runoff. As a result, even moderate rainfall events can produce higher peak flows and faster runoff response times compared to natural conditions. In densely built environments, this transformation increases flood risk and places pressure on existing drainage stormwater management systems (Construction Industry Research and Information Association [CIRIA], 2007; Kazak et al., 2022; National Academies of Sciences, Engineering, and Medicine, 2019).

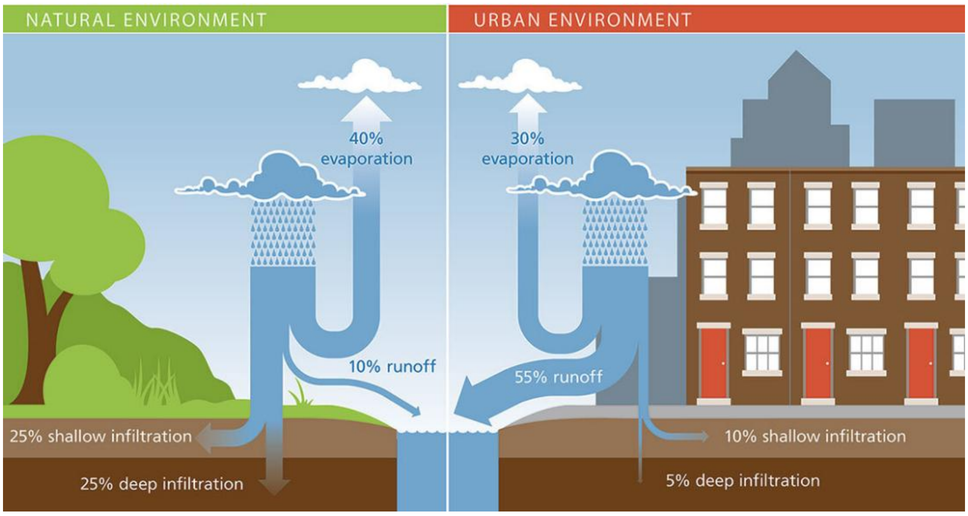

Figure 2: The presence of trees and natural vegetation significantly reduces surface runoff and enhances water infiltration into the soil compared to urban environments (Source: The Nature Conservancy, 2022)

In Greece, flood events have become more frequent and more impactful in recent decades, particularly in large urban centers (Papagiannaki et al., 2021). Regional flood assessments indicate that Central Macedonia and particularly Thessaloniki, experience a high frequency of urban flood events. Thessaloniki is the second-largest city in the country. The city has been identified as an area of elevated flood risk due to its dense development, geomorphological features and ageing drainage network (Evelpidou et al., 2023; Lazaridis and Latinopoulos, 2022). Several central districts have experienced repeated surface flooding during high-intensity rainfall events.

Region	Number of floods	Frequency per year
Western Macedonia	24	0,18
North Aegean	57	0,42
Ionian Islands	64	0,47
South Aegean	68	0,5
Western Greece	99	0,73
Crete	117	0,86
Peloponnese	123	0,9
Epirus	127	0,93
Central Greece	202	1,49
Attica	210	1,54
Thessaly	223	1,64
Eastern Macedonia and Thrace	267	1,96
Central Macedonia	413	3,04
Total	**1994**	**14,66**

Table 1: Number of flood events per region during the period 1886-2022 (Source: Evelpidou et al., 2023)

Stormwater management in Greek cities traditionally relies on underground pipe systems designed to quickly carry runoff away from urban areas. However, these systems were developed based on historical rainfall data and are often unable to cope with currentwith more intense rainfall events linked to climate change. Moreover, conventional grey infrastructure solutions - such as enlarging pipes or constructing detention basins - require high investment costs and provide limited additional environmental benefits. Finally, there is degradation of aquatic ecosystems and disruption of the hydrological balance due to the transport of pollutants and the lack of natural filtration by soil and vegetation (CIRIA, 2007; Huang et al., 2020; Kazak et al., 2022; Malinauskaite et al., 2023; National Academies of Sciences, Engineering, and Medicine, 2019; Sun et al., 2024).

Figure 3:Intense rainfall events caused significant disruption (Source: iefimerida.gr, 2020)

In recent years, there has been growing interest in nature-based approaches to stormwater management. Nature-based Solutions (NbS) integrate ecological processes into urban infrastructure and aim to address challenges such as flood risk, while also improving environmental and social conditions. In the context of stormwater management, NbS include rain gardens, permeable pavements and bioretention systems such as bioretention tree pits, which reduce runoff by promoting infiltration, temporary storage and evapotranspiration (CIRIA, 2007). Beyond hydraulic performance, Nature-based Solutions can improve urban environmental quality by enhancing biodiversity, reducing surface temperatures and contributing to more attractive public spaces. Despite increasing policy support across Europe, the implementation of NbS in Mediterranean cities remains limited. One of the main challenges is the need for clear quantitative evidence demonstrating their effectiveness under real rainfall conditions (CIRIA, 2007; Huang et al., 2020; Kazak et al., 2022; Malinauskaite et al., 2023; Sun et al., 2024; Bagiouk et al., 2024; Basdeki et al., 2024; Jeffers et al., 2022).

This study seeks to address this need by combining hydrological modeling with spatial urban analysis in a central district of Thessaloniki. The focus area is the Aristotelous Square area, a central and heavily used public space corridor characterized by mixed land use and a high percentage of impervious surfaces (Lazaridis and Latinopoulos, 2022).

The objectives of this paper are to quantify the hydraulic performance of selected Nature-based Solutions, including rain gardens and permeable pavements, under different rainfall events. The study also aims to compare runoff volume, peak discharge and runoff coefficient values between without and with NbS applications, to examine how hydraulic improvements are distributed across different urban subcatchments and to explore the broader implications of NbS implementation for enhancing urban resilience in densely built Mediterranean cities. The study uses the EPA Storm Water Management Model (SWMM) software to simulate two rainfall events comparing current conditions with conditions including NbS interventions. Through this approach, the paper links quantitative hydraulic performance with wider considerations of sustainable urban development and climate adaptation.

STUDY AREA

Thessaloniki is the second-largest city in Greece and serves as the main administrative and economic center of Northern Greece. Located along the Thermaic Gulf, the city is characterized by dense urban development, limited open space in its historic core and a drainage system influenced by both topography and coastal proximity. Rapid urban expansion during the second half of the 20th century significantly increased impervious surface coverage and altered natural drainage pathways (Lazaridis and Latinopoulos, 2022). The study area belongs to the Water District of Central Macedonia (WD10), where several urban zones are classified as areas of potentially high flood risk (Ministry of Environment and Energy, n.d.).

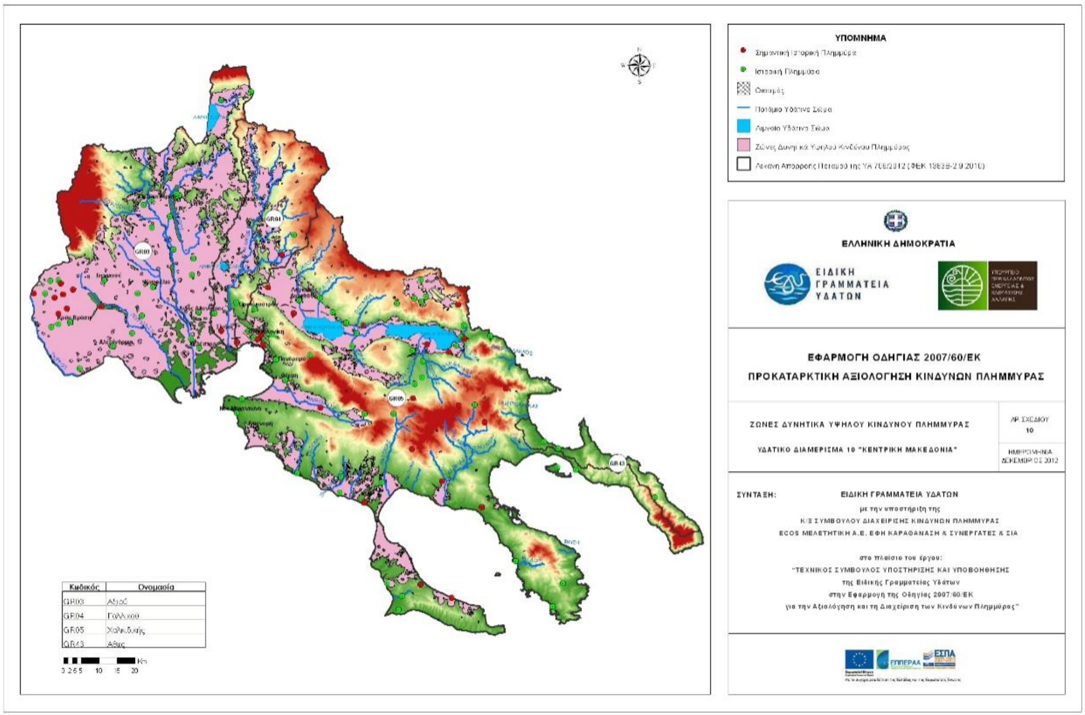

Figure 4: Central Macedonia Water District (WD10) (Source: Ministry of Environment, Energy and Climate Change)

The city experiences a typical Mediterranean climate, with hot, dry summers and mild, rainy winters. In recent years, rainfall events have increasingly included short-duration but high-intensity storm events, particularly during transitional seasons. These intense rainfall episodes are often associated with flash flooding in urbanized areas. Flood risk assessments have identified parts of central Thessaloniki as areas of elevated flood risk (Papagiannaki et al., 2021; Evelpidou et al., 2023).

Figure 5: Map of Thessaloniki showing areas vulnerable to high temperatures and flooding (Source: Lazaridis & Latinopoulos, 2022)

Recent flood incidents in Thessaloniki have caused infrastructure damage and disruptions, highlighting the vulnerability of central urban districts. The focus of this study is the Aristotelous Square area, one of the most recognizable and active public space in Thessaloniki. The area extends from the waterfront toward the upper part of the city and includes public and commercial areas, pedestrian paths and surrounding streets. Due to its central location and high daily usage, any intervention in this area must carefully balance hydraulic performance with urban functionality and public space quality.

From a hydrological perspective, the study area has a high percentage of impervious surfaces, including paved paths, roads and building footprints. The limited availability of permeable surfaces reduces infiltration capacity and promotes rapid surface runoff during intense rainfall events. Previous studies indicate that runoff in highly urbanized areas may be up to five times greater compared to natural soil conditions (CIRIA, 2007). The existing combined overflow drainage system primarily consists of underground pipe networks designed for quick runoff conveyance,with limited runoff retention capacity during intense storms (Kazak et al., 2022; National Academies of Sciences, Engineering, and Medicine, 2019).

For modeling purposes, the area was divided into multiple subcatchments based on surface slope, flow direction and drainage connectivity. This subdivision allowed a detailed representation of runoff generation and routing within the EPA SWMM model. Each subcatchment was defined using parameters such as area, percentage of impervious surfaces, slope and roughness coefficients.

Potential locations for Nature-based Solutions were identified through spatial analysis and on-site observation. Existing green areas and selected paved surfaces were evaluated as suitable areas for rain gardens and permeable pavements. The objective was to integrate these interventions into the existing urban layout without affecting urban mobility or altering the character of the space.

Given the historic and symbolic importance of Aristotelous Square axis, the integration of NbS required a balanced approach. Hydraulic improvement needed to be achieved while maintaining the identity and daily use of the public space.

By selecting a central and highly visible urban area, this study provides a realistic assessment of how Nature-based Solutions can be implemented in dense Mediterranean cities where space is limited and urban constraints are significant. The Aristotelous Square therefore serves as a representative example for evaluating distributed stormwater management approaches under real urban conditions.

METHODOLOGY

To evaluate the hydraulic performance of Nature-based Solutions, the study uses the EPA Storm Water Management Model (SWMM), a widely used tool for simulating rainfall-runoff processes in urban environments. EPA SWMM enables event-based simulation of runoff, flow routing, infiltration and temporary storage within urban catchments (Rossman & Simon, 2022).

The model was set up to simulate two recorded rainfall events that occurred in Thessaloniki on 4 September 2022 and 9 May 2023. These events were selected because they reflect different rainfall patterns. The first event was characterized by high precipitationand short duration, whereasthe second event was characterized by lower total rainfall and a longer duration. This contrast allowed the evaluation of NbS performance under different rainfall events and runoff generation conditions.

Time (h)	04/09/2022 (mm/h)	09/05/2023 (mm/h)
0	0,0	0,2
1	0,0	0,0
2	0,0	0,2
3	0,0	0,0
4	0,0	0,0
5	0,0	0,0
6	6,8	0,2
7	2,6	0,2
8	22,0	0,0
9	47,8	0,6
10	3,6	1,2
11	0,8	0,4
12	1,6	0,6
13	0,2	0,4
14	0,2	0,8
15	0,0	0,4
16	0,0	2,2
17	0,0	0,6
18	0,0	0,4
19	0,0	0,2
20	0,0	0,2
21	0,0	0,0
22	0,0	0,2
23	0,0	0,6
Total	**85,6**	**9,6**

Table 2: Timeseries of the two rainfall events (Source: Meteorological Station of Aristotle University of Thessaloniki)

Rainfall timeseries were obtained from the Meteorological Station of Aristotle University of Thessaloniki, ensuring that model inputs reflected local climatic conditions. Simulations were performed using the “Kinematic Wave” as routing method and “Horton” as infiltration model in EPA SWMM, allowing realistic representation of hydraulic interactions within the NbS implementation (Source: Rossman & Simon, 2022).

The study area along the Aristotelous Square axis was subdivided into multiple subcatchments based on topography, surface flow direction, drainage connectivity and land-use characteristics. This subdivision enabled a more detailed representation of runoff volume and routing processes across the area.

Figure 6: Subdivision of the study area into subcatchments along the Aristotelous Square axis, above Egnatia Street (Source: e-poleodomia)

Figure 7: Subdivision of the study area into subcatchments along the Aristotelous Square axis, between Egnatia and Ermou Street (Source: e-poleodomia)

Figure 8: Subdivision of the study area into subcatchments along the Aristotelous Square axis, between Egnatia and Ermou Street (Source: e-poleodomia)

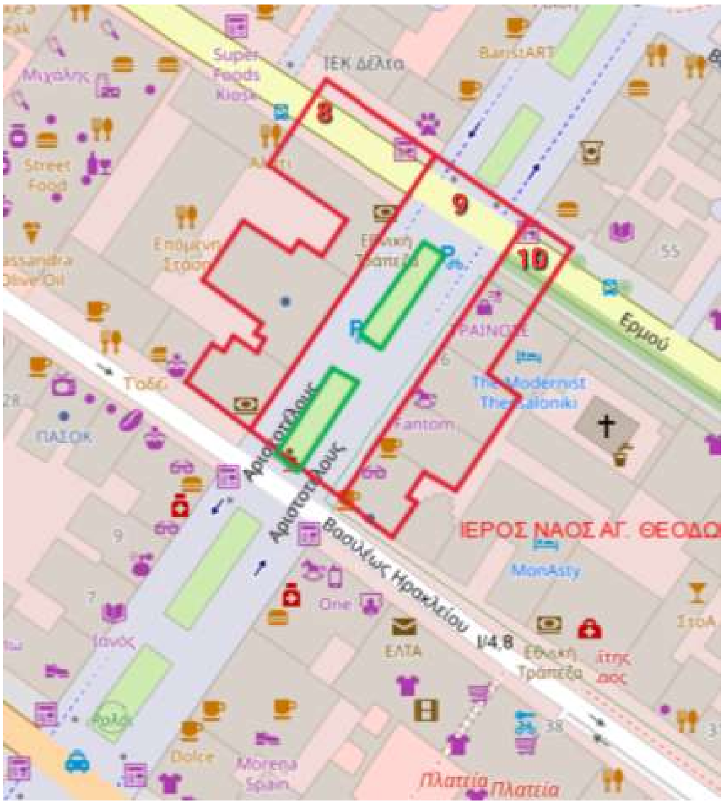

Figure 9: Subdivision of the study area into subcatchments along the Aristotelous Square axis, between Ermou and Vasileos Irakleiou Street (Source: e-poleodomia)

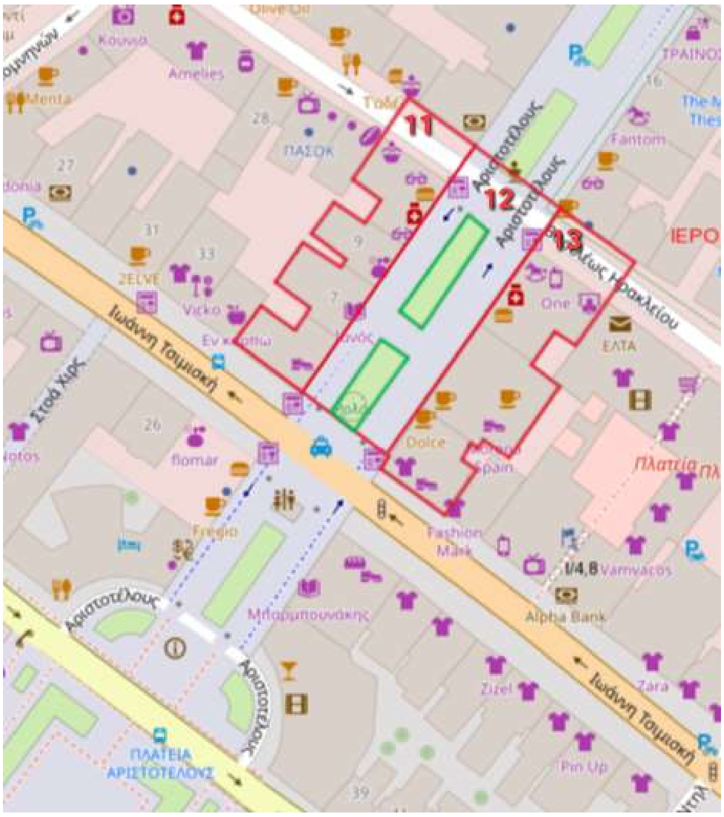

Figure 10: Subdivision of the study area into subcatchments along the Aristotelous Square axis, between Vasileos Irakleiou and Tsimiski Ioanni Street (Source: e-poleodomia)

Figure 11: Subdivision of the study area into subcatchments along the Aristotelous Square axis, between Tsimiski Ioanni and Mitropoleos Street (Source: e-poleodomia)

Figure 12: Subdivision of the study area into subcatchments along the Aristotelous Square axis, between Mitropoleos Street and Nikis Avenue (Source: e-poleodomia)

Subcatchment	Area (m²)	Total Area (m²)
Sub_1	4960	4960
Sub_2	1680	8430
Sub_3	5200	
Sub_4	1550	
Sub_5	1060	4220
Sub_6	2120	
Sub_7	1040	
Sub_8	2450	6960
Sub_9	2830	
Sub_10	1680	
Sub_11	1940	7060
Sub_12	2730	
Sub_13	2390	
Sub_14	2190	8290
Sub_15	3650	
Sub_16	2450	
Sub_17	4300	15015
Sub_18	6195	
Sub_19	4520	

Table 3: Calculated subcatchment areas by subcatchment number (Source: e-poleodomia)

Each subcatchment was defined using parameters such as total area, percentage of impervious surface, average slope, Manning's roughness coefficients for both pervious and impervious surfaces and storage parameters. Impervious surface percentages were estimated according to surface type, including paved areas, building roofs and road surfaces, while pervious surfaces mainly referred to existing green strips and landscaped spaces. Rain gardens differ from conventional green planting areas, as they are specifically designed for the collection, temporary storage and infiltration of stormwater, functioning as bioretention systems within the urban environment (Source: CIRIA (2007); Bagiouk et al. (2024); Basdeki et al. (2024); e-Poleodomia).

This spatial analysis supported the identification of areas with higher runoff volume and allowed comparison of hydraulic behavior among different parts of the study area.

The existing situation represented current urban conditions without the implementation of Nature-based Solutions. Surface runoff was calculated according to existing land cover characteristics and routed through the drainage network without additional detention or infiltration measures.

For each rainfall event, the model calculated total runoff volume per subcatchment, peak discharge and runoff coefficient values, defined as the ratio between runoff volume and total rainfall input. These outputs served as reference values for evaluating the effectiveness of NbS interventions (U.S. Environmental Protection Agency, 2022).

The NbS implementation included two intervention types: rain gardens and permeable pavements. Potential installation sites were identified through spatial analysis and field observation, focusing on existing green areas and selected paved areas along the study axis.

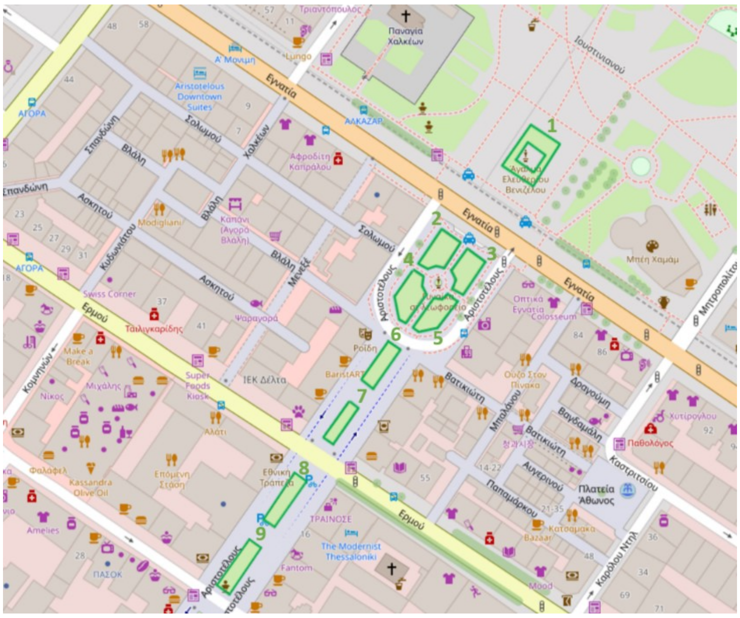

Figure 13: Placement of rain gardens 1–9 within existing landscaped areas along the Aristotelous Square axis (Source: e-poleodomia)

Figure 14: Placement of rain gardens 10–18 within existing landscaped areas along the Aristotelous Square axis (Source: e-poleodomia)

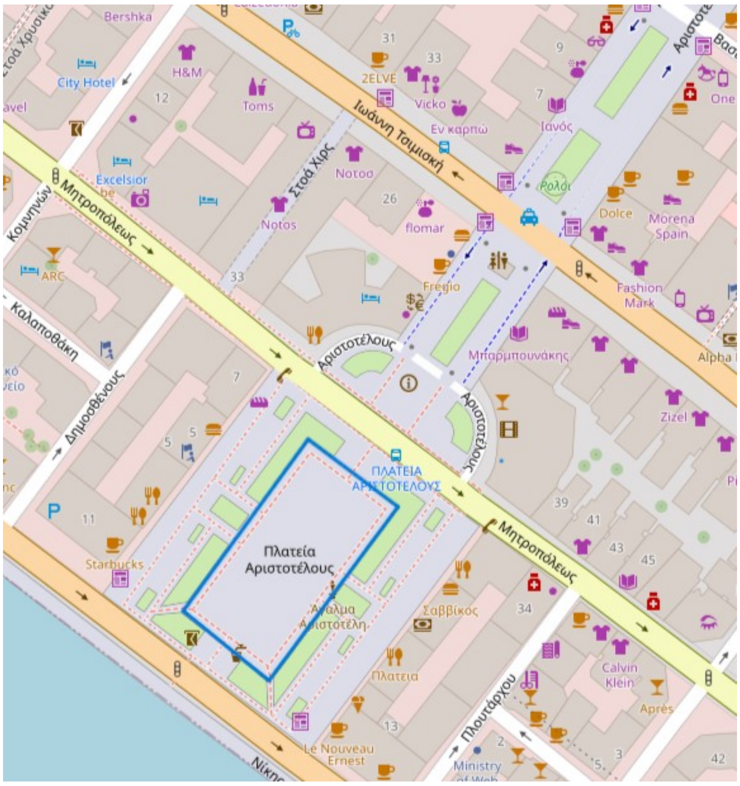

Figure 15: Placement of permeable pavement at Aristotelous Square, between Mitropoleos Street and Nikis Avenue, within the blue outline (Source: e-poleodomia)

Figure 16: Placement of the 1st rain garden installation (Source: Personal archive)

Figure 17: Placement of the 10th rain garden installation from Vasileos Irakleiou Street (Source: Personal archive)

Figure 18: Placement of permeable pavement installation (Source: Personal archive)

Within EPA SWMM, rain gardens were represented using Low Impact Development (LID) bioretention controls. Parameterization included surface storage characteristics, soil media properties and drainage layer configuration, based on the minimum values in order to examine the maximum potential performance, adopted from the literature (Rossman & Simon, 2022).

Rain gardens were designed to promote infiltration and temporary storage, while permeable pavements enhanced subsurface storage and delayed runoff discharge. The total area allocated to NbS was spread across multiple subcatchments, representing an implementation strategy.

Number of Rain Garden	Area (m²)
1	315
2	220
3	230
4	240
5	240
6	190
7	155
8	230
9	240
10	300
11	260
12	280
13	110
14	110
15	330
16	330
17	330
18	330

Table 4: Rain garden area table by number (Source: e-poleodomia)

In addition, the area of the proposed permeable pavement installation site was estimated at 3,060 m² (Source: e-poleodomia).

Both rainfall events were simulated under identical modeling assumptions with and without NbS implementation. This approach enabled direct comparison between storm events, evaluation of NbS performance under different rainfall events and identification of subcatchments showing consistent hydraulic improvement.

By maintaining consistent model parameters across scenarios, observed differences in runoff response could be attributed directly to the implementation of Nature-based Solutions.

NbS implementation (Number of Rain Garden and Permeable Pavement)	Area (m²)	Number of Rain Garden and Permeable Pavement	Total Area (m²)	Percentage of impervious surface covered by NbS (%)
1	315	1	315	6,35
2	220	2, 3, 4, 5	930	11,03
3	230			
4	240			
5	240			
6	190	6, 7	345	8,18
7	155			
8	230	8, 9	470	6,75
9	240			
10	300	10, 11	560	7,93
11	260			
12	280	12, 13, 14	500	6,03
13	110			
14	110			
15	330	15, 16, 17, 18, Permeable Pavement	4380	29,17
16	330			
17	330			
18	330			
Permeable Pavement	3060			

Table 5: Table of area per rain garden and Permeable Pavement, total Nature-Based Solutions (NbS) intervention area, and coverage percentages relative to the impervious surfaces of the study area (Source: e-poleodomia)

RESULTS

The simulation results demonstrated a clear improvement in hydraulic performance following the implementation of Nature-Based Solutions (NbS), including rain gardens and permeable pavement, across the examined subcatchments of the study area.

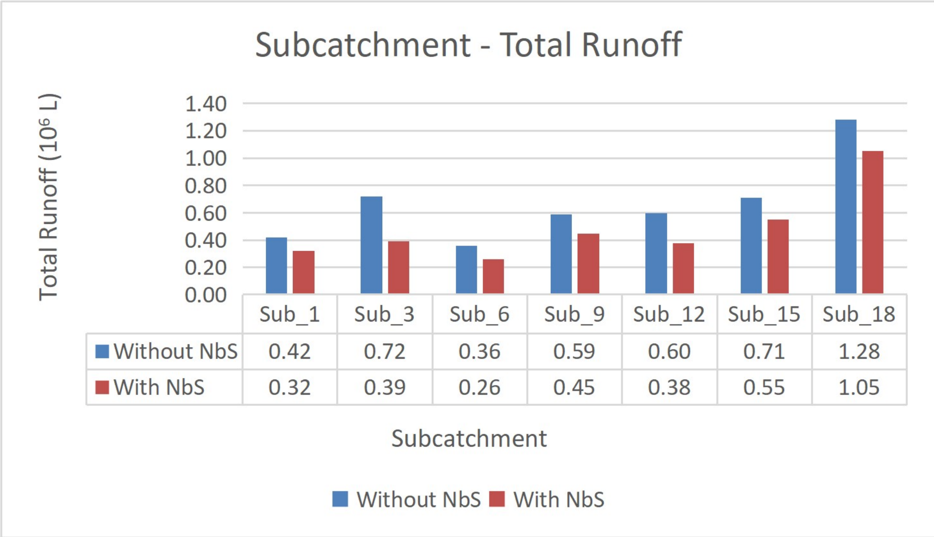

Figure 19: Comparison of total runoff per subcatchment, without and with LID implementation, for the rainfall event of 04/09/2022 (Source: EPA SWMM)

For the rainfall event of 04/09/2022, characterized by high intensity and short duration, a reduction in peak discharge was observed in all subcatchments. In addition, both total runoff volume and runoff coefficient value showed noticeable decreases compared to the current scenario, without NbS implementation. The most significant hydraulic improvement was recorded in subcatchment "Sub_3", where total runoff volume decreased from 720 * 10^3 L to 390 * 10^3 L (-45,8%), peak discharge decreased from 111,81 L/s to 98,44 L/s (-15,2%) and the runoff coefficient decreased from 0,994 to 0,535 (-46,2%). These results indicated that the combined application of rain gardens and permeable pavement could substantially reduce runoff generation and improve flow regulation during intense rainfall events.

For the rainfall event of 09/05/2023, which was characterized by low intensity and longer duration, significant reductions were also observed in peak discharge and runoff coefficient across all subcatchments. Although the total rainfall input was lower, the relative hydraulic improvements remained consistent, demonstrating that NbS performance is effective under different rainfall events and runoff generation scenarios.

Overall, the results confirmed that NbS implementation contributed to increased infiltration, temporary storage and delayed runoff response, leading to improved hydraulic behavior throughout the study area.

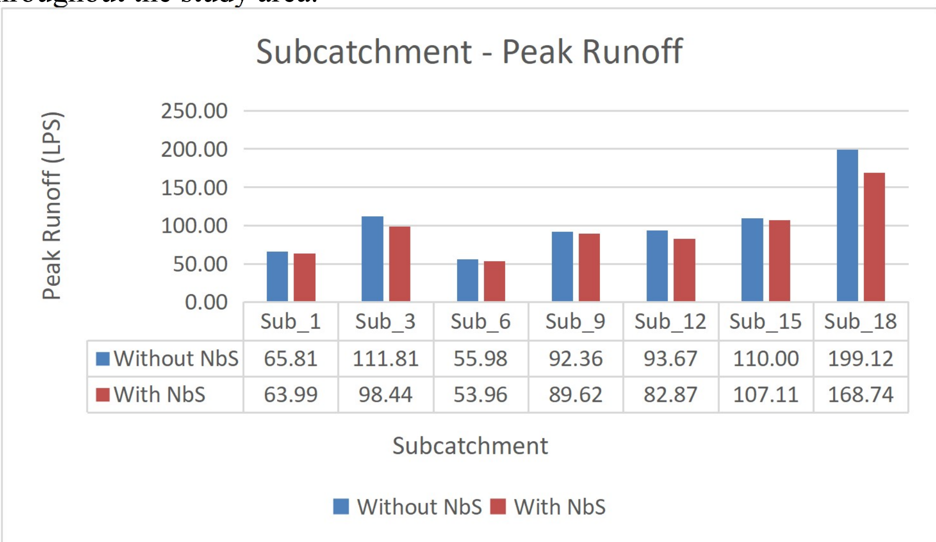

Figure 20: Comparison of peak runoff per subcatchment, without and with LID implementation, for the rainfall event of 04/09/2022 (Source: EPA SWMM)

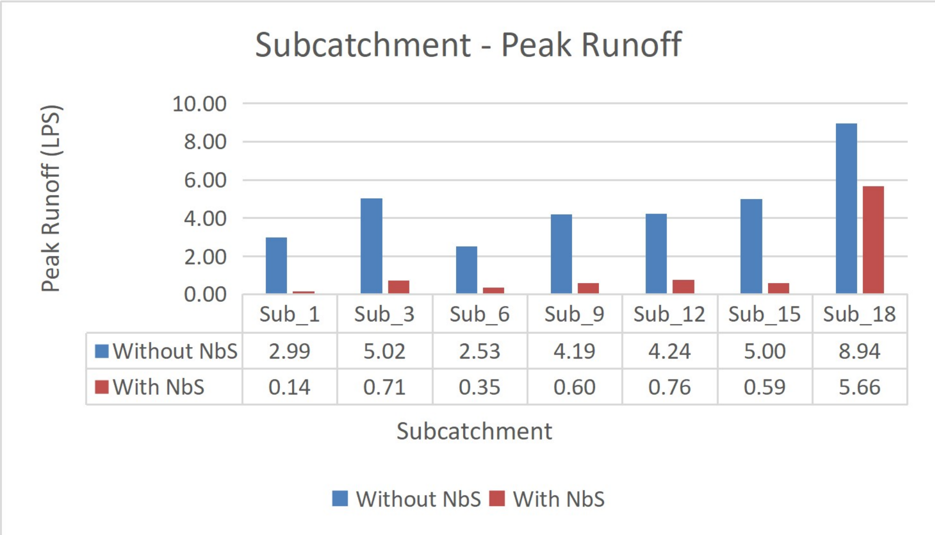

Figure 21: Comparison of peak runoff per subcatchment, without and with LID implementation, for the rainfall event of 09/05/2023 (Source: EPA SWMM)

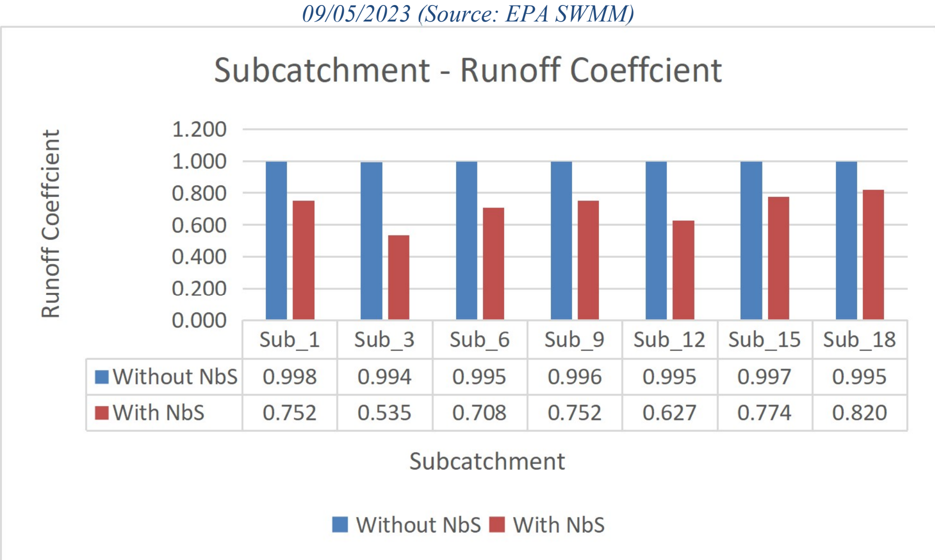

Figure 22: Comparison of runoff coefficient per subcatchment, without and with LID implementation, for the rainfall event of 04/09/2022 (Source: EPA SWMM)

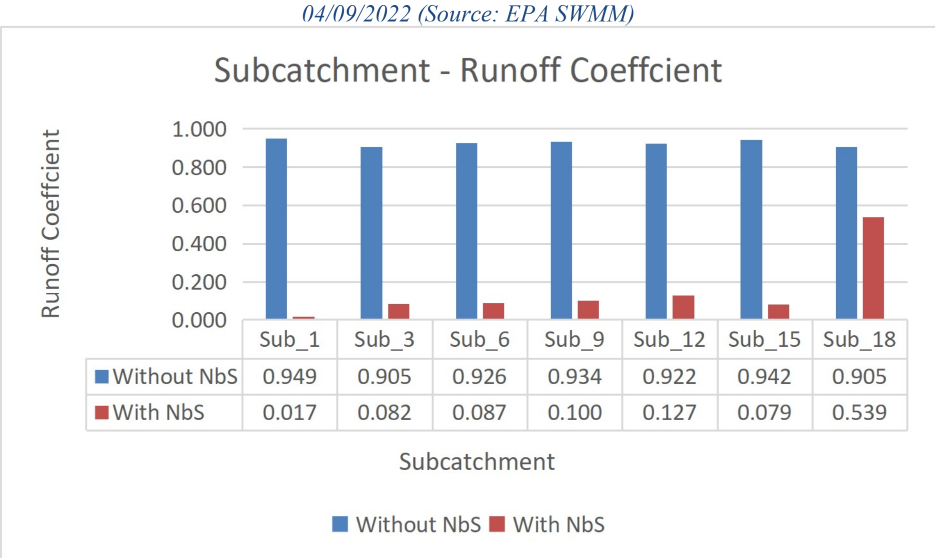

Figure 23: Comparison of runoff coefficient per subcatchment, without and with LID implementation, for the rainfall event of 09/05/2023 (Source: EPA SWMM)

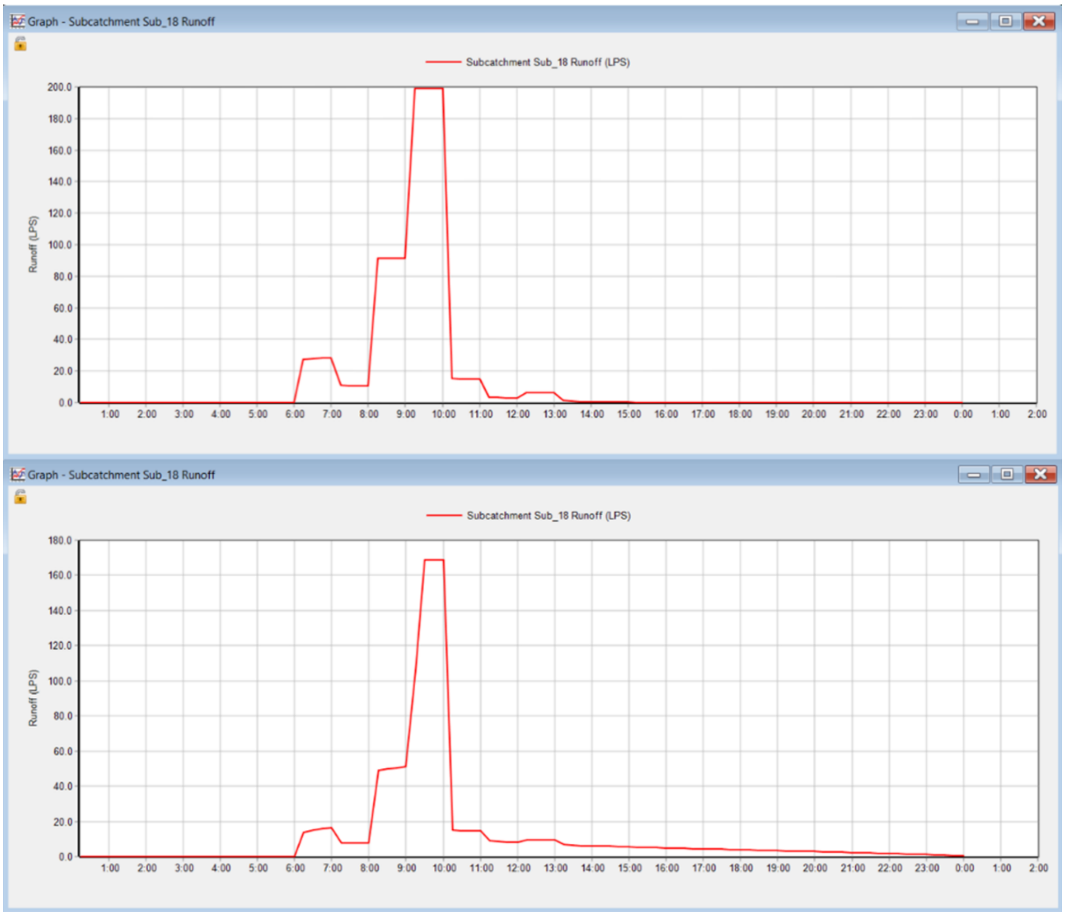

Figure 24: Simulation’s results - Subcatchment’s 18 runoff diagrams for both rainfall events, without/with NbS, for the rainfall event of 04/09/2022 (Source: EPA SWMM)

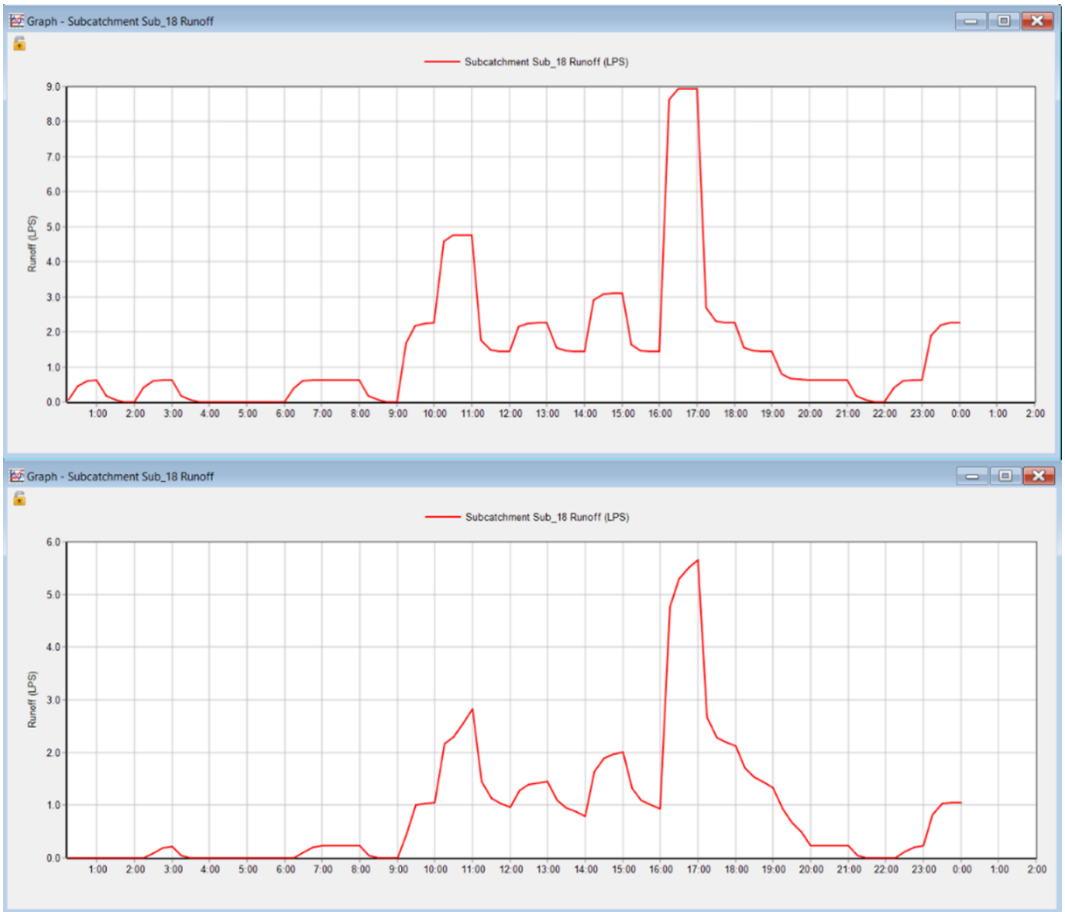

Figure 25: Simulation's results - Subcatchment's 18 runoff diagrams for both rainfall events, without/with NbS, for the rainfall event of 09/05/2023 (Source: EPA SWMM)

DISCUSSION

The results of the hydrological simulations show that Nature-based Solutions (NbS) can provide clear and measurable hydraulic benefits in dense Mediterranean urban environments. The consistent reductions observed in runoff volume and peak discharge across both rainfall events confirm that they can effectively complement existing drainage systems, even in areas with high impervious percentage.

The reductions observed in runoff volume, reaching up to 35-45% in critical subcatchments, indicate that relatively small and distributed interventions can significantly influence overall system performance. Unlike storage systems, NbS act close to the source of runoff, reducing flow accumulation before it reaches downstream parts of the network. This distributed approach improves system flexibility and lowers the risk of local hydraulic overload.

Peak discharge reductions further highlight the flood mitigation potential of NbS. The smoother hydrograph profiles and delayed peak timing suggest that runoff is released more gradually, reducing pressure on existing infrastructure during intense rainfall events. In highly urbanized areas where drainage systems often operate close to capacity, even moderate reductions in peak flow can meaningfully decrease flood risk.

An important outcome of the study is the demonstration that NbS can be integrated into a highly active and historically significant urban corridor such as the Aristotelous axis. Dense urban centers often present limited available space, making large-scale structural interventions difficult to implement. The results show that distributed and small-scale implements can still achieve substantial hydraulic improvements without major alterations to the existing urban layout.

By incorporating rain gardens and permeable pavements into existing pedestrian areas and green strips, the interventions support both hydraulic performance and urban functionality. This approach allows environmental improvements while preserving circulation patterns and the visual character of the public space.

The observed differences among subcatchments also emphasize the importance of strategic placement. Areas with higher impervious areas and larger intervention coverage achieved stronger results, indicating that careful spatial planning is essential for maximizing effectiveness.

Beyond their hydraulic role, NbS contribute to broader urban resilience goals. Mediterranean cities face multiple environmental pressures, including flood risk, heat stress and reduced ecological quality in dense urban areas. NbS can help address these challenges simultaneously by improving microclimatic conditions, supporting biodiversity and enhancing the overall quality of public space.

Rather than functioning only as drainage elements, NbS operates as multifunctional urban components that combine environmental, technical and social benefits. In highly used public spaces such as Aristotelous Square, this multifunctionality becomes particularly important, as hydraulic improvements can be achieved while also enhancing everyday urban experience.

The comparison between the two rainfall events demonstrates that NbS maintained stable performance despite differences in rainfall intensity and duration. The consistent reductions across all key indicators suggest that NbS can operate effectively under different storm types.

This stability is especially relevant under climate uncertainty, where rainfall patterns are expected to become increasingly variable. Flexible and distributed systems such as NbS may therefore provide more reliable long-term performance compared to traditional stormwater management infrastructures.

The findings support the broader integration of Nature-based Solutions into urban planning and stormwater management strategies. In Greece, stormwater management is still largely based on conventional grey infrastructure and practical examples of NbS implementation remain limited. The measurable results presented in this study provide a useful basis for supporting policy decisions and encouraging pilot applications.

Implementing NbS in central urban corridors can also serve as demonstration projects, helping municipalities evaluate performance while increasing public awareness and acceptance. Long-term monitoring and evaluation would further strengthen the evidence base and support wider adoption.

Overall, the study highlights how hydrological modeling combined with spatial urban analysis can support the transition toward more climate-adaptive and resilient stormwater management strategies in Mediterranean cities.

CONCLUSION

This study evaluated the hydraulic and spatial performance of Nature-based Solutions (NbS) applied along the Aristotelous Square axis in Thessaloniki, Greece, under two documented rainfall events with different characteristics. By combining event-based hydrological modeling in EPA SWMM software with spatial urban analysis, the research provided a quantitative evaluation of NbS performance in a dense Mediterranean urban environment.

The results showed that the implementation of rain gardens and permeable pavements can significantly reduce surface runoff and peak discharge across multiple subcatchments. Runoff volume reductions reached up to 35-45% in critical areas, while peak discharge reductions reached a maximum value of approximately 15%, depending on local conditions and spatial allocation. These findings confirmed that distributed NbS interventions could effectively improve hydraulic performance even in highly impervious and spatially constrained urban areas.

Beyond hydraulic improvements, the study also emphasized the multifunctional role of NbS within urban space. The integration of NbS along the Aristotelous axis shows that flood mitigation measures can be incorporated into active public spaces without disrupting their character or functionality. In addition to runoff control, such interventions can contribute to improved environmental quality, microclimatic conditions and overall urban livability.

The observed spatial differences among subcatchments underline the importance of careful planning and targeted placement of interventions. Hydraulic efficiency depends strongly on the proportion of impervious surfaces treated and the positioning of NbS within runoff pathways, highlighting the need to combine hydrological modeling with spatial analysis during the design process.

From a planning perspective, the results supported the wider integration of Nature-based Solutions into municipal stormwater management strategies. In cities such as Thessaloniki, where conventional grey infrastructure still dominates, the quantitative evidence provided by this study offers practical support for pilot applications and future policy development.

Overall, the methodological approach adopted in this research provides a transferable framework for other Mediterranean cities facing similar climatic and spatial challenges. Future work could focus on cost-benefit assessment, long-term monitoring and the evaluation of hybrid green-grey infrastructure systems in order to further support implementation at larger scales.

In conclusion, Nature-based Solutions represent an effective and realistic pathway toward more resilient, multifunctional and climate-adaptive urban stormwater management.

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