Preventing Urban Floods by Optimized Modeling: A Comparative Evaluation of Alternatives in Izmir (Türkiye)

Bertan Arslan[1(✉)] and Stefano Salata[2]

[1] Department of City and Regional Planning, Izmir Institute of Technology, Urla, 35430 İzmir, Turkey
bertanarslan@iyte.edu.tr

[2] Department of Architecture and Urban Studies (DAStU), Lab PPTE, Polytechnic University of Milan, Piazza Leonardo da Vinci, 32, 20133 Milan, MI, Italy
stefano.salata@polimi.it

Abstract. It is widely acknowledged that coastal cities will be heavily threatened by climate change globally. Among these cities, the Mediterranean suffers from a coupled dynamic of sea level rise and pluvial flooding due to their landform and soil characteristics. In this situation, analyzing the morphological and hydrological characteristics to define vulnerable areas is a prerequisite to designing performance-based solutions. But how does the flood vulnerability change with the different configurations of pervious and impervious surfaces? How do soil and landform characteristics affect flood vulnerability? This study assumes the possibility of re-naturing the coastal neighborhood of Karsiyaka, Izmir (Türkiye) while using fifteen alternative scenarios. We modeled the Urban Flood Risk Mitigation using InVEST (Natural Capital Project) and integrated the results with an analysis of the flow accumulation. According to our results, when the de-sealing process occurs in soils with low hydraulic conductibility, the results in terms of run-off containment can be dramatically limited or non-perceptible. The findings demonstrate that modeling with scenarios can guide the decision-makers while understanding exactly where the de-permeabilization can achieve its maximum efficiency. Therefore, performance-based solutions designed to increase water infiltration should carefully consider ex-ante empirical modeling to prevent urban flooding.

Keywords: Urban Flood Management · Soil Permeability · Performance-Based Urban Planning · Ecosystem Services Modeling

1 Introduction

Global climate change has several effects on urban areas [1]. Changing climates also increase urban flood frequency and severity [2]. Pluvial floods occur when poor infiltration during cloudbursts prevents runoff management [3–5].

Urbanization, which increases the footprint of anthropic uses in the city and affects land use, makes stormwater management difficult and has many other detrimental

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impacts [6, 7]. Built-up regions diminish water penetration and increase runoff, making urban areas more susceptible to flooding [8–10]. Thus, the traditional planning approach, which prioritizes grey elements (roads, buildings, etc.) over green ones and arranges infrastructure elements like utilities and public facilities to create functional and livable communities [11], often falls behind in reducing runoff, especially in dense coastal cities where precipitation and storm events are common.

Deforestation, agricultural land destruction, and increasing impermeable areas for rapid city development to meet rising population and demand make flood disasters almost inevitable [12, 13]. To avoid flood damage, towns should be redesigned with natural environmental values. City natural features manage flood episodes via infiltration based on soil conditions and vegetation [14]. Planners must adapt to climate resilience as cities grow and climatic phenomena change quickly [15]. Ecosystem services and its components should be used to preserve city life for long-term adaptation [16].

As artificial land increases, biodiversity decreases, and natural areas are lost, integrating fast-developing cities with ecosystems to design performance-based natural solutions in urban spaces becomes more complex [17]. NBS measures evolve from the European Commission's ecosystem-based planning approach [18]. "Cost-effective solutions inspired and supported by nature, which simultaneously provide environmental, social, and economic benefits and help build resilience" are their description. "Locally adapted and systemic interventions bring diverse natural features and processes into cities," according to the European Commission [19]. These multifunctional processes help cities adapt to changing climates and benefit society [20, 21].

Due to conventional infrastructure's failure to manage the urban water cycle, interest in urban resilience has grown [22]. Long-term development is needed due to urban catastrophes' unexpected spread and climate change-induced severity [23]. Thus, cities must incorporate resilience into urban planning to improve disaster response [24]. NBS improve urban soil permeability, making "cloudburst resilient" cities possible. Cloudburst-resilient cities can swiftly recover from precipitation events and limit their negative consequences [3]. Densely vegetated, porous cities may absorb and retain more precipitation than sealed urban structures. By learning from past catastrophes, they may create and apply urban policies to mitigate future disasters [25].

In this manuscript, we tried to analyze the response of Izmir's land uses to flood risks through scenario development. The reason for the disasters experienced by the city was questioned in the following section. We then set fifteen different land use scenarios for the coastal neighborhood of Karsiyaka, Izmir (Turkey). While keeping in all scenarios the ratio between permeable and impermeable areas, we demonstrated how soil permeability and slope factor affect flood risk and runoff retention, thus influencing the final performance of NBS. We tested our results while modeling the Urban Flood Risk Mitigation with Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST). Though the model of InVEST is successful in measuring urban flood risk, it does not consider the slope factor. Since slope analyses alone cannot provide this data, we performed the FA analysis and integrated the results with InVEST model outputs.

Moreover, the flow accumulation (FA) process allows us to determine urban flood risk assessment, including the topographic condition of the area. Due to the slope factor, stormwater is unstable and always in constant motion [26]. In detail, the slope characteristic of an area plays a very important role in the fight against urban flooding [27]. Knowing the movement behavior of water during rainfall is critical in flood prevention efforts [28]. Integrating InVEST output and FA, we generated a flood vulnerability analysis that includes slope, soil structure and urbanization characteristics as input, directly affecting flood. We concluded the study by highlighting important policy implications and addressing possible studies that should be carried out in the future.

2 Materials and Methods

2.1 Area of Interest

Due to its semi-closed character, the Mediterranean Sea is changing quicker than the world average [38]. The Mediterranean is one of the most impacted areas in the world by the combined impacts of climate change, pollution, and urbanization [38]. Due to climate change and urbanization, Turkey may experience frequent and intense disasters like precipitation imbalances, temperature increases, and drought [39, 40].

Due to the intensive coastal population in Turkey's Western Aegean area, Izmir has a high sealed surface rate [41]. The province contains the study area, with a characteristic Mediterranean climate with warm, humid winters and scorching, dry summers. The province's annual average temperature is 18 °C, with winter temperatures of 9 °C and summer temperatures of 28 °C [42, 43].

Izmir has survived several tragedies over 500 years, developing a tenacious spirit that has helped it be a large city. Due to its dense structure and geography, the city has seen frequent floods, earthquakes, and fires [44]. Izmir's unsuitable and uneven urbanization is primarily overrun with agricultural lands, yet its natural and environmental qualities raise natural catastrophe risks [45]. This puts Konak, Karsiyaka, and Bayrakli at risk of flooding in Izmir [15].

With 4,425,789 residents [46], Izmir is Turkey's third most populous city. Due to that demand, the city's population has expanded by more than 50% between 1990 and 2018, and the urbanization process on sealed surfaces has surged to 99.3% and continues to increase [47]. This procedure has occurred throughout several floods. Floods at Karsiyaka and Cigli, Izmir, killed around 60 persons in 1995 [48]. In February 2021, the same cloudburst occurred. "Rainfall was 126 kg/m^2. 18% of rainfall is normally seen throughout the year," said Izmir mayor Tunç Soyer. This flood caused significant economic harm to the cities [49]. These instances demonstrate the need for an Izmir stormwater action plan or strategy [50].

This research sampled the Karsiyaka district as a case study (see Fig. 1). This sample was chosen because of its significant flood risk and urban transformation potential [15].



Fig. 1. Area of interest.

2.2 Urban Flood Risk Mitigation Model

The InVEST Urban Flood Risk Mitigation model is one of the most widely used tools to assess urban flood safety and risk areas [29–31]. The model simplifies infiltration using soil and land cover characteristics: locations with surfaces constructed on less porous soils (low drainage capacity) and large impermeable surfaces are at high flood risk. Thus, roads and industrial areas built on hydrologically impermeable soil have the highest risk of flooding [32]. The Runoff Curve Number (RCN) matrix calculates runoff using the parametric link between land use permeability and soil hydrological properties [33, 34]. RCN determines runoff from urban land use and soil hydrological conductivity.

An accurate biophysical estimation of urban runoff during a cloudburst can be difficult and complex [35] due to multiple variables affecting the discharge capacity of the area during a single rain event, such as building quality and quantity, infrastructure quality and capacity [36, 37]. InVEST model output indicates rain event runoff retention index and millimeters. InVEST's Urban Flood Risk Mitigation model requires five inputs: watershed vector data representing the area of interest, depth of rainfall for one cloudburst event in mm, a Land Use Land Cover (LULC) map representing the surfaces' impermeability ratio, a raster map of soil hydrologic conductibility, and biophysical values for each land use land cover class.

2.3 Land Use Land Cover Dataset

Table 1 shows the association between urban soil permeability and RCN categories (A, B, C, and D) in this study's land use categorization system. ArcMap sessions used

USDA classes and the Imperviousness High-Resolution Layer (HRL) database from the Copernicus Land Monitoring Service website (https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness, accessed 25.10.22) to classify land use. The HRL database shows the geographical distribution of artificially sealed regions and their sealing density [38]. Semi-automated categorization using calibrated Normalized Difference Vegetation Index (NDVI) readings determines the degree of sealed soil from 1–100% [39]. The dataset shows soil sealing rates and temporal change and defines sealed/impermeable places where the original natural/semi-natural land cover or water surface has been replaced with an artificial, typically impervious cover. These artificial surfaces need long-term maintenance.

In the research, the LULC map was constructed using two land use codes: green for permeable open places like urban parks and grey for artificial surfaces. The LULC setups utilized in the modeling situations will be explained.

Table 1. The relationship between the categories of land use and land cover and the runoff curve number. Source: United States Department of Agriculture (1986). Urban hydrology for small watersheds. Technical Release 55 (TR-55) (Second ed.). Natural Resources Conservation Service, Conservation Engineering Division.

Cover description		Curve numbers for hydrologic soil groups				LUCODE
		A	B	C	D	
Open space (lawns, parks, golf courses, cemeteries, etc.)	Fair condition (grass cover 50 to 75%)	49	69	79	84	Green
Residential districts by average lot size	$^1/_8$ acre or less (town houses) (65% imp.)	77	85	90	92	Grey

2.4 The Soil Hydraulic Conductibility

The second crucial input for the model is the map of saturated hydraulic conductivity (Ksat, mm/h, as shown in Table 2), which is defined as the soil's ability to be vertically crossed by fluids when saturated [40]. Hydraulic conductivity depends on soil porosity and, in turn, soil texture: clay soils generally have lower conductivity than sandy and gravel soils [41]. Soils with good porosity and conductivity allow for water retention and movement quickly. Water quickly reaches the aquifer with high conductivity, resulting in limited surface flow processes [42, 43]. In contrast, low infiltration in soils with poor conductivity generates high surface runoff rates [44].

For this study, an ancillary dataset was developed based on the more precise Geological Unit, utilizing raster reclassification. The classification process to assign a specific Hydrological Soil Classification, as proposed by Ross et al. (2018), is synthesized in Table 3. Additionally, the results of the classification are reported in the following Fig. 2.

Table 2. Parameters related to the ability of soil to transmit water. Source: InVEST User's Guide available at: https://invest-userguide.readthedocs.io/en/latest/urban_flood_mitigation.html

	Group A	Group B	Group C	Group D
Saturated hydraulic conductivity of the least transmissive (soil depth 50 and 100 cm)	>40 m/s	[40;10] m/s	[10;1] m/s	<1 m/s

Table 3. Table for conversion of Hydrological Soil Classification

Geological Units	Soil Groups	Geological Units	Soil Groups	Geological Units	Soil Groups
Clastic rocks	A	Pyroclastic units	D	Granitoid	D
Lime soil	A	Granitoid	D	Clastic units	B
Sediment soil	A	Oligocene volcanic units	C	Schist	D
Terrestrial clastic units	B	Volcano-sedimentary units	C	Gneissoid	D
Lacustrine limestone	D	Flysch	D	Meta-granitoid	D
Marn	D	Nautical limestone	B	Metamophic units	B
Shale	D	Ophiolite-serpentinite-basalt	D	Clastic units	B
Rhyolite	C	Marble	B	Carbonate units	B
Basalt	C	Limestone	B	Quartzite	D
Dacite	C	Neritic limestone	B	Quartzit-schist	D
Andesite	C	Carbonate	B	Phyllite	D

2.5 Flood Vulnerability Assessment

Landform-based FA shows water flow [46]. Pixel-based data predicts water pools. The slope factor influences water flow. A visual model of stormwater movements based on topography was created using 1:20,000 Copernicus Digital Elevation Model (DEM) data. FA maps are made in three steps. We adjusted base data pixel biases using Fill Sinks first. Since raster data may contain pixel-based inaccuracies, this phase is crucial for accurate analysis. Flow Direction estimated water flow directions during a cloudburst. Output analysis followed this. After these steps, the FA visual model was generated. Flood susceptibility was calculated by overlapping runoff and FA indexes. Theoretically, this stage indicates high-slope and stream areas where runoff may be more detrimental than expected.

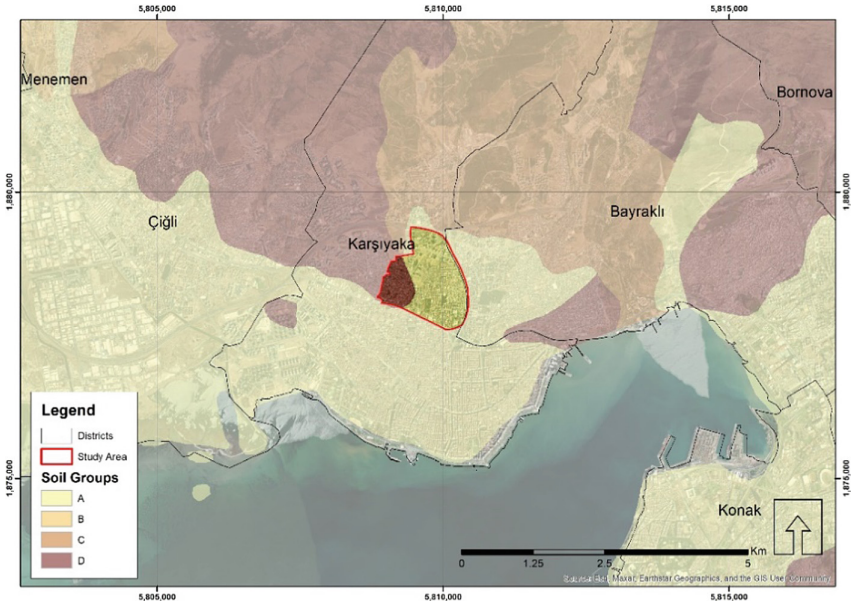


Fig. 2. Groups of soil types according to their hydraulic conductivity.

Karsiyaka's 70 mm cloudburst hazard zones may be recognized early using the composite index. It was selected because it met the "cloudburst" requirement but fell short of the November 2020 event's rainfall [29]. Turkey's Meteorological Agency (Meteoroloji Genel Müdürlüğü: MGM) recorded 42.1 mm of rain in Menderes and 77.3 mm in Karabağlar in November 2020, with other locations receiving 103.4 mm to 147 mm. The 70 mm depth and 200-year return length were rare, according to the IZSU water management evaluation [47]. In February 2021, MGM recorded 123.9 mm of rain in Konak and 130.9 mm in Menderes.

After building the visual model, FA and modeling findings were merged to perform the final Flood Vulnerability Index (FVI) of the area. ArcMap 10.8's Spatial Analyst Weighted Sum tool overlapped FA and InVEST values to construct the FVI.

It is crucial to note that because no threshold is provided in the urban flood vulnerability literature [48], the coefficients were deemed equal by accepting both inputs as equal. FVIs were created by normalizing and merging the two data sets. The index varied from 2 (InVEST output + FA (1)) to 0.

2.6 Scenario Settings

Fifteen LULC scenarios were created in the district using the Create Fishnet tool of ArcMap 10.8 to divide the area into equal 10 m tiles, classified as green (permeable) and grey (impermeable). The quantitative criteria used required green areas to cover 50% of the site, distributed in various ways to produce slightly different effects on flood risk (see Fig. 3). The scenarios are labeled based on the location of the green areas, with the first

eight scenarios following cardinal point and cartesian principles. The remaining scenarios are relatively homogeneous and designed by placing permeable areas vertically, horizontally, or intersecting each other. The last three scenarios, Horizontal Pinstripe, Vertical Pinstripe, and Tartan, are the most homogeneous and fragmented.

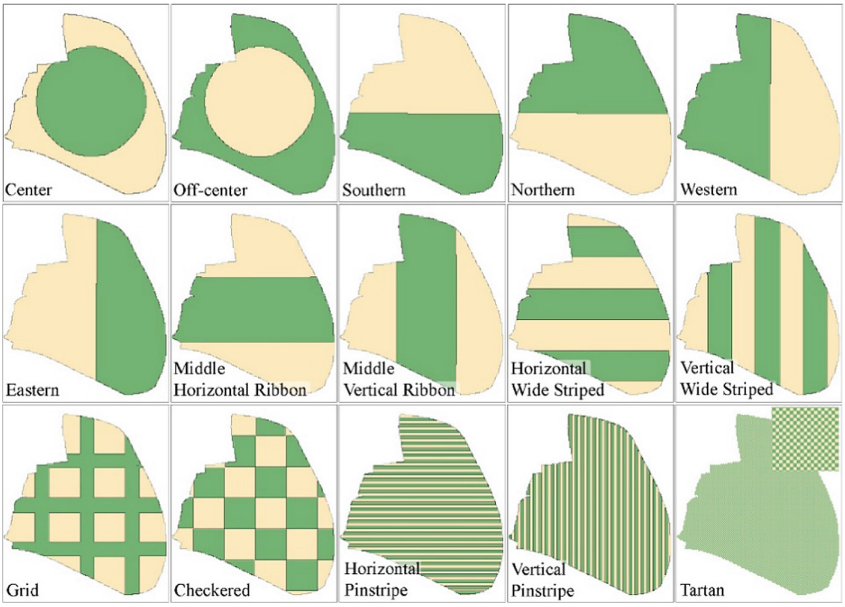


Fig. 3. Urban land use scenario designs produced within the scope of the study (green: permeable; beige: impermeable). (Color figure online)

3 Results

To measure the FVI, we used two indexes: runoff and FA. The results, presented in the Table 4, indicate a slight variation in the average values of runoff and FVI among the different scenarios.

The study's results revealed that the average runoff across all scenarios was 18.3 mm. The Western scenario had the highest runoff value of 18.954 mm, while the Eastern scenario had the lowest value of 17.593 mm. This indicates that the Western scenario had a higher runoff than the Eastern scenario. The difference in runoff between these two scenarios was 1.36mm, representing a 7.7% change.

Additionally, other scenarios had varying levels of runoff and FVI. For example, the Southern scenario had a runoff value of 18.386 mm and an FVI value of 0.376. The Northern scenario had a runoff value of 18.160 mm, and an FVI value of 0.368. The Center scenario had a runoff value of 18.177 mm and an FVI value of 0.370. These values demonstrate that while the Western and Eastern scenarios had the highest and lowest values, respectively, the other scenarios had values that fell in between.

It is also worth noting that even though the difference between the highest and lowest values in all the two cases (runoff and FVI) is not substantial. It indicates that the land use arrangements in the Western scenario make it more vulnerable to floods when compared to the Eastern scenario.

FA's influence on flooding risk (Table 5) shows that the two scenarios with the greatest risk (Western and Middle Horizontal Ribbon) and lowest risk (Eastern, Middle Vertical Ribbon) have not altered. The Northern, Center, Off-center, Checkered, and Southern situations remain in both rankings. This shows that FA little influences these scenarios' ranking changes between runoff and FVI.

In intermediate conditions, flood vulnerabilities shift. The Horizontal Wide Striped (runoff: 18.137 mm) scenario is the third least susceptible without topography, but with FA, it falls to seventh place with an FVI score of 0.370. When topography is included, the Vertical Wide Striped (runoff: 18.281 mm) scenario becomes the third least susceptible with an FVI score of 0.367. This scenario has improved the most among the fifteen scenarios in the calculation.

The Horizontal Pinstriped scenario upshifted two positions, making it less vulnerable to flooding, while the Vertical Pinstriped scenario downshifted two positions, making it more vulnerable, the Grid scenario upshifted one position, and the Tartan scenario downshifted three. Vulnerability has been utilized according to scenario rank.

It is fundamental to note that the flood vulnerability in the scenarios where the positioning of green areas are opposite can vary greatly, with one scenario being significantly high while the other being quite low (see Fig. 4). To explain, the Eastern and Western scenarios are obtained by designing permeable and impermeable areas in opposite positions. Similarly, in the Horizontal Wide Striped and Vertical Wide Strip scenarios, green areas are designed vertically in one and horizontally in the other.

4 Discussion

4.1 Investigation on Best Urban Settings Managing Flood Risk

In our analysis of the outputs generated by the InVEST model and the flood vulnerability maps, we discovered that the order of the maximum and minimum values of the scenarios did not undergo any alteration, implying that the influence of topography is not as significant as the hydrological conductivity of soil groups. In scenarios characterized by a low FVI, a frequent observation was the presence of densely concentrated green areas situated on soil with good porosity. If these green spaces are situated on soil with high permeability, the vulnerability of these scenarios to flooding is the least, and vice versa. This finding highlights the crucial role that soil types play in determining flood vulnerability compared to the area's topographic characteristics represented by FA.

Additionally, the urban scenarios developed within the scope of our work emphasize the pivotal role that land structure plays in preventing floods, in contrast to the influence of FA. Specifically, the difference between the Eastern scenario, which is the least vulnerable, and the Western scenario, which is the most vulnerable, can be attributed to the clustering of green and gray land uses in the east and west of the area, respectively. As can be inferred from the analysis, the Eastern scenario represents the optimal scenario for incorporating NBS into flood management plans.

Table 4. Measurement results of scenarios

Scenarios	Measurements	LUCODE	MEAN	SUM	Average
Center	Runoff (mm)	Grey	29.35	271,599.88	18.17766557
		Green	7.00	64,777.82	
	FVI	Grey	0.60	886.48	0.370379041
		Green	0.14	209.47	
Off-center	Runoff (mm)	Grey	27.79	257,091.14	18.36700177
		Green	8.95	82,790.23	
	FVI	Grey	0.57	836.91	0.374656687
		Green	0.18	271.70	
Southern	Runoff (mm)	Grey	27.65	255,806.88	18.38635431
		Green	9.13	84,432.60	
	FVI	Grey	0.56	834.49	0.376198328
		Green	0.19	278.68	
Northern	Runoff (mm)	Grey	29.49	272,930.14	18.16068613
		Green	6.82	63,133.36	
	FVI	Grey	0.60	888.90	0.3688374
		Green	0.14	202.49	
Western	Runoff (mm)	Grey	23.00	212,833.33	18.9548053
		Green	14.91	137,925.34	
	FVI	Grey	0.47	691.73	0.385708938
		Green	0.30	449.58	
Eastern	Runoff (mm)	Grey	34.14	315,926.68	17.59342168
		Green	1.04	9,639.58	
	FVI	Grey	0.70	1,031.66	0.35932679
		Green	0.02	31.59	
Middle Horizontal Ribbon	Runoff (mm)	Grey	25.15	232,690.72	18.69181125
		Green	12.24	113,201.25	
	FVI	Grey	0.51	746.48	0.378152859
		Green	0.25	372.47	
Middle Vertical Ribbon	Runoff (mm)	Grey	32.96	305,010.16	17.73618214
		Green	2.51	23,197.89	
	FVI	Grey	0.67	991.91	0.362423975

(*continued*)

Table 4. (*continued*)

Scenarios	Measurements	LUCODE	MEAN	SUM	Average
		Green	0.05	80.50	
Horizontal Wide Striped	Runoff (mm)	Grey	29.69	274,724.15	18.13787199
		Green	6.58	60,917.17	
	FVI	Grey	0.61	899.25	0.370647645
		Green	0.13	197.50	
Vertical Wide Striped	Runoff (mm)	Grey	28.49	263,655.46	18.28175123
		Green	8.07	74,648.34	
	FVI	Grey	0.58	834.14	0.367484817
		Green	0.17	253.25	
Grid	Runoff (mm)	Grey	28.10	260,082.04	18.33046095
		Green	8.55	79,123.14	
	FVI	Grey	0.57	836.19	0.370734129
		Green	0.17	260.82	
Checkered	Runoff (mm)	Grey	27.75	256,745.08	18.37395695
		Green	9.00	83,264.99	
	FVI	Grey	0.57	844.96	0.375710672
		Green	0.18	266.77	
Horizontal Pinstripe	Runoff (mm)	Grey	28.59	264,519.92	18.27096535
		Green	7.95	73,584.29	
	FVI	Grey	0.58	857.95	0.37064677
		Green	0.16	238.79	
Vertical Pinstripe	Runoff (mm)	Grey	28.59	264,554.63	18.27025189
		Green	7.95	73,536.38	
	FVI	Grey	0.59	860.04	0.370666329
		Green	0.16	236.77	
Tartan	Runoff (mm)	Grey	28.57	264,295.82	18.27081831
		Green	7.98	73,805.67	
	FVI	Grey	0.58	861.64	0.372051938
		Green	0.16	239.26	

To continue, the impermeable D-group soils are located west of the area, while the permeable A-group soils are east. Although the D-group soils occupy only a relatively small area, accounting for roughly one-third of the total area, their location in conjunction with green spaces increases the FVI of the area. In contrast to the study by Yang and Lee (2021), our findings demonstrate that by clustering green areas, on the soil types

Table 5. Comparative ranking of scenario results

Rank	Scenario	Avg. Runoff (mm)	Rank	Scenario	FVI
1	Eastern	17.59342168	1	Eastern	0.35932679
2	Middle Vertical Ribbon	17.73618214	2	Middle Vertical Ribbon	0.362423975
3	Horizontal Wide Striped	18.13787199	3	Vertical Wide Striped	0.367484817
4	Northern	18.16068613	4	Northern	0.3688374
5	Center	18.17766557	5	Center	0.370379041
6	Vertical Pinstriped	18.27025189	6	Horizontal Pinstriped	0.37064677
7	Tartan	18.27081831	7	Horizontal Wide Striped	0.370647645
8	Horizontal Pinstriped	18.27096535	8	Vertical Pinstriped	0.370666329
9	Vertical Wide Striped	18.28175123	9	Grid	0.370734129
10	Grid	18.33046095	10	Tartan	0.372051938
11	Off-center	18.36700177	11	Off-center	0.374656687
12	Checkered	18.37395695	12	Checkered	0.375710672
13	Southern	18.38635431	13	Southern	0.376198328
14	Middle Horizontal Ribbon	18.69181125	14	Middle Horizontal Ribbon	0.378152859
15	Western	18.9548053	15	Western	0.385708938

characterized by high hydrological conductivity and vice versa, a heterogeneous design can be established to create the least vulnerable urban district to floods.

The increasing built environment and soil loss with good hydraulic conductivity due to urban sprawl [50] make cities such as Izmir more susceptible to urban floods. Our results suggest that the strategic placement of green spaces can significantly reduce the risk of urban floods. These findings provide valuable insights into the relationship between land use configurations and runoff vulnerability and can aid in developing effective urban flood mitigation strategies.

4.2 Investigation on Effect of Flow Accumulation

The significance of FA in mitigating flood disasters has been widely acknowledged in the literature, as indicated by several studies [51–56]. Although the data did not significantly alter the ranking of the scenarios with varying levels of vulnerability, it did demonstrate a notable impact on the vulnerability index of certain areas in some scenarios (such as Tartan) in either a positive or negative direction. This underscores the fact that the FA is

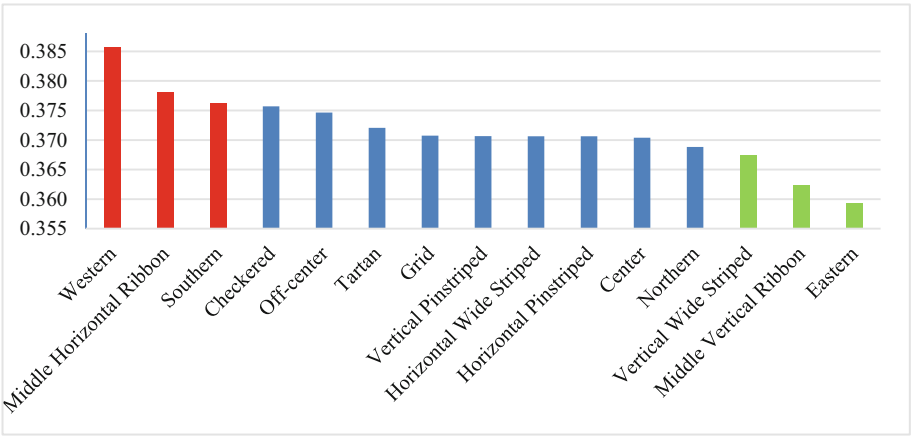


Fig. 4. Flood vulnerability indexes of the scenarios.

one of the most crucial factors to consider, after soil characteristics, in mitigating urban flood risk.

It is crucial to remember that integrating FA into urban planning and design is both a technical and policy challenge. Governments and regulatory bodies must create the necessary legal frameworks and standards to ensure the proportionality of soil and FA characteristics in urban planning and design processes. To assist this, a multidisciplinary approach involving the professions like urban planners, landscape architects, architects, geologists, and civil engineers is needed to effectively address urban flood risk and design sustainable urban drainage systems. Furthermore, the creation of legislation and policies is critical in the development of integrated and sustainable urban drainage systems that are based on NBS. Such systems prioritize the use of natural elements such as vegetated roofs, green walls, rain gardens, and permeable pavements to reduce runoff and enhance water infiltration. Implementing such systems, combined with the effective management of FA, can greatly enhance the resilience of urban areas to flood risk.

Overall, there is an urgent need to take action in countries where the urban flood risk is prevalent and has not been effectively addressed. Collaboration between relevant professional groups is critical to developing effective flood mitigation strategies, including implementing NBS and integrated sustainable urban drainage systems. The prioritization of such systems in areas with high FA can help mitigate the risk of urban floods, improving the resilience and safety of urban living areas.

4.3 Limitations

The results of this study must be evaluated considering several important limitations that may impact the validity and generalizability of the findings.

It is important to note that while the Eastern scenario had the lowest average values for both runoff and FVI, this result should not be interpreted as an indicator of the optimal scenario for reducing runoff and flood vulnerability. Other scenarios may have

outperformed the Eastern scenario in specific areas or for specific purposes, but these were not considered in this study.

Furthermore, the study relied on a simplified representation of hydrological processes and land use configurations. It did not consider other important factors that may influence flood vulnerability, such as infrastructure, land use planning policies, and demographics. It is essential to consider these factors in future studies to gain a more comprehensive understanding of flood risk and the most effective mitigation strategies. Additionally, using a single method for quantifying flood vulnerability in this study may not have captured all of the complex interactions and feedback between the different drivers of flood risk, and alternative methods may have provided different results. This highlights the importance of considering a range of methods and perspectives when analyzing flood vulnerability and developing strategies for reducing it.

Finally, the scope of this study was limited to the urban environment of part of a neighborhood in Izmir. It may not accurately represent the conditions in other regions or cities. The findings of this study are related to the study area and cannot be assumed to be directly applicable to other regions without further investigation and analysis. The results and conclusions drawn from this study may not accurately reflect the reality of other cities with different geographic, climatic, socio-economic and cultural conditions. Considering each region's unique features and characteristics is crucial before generalizing this study's results to other areas. This study serves as a valuable contribution to the existing literature on urban flood risk mitigation, but further research is needed to expand the findings to a broader context.

Given these limitations, it is recommended that future research should consider a more comprehensive dataset and a wider range of methods for quantifying flood vulnerability in order to understand better the complex relationships between land use configurations, hydrological processes, and flood risk. This will require a collaborative effort between researchers, practitioners, and policymakers to develop and implement more integrated and comprehensive approaches to flood risk assessment and management. Future research could further explore the potential of ecosystem service modeling approaches in urban planning and climate resilience and the effect of land use change on soil characteristics and hydrological processes.

5 Conclusion

In conclusion, this study aimed to investigate the impact of varied land use configurations on runoff vulnerability in the Karsiyaka district of Izmir, Türkiye. Using the InVEST model and an analysis of FA, we have demonstrated that the hydrologic characteristics of the soils have a greater impact on flood vulnerability than FA. Our findings have important implications for urban planning and resilience efforts, as they highlight the importance of considering soil characteristics when designing land use plans and implementing mitigation measures. Furthermore, this paper simulated the runoff reduction effect of different arrangements to find an optimal strategy for city planning for urban stormwater treatment. The method used in the manuscript is more effective than traditional hydrology models in simulating and comparing the results of many other city planning scenarios since it requires fewer data and effort to run. This means that it could be used for land-use

optimization for green space allocation and policy making. Overall, this study provides valuable insights for decision-makers in urban planning and flood management. Further research could explore the potential of ecosystem service modeling approaches in urban planning and flood resilience.

As we delve deeper into the interplay between land use and flood vulnerability, one factor shines brighter than the rest - soil structure. In crafting urban flood management strategies, it's imperative to have a comprehensive understanding of the soil and its drainage capacities. When mapping out the blueprint of a city, the land structure, encompassing both soil and topography, must be an integral part of the equation and considered in tandem with NBS. Though our study relied on simplified simulations, its findings shape planning dynamics and guide decision-making processes toward a more resilient future.

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