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Examining the Ecosystem Service Context of Green Spaces in Reducing Urban Flood Risk: The Case of Çanakkale City Center

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ABSTRACT: Urban flood-prone areas refer to city regions exposed to inundation due to heavy rainfall, increased surface runoff, and insufficient drainage infrastructure. These areas generally emerge where natural drainage pathways have been disrupted, infrastructure is lacking or undersized, and rapid urbanization has reduced water retention capacity. In recent years, urban flood risk has increasingly been addressed in the context of climate change and has become an important part of strategies for creating resilient cities. In particular, nature-based solutions and urban green infrastructure practices have come to the forefront due to their potential to regulate hydrological processes, support ecological continuity, and reduce flood impacts.

In this study, the spatial distribution of green areas in Çanakkale city center and Kepez district was classified; parameters such as rainfall intensity, slope, surface impermeability, and drainage capacity were used to produce flood risk maps. GIS-based modeling was employed to examine the relationship between ecosystem services and urban flood risk, and to evaluate the role of green areas in reducing surface runoff and enhancing urban resilience. Field observations and land-use analyses were also incorporated to realistically represent local conditions. The findings demonstrate that green areas play an important role in mitigating flood impacts by increasing infiltration, slowing runoff, and supporting natural waterways.

The model developed for Çanakkale city center and Kepez district within the scope of ecosystem services is intended to serve as a guide for sustainable urban planning and climate-adaptive development processes. The results aim to provide a scientific basis for urban transformation, land-use planning, and green infrastructure investments, contributing both to flood risk reduction and to the enhancement of ecological and social resilience.

KEYWORDS: Urban green areas, Ecosystem services, Urban flood risk, Water management, InVEST, GIS

1. INTRODUCTİON

Climate change is increasingly exerting significant impacts on cities today. In Turkey, the decline of water resources, intensifying drought, extreme weather events, and the growing risk of floods directly affect both natural and urban systems [1]. Combined with urbanization processes, these climatic changes particularly increase flood and inundation risks in riverbank settlements [2]. Green infrastructure and urban landscape design have emerged as important tools for reducing climate-related risks. Parks, green corridors, permeable surfaces, and nature-based designs help regulate surface runoff, reduce flood risk, and strengthen urban resilience [3]. Moreover, by supporting biodiversity through ecosystem services, these solutions enhance quality of life and contribute to urban sustainability.

The concepts of urban vulnerability and resilience form the foundation of climate adaptation strategies in modern urban planning. Systematic planning of green infrastructure supports natural drainage pathways, reduces flood risk, and simultaneously provides social and environmental benefits [1]. As demonstrated in both Turkish examples and international literature, urban landscape design and ecological restoration practices play a critical role in building resilient cities [1],[2].

Past flood events in Turkey highlight the vulnerability of cities to such risks. In Çanakkale, major floods occurred in 1962 and 1964, with the Sarıçay River overflowing in 1964 and inundating 90% of the city. Although disasters of similar scale are not observed today, local floods and inundations still occur around Sarıçay during periods of heavy rainfall. These events generally result from inadequate infrastructure and sudden rainfall variations, producing short-term impacts [6].

Similar risks are observed globally. For instance, floods in Vietnam in 2025 caused at least 98 deaths, 12 missing persons, and damage to 51,800 hectares of farmland and more than 186,000 houses. In Asia, monsoon rains in countries such as China, India, Bangladesh, and Vietnam cause severe flood damage annually. In the Americas, the United States, Brazil, and Mexico frequently face flood disasters due to tropical storms and heavy rainfall, while in Africa and Europe, countries such as Sudan, Mozambique, Italy, and Portugal remain highly vulnerable due to inadequate

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infrastructure and the impacts of climate change [9],[5]. These examples demonstrate that climate change has tangible impacts on urban areas not only in Turkey but worldwide, underscoring the importance of green infrastructure solutions.

This study aims to examine the role of green areas in Çanakkale city center and Kepez district in reducing urban flood risk within the framework of ecosystem services. The findings will provide a scientific basis for urban renewal and the planning of new development areas. In this way, the resilience of cities against climate change will be strengthened, while a sustainable and ecologically balanced urban planning approach will be supported.

2. MATERİALS AND METHODS

2.1.1. Research Location

This research was conducted in Çanakkale Province, located in the Marmara Region of Turkey, at 40.04° North and 26.56° East coordinates. Çanakkale occupies a strategic position connecting the continents of Asia and Europe and possesses significant ecological and socio-economic **characteristics along the Dardanelles Strait. The map of the study area is presented in Figure 1.**



Figure 1. Study Boundary (source: generated from Google Earth Pro, 2025).

As of 2024, the population of Çanakkale is 568,966 [4]. In the context of building resilient cities, urban vulnerability and ecological restoration are critical considerations. This study was conducted within the boundaries of Çanakkale city center and Kepez district. Within the study area lies the Sarıçay Stream, which flows into the Dardanelles Strait.

Due to its geographical location, Çanakkale exhibits a transitional climate between the Mediterranean and the Black Sea. Summers are hot and dry, while winters are cool, rainy, and windy. According to long-term data from the Turkish State Meteorological Service, the province's annual average temperature is approximately 15–16 °C, and the annual precipitation ranges between 650–700 mm. This climatic structure directly influences the region's agricultural production patterns and ecological diversity [8].

2.1.2. Data Sets

In this research, the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) modeling tool was employed to assess ecosystem services in reducing urban flood risk in Çanakkale city center and Kepez district. Specifically, the Urban Flood Risk Mitigation module of the InVEST software was applied. The datasets used in the study were prepared in accordance with the parameters required by the model. When examining the data requirements of the InVEST model, it is observed that they consist of two main groups: mandatory data (e.g., land cover, rainfall data, topography) and optional data (e.g., socio-economic indicators, infrastructure information).

Table 1: Data Types and Sources

Data Type (Recent Literature Review)	rce (Open Access Website)
Meteorological Data: Long-term precipitation, temperature, and extreme weather event records (1929–2021)	Turkish State Meteorological Service
Digital Zoning Plan: If needed, details of urban development are addressed at the 1/1000 scale plan level	Çanakkale Municipality
Soil Hydrologic Group: Used in flood risk analysis and ecosystem services studies	U.S. Army Corps of Engineers, Hydrologic Engineering Center. (2010). *HEC-HMS Technical Reference Manual*. Davis, CA: Hydrologic Engineering Center
Land Cover Data: Classifies land use and land cover	CORINE Land Cover (Copernicus)
DEM (Digital Elevation Model): Used in hydrological analyses, slope calculations, flow direction, and watershed boundary delineation	USGS Earth Explorer

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InVEST Model Guide	Natural Capital Project (Stanford University)
InVEST Urban Flood Risk Mitigation Model	Natural Capital Project (Stanford University)

2.2. Methods

2.2.1. Invest Model

In this research, the Urban Flood Risk Mitigation model of InVEST version 3.15.1 was used.

Flood hazard comes from different sources, including: riverine (or fluvial) flooding, coastal flooding, and stormwater (or urban) flooding - the focus of this InVEST model. Natural infrastructure can play a role for each of these flood hazards. Related to stormwater flooding, natural infrastructure operates mainly by reducing runoff production, slowing surface flows, and creating space for water (in floodplains or basins)[7].

The InVEST model takes a simple curve number approach to calculating rainfall runoff reduction due to land use/land cover and soil characteristics. Runoff reduction can also be thought of as the amount of runoff retained per pixel compared to the storm volume. For each watershed, it also estimates the potential economic damage, and ecosystem service provided, to built infrastructure.[7].

$$Q_{p,i} = \begin{cases} \frac{(P-\lambda S_{max,i})^2}{P+(1-\lambda)S_{max,i}} & if \quad P > \lambda \cdot S_{max,i} \\ 0 & otherwise \end{cases}$$

For each pixel i, defined by a land use type and soil characteristics, we estimate runoff Q (mm) with the Curve Number method: [13].

Where P is the design storm depth in mm, Smax,i is the potential retention in mm, λ. Smax and is the rainfall depth needed to initiate runoff, also called the initial abstraction (λ = 0.2 for simplification). [7].

Smax (calculated in mm) is a function of the curve number, CN , an empirical parameter that depends on land use and soil characteristics (NRCS 2004):

$$S_{max,i} = \frac{25400}{CN_i} - 254$$ [13].

$$R_i = 1 - \frac{Q_{p,i}}{P}$$ [33].

$$Q_m3_i = Q_{p,i} \cdot pixel.area \cdot 10^{-3}$$ [13].

$$R_m3_i = R_i \cdot P \cdot pixel.area \cdot 10^{-3}$$ [13].

$$\text{Affected.build}_W = \sum_{b \subset B} a(b,W) \cdot d(b)$$ [13].

$$\text{Service.built}_W = \text{Affected.build}_W \cdot \sum_{i \subset W} R_m3_i$$ [13].

2.2.2. Data Analysis

In this study, the role of green areas in reducing urban flood risk in Çanakkale city center was analyzed within the framework of ecosystem services using the InVEST Urban Flood Risk Mitigation model. The study area was defined to include the city's residential zones, transportation corridors, existing green spaces, and the urban sub-basins influencing these areas.

Land use and land cover data were generated based on field surveys rather than remote sensing. For this purpose, the study area was visited on-site, land-use types were observed, and GPS-supported fieldwork was conducted to classify them. The collected data were cross-checked with municipal planning records, digitized, and categorized into highly urbanized areas, low-density urbanized areas, green spaces, transportation surfaces, agricultural lands, and water bodies.

For topographic analyses, a digital elevation model (DEM) with 10 m resolution was used, from which slope and flow direction maps were generated. Soil data were obtained from national databases, classified into hydrologic soil groups, and their infiltration characteristics were integrated into the model. Precipitation data were based on long-term average rainfall values and extreme rainfall statistics provided by the Turkish State Meteorological Service.

All datasets were standardized to a common coordinate system and spatial resolution. Curve Number (CN) values were assigned according to land use and soil groups, enabling the calculation of surface runoff potential for each pixel. Three scenarios were developed in the study: the current situation, an impervious surface expansion scenario, and a green infrastructure scenario with increased green areas. For each scenario, the model was run to estimate surface runoff volume, water retention capacity, and flood mitigation potential.

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Model outputs were analyzed in a Geographic Information Systems (GIS) environment, where areas of high flood risk were compared with the distribution of green spaces, and spatial evaluations were conducted. The results were interpreted together with local flood observations and assessed at the planning scale. The methodological workflow is illustrated in Figure 2 below

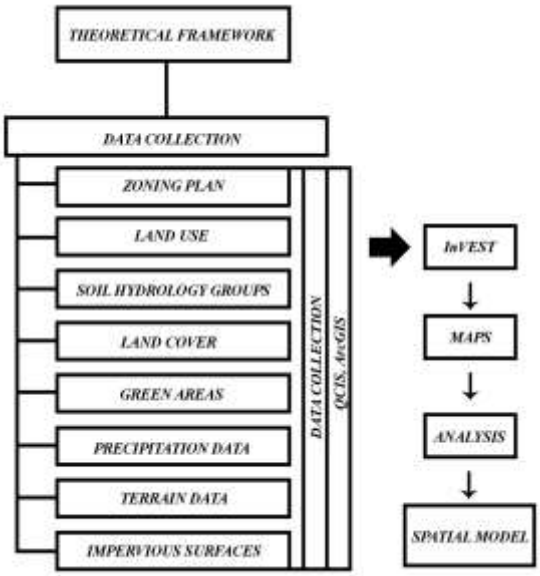


Figure 2. Methodological Workflow Diagram

This diagram systematically summarizes the spatial modeling process, starting from the upper framework with data collection, GIS-based analysis, and the generation of output maps using the InVEST model. Land use, slope, imperviousness, and precipitation data were processed within the GIS environment to conduct spatial analyses related to urban flood risk

3.RESULT AND DISCUSSIONS

3.1.1. Result

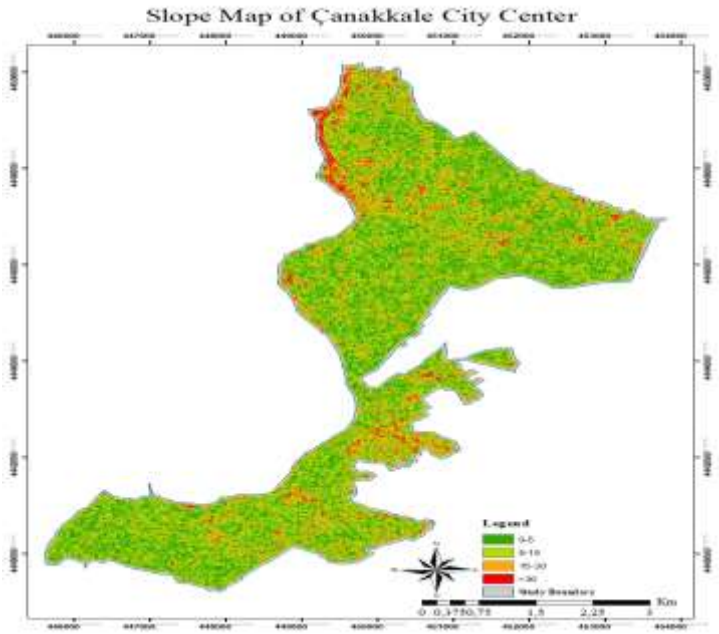


Figure 3. Slope Map

The slope map of Çanakkale city center and Kepez district was used as a fundamental topographic input in the InVEST Urban Flood Risk Mitigation model. Low-slope areas (0–5°) indicate regions where water tends to accumulate, while high-slope areas (>15°) representzoneswhere surface runoff accelerates and flood risk increases. These data played a critical role in generating flow direction and flood risk maps.

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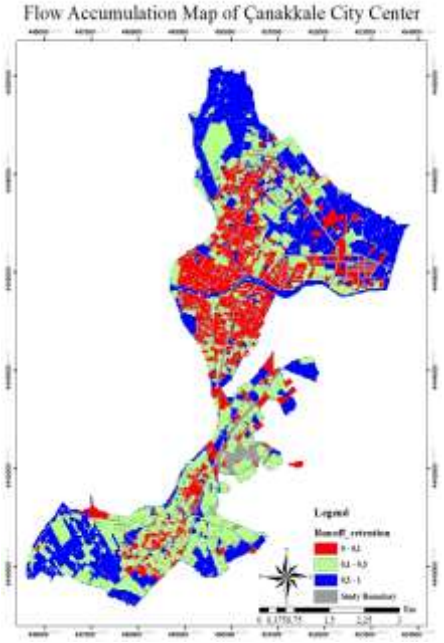


Figure 4. Flow Accumulation Ratio

The flow accumulation ratio per pixel was derived from the input datasets and processed within the GIS environment. The resulting map was classified into three categories: (i) 0–0.1 (Low Accumulation), (ii) 0.1–0.5 (Moderate Accumulation), and (iii) 0.5–1 (High Accumulation). In this classification, low-accumulation areas correspond to impervious surfaces such as buildings, roads, and paved grounds. Moderate-accumulation areas include residential zones with green spaces, medians, picnic areas, and lawns. High-accumulation areas represent forests, afforested lands, and vacant lands.

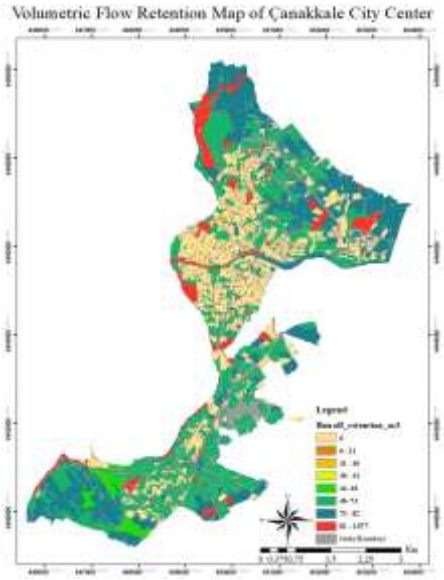


Figure 5. Volumetric Flow Retention

The rainfall volume per square meter in the study area was generated through the processing of input datasets. The map was produced using a GIS environment and classified into eight categories:
Red: Park
Dark Blue: Open Space (grassland)
Dark Green: Residential + green (green space density below 50%)
Light Green: Residential + green (green space density above 50%)
Yellow: Afforested Area
Orange: Coastal Recreation
Brown: Picnic Area
Beige: Impervious Surface

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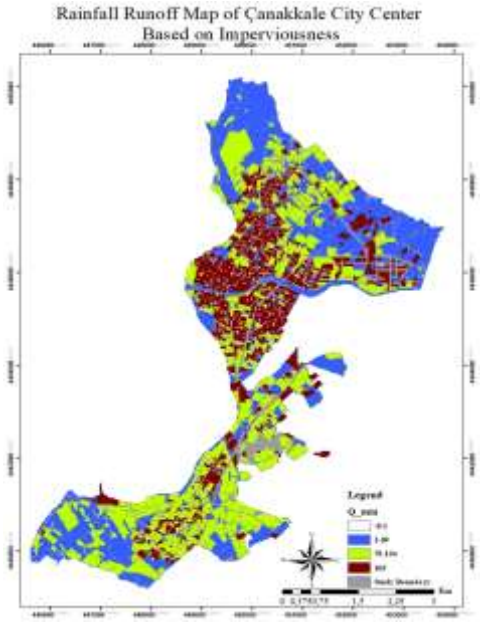


Figure 6. Rainfall Runoff Based on Imperviousness

The runoff map based on imperviousness conditions was generated using rainfall data processed in the GIS environment. The highest runoff values were obtained in impervious surfaces such as roads, buildings, and paved areas. The map was classified into four categories as follows:
–8 to 1: Very High Runoff
1 to 69: High Runoff
70 to 104: Moderate Runoff
105: Low Runof

3.1.2. Flood Risk Service

The map outputs were processed to obtain average values for the study area. These are as follows:
rnf_rt_idx: 0.36
rnf_rt_m3: 103
flood_vol: 182
Based on these values, the flood risk status of the study area was quantitatively determined in terms of urban flood vulnerability. All values were generated from map data produced within the GIS environment.

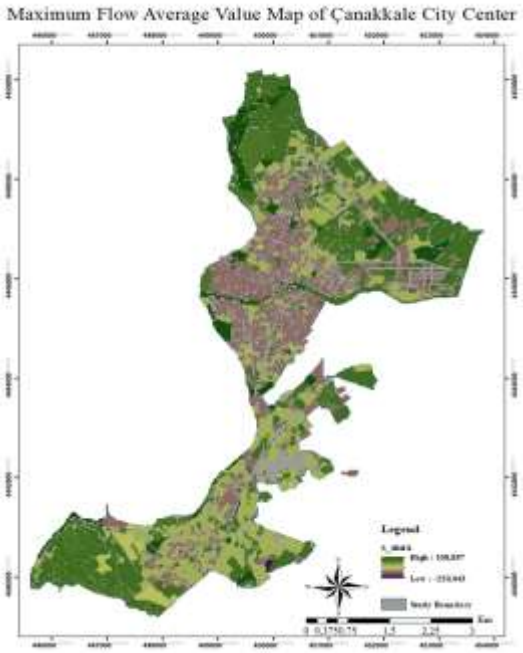


Figure 7. Rainfall Runoff Based on Imperviousness

The percentage-based average flood risk status map according to land use was generated using the GIS environment.

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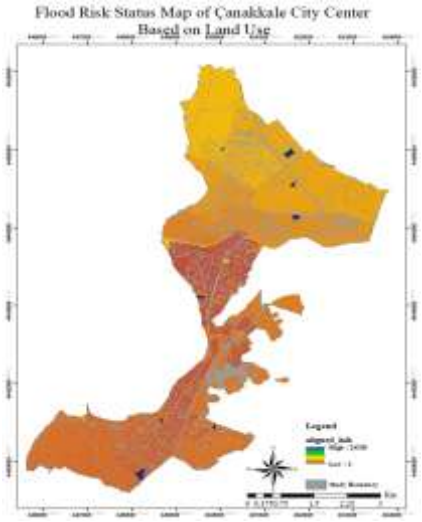


Figure 8. Rainfall Runoff Based on Imperviousness

The map of maximum average runoff values according to land use was generated using the GIS environment.

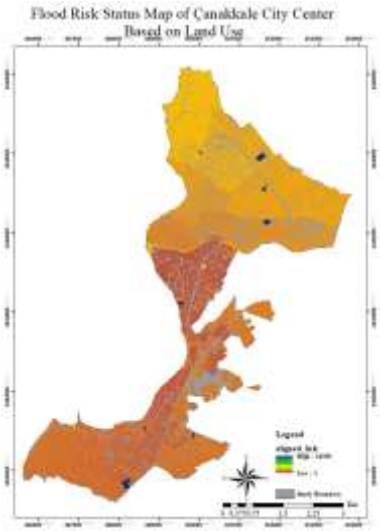


Figure 9. Rainfall Runoff Based on Imperviousness

The average imperviousness map based on land use was generated using the GIS environment.

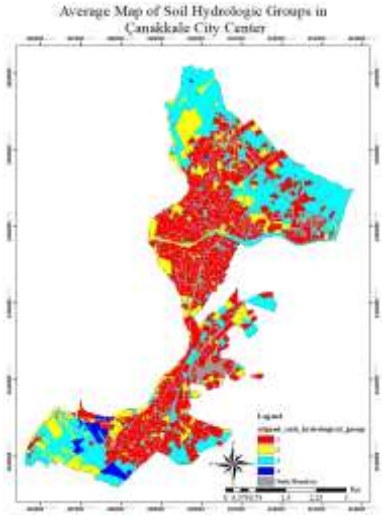


Figure 10. Rainfall Runoff Based on Imperviousness

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The average value map of land use according to hydrologic soil groups was generated using the GIS environment. The map was classified into four groups based on average values, thereby revealing the urban flood risk potential of the study area.

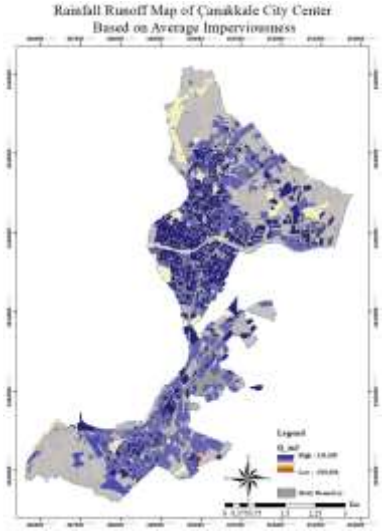


Figure 11. Soil Classification

The map was generated by inputting soil hydrologic permeability data for the study area, covering Çanakkale city center and Kepez district. Green tones (Groups A and B) represent areas with high infiltration capacity and low surface runoff, whereas yellow and red tones (Groups C and D) indicate low-permeability zones with higher surface runoff and flood risk. Within the framework of the InVEST Urban Flood Risk Mitigation model, this classification plays a critical role in determining the flow direction and accumulation potential of water after rainfall events.

3.2. Discussions

When previous flood risk studies conducted in Çanakkale are examined, it is seen that the research has largely relied on hydraulic modeling and AHP–GIS based multi-criteria evaluation methods. For instance, the study on the collapse scenario of the Çokal Dam focused on hydraulic flood propagation[10], while the paleoflood analysis and GIS-based mapping in the Sarıçay basin evaluated basin morphology and traces of past floods [11]. The flood risk analysis carried out in the Kepez settlement using the AHP method was based on classical criteria such as slope, geology, and land use [12]. However, none of these studies considered the functions of green spaces (such as water retention, infiltration, and reduction of surface runoff) as model inputs. Therefore, the green space–based flood risk model employed in this study differs methodologically from previous works and stands out as one of the first examples applied in Çanakkale. Moreover, the adaptation of the INVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) approach to flood risk and green infrastructure planning represents an application not encountered in the literature specific to Çanakkale. This positions the research as pioneering both at the regional scale and within national studies addressing the relationship between green infrastructure and flood management

4.CONCLUSIONS

In this study, flood risk across the Çanakkale city center and the Kepez district was evaluated through an integrated GIS-based approach that incorporated slope, flow direction, flow accumulation, land use/land cover, and surface permeability. The results indicate that the highest flood risk is concentrated in urbanized areas characterized by extensive impervious surfaces. This finding is consistent with earlier national research demonstrating that increased imperviousness accelerates surface runoff and enhances the likelihood of flooding in urban settings [15],[18]. The interruption of natural drainage paths by dense building patterns and infrastructure further contributes to this outcome.

Conversely, areas with higher proportions of green and permeable surfaces were associated with lower flood-risk categories. This highlights the critical role of green infrastructure in regulating runoff, promoting infiltration, and reducing peak flow, aligning with previous studies conducted in various Turkish cities [17],[16]. These findings also correspond with the international literature, which emphasizes the ability of urban green spaces to mitigate flood hazards and enhance resilience, especially in highly urbanized environments [20],[19]. The results of this study reinforce these broader scientific insights.

The analyses also underscore the influence of local topography on flood distribution. Low-slope areas exhibited a tendency for water accumulation, whereas zones with high flow accumulation values functioned as natural drainage corridors. In Çanakkale, particularly around the Sarıçay Stream, this pattern is evident and mirrors observations from other GIS-based flood studies in Turkey[18]. In the Kepez district, the presence of larger green areas away from the dense urban core contributes to a more balanced surface-runoff pattern; however, the district's rapid urbanization trend suggests potential increases in imperviousness in the future.

Taken together, the flood-risk maps generated in this research provide a detailed representation of how urban growth patterns and land-use characteristics interact with hydrological processes. The findings emphasize the importance of increasing green-space availability, controlling the expansion of impervious surfaces, improving drainage systems, and maintaining natural flow paths to mitigate urban flood risk. Showing strong consistency with both national and international literature, this study contributes valuable insights into the relationship between green infrastructure and flood management in the context of Çanakkale and, more broadly, within the scope of flood-risk research in Turkey.

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