Research Article
https://doi.org/10.33904/ejfe.1527247

Eur J Forest Eng 2025, 11(1):1-14

A GIS Based Quick Assessment Method of Flood Vulnerability: Susurluk Basin Case

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Abstract

There are various methods available for evaluating flood risk in a basin, ranging from identifying high-risk areas to analyzing the frequency and magnitude of potential flooding events. Our approach utilizes readily available spatial data to discern vulnerable locations to flooding of varying levels. In this study, the Analytical Hierarchy Process (AHP), a multi-criteria evaluation technique was applied in the Susurluk River basin of Turkey using factors were analyzed such as land use, precipitation, elevation, drainage density, slope, soil, and topographic wetness index. Annual precipitation emerged as the most significant factor in our predictive model, with a weight value of 36%. For slope, land use type, elevation, and drainage density, the weighted values were weighted at 23%, 6%, 12%, and 11%, respectively. The results showed that 88.31% of the basin exhibited vulnerability to flooding, whereas only 0.83% demonstrated resilience. These findings can inform policymakers in their decision-making regarding land planning. As such, this study underscored the importance of flood vulnerability assessments in identifying regions that require additional attention in implementing prevention measures and early warning systems.

Keywords: Climate change, vulnerability, flood, analytic hierarchy process.

1. Introduction

The impacts of climate change are evident in both physical and ecological systems (Adger et al., 2005). Human-induced climate change has increased extreme precipitations, resulting in more frequent and severe river floods (IPCC, 2022). These natural disasters test the resilience of communities, and in recent years, the global effects have included loss of life, property damage, and economic losses (Getahun and Gebre, 2015; Mohammad, 2016; Kittipongvises et al., 2020). Risk assessments have been used for a long time, and various options are considered, each with their advantages and disadvantages (Aven, 2015). Flood simulation and risk assessments are strategic planning tools that can help mitigate flood risk and damage while providing insight into the likelihood and consequences of potential flood damage (Blistanova et al., 2016; Van et al., 2019). GIS-generated hazard or vulnerability maps based on topographic maps and imagery, along with vulnerability surveys, are necessary for a thorough risk analysis procedure. These maps are used to identify hotspots or locations that need attention. To identify the factors that pose the greatest threat to people and property, risks and vulnerabilities should be considered when prioritizing hazards (Eguaroje et al., 2015). Flood risk management is critical to adapting to global change (Moel et al., 2015). Therefore, flood vulnerability analysis and risk assessments are essential in reducing flood damage (Dandapat et al., 2017).

Floods can occur for various reasons, such as land use changes, heavy rainfall, and saturated soils. Human activities like urbanization, deforestation, and agricultural expansion can also increase the risk of flooding by reducing water absorption into the soil. There have been predicted to be fewer river floods in Mediterranean regions (IPCC, 2022). It is important to identify areas prone to flooding to plan cities and manage natural disasters effectively (Feloni et al., 2020). The vulnerability to floods is determined by proximity, geology, altitude, and flood return time (Mohammad, 2016). The occurrence of basin-based floods depends on features specific to the basin, such as meteorology, topography, and geology (Merz et al., 2014). Flood assessment studies aim to pinpoint areas at risk of flooding, generate maps of these areas, devise plans to mitigate damage, and minimize risks. These studies play a vital role in city planning and natural disaster management policies. GIS based multi-criteria analysis methods have been developed to locate flood-prone areas and demonstrate the spatial distribution of risk reduction

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Received: 05 August 2024; Accepted: 20 October 2024

measures (Meyer et al., 2007; Ouma and Tateishi, 2014; Getahun and Gebre, 2015; Feloni et al., 2020).

Studies have been conducted in various regions to assess flood vulnerability and risk using techniques like the analytical hierarchy process and GIS. According to Kittipongvises et al. (2020), the intensity of urbanization is closely related to flood hazards on Ayutthaya Island, with factors such as runoff, watershed areas, and road densities playing important roles. It's important for public policy to prioritize the development of strategies for managing floods in urban areas and creating multi-disaster zones. Blistanova et al. (2016) also conducted a study using multi-criteria analysis with GIS in the Bodva River basin, evaluating flood vulnerability in four classes: acceptable, moderate, undesirable, and unacceptable. Based on the results, this study identified areas requiring flood protection measures.

Moreover, Hussain et al. (2021) used a GIS-based multi-criteria approach to assess flood vulnerability and map 21 criteria in the Shangla Region. The criteria were scaled using the AHP to determine their weights. The study found that areas with high and very high vulnerability were located near wetlands, with high precipitation, elevation, and other socioeconomic factors contributing to the risk. In another study, Seejata et al. (2018) evaluated flood hazard areas in the Sukhothai province of Thailand using spatial analysis in a GIS environment. Six factors were chosen to estimate flooded risk regions, including precipitation amount, slope, elevation, drainage density, land use, and soil permeability. Comparative matrices were applied through the AHP process to obtain weight values, and flood hazard zones were mapped accordingly. In recent years, flood events have increased in Japan, prompting the need to identify vulnerable areas against floods. Slope maps, drainage density, precipitation data, soil, and land cover data were used to identify these areas, along with GIS systems and AHP methods (Rimba et al., 2017).

The studies by Dandapat and Panda (2017) and Desalegn and Mulu (2020) indicated that residential and agricultural areas within their study areas were highly vulnerable to flooding. Hence, the generated flood risk map can help develop adaptation measures to reduce future losses and can also hinder social and economic development. In addition, Eguaroje et al. (2015) used multiple criteria to assess flood vulnerability, including annual precipitation, slope, land use, aspect, drainage level, and soil type. The study identified weight values for each criterion and divided flood vulnerability into four classes, with the least fragile areas being the most prevalent. These studies can help in the development of effective flood management strategies.

This study aims to assess the vulnerability of the Balıkesir-Susurluk Basin to floods by utilizing GIS tools and a multi-criteria analysis method. Assessing flood vulnerability in the Susurluk Basin will evaluate the potential distribution of flood risk on a regional scale. In order to assess flood risk, factors contributing to floods, such as precipitation, soil type, land use, basin slope, drainage density, topographic wetness index (TWI), and elevation, were considered. The AHP method was used to determine the weights of these factors, which involved examining previous studies and seeking expert opinion to evaluate the decision-making process and reveal the variables' weights. The criteria weights were analyzed by using the ArcGIS (10.8.x) environment. A flood vulnerability assessment map was generated for the study area using a multi-parameter approach that considered physical, morphometric, and topographic variables. The results of this study will benefit disaster managers, decision-makers, and local government in measuring the spatial vulnerability of the floodplain and developing adaptation plans and strategies for flood risk assessment in the study area.

2. Materials and Methods

2.1. Study area

The research was conducted in the Susurluk Basin, the Marmara Region. The area of the basin is approximately 24.035 km², and it is positioned between 27°9'50'' - 29°51'42'' E and 39°1'8'' - 40°31'43'' N (Figure 1). The Susurluk Basin's average altitude is 631.24 m, and its slope ranges from 6-12% (Aytekin and Serengil, 2022). The Susurluk River Basin, situated south of the Marmara Sea, is a significant contributor to the pollution of the sea. The growing population in the urban areas of the Basin poses a potential threat to water security and safety. The CORINE land use map (2018) indicates that within the Susurluk Basin, there are higher percentages of coniferous forests (15.3%) than deciduous forests (8.5%). Additionally, the region experiences an average annual precipitation of 621.7 mm and an average temperature of 13.1°C (Aytekin, 2021). The Basin experiences a climate that blends characteristics of the Mediterranean and continental Anatolian regions. As a result, it has a typical dry summer season and variation in precipitation throughout the year.

2.2. Data collection and methodology

Managing water resources and mitigating flood risks often relies on multi-criteria analysis. Multi-criteria analysis methods are widely used in managing water resources and mitigating flood risks. Various studies have widely applied this method in assessing flood risks (Scolobig et al., 2008; Blistanova et al., 2016; Cai et al., 2016; Dandapat and Panda, 2017). Geographic information systems have also been utilized to investigate the spatial and temporal patterns of flood formation and identify relationships between factors that contribute to flooding (Tanavud et al., 2004; Wang et al., 2011; Ajin et al., 2013; Papaioannou et al., 2015; Desalegn and Mulu, 2020; İnan and Öztürk, 2022). The analytical hierarchy process (AHP) is a commonly used multi-criteria method to evaluate flood vulnerability (Saaty, 1980).

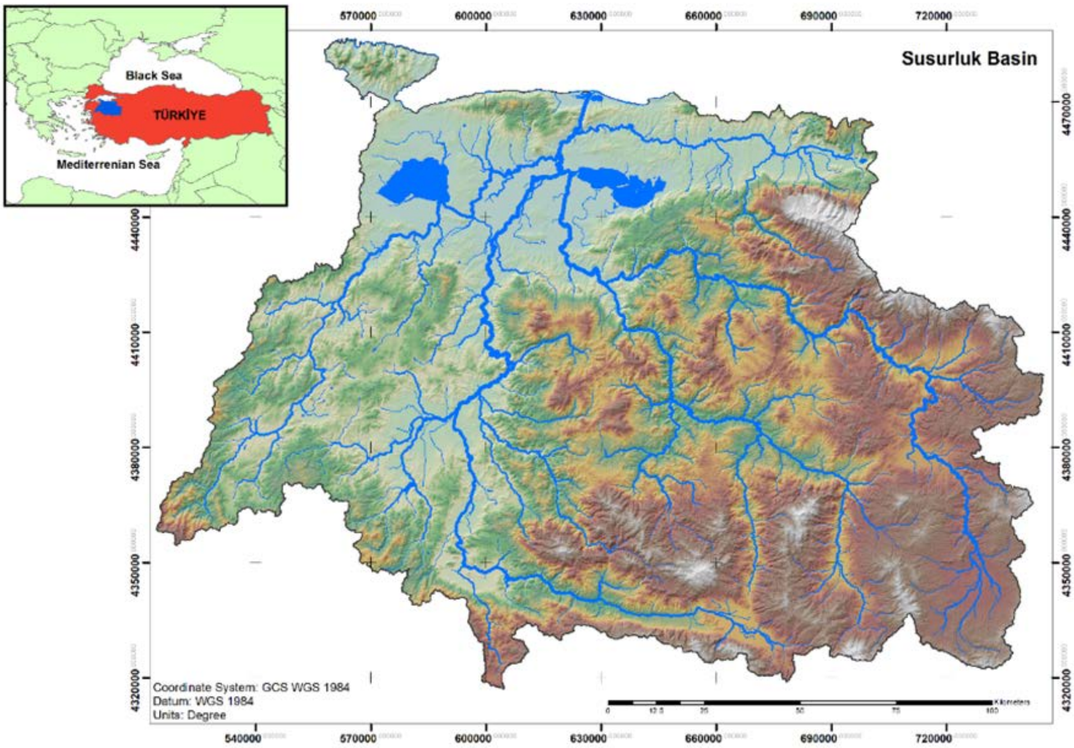

Figure 1. Study area map of Susurluk Basin

To assess flood vulnerability in the study area, we considered various factors, such as slope, elevation, land use, drainage density, precipitation, soil properties, and topographic wetness index. The digital elevation model, obtained from a 25 m resolution raster format (EU-DEM), was used to generate slope, elevation and drainage density data. After generating slope data for the study area, it was classified into five subgroups, each spaced equally apart. These subgroups were visually represented in Figures 2 and 3.

The slope grades have been reclassified and assigned a value from one to five, with a rating of 1 for high-flood-risk areas and 5 for low-risk areas. Therefore, an area with a low slope was assigned a rating of as five, and an area with a high slope was was assigned a ratingof one, as shown in Table 1.

We categorized DEM data into five subgroups of equal spacing, as illustrated in Figures 2 and 3. The elevation steps were then reclassified based on their flood risk, with higher values assigned to areas with higher risk. For instance, areas with very low flood risk were assigned a value of 1, while those with high flood risk were assigned a value of 5. As a result, flat areas were ranked as five, while very high areas were graded as one, as indicated in Table 1.

For this study, annual average precipitation data was acquired from 32 meteorology stations (MGM, 2018), and the annual average precipitation was calculated for each station. Then, a precipitation map was generated using a well-known interpolation technique, the inverse distance-weighted method (IDW). The map was classifed into five classes using an equal interval. These newly generated five classes of precipitation data were reclassified based on flood risk, with lower values indicating lower flood risk and higher values indicating higher flood risk. The areas with the least precipitation were rated one, while those with the most precipitation was rated five (as shown in Figures 2 and 3 and Table 1). For the study areas land use data, we used Corine (2018) maps and categorized the land use into 5 classes using ArcGIS 10.8.x, based on the Corine land classification. The Susurluk Basin's land use data was remapped into five subgroups, as seen in Figures 2 and 3. We revalued the reclassified land use data from one to five, with higher values indicating areas with a higher flood risk. Thus, forested areas with low flood risk were assigned a value of 1, while wetland areas with high flood risk were assigned a value of 5 (see Table 1).

Drainage density data was generated using DEM and divided into five subgroups with equal spacing, as depicted in Figures 2 and 3. These subgroups were assigned values from one to five, with higher values indicating greater flood risk. Thus, the area with the lowest drainage density was ranked one, while the area with the highest drainage density was rankedfive (see Table 1).

The study area has 18 soil groups, classified into five subgroupd based on literature review and soil characteristics. Table 1 and Figures 3c represent the classified soil map (L:brown forest soils, B:brown soils, O: organic soils, K: colluvial soils, and A: alluvial soils). The reclassified soil groups are ranked from one to five, with a value of 1 for areas with very low flood risk and 5 for areas with high flood risk. Soil groups in Category A are given a rating of five, while those in Category L are rated as one.

We used the Topographic Wetness Index (TWI), developed by Beven et al. (1984), to assess flood vulnerability for our study. It is formulated as follows:

$$TWI = ln\ (\alpha / tan\beta) \quad (1)$$

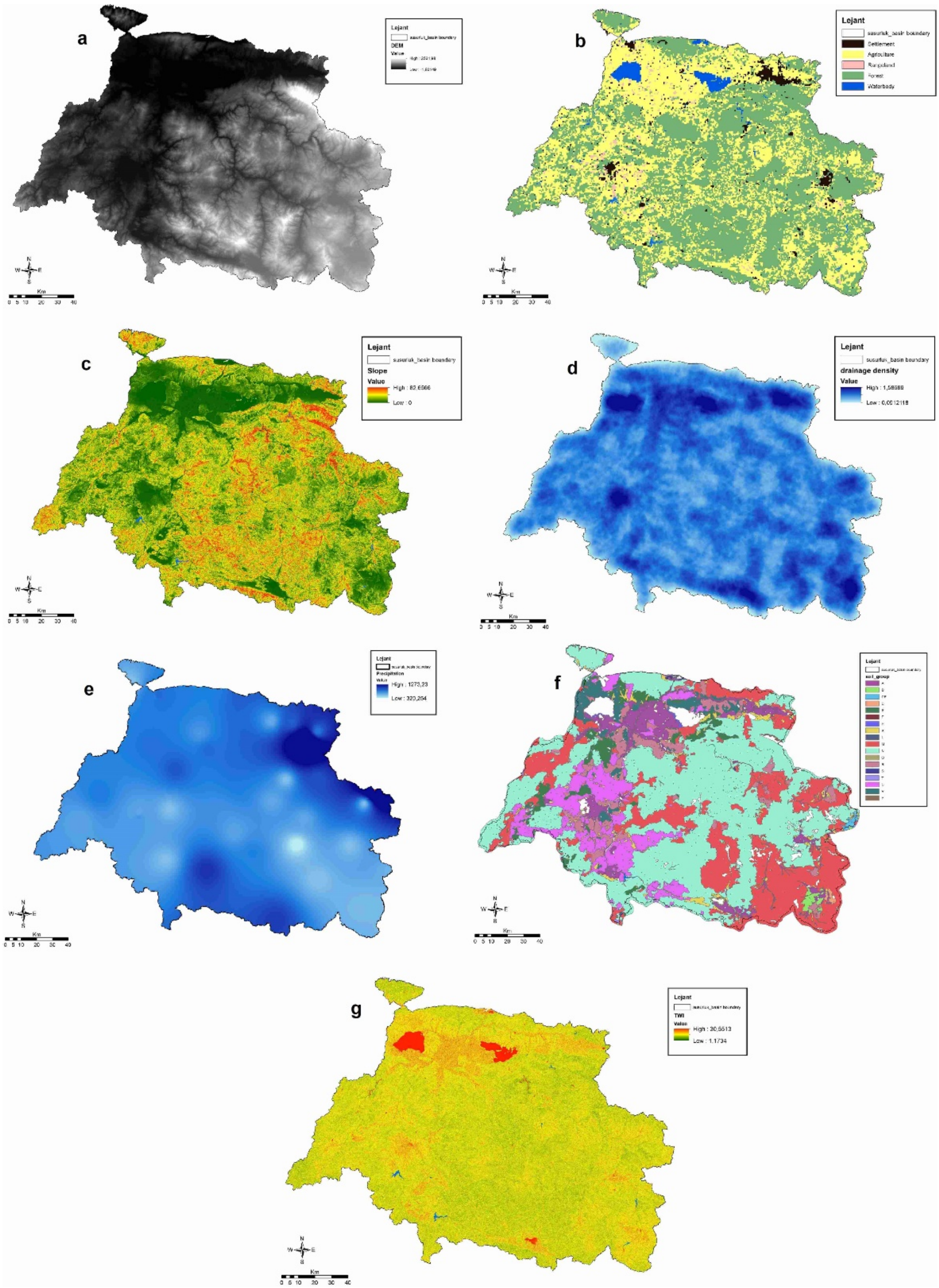

Figure 2. Flood vulnerability assessment parameters; (a) DEM, (b) Land use, (c) Slope, (d) Drainage, (e) Precipitation, (f) Soil, (g) TWI

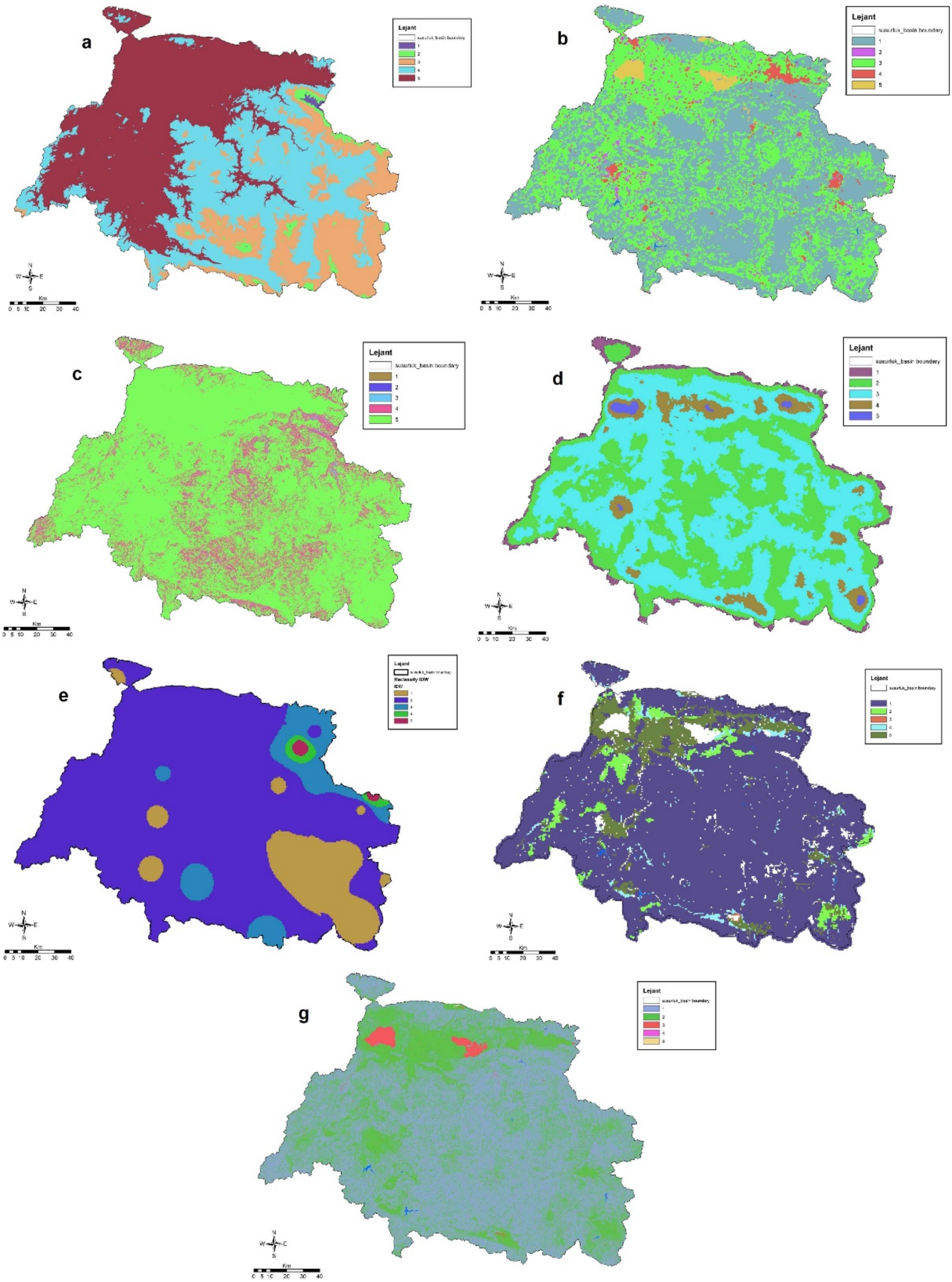

Figure 3. Reclassification of parameters used in flood vulnerability assessment; (a) Elevation, (b) Land use, (c) Slope, (d) Drainage density, (e) Precipitation, (f) Soil, (g) TWI

Table 1. Flood vulnerability criteria and sub-criteria ranges for flood vulnerability assessment

Flood criteria	Unit	Class	Vulnerability Class Ranges	Importance of factor's
Slope	%	66.13-82.66	Very Low	1
		49.60-66.12	Low	2
		33.06-49.59	Moderate	3
		16.54-33.05	High	4
		0-16.53	Very High	5
Elevation	m	2025.23 <	Very Low	1
		1518.47 – 2025.22	Low	2
		1011.72 – 1518.46	Moderate	3
		504.96 – 1011.71	High	4
		< 504.95	Very High	5
Precipitation	mm/year	320.27 – 510.86	Very Low	1
		510.87 – 701.46	Low	2
		701.47 – 892.05	Moderate	3
		892.06 – 1082.64	High	4
		1082.65 – 1273.24	Very High	5
Land use		Forest	Very Low	1
		Range	Low	2
		Agriculture	Moderate	3
		Built	High	4
		Wetland	Very High	5
Drainage density	km/km^2	0.091-0.390	Very Low	1
		0.391-0.689	Low	2
		0.690-0.988	Moderate	3
		0.989-1.287	High	4
		1.288-1.587	Very High	5
Soil*		L	Very Low	1
		B	Low	2
		O	Moderate	3
		K	High	4
		A	Very High	5
Topographic Wetness Index (TWI)		1.17-6.13	Very Low	1
		6.14-7.74	Low	2
		7.75-10.04	Moderate	3
		10.05-13.62	High	4
		16.63-30.55	Very High	5

*L: Regosols, brown forest soils, non-calcareous brown forest soil, rendzinas, non-calcareous brown soils, mountain meadow soils; B: brown soils, chestnut soil, reddish chestnut soil, terra rossa soil, red Mediterranean soil; O: organic soils, K: colluvial soils; A: alluvial soils, hydromorphic soils, alluvial coastal soils, vertisols, reddish brown soils.

Where α represents the local upslope area draining through a certain point per unit contour length, and β denotes the local slope. In order to determine the topographic wetness index, we used DEM and calculated within ArcGIS. The generated topographic wetness index was then divided into five subgroups, each representing a different level of risk for flooding (ranging from very low to high). Areas with high levels of risk were given a value of five, while areas with low levels of risk were given a value of one (as outlined in Table 1). Figures 2 and 3 represent visually the topographic wetness index.

2.3. Multi-criteria decision analysis – Analytical Hierarchy Process (AHP)

Multi-criteria decision analysis is a commonly used method for making decisions in situations where multiple criteria need to be considered. This method involves defining the problem, alternatives, and criteria and then determining the best alternative based on those criteria (Saaty, 1980; Zlaugotne et al., 2020; Taherdoost and Madanchian, 2023). One popular type of multi-criteria decision analysis is the analytical hierarchy process (AHP), which uses a hierarchical structure to establish priorities and create a significance scale among the criteria, as seen in Table 2 (Saaty, 1977).

Table 2. Significance scale and definition

Importance value	Definition
1	Equal importance of criteria
3	One criterion is slightly more important than the other
5	One criterion is more important than the other
7	One criterion is very important compared to the other criterion
9	One criterion is more important than the other
2,4,6,8	Intermediate values

The AHP method involves determining a goal and comparing the criteria through stages to create a matrix that identifies the best method. The first step is to apply the pairwise comparative matrix, as shown in Table 3., the pairwise comparison matrix and the equation provided by Saaty (2004) (Equation 2) were used to determine the weighting values for flood criteria using the AHP method.

$$Aw = \begin{bmatrix} w1/w1 & \dots & w1/wn \\ . & & . \\ wn/w1 & \dots & wn/wn \end{bmatrix} \quad (2)$$

where *Aw* is the weight of the criteria. For each criterion, a pairwise comparison is made according to Table 2 and a matrix is created as in Table 3.

As a second step, the pairwise comparison matrix was converted to a standard comparison matrix and calculated (Table 4). Each column was summed in the pairwise comparison matrix, and the weights were obtained by dividing each column in the matrix by the total.

In the next step, eigenvector weights were calculated from our normalization decision matrix to evaluate the reliability of the estimated weights. The consistency of the eigenvector matrix created for AHP needs to be checked and calculated with the following index (Equation 3).

$$CR = \frac{Cl}{RI} \quad (3)$$

where *CR* is consistency ratio, *CI* is the consistency index and *RI* is the random consistency index. The RI value was accepted as 1.35 in Table 6. *Cl* value (Equation 4);

$$Cl = \frac{\lambda - n}{n - 1} \quad (4)$$

Table 3. Pairwise comparison matrix

	Slope	Elevation	Precipitation	Landuse	Drainage density	Soil	TWI
Slope	1	5	1/3	3	3	7	3
Elevation	1/5	1	1/5	2	2	3	3
Precipitation	3	5	1	5	3	7	5
Landuse	1/3	1/2	1/5	1	1/3	4	1/3
Drainage density	1/3	1/2	1/3	3	1	5	1
Soil	1/7	1/3	1/7	1/4	1/5	1	1/3
TWI	1/3	1/3	1/5	3	1	3	1
Sum	5.34	12.67	2.41	17.25	10.53	30.00	13.67

Table 4. Normalization comparison matrix

	Slope	Elevation	Precipitation	Landuse	Drainage density	Soil	TWI
Slope	0.19	0.39	0.14	0.17	0.28	0.23	0.22
Elevation	0.04	0.08	0.08	0.12	0.19	0.10	0.22
Precipitation	0.56	0.39	0.42	0.29	0.28	0.23	0.37
Landuse	0.06	0.04	0.08	0.06	0.03	0.13	0.02
Drainage density	0.06	0.04	0.14	0.17	0.09	0.17	0.07
Soil	0.03	0.03	0.06	0.01	0.02	0.03	0.02
TWI	0.06	0.03	0.08	0.17	0.09	0.10	0.07

Table 5. Eigenvector matrix weights

	Slope	Elevation	Precipitation	Landuse	Drainage density	Soil	TWI	Criteria weight	Influence (%)
Slope	0.137	0.228	0.101	0.208	0.264	0.255	0.212	0.23	23
Elevation	0.046	0.076	0.072	0.139	0.088	0.109	0.091	0.12	12
Precipitation	0.690	0.532	0.510	0.490	0.441	0.260	0.212	0.36	36
Landuse	0.046	0.038	0.072	0.069	0.088	0.145	0.182	0.06	6
Drainage density	0.046	0.076	0.101	0.069	0.088	0.182	0.212	0.11	11
Soil	0.020	0.025	0.072	0.017	0.018	0.036	0.061	0.03	3
TWI	0.020	0.025	0.072	0.012	0.013	0.018	0.030	0.09	9

Table 6. Random index values (Saaty, 2000)

N	1	2	3	4	5	6	7	8	9	10
Random index (RI)	0	0	0.55	0.89	1.11	1.25	1.35	1.40	1.45	1.49

After applying the formula, the Cl value was calculated as 0.10, and the CR value as 0.08. Since the CR value is 0.08 (<0.1), the AHP matrix was deemed acceptable.

The eigenvector coefficients, developed by Saaty (1980), were used to generate a flood vulnerability assessment (FVS) map. These coefficients became the basis for determining flood factors, such as slope, elevation, precipitation, land use, drainage density, soil, and topographic moisture index group layers.

$$\begin{aligned} \mathrm{FVS} = {} & ([\mathrm{slope}]\mathrm{x}0.23]) + ([\mathrm{elevation}]\mathrm{x}0.12) \\ & + ([\mathrm{precipitation}]\mathrm{x}0.36) \\ & + ([\mathrm{landuse}]\mathrm{x}0.06) \\ & + ([\mathrm{drainage\ density}]\mathrm{x}0.11) \\ & + ([\mathrm{soil}]\mathrm{x}0.03) \\ & + ([\mathrm{TWI}]\mathrm{x}0.09) \qquad (5) \end{aligned}$$

3. Results and Discussion

We conducted a detailed analysis of the Susurluk Basin to identify areas prone to flooding. According to our findings, 200.31 km^2 is classified as resilient and less likely to be affected by flooding. However, there is a considerable amount of land at risk in the Basin. Specifically, 21224.54 km^2 of land is at high risk of flooding, while an additional 2610.67 km^2 is classified as moderate risk.

The annual precipitation, slope, land use, elevation, drainage density, topographic wetness index, and soil were used as criteria in the flood vulnerability assessment for the Susurluk Basin. Among these, annual precipitation had the most significant impact and was the most accurate representation in the model. The weight values for the criteria are as follows: annual precipitation (36%), slope (23%), land use (6%), elevation (12%), drainage density (11%), topographic wetness index (9%), and soil (3%). The assessment results were categorized into five classes and are available in Table 7.

The precipitation causes flooding with its intensity and influence on the initial soil moisture. Furthermore, the precipitation generally on the upstream portion of the basin is the main driver of flooding. The surface runoff initiates and flows downstream to cause flooding of the downstream plains of the basin (Fang et al., 2022). One of the primary causes globe flood risk is extreme rainfall events (Lan-Fen et al., 2012). However, flood events are generally influenced by various factors related to the characteristics of a basin. In basin-based assessments, the land cover and use of a basin have significant impacts on hydrology, affecting the frequency and magnitude of floods. Among the fundamental morphometrics of a basin, factors such as land cover and slope are crucial for infiltration effect. Reducing vegetation cover can affect the amount of infiltration into the soil in places with high rainfall, which may increase surface runoff and create flood risk (Norman et al., 2010; Tehrany et al., 2013; Kazakis et al., 2015; Nahin et al., 2023).

The flood potential of a stream is related to numerous morphometric parameters, including drainage density, stream frequency, average bifurcation rate, drainage attributes, and elongation ratio (Meraj et al., 2015). Furthermore, hillslope processes strongly influence catchment morphology and drainage density (Tucker and Bras, 1998). The Dikala Basin study conducted in the Kobo Woreda Amhara Region of Ethiopia found that agricultural low-slope plains and sub-basins with high population density are at a high risk of experiencing flood hazards (Ayenew and Kebede, 2023). In our case, the influence of topography and land use was also critical. Several studies have emphasized the significant influence of slope on flood risk (Kazakis et al., 2015; Wondim, 2016; Ghosh and Kar, 2018; Choubin, 2019; Hamlat et al., 2021; Ayenew and Kebede, 2023; Nahin et al., 2023). Steep slopes increase the likelihood of excess rainfall becoming surface flow, increasing the flood risk. Conversely, flat areas with limited drainage have a higher risk of floods. Figure 4 shows that resilient areas comprise only 0.83% of the Susurluk basin, while moderate areas cover 10.86% and vulnerable areas comprise 88.31%.

The downstream croplands around the lakes were identified as vulnerable parts of the Basin. However, several flat lands at the headwater were also identified as vulnerable. The western plains, covered mostly by croplands. were also vulnerable compared to southeast forested highlands. The analysis also revealed that city centers of Bursa and Balıkesir are vulnerable to flooding.

Table 7. Flood vulnerability assessment classification

Category	Classification	Percentage of Area Covered (%)
2.00 – 3.40	Resilient	0.83
3.41 – 4.80	Moderate	10.86
4.81 – 6.20	At Risk	33.55
6.21 – 7.60	Vulnerable	41.14
7.61 – 9.00	Very Vulnerable	13.62

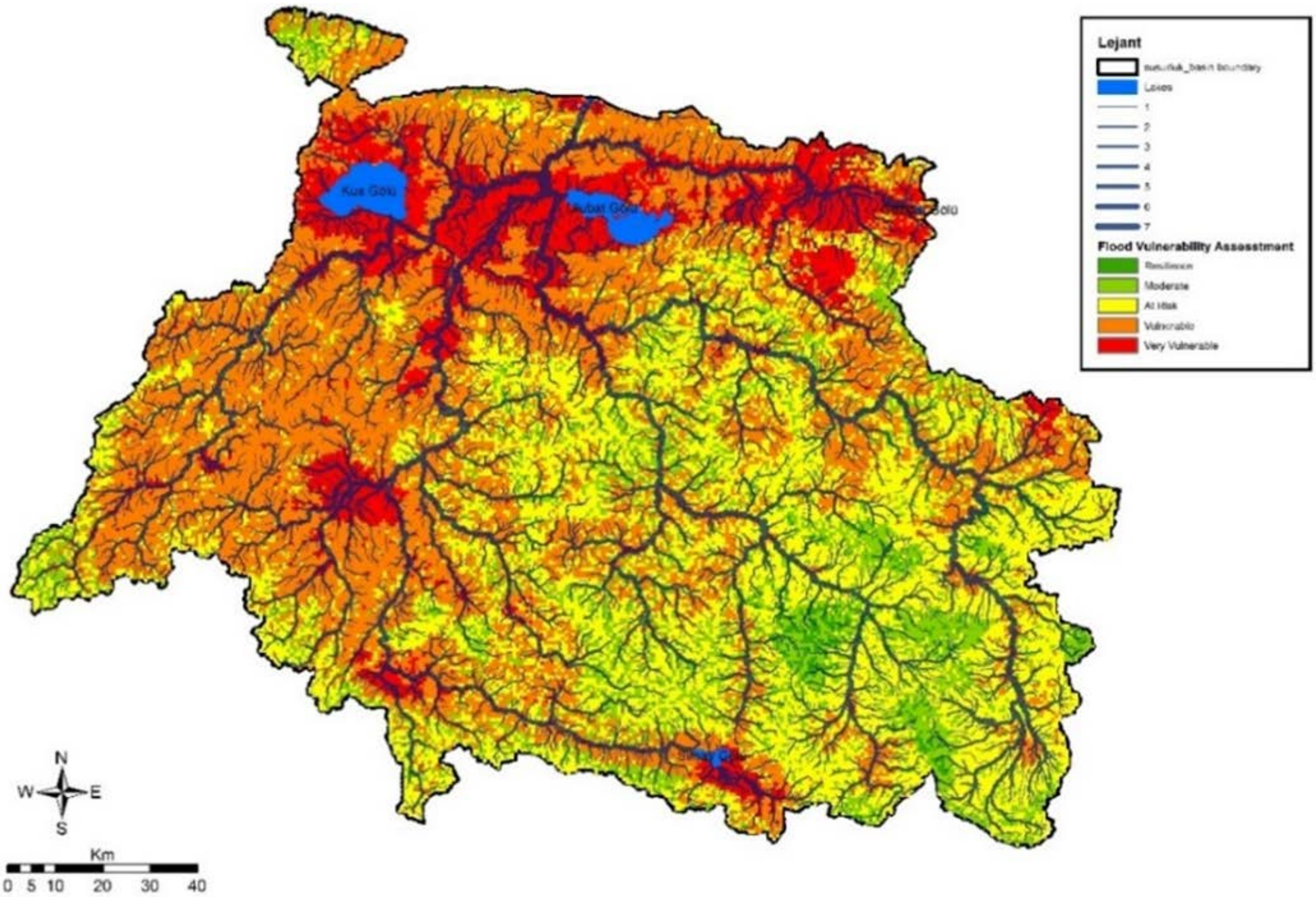

Figure 4. Flood vulnerability assessment map

Drainage density is an important factor in flood risk assessment. Increasing drainage density can lead to higher water volume and faster travel times to the basin outlet, making downstream areas more vulnerable to floods. (Vijith and Satheesh, 2006; Ogden et al., 2011; Elmoustafa, 2012; Wondim, 2016; Choubin et al., 2019; Nahin et al., 2023). Soil type is also crucial to how rainfall water infiltrates the subsoil and its infiltration rate (Mohamed, 2019). A study by Ayenew and Kebede (2023) shows that soil type plays a vital role in infiltration and indicates that vertisol soils increase flood vulnerability. Similarly, our study classifies soil types such as alluvial soils, hydromorphic soils, alluvial coastal soils, vertisols, and reddish-brown soils as high-risk regarding vulnerability properties.

Various studies have been conducted in flood-prone areas worldwide. For instance, a regional study conducted in Greece's Rhodope–Evros region utilized physical factors such as rainfall intensity, slope, runoff accumulation, elevation, and drainage network density to identify flood-prone areas (Kazakis et al., 2015). Meanwhile, a study in the Nakhon Pathom-Salaya Region of Thailand employed Geographic Information Systems (GIS) to identify policies and strategies in flood risk areas (Sakulsri et al., 2015). Arca and Yalçın (2023) compared the analytical hierarchy process and the fuzzy logic approach for flood susceptibility mapping in the İnebolu Basin, located within the borders of Kastamonu province in the west of the Black Sea Region of Türkiye. They calculated the weights of seven evaluation criteria and found that rainfall was the most significant criterion, followed by slope, land use, elevation, aspect, distance to the stream, and lithology. Another study conducted by Hassanuzzaman et al. (2022) used the AHP method to assess various parameters such as altitude, precipitation, topographic wetness index, slope, distance to rivers, and land use land cover to evaluate the vulnerability of the Torsa-Raidak River integrated basin to floods by smplying AHP method. This study revealed that rainfall and land use values were more crucial than other parameters. Tehrany et al. (2013) highlighted that annual flood events in Kelantan, Malaysia, result in loss of life and property. They emphasized the importance of developing flood models to identify vulnerable areas in basins for decision-makers. The authors also suggested that remote sensing (RS) and geographic information system (GIS) techniques can provide fast and accurate analysis and are helpful in hydrological studies.

In one of the previous studies conducted in Slovakia's Bodva River basin, factors such as daily rainfall amount, basin size, land use, slope, and soil type were taken into account (Zelenakova et al., 2017). Similarly, a study was conducted in Algeria's M'zi Wadi Basin to map flood hazard potential areas using the analytical hierarchy process method. The study revealed that key parameters include land use, drainage density, runoff accumulation, elevation, and precipitation (Hamlat et al., 2021). In the Western Shoa Region's Ambo Basin, Ogata et al. (2020) used a multi-criteria analysis method to examine flood hazard and risk. The study evaluated factors such as land use/land cover, elevation, slope, drainage density, soil, and rainfall parameters to determine the flood factors. In the Jamalpur region, Nahin et al. (2023) emphasized that factors such as hydrology and geomorphology play a key role in flood vulnerability. Physical parameters such as rainfall, drainage density, distance from the river, slope, land use/land cover, elevation, and soil type were evaluated to understand the situation better. Another study in the Lower Awash Sub-Basin aimed to map flood hazards and risks in a GIS environment using a multi-criteria analysis method. The study used slope, elevation, land use, soil, and drainage density parameters for flood risk assessment. The resulting geographic database provides a valuable perspective for managers to make informed land use decisions regarding flood hazards and risks in the region. The study also revealed that flat areas near the Awash River are at very high risk of flooding (Wondim, 2016). In another study conducted in the Subarnarekha River Basin of India, eight factors affecting the flood situation, such as rainfall, geomorphology, land use/land cover, soil type, drainage, slope, and topographic wetness index (TWI), were considered. Elevation is one of the most important flood hazard assessment criteria, as Samanta et al. (2018) noted. In similar research, TWI, precipitation, slope, drainage density, elevation, land use, and distance from the river were considered in flood susceptibility mapping of the Peddavagu River Basin. At the same time, precipitation (28.6%) was evaluated as the most critical parameter (Shekar and Mathew, 2023). According to the study conducted by Nsangou et al. (2022) in the Mfoundi Basin, land use (20%), altitude (17%), geology (17%), and precipitation (13%) parameters were determined as important parameters for flood susceptibility modeling.

For the Susurluk Basin, precipitation (36%), slope (23%), elevation (12%), drainage density (11%), and TWI (9%) were determined as the most important parameters. Similar research to our present study was carried out by Das (2020) on the West Ghat coast. This study mapped flood vulnerability zones and identified critical areas for flood-prone areas that local authorities should significantly evaluate. According to the study by Anuar (2022), the precipitation (26%) factor had the highest weight. As a result of the AHP method used in the study, the percentage of areas with moderate flood vulnerability was calculated as 74%. One of the essential results of this study, similar to our study in the Susurluk Basin, is that the critical evaluation of the factors used can provide detailed and accurate results in flood vulnerability mapping. Studies demonstrating precipitation and slope as the most important factors in flood vulnerability assessments and showing that the analytical hierarchy process can effectively assess and map flood risk using GIS (Danumah et al., 2016) are similar to our studies. Another study by Vignesh et al (2020), precipitation, slope, drainage density, land use land cover, elevation, soil, geology, geomorphology, surface flow, and topographic wetness index parameters that will affect the flood were evaluated by the AHP method. Similar to our study, precipitation (22%), slope (12%), and drainage density (15%) criteria were calculated as the most important parameters. The results of this study were similar to ours, and it was determined that the flood risk and very vulnerable regions are located where the slope is low and the precipitation is high. Assessing flood vulnerability is an essential non-structural measure to combat climate change. In the IPCC Third Assessment Report, vulnerability to climate change was defined, and three basic assessment components were identified: exposure, sensitivity, and adaptation. Flood vulnerability assessments have become increasingly necessary as flooding incidents continue to rise, causing widespread damage (IPCC, 2001; Nasiri et al., 2016; Lee and Choi, 2019).

When it comes to flood assessment methods, the most commonly used and widely recognized approach is the multi-criteria approach implemented with the GIS techniqueworldwide. While some studies have included social indicators in flood vulnerability assessments (Hoque et al., 2019; Nahin et al., 2023), our study considered parameters that could influence the hydrological cycle and lead to floods. Multi-criteria decision-making methods, such as the analytical hierarchy process, may contain subjectivity because they rely on expert opinions. Flood risk assessment, on the other hand, is based on probabilities derived from numerical approaches and data evaluation. Hydrological analyses using GIS techniques provide quick and reliable information for flood risk assessments. Therefore, we believe the methodology can be improved as an easy-to-use support tool for decision-making in flood-prone areas.

4. Conclusion

Studies show that climate change is currently the most significant environmental issue worldwide, and it will continue to be so in the future. Among its many impacts, it causes an increase in flood events, which can have adverse economic and social effects on countries. A flood vulnerability map was generated for the Susurluk Basin to address this. The map considers various factors, including slope, elevation, precipitation, drainage density, land use, soil type, and topographic wetness index. The factors were scaled using the analytical hierarchy process, and geographic information systems were used to analyze the resulting weights, creating a flood vulnerability assessment map. The study found that the precipitation is the most critical parameter for the Susurluk Basin. The amount, intensity, and duration of precipitation events directly influence the hydrological response of a watershed, impacting the rate of runoff and, consequently, the likelihood of flooding. Comprehensive flood risk assessments necessitate an in-depth understanding of precipitation patterns, including seasonal variations and extreme events, as well as the spatial distribution of precipitation across a given region.

Consequently, precipitation serves as a critical input parameter in flood risk assessments, forming the basis for understanding and predicting the hydrological response of a watershed to atmospheric conditions.

Flood risk and its spatial distribution can support prevention decisions, and a GIS-based AHP model to analyze the criteria is an effective way to evaluate flood vulnerability. Our study has shown how tools such as GIS and AHP can be used to assess the flood susceptibility of the Susurluk Basin and thus develop strategies to identify and reduce flood risks. The results of our research have shown that only 10.86% of the Susurluk Basin is at moderate flooding. In contrast, the region has 88.31% flood risk (risk, vulnerable, and very vulnerable), and 0.83% is resilient. This provides an important basis for developing strategic decisions on flood disasters. In addition, identifying these sensitive regions can help determine the protective and preventive measures.

However, some limitations of the study should also be considered. To determine the flood risk, this study analyzed seven factors; soil type, slope, altitude, precipitation amount, drainage density, land use, and topographic wetness index. These factors are commonly used in evaluating flood risk, but they can vary from region to region and over time. The changes in these factors should be considered primarily due to climate change, and the models' accuracy should be periodically updated. Future research may require the inclusion of more factors to increase the sensitivity and accuracy of the model. In particular, other factors that may be important in determining flood risk, such as socioeconomic factors and the impact of human activities, should be considered. In addition, taking into account seasonal changes and changes in climate conditions can increase the sensitivity and accuracy of the model. Ultimately, this study emphasizes the importance of flood susceptibility assessments, especially in adapting to climate change and reducing risks. In particular, they can play a significant role in identifying sensitive areas and implementing flood prevention systems. It can help policymakers, planners, and local governments to manage flood risk more effectively and thus adapt better to the effects of climate change.

Finally, this study demonstrates how GIS-based AHP can effectively assess flood risk in the Susurluk Basin. This methodology can be an essential tool in identifying and reducing flood risk and a valuable guide for governments and other relevant organizations in their fight against environmental hazards.

Acknowledgements

The authors would like to acknowledge the Turkish State Meteorological Service (MGM) for sharing the data in the public domain for free access. This study was supported by the Scientific and Technical Research Foundation of Türkiye (TUBITAK) within the project number ÇAYDAG 116Y446/1003.

Ethics Committee Approval: N/A.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept: M.A., Y.S., M.I.; Design: M.A., Y.S., M.I.; Supervision: Y.S., M.I.; Resources: M.A, Y.S., M.I.; Data Collection: M.A., M.I; Analysis: M.A., M.I.; Literature Search: M.A; Writing Manuscript: M.A.; Critical Review: M.I., Y.S.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: This study was supported by the Scientific and Technical Research Foundation of Türkiye (TUBITAK).

Cite this paper as: Aytekin, M., Serengil, Y., Inan, M. 2025. A GIS Based Quick Assessment Method of Flood Vulnerability: Susurluk Basin Case, *European Journal of Forest Engineering*, 11(1):1-14.

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