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Flood risk assessment and mapping: a case study of the Aksu River Basin (Giresun), Türkiye

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Abstract

Flood is considered to be the most common natural disaster worldwide during the last decades. Flood risk potential mapping is required for mitigation of flood, preventing, management, and minimizing losses. The purpose of this study is to present flood risk potentiality areas in the Aksu River Basin using Multi-Criteria Decision Making method and Geographic Information Systems and risky structures were identified in basin. Within the scope of this purpose, six criteria (slope, aspect, rainfall, land use, distance to river, and geology) that will affect the flood risk were determined. As a result of the study, it was determined that 0.64% of the basin is very high risk, 9.59% high risk, 50.54% moderate risk, 33.54% low risk, and 5.69% very low risk. Also, it was determined that there are 110 real estate within the very high flood risk area and 1362 real estate within the high flood risk area. Declaring areas with very high and high risk as "disaster-prone zones" in accordance with Article 2 of Law No. 7269 dated 1959 and not allowing construction and should be relocated to more suitable areas is crucial. The zoning plans should be updated accordingly.

1. Introduction

Flood is a recurrent hazardous phenomenon that has become the most common natural disaster worldwide during the past decades, causing many environmental and socio-economic consequences within the affected area (Rahmati et al. 2016). The intensity of flood risk is directly related to several associated factors such as urbanization, inefficient drainage system, improper river improvement works, inadequate infrastructure, inappropriate land use change, climate change, etc. and results in loss of life and property. Therefore, assessing, managing, and mapping flood risk is crucial to combating and preventing the adverse effects of severe floods. Flood risk maps are useful tools for planning the future direction of city growth and are usually used to identify flood-susceptible areas (Tehrany et al. 2014).

Flood risk analysis and assessment often involve multiple criteria that have to be geographically related to one another. Therefore, Geographic Information Systems (GIS) possessing the capabilities of collecting, storing, analyzing, managing, and visualizing large amounts of spatial data are an important tool. Multi-Criteria Decision Making (MCDM) methods provide convenience to decision makers in designing and solving complex problems with many criteria or evaluating possible alternative ways (Feizizadeh et al. 2014). Spatial MCDM methods, on the other hand, were developed on the basis of combining spatial analyzes in GIS with MCDM methods. Today, many MCDM methods such as Analytical Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) in GIS has proven successful in natural disaster analysis and other geo-environmental studies (Radwan et al. 2019; Pathan et al. 2022).

The purpose of this study is to present flood risk potentiality areas using MCDM methods with GIS support and risky structures were identified in these areas.

2. Study Area

The Aksu River Basin is located within the borders of the Giresun province in the northeast of Türkiye (Figure 1). The basin is located between 40°54'50''-40°27'16'' north latitudes and 38°34'11''-38°10'00'' east longitudes. The area of the Aksu River Basin is 899.4349 km^2. According to the census data of 2022, the total population of the settlements within the basin is 183,653.

Aksu River, which gave its name to the basin, is the most important water source of the basin. Aksu River originates from the Karagöl region at an altitude of 3039 meters and flows into the Black Sea. The elevation difference in the basin is quite high with 3107 meters and the slope values vary between 0° and 70°. Settlements in the basin have developed along the riverbeds and steep slopes due to the rugged topography. Floods of disaster

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magnitude occur during periods of heavy rainfall because flood risk was not taken into account in the urban development (Avcı and Sunkar 2015).

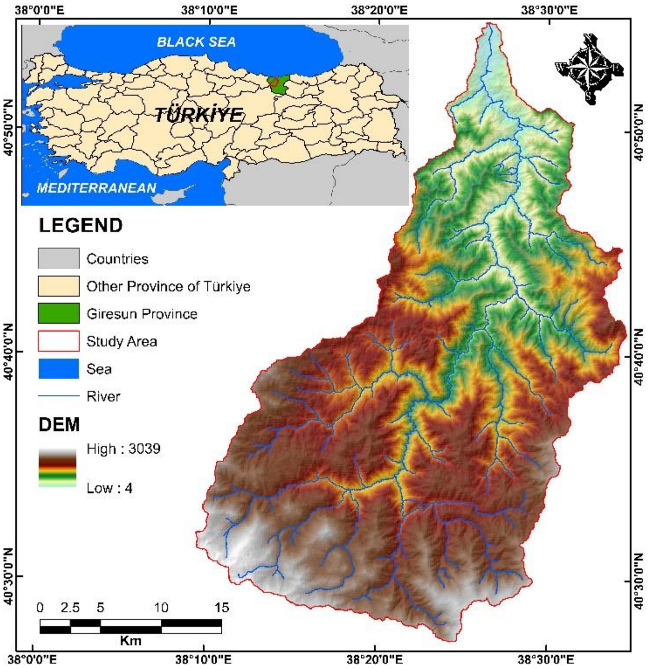

Figure 1. Study area

3. Materials and Methods

Six criteria were used to identify flood risk areas. These criteria are "slope, aspect, land use, distance to river, geology, and rainfall." The criteria were determined based on literature research, consultation with five expert academics, and the characteristic features of the study area (Özcan 2017; Pathan et al. 2022). The criteria were obtained from various data sources. Slope and aspect data were generated from Digital Elevation Model (DEM) data. The DEM data were obtained from the United States Geological Survey data portal. The land use and land cover map of the study area was obtained from the CORINE 2018 data produced by the European Environment Agency. The riverbeds were digitized using 1:25000 topographic maps and OpenStreetMap data. The geological structure of the study area was digitized from 1:100000 geological maps obtained from the Mineral Research and Exploration Regional Directorate II (Konya). Rainfall was obtained by interpolating data from the Meteorology General Directorate stations within the basin using the Schreiber method. ArcGIS software was used for data collection, storage, processing, spatial analysis, and mapping.

The risk classes and scores of the criteria were determined through literature research and adjusted to fit the environmental conditions of the Aksu River Basin based on expert opinions (Figure 2). The risk classification of the criteria (very low, low, moderate, high, very high) was determined through literature research (Radwan et al. 2019). Very high was scored as 5, while very low was scored as 1. The risk classes and scores of the criteria are shown in Table 1.

The AHP, one of the MCDM methods, was used to determine the relative importance of criteria in identifying flood risk areas. To evaluate the consistency of expert judgments in pairwise comparisons, the consistency ratio (CR) should be calculated. If CR ≤ 0.10, the pairwise comparison matrix is considered consistent, and the generated weights can be used. If CR ≥ 0.10, the pairwise comparison matrix is considered inconsistent, and it needs to be revised (Saaty 1990). The criterion maps and weights determined by the AHP method were combined using the weighted overlay method to determine flood risk areas in the Aksu River Basin. In the final stage of the study, risky structures (residential, commercial, industrial, social facilities, etc.) located in flood risk areas were identified.

3.1. Identification of criteria

As the degree of slope increases, the water holding capacity of the soil decreases, and the flow rate and amount of erosion and surface water increases (Özdemir 2020). Therefore, low slope areas cause water accumulation and flood risk. In the study, the degree of slope >30% were classified as very low risk, while the degree of slope <%3 were classified as very high risk.

Aspect affects the amount of heat energy received from the sun, and therefore affects water loss through sweating and evaporation. Due to the orographic structure and aspect, north-facing slopes in the Eastern Black Sea region receive excessive rainfall (Avcı and Sunkar 2015). Therefore, north-northeast directions were classified as "very high risk" and south-southeast-southwest directions were classified as "very low risk".

The most important factor in frequent floods and inundations in Giresun is the high amount of rainfall (Avcı and Sunkar 2015). As the amount of rainfall increases, the probability of flood risk also increases (Souissi et al. 2020). Therefore, in the study, areas with an annual average rainfall of more than 2820 mm were classified as very high risk (Table 1).

Land use is a factor that directly affects the flood risk. There is an inverse relationship between flooding and vegetation density, meaning that an area with high vegetation density has a lower risk of flooding (Rahmati et al. 2016). Forest, due to its characteristic structure, retain flowing water, slow down its speed, and enable it to penetrate the soil. Therefore, in this study, forest areas were classified as very low risk, while settlement and wetland areas were classified as very high risk and high risk, respectively (Figure 2).

One of the most significant criteria affecting flood risk is the distance from the river. Areas closer to the riverbed are at a higher risk of flooding than those farther away (Fernandez and Lutz 2010). Thus, in this study, areas within 250m of the river were classified as very high risk.

Another important criterion in flood risk assessment is the geological structure of the area. This is because the type, porosity, and permeability of geological structures in the study area are important factors in surface water flow and therefore in flood risk. Therefore, areas with meta-siltstone geological structure were classified as very low risk, while alluvium and carbonate geological structure were classified as high risk (Figure 2, Table 1).

Table 1. The risk classes, scores, weights and consistency ratio of flood risk criteria

Criteria	Unit	Very High (5)	High (4)	Moderate (3)	Low (2)	Very Low (1)	Weight	Consistency Ratio
Slope	%	0-3	>3-10	>10-20	>20-30	30<	0.180	
Aspect	-	North, Northeast	Northwest	West, East	-	South, Southwest, Southeast	0.033	
Rainfall	mm	>2530	<2530-2230	<2230-1930	<1930-1630	<1630-1320	0.273	0.07
Land use	-	Wetlands and Water bodies	Artificial surfaces	Agricultural	-	Forest	0.144	
Distance to river	m	<250	>250-500	>500-1000	>1000-1500	>1500	0.261	
Geology	-	-	Alluvium, Carbonate	Volcanic rocks	Limestone	Metasiltstone	0.109	

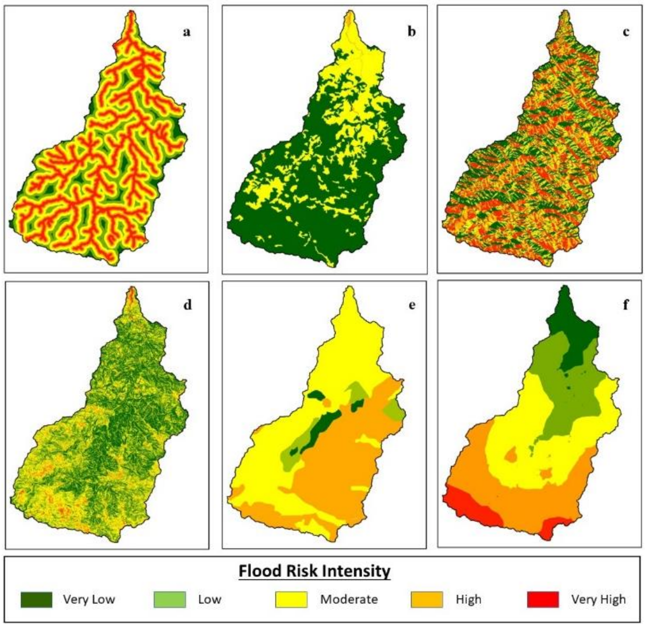

Figure 2. Flood risk maps of criteria (a) distance to river, (b) land use, (c) aspect, (d) slope, (e) geology, (f) rainfall

4. Results

When the criteria weights determined by the AHP method were compared, the criteria with the highest importance were calculated as "rainfall (0.273)" (Table 1). This criterion is followed by "distance to river (0.261), slope (0.180), land use (0.144), geology (0.109), aspect (0.033)" criteria, respectively. The consistency ratio of the pairwise comparison matrix created for the criteria was calculated as 0.07. This result indicates that the pairwise comparison matrices made by the experts are consistent (CR ≤ 0.10).

The flood risk areas map of the Aksu River Basin is shown in Figure 3. When the areas under flood risk in the study area were examined, it was determined that 0.64% very high risk, 9.59% high risk, 50.54% moderate risk, 33.54% low risk, and 5.69% very low risk (Table 2).

In the study, the number of real estates located within the very high and high flood risk areas were calculated. Accordingly, it was determined that there are 110 real estate within the very high flood risk area and 1362 real estate within the high flood risk area. Some of the real estates located in the high-risk area is shown in Figure 4.

Table 2. Areal extent of flood risk within in Aksu (Giresun) River Basin

Flood Risk Classes	Area (km^2)	Rate (%)
Very Low	51.1793	5.69
Low	301.6518	33.54
Moderate	454.5338	50.54
High	86.3006	9.59
Very High	5.7694	0.64

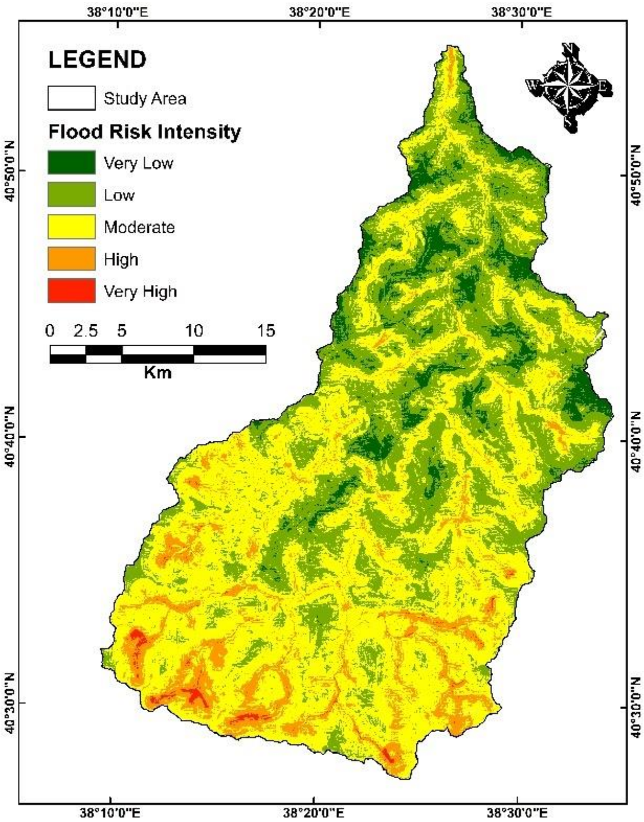

Figure 3. Flood risk maps of Aksu River Basin

5. Discussion

The flood risk mostly occurs in valley bottoms and at the mouth of rivers in the study area. When the causes of flood risks are examined, it is seen that the area receives rainfall throughout the year, which leads to quick saturation of the soil. In addition, the high slope of the area, high velocity of the streamflow, accumulation of material due to erosion in the valley bottoms where the slope decreases, and narrowing of the riverbed due to the accumulated material are other factors. Unplanned urbanization, settlements in riverbeds, narrowing of the river width, and inadequate rainwater drainage and discharge lines also contribute to the problem.

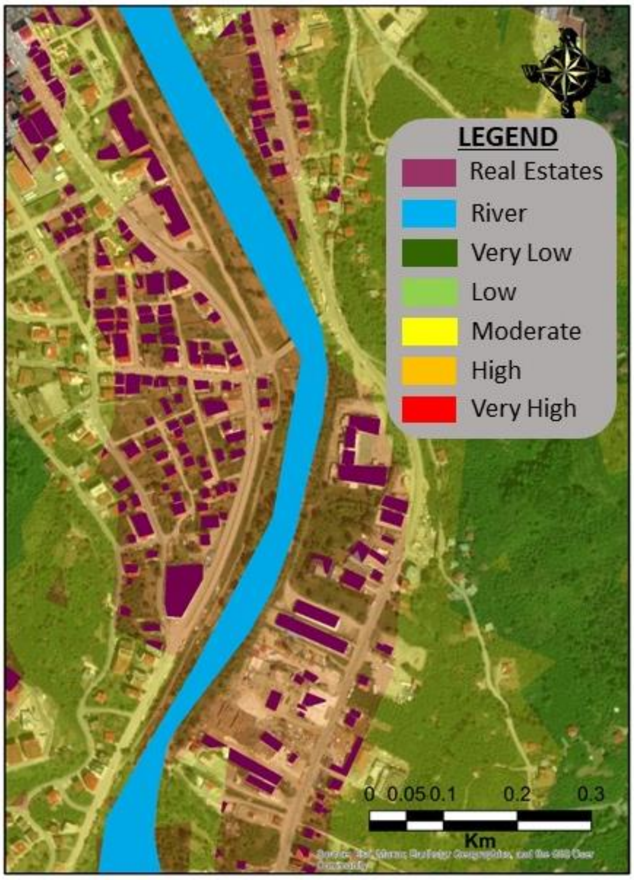

Figure 4. The map of real estates within the high flood risk

In order to reduce and prevent the risk and impact of floods in the study area, necessary measures must be taken. To achieve this, blockages caused by sediment and waste in the engineering structures within the riverbed should be prevented. The cross sections of existing engineering structures should be improved. Taking material from or discharging material into the riverbed, which could affect the flow regime and bed morphology, should be prohibited. Settlements identified as having a very high or high risk of flooding should be relocated to more suitable areas, and zoning plans should be updated accordingly.

6. Conclusion

The ratio of flood damages to total natural disaster damages in the study area is approximately 40%, which is the highest percentage. In addition to residential and commercial buildings, flood damages also affect roads and all infrastructure facilities. Therefore, flood damages, which cause significant economic losses in addition to threats to human life, disrupt the normal flow of life and affect large areas. Taking into account this situation and the other reasons mentioned in the study, conducting flood risk analysis throughout the basin, updating the risk maps at regular intervals, prioritization studies, and incorporating risk maps into zoning plans are of great importance. In addition, declaring areas with very high and high risk as "disaster-prone zones" in accordance with Article 2 of Law No. 7269 dated 1959 and not allowing construction in these areas is crucial.

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