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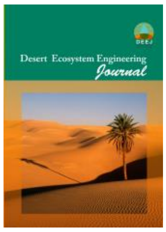

Flood Probability Mapping and Zoning in the Tanguiyeh Basin, SirjanAbstract

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Abstract

Flooding is recognized as one of the most complex and destructive natural hazards, causing more annual damage globally than any other natural disaster. Flood hazard zoning maps are crucial tools for identifying vulnerable and at-risk areas, thereby facilitating the implementation of effective management strategies. This study aimed to map flood probability within the Tanguiyeh Basin. To achieve this, key variables including vegetation cover, land use, drainage network density, distance from the drainage network, lithology, rainfall, topography, and slope were identified from various sources and integrated as informational layers into ArcGIS. Subsequently, a panel of 30 experts and flood hazard specialists weighted these variables in two rounds. The flood hazard zoning map of the Tanguiyeh Basin was then generated by integrating these weighted layers. The results indicate that areas with very low flood probability constitute 1.36% (15.48 km²) of the basin, low probability areas cover 8.79% (100.064 km²), medium probability areas represent 67.47% (767.82 km²), high probability areas comprise 22.37% (254.553 km²), and very high probability areas account for 0.01% (0.121 km²). Furthermore, the northern, eastern, and southern sections of the region show higher flood potential, primarily attributed to increased rainfall, lower permeability, and steeper slopes.

Keywords: Drainage Network Density**,** Flood Hazard Zoning, Land use, Lithology, Tanguiyeh Basin.

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1. Introduction

Floods are recurring natural phenomena that can occur in almost any geographic location, standing as one of the most formidable environmental hazards today. They impact communities and infrastructures worldwide with often unpredictable and wide-reaching consequences (Fagunloye, 2024; Green et al., 2025). Beyond significant economic costs, floods also facilitate the transfer of pathogens to both urban and rural environments, promoting microbial proliferation in buildings and infrastructure (Li et al., 2022). The complexity of flood events stems not only from heavy rainfall or rapid snowmelt but also from a range of interconnected hydrological and human-induced factors, making them a critical subject of study in disaster management. As climate change intensifies weather extremes, understanding and mitigating flood risks becomes ever more crucial (Roohi et al., 2025).

Effective flood prevention begins with identifying highly susceptible areas, followed by a detailed analysis of the specific contributing factors (Ahmad & Kumar, 2023). Flood zoning offers a practical and data-driven approach to delineate areas by their susceptibility to flooding. This methodology leverages advanced geospatial tools such as Geographic Information Systems (GIS) and remote sensing technologies to compile and analyze diverse datasets. Key variables include rainfall intensity, topographic nuances, soil permeability, vegetation cover, drainage network characteristics, and land-use patterns. By assigning risk weights to each parameter through expert evaluation and empirical research, the resulting flood zoning maps effectively classify regions into high, moderate, or low-risk zones. The methods underpinning such analyses are supported by guidelines from reputable organizations like the National Oceanic and Atmospheric Administration (NOAA) and the Federal Emergency Management Agency (FEMA) (Hughes & Lopez, 2024). Beyond its role in risk assessment, flood zoning is instrumental for urban planners and policymakers. The spatial insights from these maps enable strategic decisions regarding land use, emergency preparedness, and infrastructure development. By prioritizing interventions in high-risk areas, communities can enhance resilience, reduce potential economic losses, and ultimately protect lives against the mounting challenges posed by extreme weather events (Peiris, 2024).

Consequently, extensive research has been conducted in this area. For instance, Arji et al. (2021) applied GIS to evaluate flood risk across the Gorganroud watershed, finding that almost 20% (19.97%) of the region is extremely susceptible to flooding. Similarly, Esfandiari et al. (2022) investigated flood hazards in the Kiwi Chay River basin, revealing that floods with a return interval shorter than 10 years rarely pose serious risks to residential areas. Meanwhile, Mishra and Sinha (2020) combined the Analytic Hierarchy Process with GIS to identify flood-vulnerable zones within the Kosi River basin in eastern India. Additionally, Ogato et al. (2020) examined the flood susceptibility of the Embo city basin, determining that factors such as land-use changes, vegetation cover, elevation, slope, drainage density, soil type, and rainfall are key drivers. Finally, Ajjur and Mogheir (2020) used multi-criteria decision analysis alongside GIS to delineate urban zones in Argentina at increased risk of flooding.

Given Iran's location within the global desert belt, flooding stands as one of the most significant natural hazards in the country. Between 1951 and 2001, over 3,700 flood-related hazards were recorded. Furthermore, between 1982 and 1992, 481 floods occurred, resulting in 630 fatalities (Sharifi et al., 2002: 264). For this reason, assessing the factors affecting flood occurrence and zoning different regions by their flood potential are of great importance. Moreover, the scarcity of hydrometric stations and essential data has led many researchers to employ modeling methods to overcome this challenge (Asadi et al., 2022). The Tanguiyeh Basin, situated in the arid southeastern region of Iran with an irregular topography, has experienced an intensification of flood occurrences in recent years. Since 2011, more than 20 destructive floods have affected this area. Additionally, the presence of over 900 villages, gardens, farms, and mining facilities within this basin means significant damage in the event of a flood. Therefore, considering the lack of prior research on flood risk in this specific basin, this study aims to assess its flood potential. The findings will provide crucial information for crisis management organizations, natural resources and watershed management departments, road and urban development authorities, and governorates for implementing flood-related projects.

2. Materials and Methods

2.1. Location of the Study Area

The Tanguiyeh Basin, the designated study area, is situated in Sirjan County, Kerman Province, northeastern Iran. It lies between approximately 29°31' to 29°51' N latitude and 56°27' to 56°55' E longitude. This basin is characterized by several rivers, including the Tangouiyeh, Ostoor, and HoseinAbad Rivers. The Tangouiyeh River is the most significant, formed by the confluence of the Palngi and Sookhteh Chal rivers. These rivers originate from the northeastern highlands of the basin and serve as primary water sources for the Sirjan Plain. The Tangouiyeh River has an average annual discharge of 47.048 million m³, which is impounded by the Tangouiyeh Dam (Pirzadeh & Asvar, 2020).

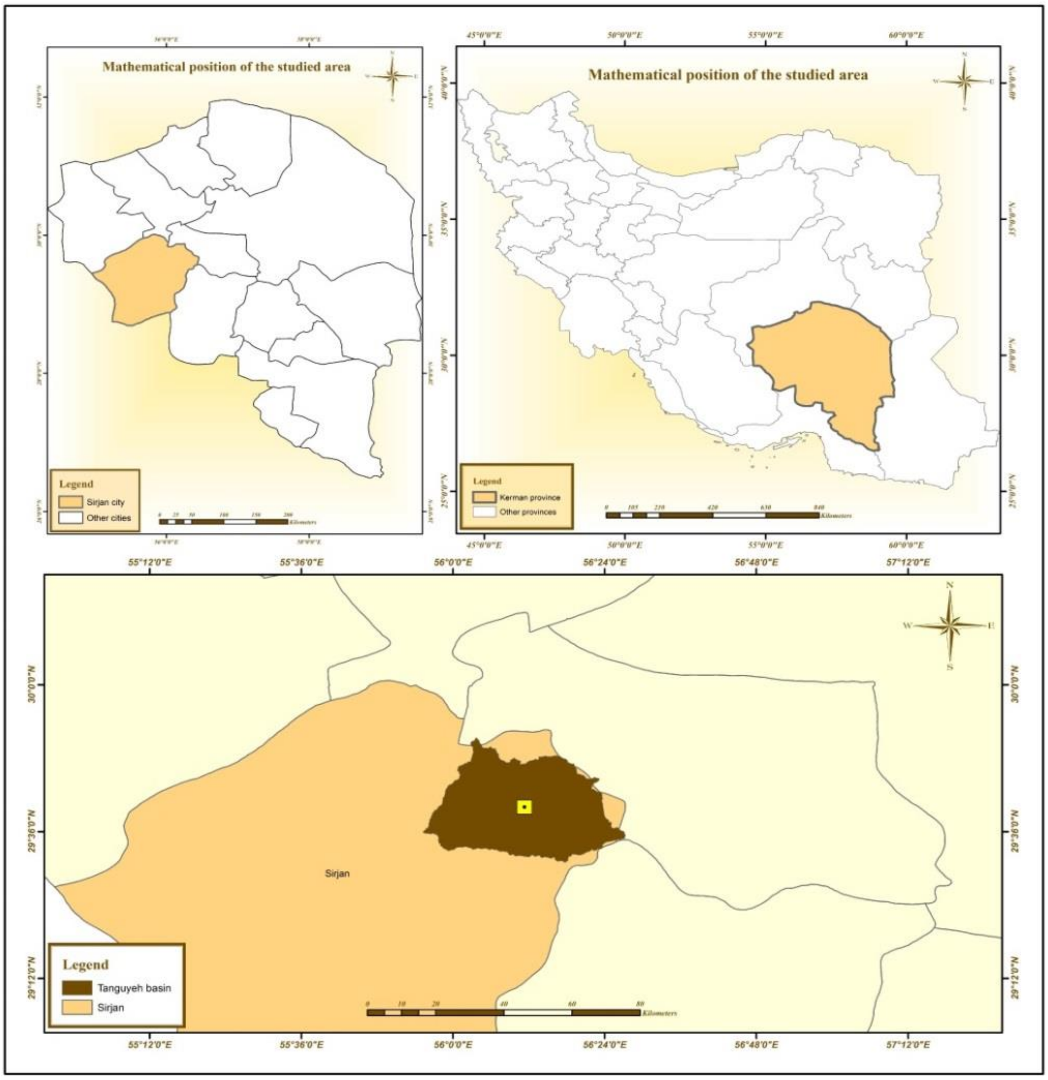

Figure (1): Location of the study area

Based on the Demarton climatic classification, the Tanguiyeh Basin exhibits five distinct climatic zones, ranging from arid at lower altitudes (near the Tanguiyeh Dam) to humid at higher elevations. Notably, approximately 72% of the basin's area is characterized by a semi-arid climate.

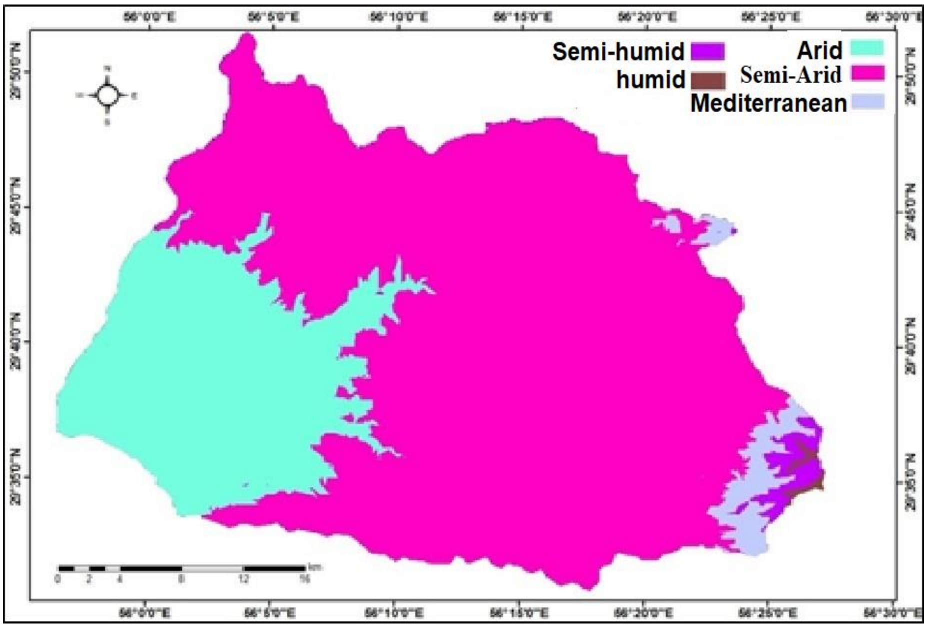

Figure (2): Tanguiyeh Basin Climatic Classification Map

2.2 Methodology

This study employed an applied, descriptive, and analytical approach to investigate flood occurrences. We identified and examined several key factors influencing floods: vegetation cover, drainage network density, distance from the drainage network, land use, lithology, rainfall, topography, and slope.

For each factor, a corresponding map was generated using the following methods:

Vegetation Cover: The vegetation cover map was derived from Landsat 9 satellite imagery (captured August 9, 2024, path 60, row 039). This involved two steps:

Land Surface Temperature (LST) Calculation: The digital number (DN) of the thermal band images was converted to spectral radiance using the following formula:

$$L\lambda = \frac{(LMAX - LMIN)}{QMAX - QMIN} \times (DN - QMIN) + LMIN \quad (1)$$

Normalized Difference Vegetation Index (NDVI) Calculation: The NDVI, an indicator of vegetation cover, was calculated using the difference between the near-infrared and red bands with the following formula:

$$\text{NDVI} = \frac{(pNIR - pRED)}{(pNIR + pRED)} \quad (2)$$

Drainage Network: The drainage network was extracted from the Digital Elevation Model (DEM) of the study area using Arc Hydro software. Subsequently, maps illustrating drainage network density and distance from the drainage network were produced in ArcGIS. Drainage density was calculated using Horton's equation:

$$\text{DD} = \frac{\sum_{i=1}^{n} S_i}{A}$$

In this equation, L represents the total length of drainage channels (km), and A is the watershed area (km²).

Lithology and Slope: These maps were created by integrating geological maps (specifically, the Chahargonbad Geological map, number 7249, scale 1:100,000) with the DEM.

Rainfall: The rainfall map was prepared using data from climatological and synoptic stations.

Land Use: A dedicated land use map of the study area was developed.

Finally, all generated maps were converted to raster format and classified to facilitate subsequent analysis. Thirty specialists determined the weights for both the individual classes within each map and the overall criteria. These weights were then integrated into a Weighted Overlay model to produce the final flood hazard map.

3. Results and Discussion

To identify and delineate areas with high flood potential within the Tanguiyeh Basin, the following thematic maps were prepared and utilized in our analysis:

3.1. Vegetation Cover

Vegetation cover plays a crucial role in flood mitigation by reducing runoff velocity and enhancing water infiltration into the soil, thereby significantly diminishing the impact of destructive floods (Abedini & Fathi Joukdan, 2016). In this study, we prepared the vegetation cover map using the Normalized Difference Vegetation Index (NDVI).

Within the ArcGIS environment, we generated two distinct layers: one representing vegetated areas and another for non-vegetated areas. These layers were then combined and assigned appropriate values to create the final vegetation cover map of the study area. Figure 3 illustrates this vegetation cover map.

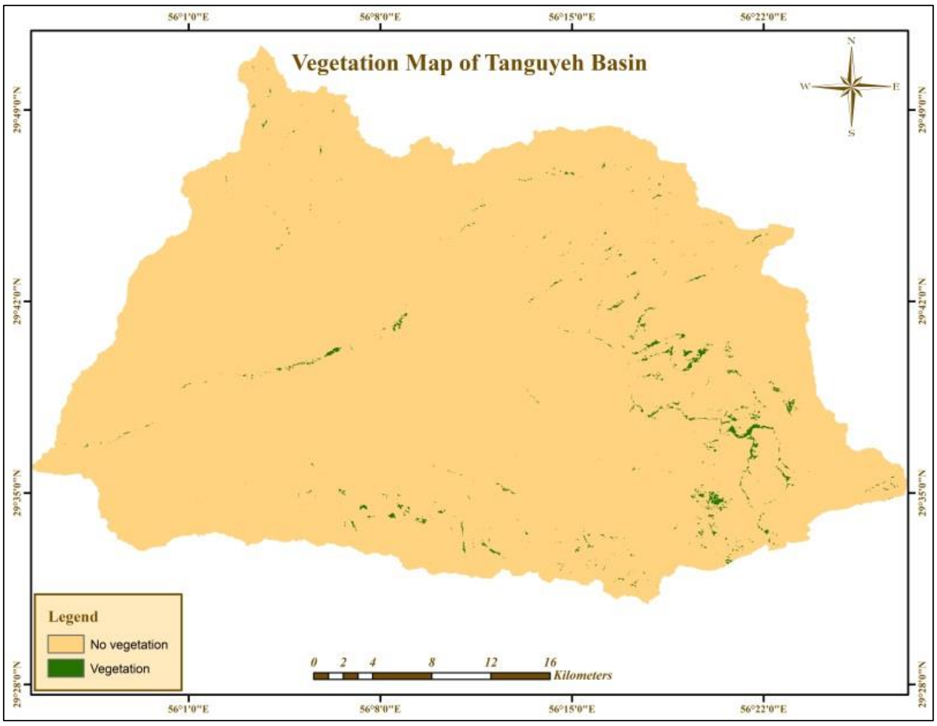

Figure (3): vegetation cover map of the Tangouiyeh Basin

3.2. Drainage Density

Drainage density is intrinsically linked to lithology, slope, topography, and climatic conditions, playing a crucial role in determining the time of concentration and flood hydrograph (Bahrami et al., 2008). In essence, a drainage density map illustrates the spatial distribution and efficiency of a basin's drainage network.

To create the drainage density map for this study, we utilized a Digital Elevation Model (DEM) and the Line Density function within ArcGIS software. The drainage density across the study area ranges from 0 to 2.99 km/km² (Figure 4).

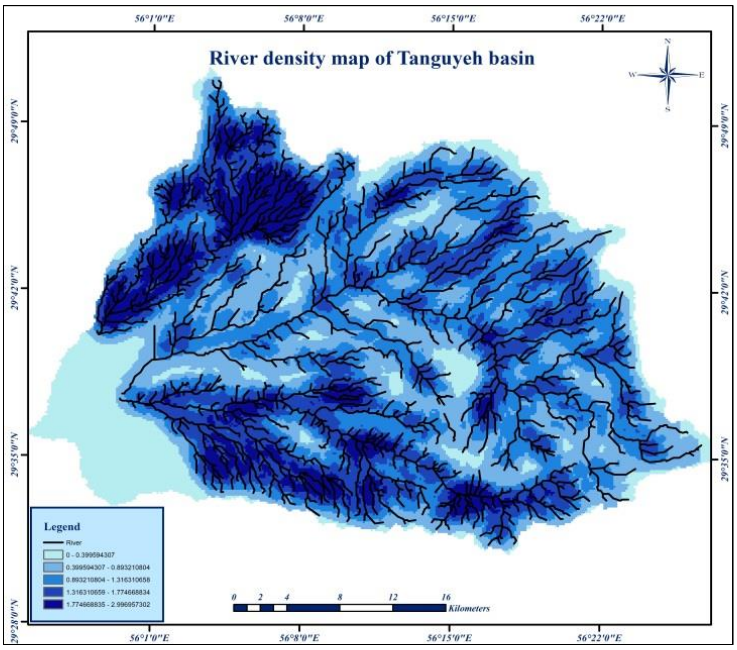

Figure (4): Drainage Density map of the Tangouiyeh Basin

3.3. Distance from the drainage network

Proximity to the drainage network directly correlates with an increased risk of flooding. Consequently, the distance from a drainage network is a critical environmental factor influencing flood magnitude, flow velocity, river overflow, and overall water flow dynamics.

To quantify this, the river distance map for the Tanguiyeh Basin was generated using the Euclidean Distance tool in ArcGIS software. Within the study area, the distance from a water channel ranges from 0 to 7,393 meters (Figure 5).

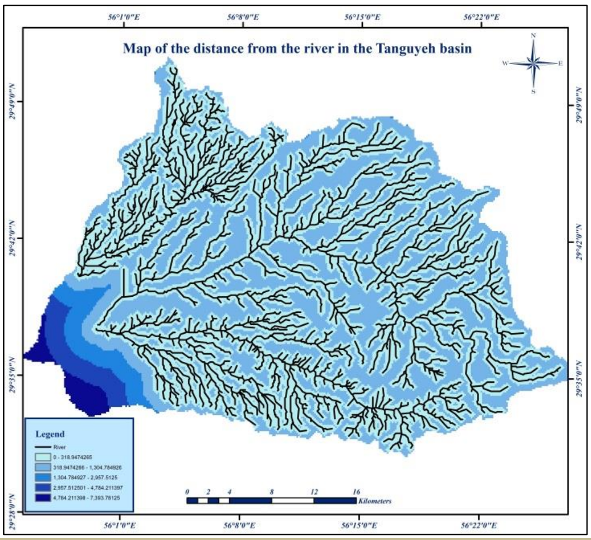

Figure (5): Distance from the drainage network of the Tangouiyeh Basin

3.4. Lithology

Lithological conditions are pivotal in determining a basin's flood potential. The underlying rock and soil properties directly influence both the intensity and capacity of soil permeability, which, in turn, significantly affects surface runoff. Generally, more consolidated or harder geological formations exhibit lower permeability, leading to increased surface runoff and a higher flood risk (Abedini & Fathi Joukdan, 2016). Figure 6 illustrates the lithological map of the study area.

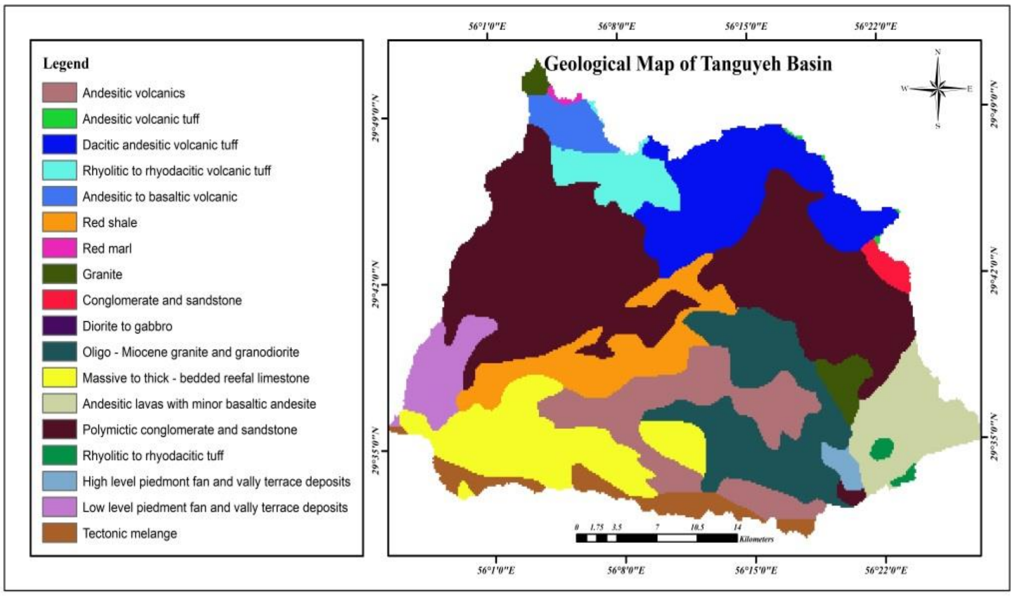

Figure (6): Geological map of the Tangouiyeh Basin

3.5. Topography and Slope

Topography significantly influences flood control by governing spatial variations in hydrological conditions and soil moisture (Bui et al., 2020). Topographic features also affect vegetation cover and precipitation characteristics. Generally, higher elevations tend to correlate with a greater flood risk compared to lower-lying areas (Zarei et al., 2022). For the study area, the Tanguiyeh Basin, elevations range from a maximum of 3,752 meters in the northeastern part to a minimum of 2,000 meters in the southwestern part.

Slope is another critical factor in flood occurrence due to its direct impact on infiltration and surface runoff (Youssef et al., 2016). Steeper slopes specifically accelerate surface runoff, consequently increasing the likelihood of flooding. In the Tanguiyeh Basin, the slope varies from 0° to 47° (Figure 7).

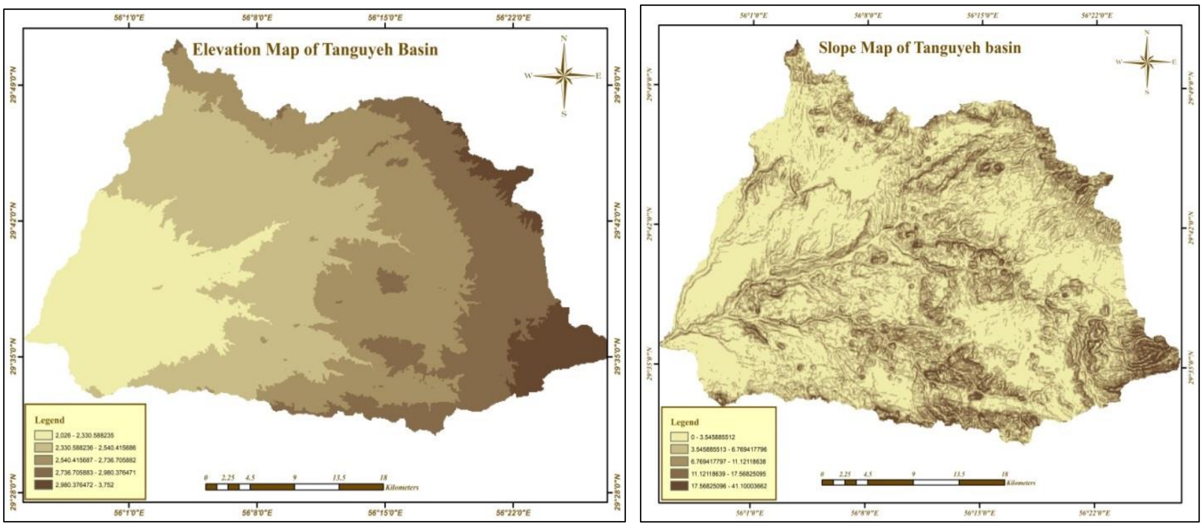

Figure (7): Elevation and Slope maps of the Tangouiyeh Basin

3.6. Land Use

A comprehensive land use map is crucial for effective flood zoning, particularly in basins exhibiting diverse land use types such as rangelands, agricultural areas, residential zones, mountainous regions, and plains. In this study, the land use map was acquired from the Natural Resources and Watershed Management Department of Kerman Province. This layer categorizes various cover types, including vegetation of varying densities (poor to good), forests, orchards and agricultural lands, bare land, and water bodies. Figure 8 illustrates the land use map of the Tanguiyeh Basin.

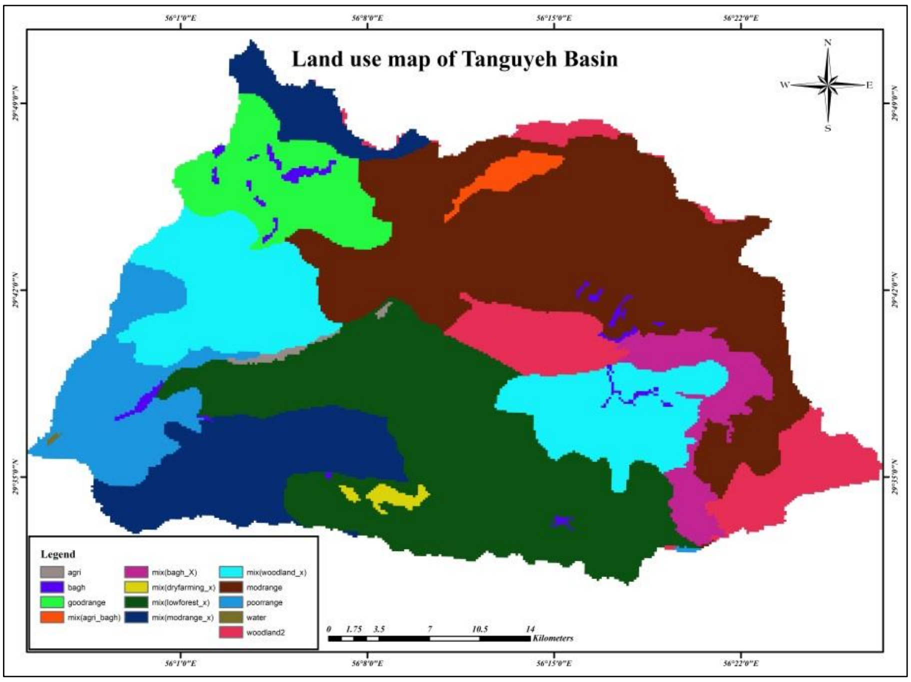

Figure (8): Land use map of the Tangouiyeh Basin

3.7. Rainfall

Rainfall and precipitation patterns are undeniably influential factors in the generation and manifestation of surface runoff within a watershed. Their amount and intensity directly affect flood occurrence, time of concentration, and the shape of the flood hydrograph.

In this study, to prepare the isohyet map of the Tanguiyeh Basin, we first established the relationship between rainfall and elevation using data from 11 meteorological stations (both synoptic and climatological) located both within and around the basin.

Table (1): Specifications of meteorological stations

station	Station Type	Elevation	X	Y	Average Precipitation
Shahr-e-Babak	Synoptic	1834	55° 08´	30° 06´	150/27
Sirjan	Synoptic	1739	55° 41´	29° 28´	115
Baft	Synoptic	2280	56° 35´	29° 14´	233/5
Rafsanjan	Synoptic	1580	55° 54´	30° 25´	70/4
Ostoor	Climatology	2027	56° 08´	29° 02´	178
Balvard	Climatology	2068	56° 03´	29° 25´	173/7
Saadatabad	Climatology	1990	55° 49´	29° 38´	148/5
Pariz	Climatology	2349	55° 45´	29° 52´	208
Baghkhoshk	Climatology	2431	55° 59´	29° 49´	242/4
"Chahargonbad	Climatology	2500	56° 11´	29° 44´	278/4
Zamzerj	Climatology	2040	56° 08´	29° 22´	155/6

Subsequently, utilizing this derived rainfall-elevation relationship (Figure 9) and the Digital Elevation Model (DEM) of the area, the rainfall map of the region was generated in ArcGIS software (Figure 10). The results indicate that the basin's estimated minimum annual rainfall is 167.63 mm, while its maximum is 511.62 mm.

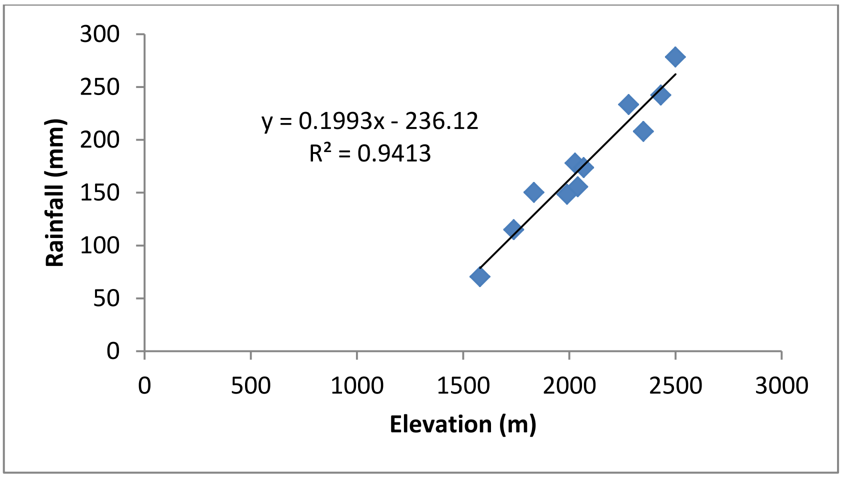

Figure (9): The Relationship between Rainfall and Elevation

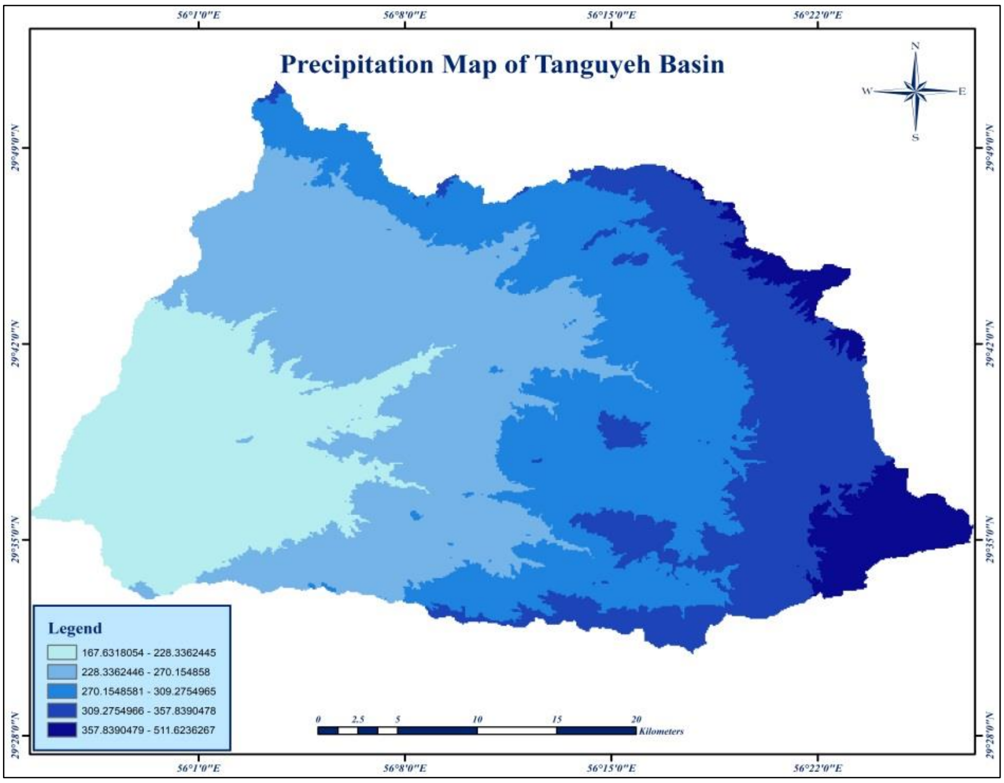

Figure (10): Rainfall map of the Tangouiyeh Basin

3.8. Flood hazard zoning map

After identifying the key variables influencing flood occurrence, their corresponding layers were prepared within a GIS environment. Each variable was then categorized into five classes, ranging from very low to very high potential for flood contribution. The only exception was vegetation cover, which was classified and valued into two categories: vegetated and non-vegetated areas. Additionally, specific weighting was applied to the classes within the lithology and land use criteria.

In the final stage, all these layers were weighted based on expert opinion, ensuring their total sum amounted to 100%. The determined weights for each criterion were as follows:

Drainage Network Density: 20%
Distance from Drainage Network: 15%
Slope: 25%
Precipitation: 10%
Lithology: 10%
Land Use: 10%
Vegetation Cover: 5%
Elevation: 5%

Finally, using the Weighted Overlay model in GIS, these weighted and merged layers were integrated to produce the Flood Hazard Zoning Map of the Tanguiyeh Basin. This map delineates the basin into five distinct flood hazard zones.

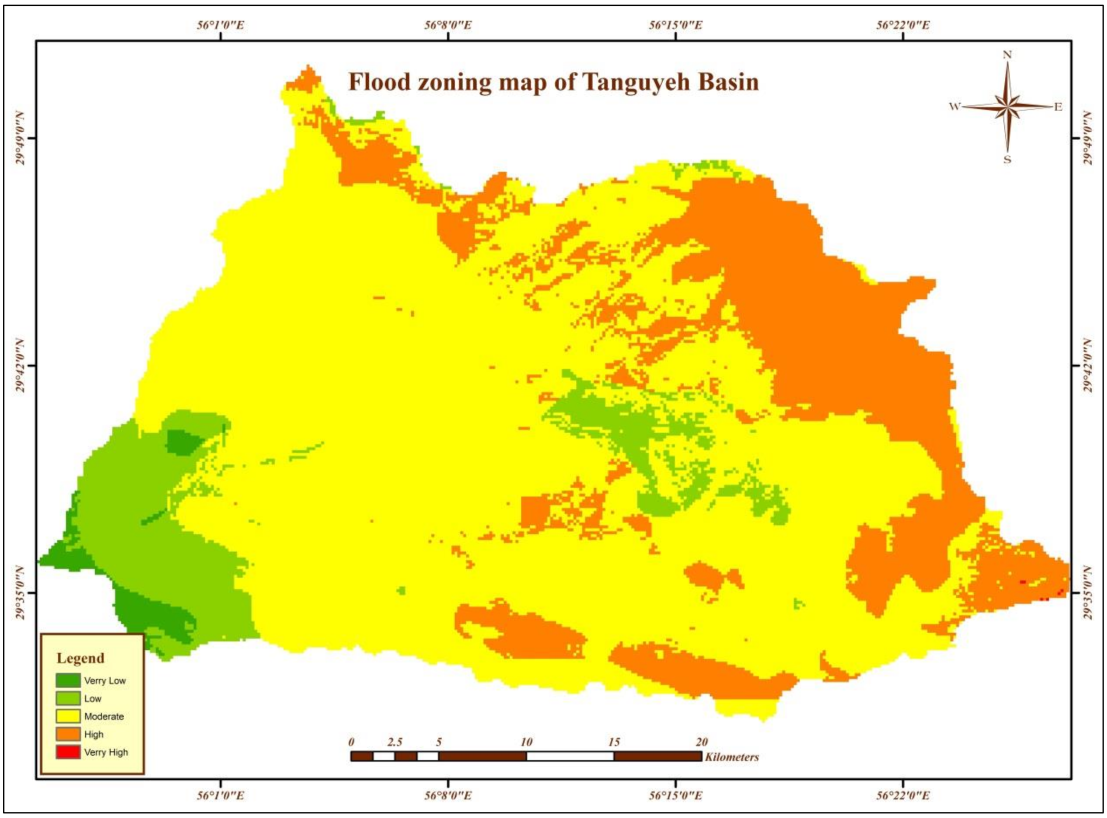

Figure (11): Flood hazard zoning map for the Tangouiyeh basin

4. Conclusion

Floods are among the most prevalent natural hazards globally, causing substantial annual financial and human losses. Consequently, the development of flood hazard zoning maps is vital for informed management and decision-making.

This research identified key factors influencing flood susceptibility within the Tanguiyeh Basin. Our analysis revealed that the highest vegetation cover is concentrated in the eastern and northeastern parts of the region, as well as along riverbeds. Correspondingly, areas exhibiting the highest rainfall, densest drainage network, shortest distance to the drainage network, highest elevation, and steepest slopes are predominantly located in the northeastern and eastern sections of the basin. Regarding land use, moderate rangelands and agricultural areas comprise the largest proportion of the basin. From a lithological perspective, the region is primarily characterized by igneous and metamorphic formations in the northern, northeastern, and eastern parts, with significant alluvial deposits also present. Critically, among the factors assessed for flood susceptibility in the Tanguiyeh Basin, poor vegetation cover, hard and impermeable geological formations, and steep slopes emerged as major contributors to flood risk. These findings align with previous research; for instance, Khdemtzadeh and Hasani (2020) similarly concluded that vegetation cover, geological formations, and steep slopes significantly increase flood susceptibility in the Chai Basin in Urmia. Furthermore, Ziyari et al. (2021), in their flood zoning study of Ilam city, identified vegetation cover, geological formations, slope, land use, and drainage network characteristics as crucial factors affecting flood susceptibility, which is also consistent with the present study's findings. Ultimately, our flood hazard zoning map indicates that the northeastern and eastern parts of the Tanguiyeh Basin exhibit a higher potential for flooding. Quantitatively, the basin's flood probability distribution is as follows: 1.36% (very low), 8.79% (low), 67.47% (moderate), 22.37% (high), and 0.01% (very high). These detailed insights provide essential information for local crisis management, natural resource management, and urban development authorities to implement targeted flood mitigation strategies.

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