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Research Article

Flood zoning of sub-basins of villages in the western part of Zaribar Lake (Marivan, Kurdistan)

Mohammad Mahdi Hosseinzadeh[1 *], **Somaye Moradi**[1]

1-Department of Physical Geography, Earth Sciences Faculty, Shahid Beheshti University, Tehran, Iran

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Abstract

Floods represent one of the most prevalent and devastating natural disasters, impacting the lives of millions and disrupting natural ecosystems both directly and indirectly. This research focused on assessing the flood risk across the sub-basins of the villages located in the western region of Zaribar Lake, specifically Barda-Rasheh, Yangijeh, Kani-Spikeh, and Pir-Safa. To evaluate the susceptibility of these sub-basins to flooding, the study employed the analytic hierarchy process alongside a multi-criteria decision-making approach, taking into account ten significant factors: elevation, slope, aspect, geology, land use, flow accumulation, distance from drainage network, rainfall, curvature of the topography, and drainage density. The data layers were integrated through the fuzzy sum technique, resulting in the categorization of flood risk into five distinct levels: no risk, low risk, medium risk, high risk, and very high risk. The findings indicated that the eastern regions of the study area are free of flood risk, whereas the western sections of the basin, particularly sub-basins 8, 10, and 14, exhibit the highest levels of flood risk. The predominant portion of the region, accounting for 52.94%, falls within the medium risk classification, while 17% is categorized as high risk, and less than 1% is classified as very high risk. Additionally, 22.48% of the area is deemed risk-free, and 7.50% is identified as low risk. An analysis of the contributing factors revealed that slope, elevation, distance from drainage network, and drainage density significantly influence the region's flooding. These findings are applicable for planning in water resource management and for mitigating flood risks in the study area.

Keywords: Flood zoning, Natural hazards, Analytical Hierarchy Process (AHP), Zaribar Lake, Marivan

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* Corresponding author E-mail address: m_hoseinzadeh@sbu.ac.ir

Introduction

Natural disasters have consistently been significant challenges impacting human existence throughout history and are recognized as major impediments to development. Events such as floods, tsunamis, and intense storms, which have markedly intensified due to global warming, present substantial threats to human life on the planet (Sloggy et al, 2021; Collins, 2013). The aftermath of these disasters disrupts societal operations and inflicts damage on individuals, the economy, and the environment, necessitating management efforts that exceed the capabilities of the affected community and require external support (Baker and Refsgaard, 2007). Floods represent one of the most prevalent and devastating natural disasters, impacting the lives of millions and disrupting natural ecosystems both directly and indirectly (Mignot et al, 2019; Mishra and Sinha, 2020). Annually, these events inflict considerable damage on agriculture, infrastructure such as roads and bridges, and water management systems, often resulting in loss of life among humans and wildlife alike. This devastation leads to the collapse of social structures and incurs substantial financial and human costs (Estelaji et al, 2023; Hosseinzadeh et al, 2022). The rising frequency and severity of flooding in recent decades, driven by climate change, rapid population growth, and unsustainable resource exploitation, pose a significant threat to sustainable development, particularly in rural regions. Areas adjacent to lakes and rivers are especially susceptible to flooding due to their geographical features and unique hydrological conditions. Numerous factors contribute to the occurrence and escalation of floods, with climate change being paramount. This includes the effects of heavy rainfall, variations in ambient temperature, and soil moisture levels. Additionally, hydrological conditions and the morphological features of watersheds, along with the degradation of natural resources, improper land use, uneven infrastructure development, and inadequate engineering practices in road construction, are significant contributors (Tarasova et al, 2023; Gudde et al, 2024; Ziwei et al, 2023). In various regions, even where average annual precipitation remains stable, the interplay of topographic features and environmental conditions has resulted in an increased runoff coefficient and concentration of water flow, ultimately culminating in severe flooding (Ahn and Merwade, 2016; Junger et al, 2022). Research indicates that morphometric parameters—such as slope, drainage density, basin shape, slope coefficient, proximity to watercourses, precipitation levels, and land use characteristics—serve as critical criteria that significantly influence watershed flooding, thereby facilitating a more precise identification of flood-prone areas (Waseem et al, 2023; Srivastava and Roy, 2023). Conversely, the management of flood risks and the enhancement of community resilience to such events have emerged as critical priorities within urban and regional planning. Innovative management strategies that integrate engineering, environmental, and socio-ecological dimensions can significantly contribute to the formulation of effective flood resistance strategies (Zevenbergen et al, 2020). Furthermore, methodologies such as the Analytic Hierarchy Process (AHP) and Geographic Information Systems (GIS) have proven helpful in identifying high-risk zones and devising suitable interventions to mitigate flood-related damages (Papaioannou et al, 2015; Lyu et al, 2019; Ziwei et al, 2023; Dewa et al, 2023; Ullah et al, 2024). Previous research findings suggest that the amalgamation of topographical, precipitation, and hydrological data enhances the accuracy of flood risk forecasting and management. Iran, characterized by its arid and semi-arid climate, consistently encounters various challenges in managing its water resources. Notably, flooding emerges as a significant threat, inflicting considerable damage on both the environment and human infrastructure each year. Surveys indicate that approximately 40 floods occur annually across different regions of the country, with estimates suggesting that around 91 million hectares are susceptible to flooding (Yari et al, 2019; Hosseinzadeh et al, 2022). The rainfall during Nowruz 2019 occurred in multiple successive phases, further intensifying this issue. To mitigate flood damage, one proposed strategy involves managing this issue at its upstream drainage areas, specifically at the sub-basin level. It is crucial to identify areas within watersheds that are susceptible to flooding, given the extensive nature of these regions, as it is impractical to apply remedial measures universally across all areas (Asdak et al, 2018). In this context, the implementation of flood zoning maps emerges as a viable solution to alleviate the adverse effects of flooding.

Flood zoning offers essential insights into flood characteristics, their repercussions on floodplains, and establishes acceptable development limits near riverbanks. This methodology facilitates more accurate planning and diminishes the risks associated with flooding. Lake Zaribar, recognized as one of Iran's most distinctive freshwater lakes, not only holds significant ecological and environmental importance but also contributes substantially to the livelihoods and sustainability of nearby communities. Nevertheless, factors such as climate change, increased rainfall, unsustainable resource utilization, population growth, and the resulting expansion of residential areas and deforestation have heightened the risk of flooding in the western sub-basins of this lake, thereby posing a grave threat to rural settlements and local infrastructure. In recent years, the study area has experienced significant changes due to the expansion of human settlements and increased construction activities. This development has often led to the establishment of unstable structures vulnerable to hazards, encroachment upon riverbanks, and the creation of residential zones in valleys and areas prone to flooding. Additionally, heavy rainfall, deforestation, and the clearing of trees for residential, agricultural, and orchard purposes, coupled with economic incentives and the establishment of villages near the lake's foothills, have heightened the necessity for effective flood zoning. This research specifically examines flood zoning in relation to the sub-basins located in the western region of Zaribar Lake, focusing on the villages of Bardasheh, Yangijeh, Kani-Spikeh, and Pir-Safa within the Khaomirabad district of Marivan city.

Materials and Methods

Study Area

The study area is Marivan County, situated in the Kurdistan Province in west Iran. This county is located in the western part of Kurdistan Province, with geographical coordinates ranging from 35 degrees 48 minutes to 35 degrees 2 minutes north latitude and from 46 degrees 45 minutes to 45 degrees 58 minutes east longitude relative to the Greenwich Meridian. Marivan County, situated in the western part of Kurdistan Province, comprises three central districts: Khavomirabad and Sarshivo, which encompass the rural districts of Zaribar, Sarkal, Kumasi, Khavomirabad, Sarshivo, and Golchidar. The Khavomirabad District, with its administrative center in the village of Barda-Rasheh, contains one rural district named Khavomirabad, which is home to 40 villages, of which 32 are inhabited and 8 are uninhabited. This study focuses on four villages: Barda-Rasheh, Yangijeh, Kani-Spikeh, and Pir-Safa, all situated at an elevation of approximately 1,400 meters and located between 4 to 10 kilometers from the Iran-Iraq border (Fig. 1). The study area, encompassing 14.2 km², is situated within the Zaribar Lake basin, specifically in the western section of the lake. Rainfall runoff is channeled into Zaribar Lake through several rivers. The eastern regions of the basin, which border the lake, exhibit a lower elevation compared to other areas in the vicinity. The Zagros Mountains constitute the predominant feature of the county's rugged landscape. This area is commonly referred to as the Northeastern Zagros Thrust Metamorphic Zone, characterized by its intricate geological composition. The geological formations in this region are comprised of alluvial fans and recent alluvial deposits, accounting for 49%, alongside flysch facies, which make up 51%. The climate of the region is cold and mountainous, tending to temperate and cold, occasionally Mediterranean conditions. The region receives an average annual precipitation exceeding 800 mm, with an average annual temperature of approximately 13.7 degrees Celsius. December marks the coldest month, averaging 0.3 degrees Celsius, while July is the warmest month, with an average temperature of 26.4 degrees Celsius.

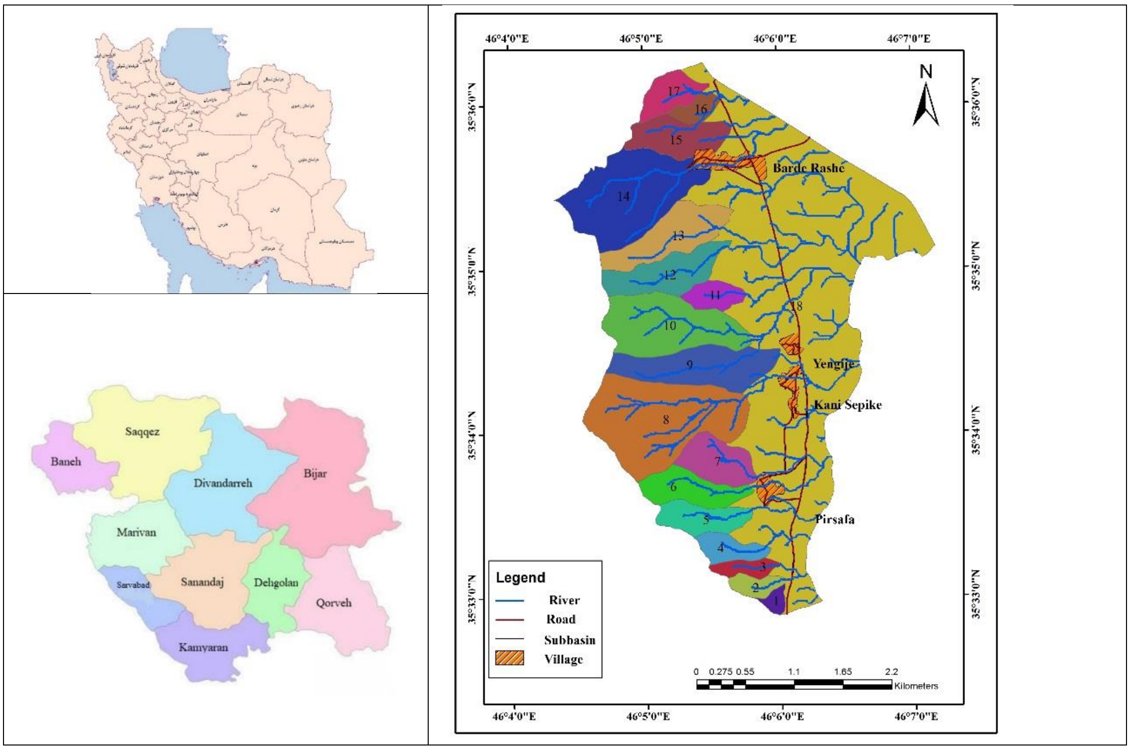

Fig. 1: Location of study area drainage basin and its subbasins (1-17)

Methods

To create the definitive flood hazard map for the area, ten variables influencing flood occurrences including elevation, slope, aspect, geology, land use, flow accumulation, distance from drainage network, rainfall, curvature of the topography, and drainage density were considered. Data collection involved library and documentary research, a comprehensive literature review, and field observations. A digital elevation model was utilized to create and delineate a network of watercourses, which were categorized according to existing watercourses, basin boundaries, and sub-basins. Geological information was extracted from 1:100,000 scale maps provided by the Geological Survey, while topographic data including elevation, slope, aspect, distance from drainage network, curvature of the topography, and drainage density was derived from a digital elevation model with a pixel size of 12 m (ALUS from the Alaska Vertex site) within a GIS software framework. The land use analysis for the region was conducted utilizing the national land use map provided by the Ministry of Jihad and Agriculture, supplemented by Google Earth imagery and field surveys. Additionally, the flow accumulation layer and topographic curvature were derived from the digital elevation model (DEM) using SAGA-GIS software. The precipitation distribution map for the area was generated through a regression model based on data from rain gauge stations, with analyses carried out in ARC-GIS software, reflecting the region's average daily precipitation. The map preparation results were finalized within the Arc GIS software environment, employing the power weighting method to assess the various criteria classes. Layer Weighting: A power-ranking weighting model was employed to assign weights to the classes of ten factors influencing flood occurrence. This approach aimed to assess the degree of impact each class has on elevating flood risk. Consequently, a distinct weight was allocated to each sub-criterion, reflecting its significance in the flooding process. In this methodology, the factors contributing to flood occurrence are prioritized according to expert assessments, and the final weights are derived from these rankings, as outlined in Equation 1 (Tables 1 and 2).

Eq. 1) $(n-rj+1)^p$

In this model, n is the number of variables, rj is the importance and rank of the variable, and p is based on expert opinion.

Table 1: Classification of parameters affecting flood zoning in the study area

Row	Parameters	Class	Class Ranking	Row	Parameters	Class	Class Ranking
1	Elevation	1294 - 1400	5	2	Land-use	Facilities	1
		1400 - 1500	3			Rainfed agricultural land	2
		1500 - 1600					
		1600 - 1700	2			Wetlands and reed beds	3
		>1700	1			Forest and garden land	4
3	Slope	0 - 5	5	4	Geology	Younger alluvial fans and terraces(Quaternary) Very low	2
		5 - 10	4				
		10 - 20	3				
		20 - 30	2			Flysh type facies(Paleocene) Low	1
		>30	1				
5	Flow accumulation	0 - 445	1	6	Aspect	South, Southwest, Southeast	1
		445 - 1575	2			East, Northeast	2
		1575 - 3082	3			North	3
		3082 - 5375	4				
		5375 - 19356	5			West, Northwest	4

Table 2: Classification of parameters affecting flood zoning in the study area

Row	Parameters	Class	Class Ranking	Row	Parameters	Class	Class Ranking
7	Ditance from river	0 - 75	1	8	Rainfall	30 - 33	5
		75 - 150	2			33 - 36	4
		150 - 225	3			36 - 39	3
		225 - 300	4			39 - 42	2
		>300	5			>42	1
9	Drainage density	0 – 6.21	1	10	Curvature	(-6.4) – (-1.28)	5
		6.21 – 16.90	2			(-1.28) – (-0.64)	4
		16.90 – 28.92	3			(-0.64) – (0)	3
		28.92 – 43.58	4			(0) – (-1.28)	2
		43.58 – 90.06	5			(1.28) – (7.68)	1

Equation 2 was employed to standardize the values of different research variables, resulting in a consistent range of index values from 0 to 1.

Eq. 2) $$Z_i = \frac{xi - \min(x)}{\max(xi) - \min(xi)}$$

Zi represents normalized values, X denotes the values of a variable, while min and max indicate the minimum and maximum values, respectively. A survey was conducted, drawing on insights from specialists in floodplains, to determine the final weighting of the layers influencing tourism, utilizing the AHP analytical hierarchy process within the Export Choice software (Table 3).

Table 3: weight of parameters based on expert opinion

Parameters	Slope	Rainfall	Ditance from river	Elevation	Aspect	Curvature	Geology	Land-use	Drainage density	Flow accumulation
weight	0.184	0.069	0.124	0.154	0.099	0.045	0.053	0.062	0.122	0.092

The formula for computing the weighted linear combination in ArcGIS software is expressed through the weighted linear combination method. To assess the flooding potential of the analyzed sub-basins, the weighted linear combination approach was employed using ArcGIS software. The standardized layers were multiplied by their respective weights, and the outcomes of all variables were aggregated and overlaid. Ultimately, the resulting flood potential map was categorized into five risk levels: no risk, low risk, medium risk, high risk, and very high risk (Equation 3).

Eq. 3) $FCZ = \sum_{i=1}^{12} K_i \times W_i \text{ , } i \; \varepsilon \; [1,12]$

In this context, Ki represents the standardized criterion, while Wi denotes the weights assigned to each criterion. The validation of predictive models is essential for assessing the precision of event zoning maps. Various methodologies for validating spatial models have been established by researchers globally. Historical flood inventory data can be utilized to validate flood susceptibility maps. In this research, historical flood sites were gathered from previously unpublished reports, and field visits were undertaken through engagement with local communities (Kayastha et al, 2013). The precision of the flood zoning map can be assessed graphically through the area under the receiver operating characteristic (ROC) curve and the associated AUC value. This assessment involves calculating the cumulative area corresponding to various flood sensitivities on one side and the total number of flood occurrences in different vulnerable regions on the other. AUC values ranging from 0.5 to 1 signify the largest area under the curve, indicating a robust model. The evaluation metrics are categorized as follows: 0.9-1 is excellent, 0.8-0.9 is very good, 0. 7-0.8 is good, 0.6-0.7 is moderate, and 0.5-0.6 is poor. This methodology was employed in the current study to assess the flood zoning map (Hosseinzadeh et al, 2023).

Results and Discussion

Results

Preparation of geospatial layers

In this study, 10 multi-source spatial data sets were used to prepare a flood susceptibility map. In this study, 10 multi-source spatial data sets were used to prepare a flood susceptibility map.

Elevation

Elevation is recognized as a crucial factor in flood management, significantly influencing water flow dynamics. Specifically, water flow is inclined to gravitate towards regions of lower elevation, thereby heightening the flood risk in these areas (Lee et al, 2012). Conversely, regions situated at higher elevations generally exhibit a reduced susceptibility to flooding. In highland basins, precipitation levels exceed those of lowland basins, with a significant portion falling as snow on the highland peaks, which is crucial for generating direct runoff. The study area exhibits an elevation range beginning at 1294 meters above sea level, extending to over 1700 meters in the western regions. While the elevated sections of the basin are not susceptible to flooding, they significantly contribute to flood dynamics; conversely, the lower-lying areas are vulnerable to flood risks (Fig. 2).

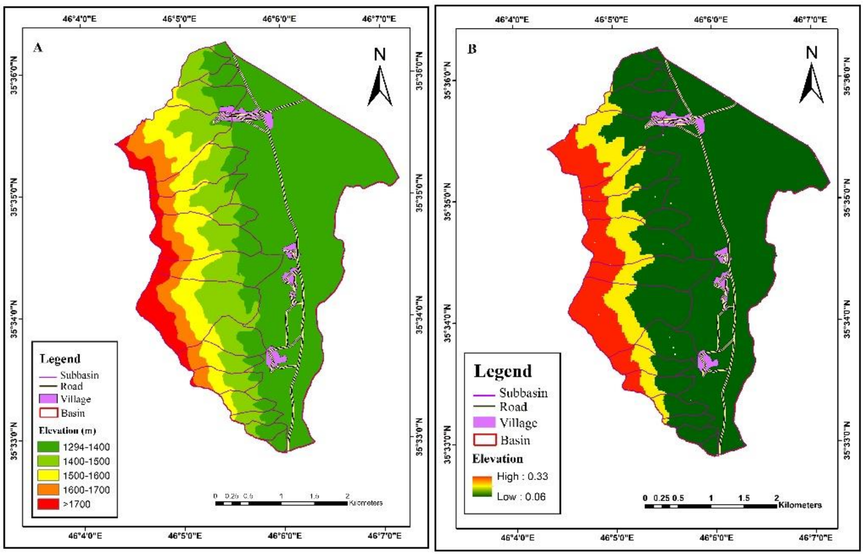

Fig. 2: Maps illustrating various flood controlling components: A: Elevation map, B: Weighted Elevation map

Slope: The gradient of a region is a crucial geomorphological characteristic that offers essential insights into the velocity and trajectory of water flow, the erosive capacity of surface currents, and the concentration time. This element significantly influences surface runoff, soil erosion rates, and flood dynamics. An increase in slope typically results in heightened water flow velocity, which can intensify riverbed erosion and elevate the risk of flooding. The slope also plays a critical role in the infiltration process; as the slope becomes steeper, the rate of surface runoff increases, leading to a reduction in infiltration capacity. Consequently, regions with a marked decline in infiltration are more susceptible to flooding. Furthermore, a steeper slope enhances the erosive potential of the river (Xiao et al., 2017). Conducting precise slope assessments is vital for forecasting flood behavior and devising strategies to mitigate associated risks. In the research region, the gradient ascends from the eastern side, which is near the lake, to the western part of the basin. In the elevated areas, the slope exceeds 30 degrees, whereas close to the lake, the incline is more gradual, ranging from zero to 5 degrees (see Fig. 3).

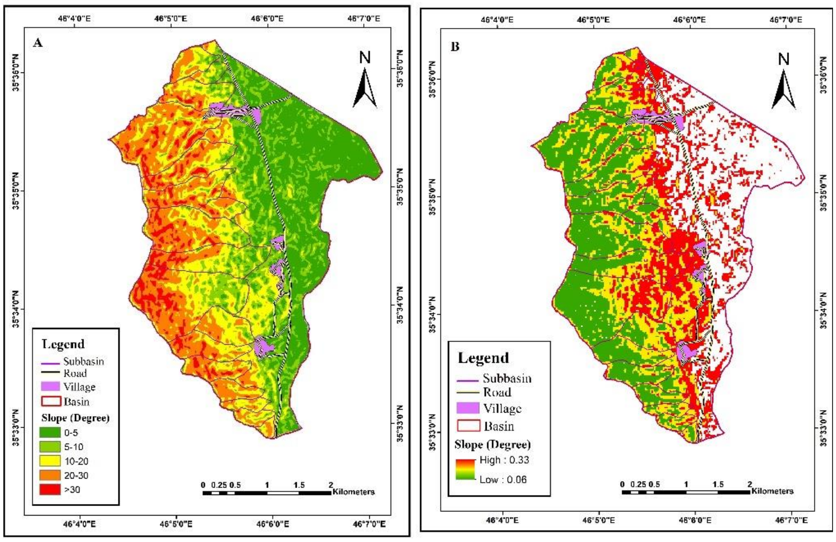

Fig. 3: Maps illustrating various flood controlling components: A: Slope map, B: Weighted Slope map

Aspect: The orientation of slopes (aspect) plays important role in influencing hydrological processes, including snowmelt and the diversity of vegetation within watersheds. In the Northern Hemisphere, southern slopes experience a more rapid snowmelt compared to northern slopes, attributable to their greater exposure to solar radiation. Conversely, northern slopes tend to maintain higher moisture levels, with erosion predominantly manifesting through mass movements such as landslides and solifluction. The analysis of the provided map indicates that the eastern slopes encompass the most extensive area within the study region (Fig. 4).

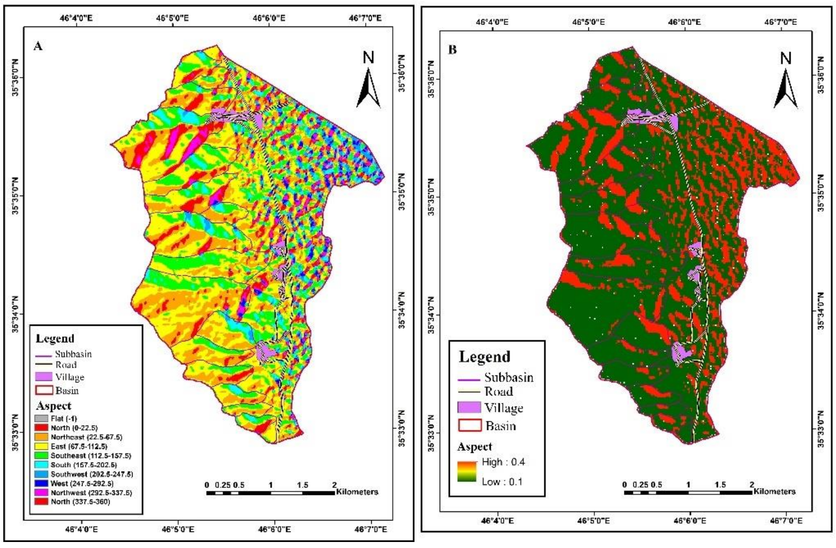

Fig. 4: Maps illustrating various flood controlling components: A: Aspect map, B: Weighted Aspect map

Geology: A significant contributor to the intensification of flooding events is the geological aspect. There exists a robust correlation between the permeability of geological formations and the volume of surface runoff. Permeable formations facilitate groundwater movement by promoting water infiltration, whereas impermeable substrates, such as crystalline rocks, exacerbate surface runoff. Additionally, karst formations uniquely contribute to the risk of flooding (Kazakis et al, 2015; Dass, 2019). In the region under investigation, the eastern sections are characterized by alluvial fans and recent alluvial deposits, while the western sections consist of flysch facies, which exhibit lower permeability compared to their eastern counterparts, leading to heightened flood intensity in the western areas (Fig. 5).

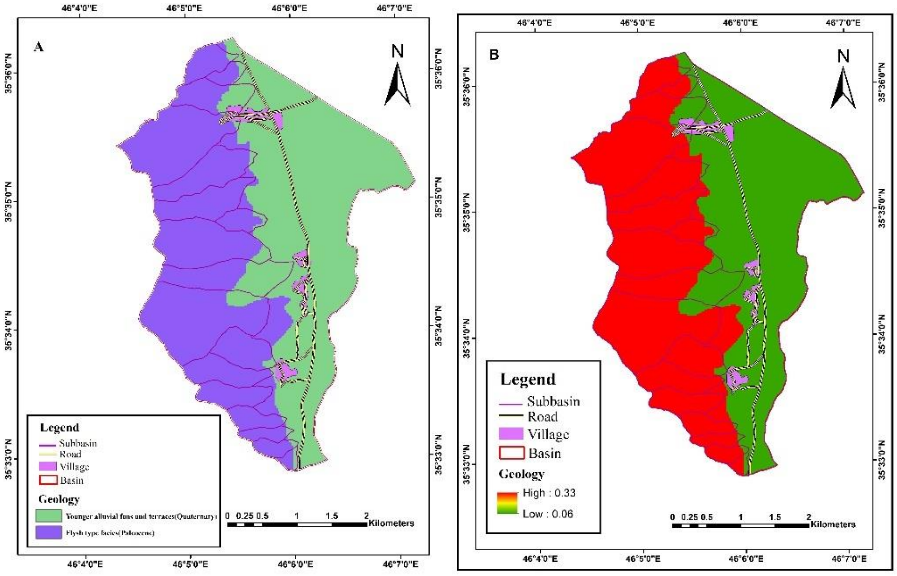

Fig. 5: Maps illustrating various flood controlling components: A: Geology map, B: Weighted Geology map

Rainfall: The interplay between global climate change and localized climatic factors influences soil moisture and snowpack variably, subsequently impacting flood occurrences. Typically, rising atmospheric temperatures enhance the capacity for water vapor retention, potentially resulting in intensified heavy rainfall and, as a result, an increased likelihood of flooding. An uptick in heavy rainfall correlates with a greater risk of flooding. Data analysis indicates a declining trend in precipitation across certain time series, with notable reductions in specific instances, suggesting a regional decrease in rainfall. Notably, the Marivan station has recorded the most significant decline during the winter months compared to other seasons. Annual studies further corroborate that within the analyzed statistical period, the downward trend in precipitation is substantial, evidenced by a Mann-Kendall statistic of -2.2 at a 95% confidence level. In other time series, variations in precipitation are primarily characterized by short-term and abrupt climatic changes. The Marivan area is influenced by Mediterranean and Atlas currents, which contribute to considerable precipitation due to the mountainous terrain and the interaction of these currents with the Zagros highlands. The precipitation distribution map for the study area indicates a west-to-east decline in precipitation levels, primarily attributed to the significant forest cover present in the western part of the region. Furthermore, a direct correlation between precipitation and altitude is evident, with higher altitudes corresponding to increased precipitation amounts. According to the collected data, the average daily precipitation in the region begins at 30 mm and exceeds 42 mm in certain locations (Fig. 6).

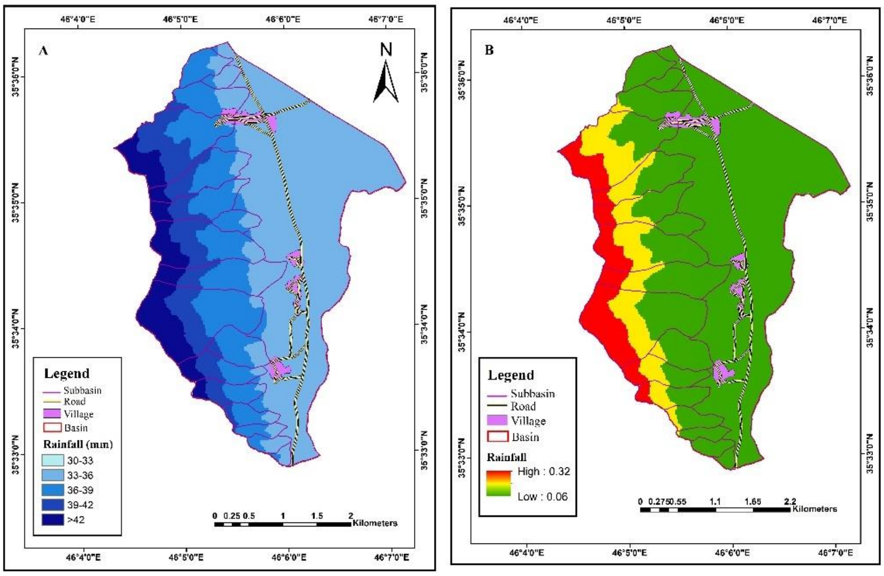

Fig. 6: Maps illustrating various flood controlling components: A: Rainfall map, B: Weighted Rainfall map

Land use: The utilization of land plays a crucial role in determining both the frequency and temporal fluctuations of flooding within a given area. This aspect significantly influences soil permeability and the rate of surface runoff. Typically, regions characterized by dense vegetation exhibit a reduced capacity for runoff generation, owing to their ability to absorb and retain water. Conversely, impervious surfaces, including urban developments and roadways, diminish the infiltration of water into the soil, thereby heightening runoff and increasing the associated flood risk. In the study area, rainfed agricultural land constitutes the predominant land use, accounting for 45.77 percent of the overall area. The western regions are primarily characterized by forest cover and orchards, whereas the eastern sections, adjacent to the lake, are largely composed of wetlands and reed beds. The least prevalent land use is residential areas and associated facilities, which occupy 5.5 percent of the total area (Fig. 7).

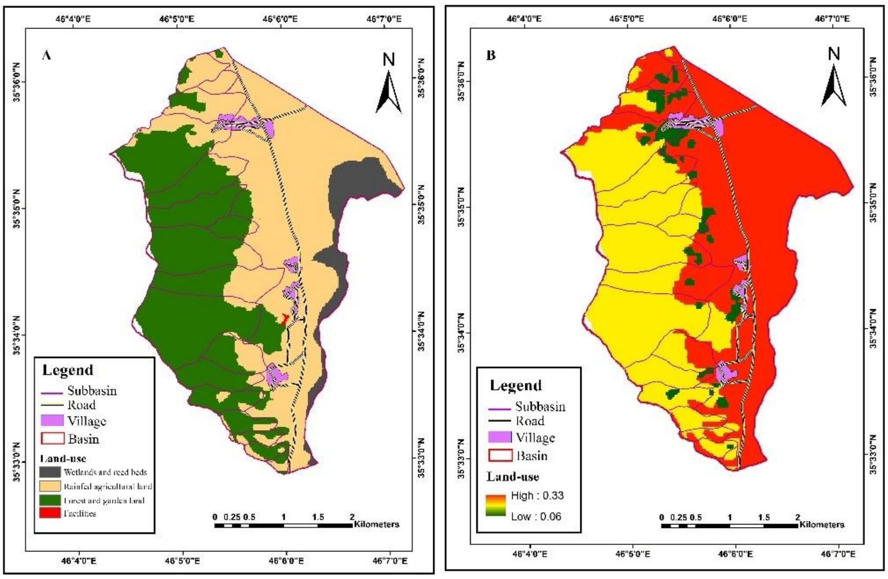

Fig. 7: Maps illustrating various flood controlling components: A: Land-use map, B: Weighted Land-use map

Flow accumulation: Flow accumulation serves as a fundamental criterion in evaluating flood risk. Elevated values of this index signify a substantial volume of runoff, thereby increasing the likelihood of flooding in the region. The computation of flow accumulation relies on the aggregation of data pertaining to pixels that naturally direct towards the basin's outlet within a raster layer (Papaioannou et al, 2015) (Fig. 8).

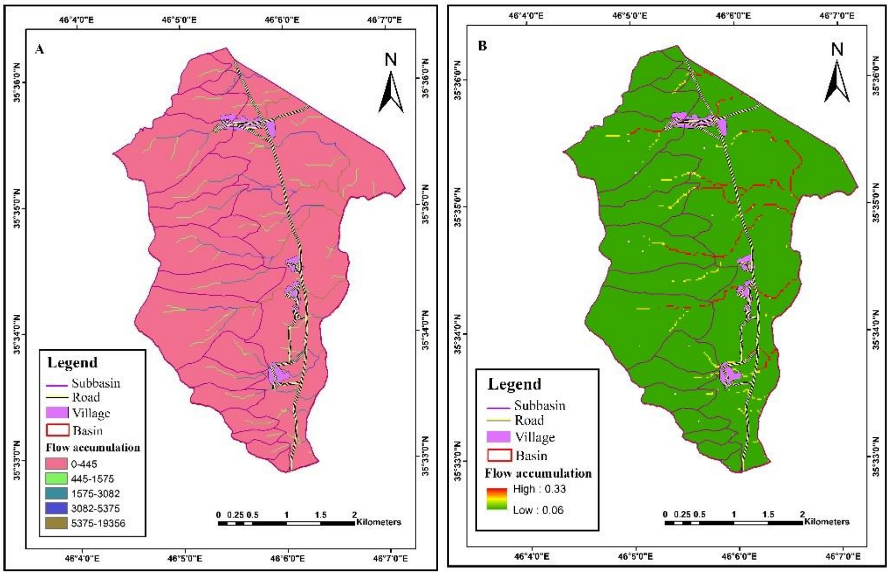

Fig. 8: Maps illustrating various flood controlling components: A: Flow accumulation map, B: Weighted Flow accumulation map

Topographic curvature: Topographic curvature pertains to the features of slopes that exhibit either convex or concave shapes, significantly influencing runoff and water permeability. In this context, positive and negative values of the slope's transverse curvature indicate convexity, which leads to flow divergence, and concavity, which results in flow convergence, respectively. In addition, positive values of the longitudinal curvature of the domain indicate concavity, which reduces the flow velocity, and negative values indicate convexity of the domain, which increases the flow velocity (Kornejady et al, 2020**)** (Fig. 9).

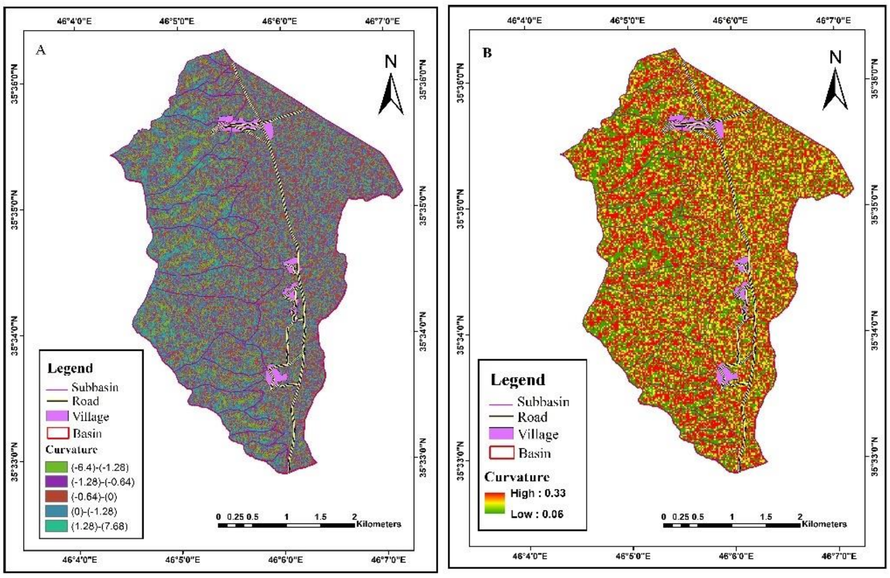

Fig. 9: Maps illustrating various flood controlling components: A: Curvature map, B: Weighted Curvature map

Distance from drainage network: The risk of flooding is influenced by the configuration of drainage systems within a watershed, with regions adjacent to rivers exhibiting a heightened susceptibility to inundation during flood events. Generally, proximity to a river correlates with increased flood vulnerability (Xiao et al., 2017). Research conducted by Samanta et al. (2016) indicates that locations situated within 100 meters of a river are classified as high-risk for flooding, whereas those located more than 20,000 meters away are significantly less prone to flood impacts (Fig. 10).

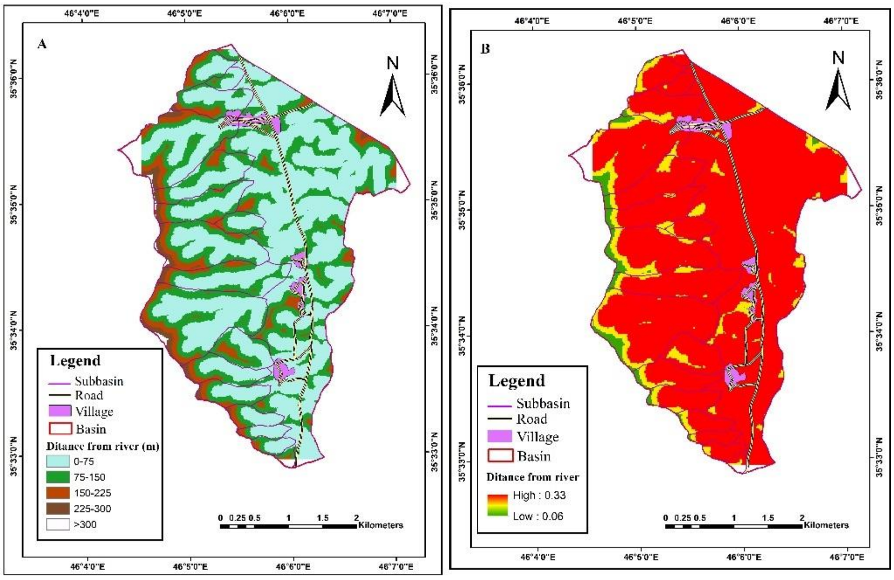

Fig. 10: Maps illustrating various flood controlling components: A: Ditance from river map, B: Weighted Ditance from river map

Drainage density: Drainage density refers to the proportion of the total length of the drainage network, encompassing both primary and secondary streams, relative to the area of the basin. This metric serves as an indirect indicator of runoff and erosion conditions across various regions of the basin, highlighting its significant correlation with the soil surface and subsurface layers' resistance to erosion. Typically, regions characterized by low drainage density exhibit greater permeability in the underlying soil layers, a more abundant vegetation cover, and a relatively smoother basin surface. Conversely, areas with reduced permeability tend to show an increase in drainage density. Generally, a rise in drainage density results in a corresponding increase in flood discharge, which may intensify bedrock erosion. Numerous studies indicate that regions with elevated surface runoff exhibit greater drainage density, particularly when contrasted with areas experiencing lower runoff. Consequently, drainage density serves as a significant parameter for evaluating runoff within each basin (Rimba et al, 2017) (Fig. 11).

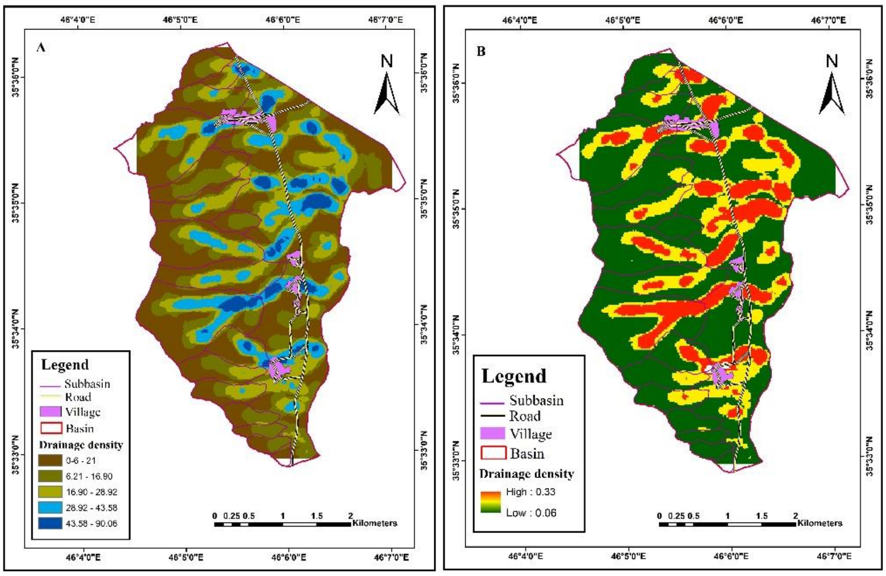

Fig. 11: Maps illustrating various flood controlling components: A: Drainage density map, B: Weighted Drainage density map

Flood susceptibility map: Floodplain zoning involves the identification, evaluation, and characterization of regions that may generate surface runoff. This evaluation relies on the hydrological and hydrogeological similarities of each region and is conducted to maximize the utilization of these potentials. Following the normalization procedures and the integration of various layers with weights determined through the weighted linear combination method, the final zoning map for the western section of Lake Zaribar and the associated sub-basins has been produced (Fig. 12 and 13 and Table 4). In this study, areas have been classified into five distinct categories, and indicators such as the average, minimum, and maximum area for each category within the sub-basins have been analyzed (Fig. 14).

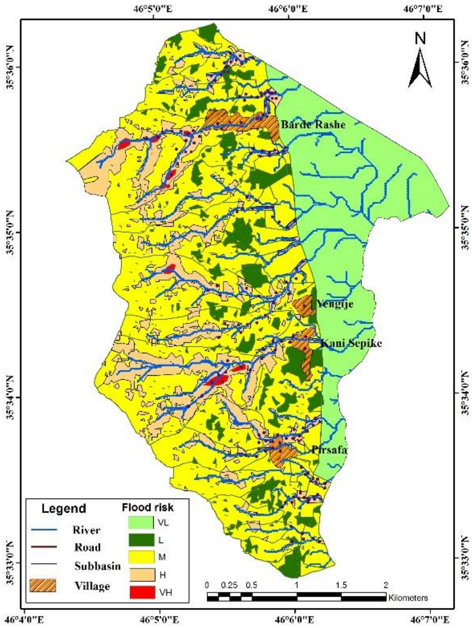

Fig. 12: Flood susceptibility map of the study area

Table 4: Flood risk ranking in the study area

Area (%)	Area (km^2)	Flood susceptibility
22.48	3.22	Very low
7.50	1.08	Low
52.94	7.59	Moderate
16.59	2.38	High
0.51	0.07	Very high
100	14.34	

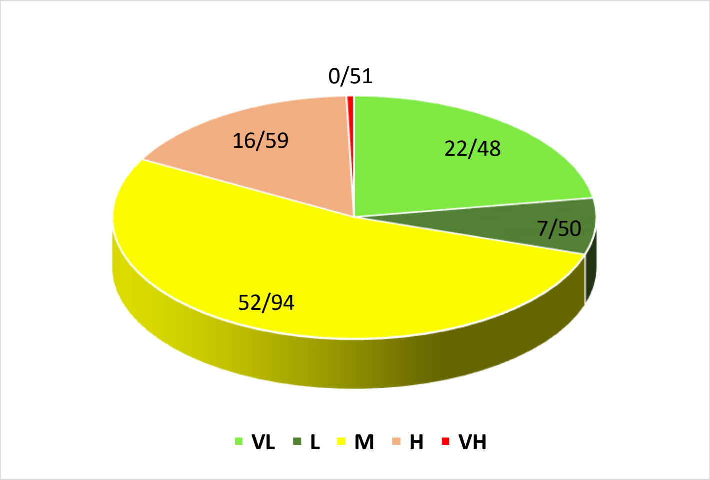

Fig. 13: Flood zoning diagram of the study area

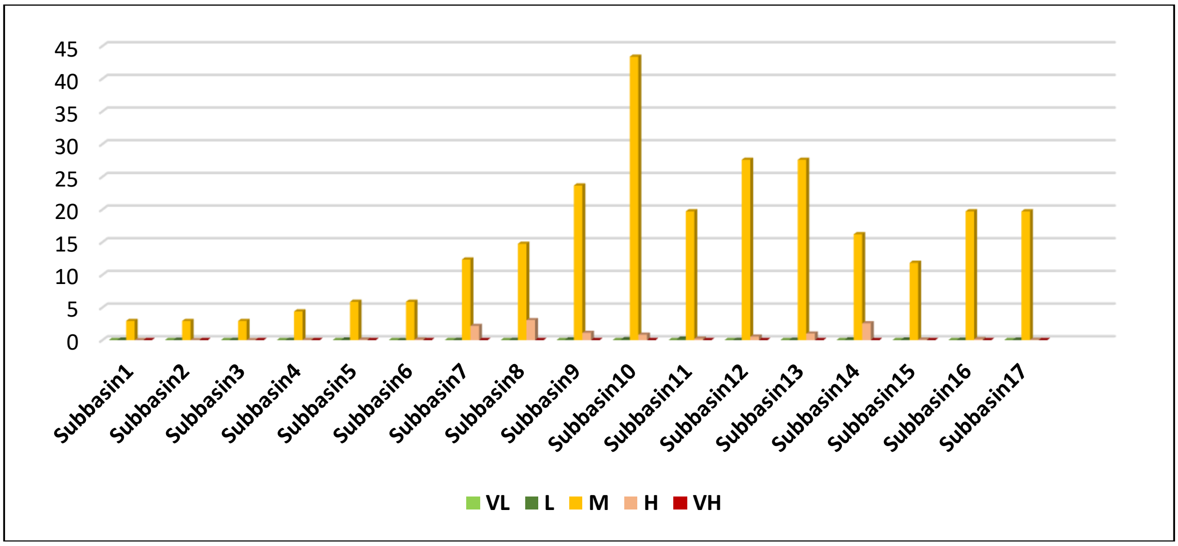

Fig. 14: Sub-basin sensitivity chart to flooding

Discussion

Through the modeling performed and taking into account ten significant factors, areas susceptible to flooding and runoff were delineated within the examined basin. Results indicated that the risk zone distribution across the basin is uneven. The highest occurrence was found in regions classified as medium risk, accounting for 52.94 percent. This was followed by non-risk areas at 22.48 percent, and high-risk zones ranked third at 16.59 percent. The presence of risk-free zones within the study area can be attributed to the flat terrain situated between the villages and Zaribar Lake. This region features a minimal slope, ranging from 0 to 5 percent, a low elevation, and limited precipitation, resulting in a significantly reduced likelihood of flooding. Consequently, these characteristics have contributed to the designation of this area as a low-risk or risk-free zone in the modeling process. In the elevated sections of the roadway linking the villages to the basin ridge, a notable variation in flood risk is evident. To conduct a more detailed analysis of these regions, the area was segmented into 17 sub-basins, with distinct flood risk categories established for each. The findings indicate that sub-basins 10, 12, and 13 exhibit the greatest flood potential. This high risk may be attributed to several factors, including steep gradients, increased precipitation, a dense network of drainage systems, significant alterations in land use, and a decrease in natural vegetation within these zones. In contrast, sub-basins 1, 2, 3, and 4, situated in the southern region of the basin, exhibit the least potential for flooding. Key factors contributing to this characteristic include a gentle slope, lower elevation, and a dense cover of vegetation. Flood zoning modeling shows that flood hazard intensity increases significantly as one moves toward the center of the basin, especially in sub-basins 9, 10, 11, 12, and 13. These regions are characterized by the largest expanse of high and very high-risk zones. Critical features such as steep slopes, elevated altitudes, substantial rainfall, a dense drainage network, and significant alterations in land use are identified as the primary factors exacerbating flood risk in these areas. Consequently, the villages situated at the confluence of these sub-basins, such as 'Yangijeh' and 'Kani-Spikeh', face the greatest flood risk and are prioritized first for risk management and intervention strategies. Following this, 'Bardeh-Rasheh' is assessed to have a moderate risk level, placing it third in the hierarchy of management actions. In contrast, 'Pirsafa' exhibits the least flood risk, thereby ranking fourth in terms of resilience and risk management efforts. Overall, the research area is susceptible to flooding and the resultant damages related to both natural and environmental factors. Statistical methods, including regression analysis, correlation, and t-tests, were employed through field interviews and community engagement, validating this assertion. Conversely, the region's social and infrastructural challenges—characterized by poor resource management, limited public awareness, substandard physical conditions, and the ineffectiveness of certain essential infrastructures—have intensified the vulnerability to flood risks. Consequently, these aspects must be thoroughly addressed in the formulation of future management strategies.

Validation of the flood susceptibility map

The flood zoning map was assessed visually through the area under the curve (ROC) methodology and the corresponding AUC value (refer to Table 5). This assessment involved correlating 125 flood points from the region with the model's output flood zoning map, which was developed based on field observations following the flood in March 2018. The evaluation yielded an AUC value of 0.768, translating to an area under the curve percentage of 76.89 percent, which signifies effective modeling of flood zoning for the study area, utilizing the available data along with the rank weighting method and AHP (illustrated in Figure 15).

Table 5: Values obtained from different flood sensitivity classes and flood-prone areas of the study area

Flood susceptibility zone	(km^{2}) Area	area (%)	Flooding locations	Flooding locations (%)	Flood density
Very low	3.22	22.45	0.00	0.00	0.09
Low	1.08	7.53	5.00	3.21	0.14
Moderate	7.59	52.93	57.00	36.54	0.14
High	2.38	16.60	88.00	56.41	0.18
Very high	0.07	0.49	6.00	3.85	0.24
	14.34	100.00	156.00	100.00	

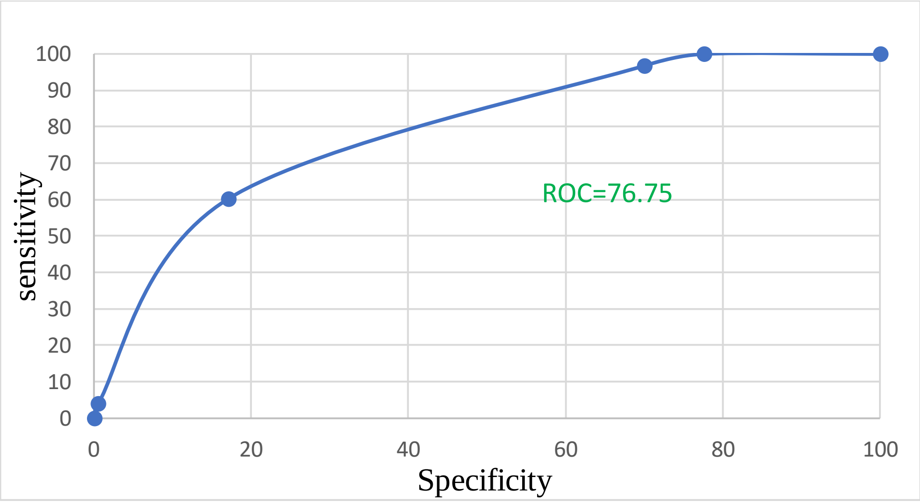

Fig. 15: Area Under the Curve (AUC) related to the validation of the flood susceptibility model

Conclusion

Flooding represents a recurring natural hazard that manifests annually across various regions globally, often resulting in significant loss of life and property. The flood risk zoning analysis conducted in the study area indicates that a mere fraction, specifically less than one percent, which corresponds to an area of 0.07 km2, is categorized as being at very high risk of flooding, a relatively minor proportion of the total area. Furthermore, 16.59 percent of the study area, amounting to 2.38 km2, is designated as high flood risk zones, predominantly situated within sub-basins 8, 10, and 14, particularly near the villages of Barda-Rasheh and Kani-Spikeh. The predominant section of the study area spans 7.59 km2, representing 52.94% of the total area, and is situated within the medium flood risk zone, encompassing the central and western regions of the basin. Furthermore, 7.50% of the area, amounting to 1.08 km2, is categorized as having a low flood risk, primarily comprising residential zones and infrastructure. Lastly, the eastern portions of the basin, covering 3.22 km2 or 22.48% of the total area, are designated as flood-free zones, predominantly consisting of agricultural lands, wetlands, and reed beds. The analysis of the factors influencing regional flooding indicates that elements such as slope, elevation, proximity to the river, and drainage density are the most significant contributors to flood risk. The final map reveals that the eastern sections of the region are devoid of flood risk, with the threat intensifying from east to west. A substantial portion of the region falls within the medium to high-risk categories, while only a minor fraction (less than one percent) is classified as being at very high risk. Furthermore, areas identified as having high and very high risk are predominantly situated in sub-basins 8, 10, and 14, particularly near the villages of Barda-Rasheh and Kani-Spikeh.

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