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Spatial Analysis of Flood Risk in Tabas Watershed Using Satellite Images and Geographic Information System

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Abstract

Among the natural phenomena, flood can be the biggest cause of damage, which always endangers the lives and properties of people. One of the management measures that can play a significant role in reducing damages is flood risk zoning. In this research, flood risk zoning has been done in the Tabas watershed. In general, the steps and this research were done in four stages. The effective criteria for creating the risk of flooding were identified, and the relevant layers were prepared. In the next step, mapping and standardization were done using fuzzy membership functions, then weighting of parameters was done using the hierarchical method, and finally overlapping of the layers was done using fuzzy operators. The criteria of distance from the river, slope, land use, rainfall, soil, digital elevation model and normalized difference vegetation index were respectively assigned the highest weight. Also, all fuzzy superposition operators (OR, AND, SUM, Product and Gamma) have been used for flood risk zoning. Among these operators, the 0.9 gamma operator shows the best and most reasonable result, so this map was chosen as the final flood risk zoning. In the final map, the total area of high-risk areas is 15432.13 ha. According to the final map obtained, areas with very high flood risk are located in the eastern part of the studied area. Areas with low risk are mostly located in the plains, valleys and depressions with less slope. The method used in this study can be used in other studies, such as zoning of earthquake risk potential, development zoning and spatial analysis of disease distribution.

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Introduction

Floods are natural disasters that, according to the United Nations Development Program, rank high in terms of loss of life and property (Beheshti et al., 2009). Floods can cause severe economic damage and pose a threat to human life worldwide (Ouma and Tateishi, 2014). Among natural phenomena, floods can be the primary cause of damage, consistently endangering the lives, properties, and assets of countless people. Iran, due to its Mediterranean climate, ranks 7th globally in terms of flooding and suffers significant damages in this regard every year. Mitigating the effects of this crisis necessitates the integration of various data, such as topography, roads, buildings, and urban facilities. The research highlights the importance of studying urban floods as a vital component of urban watershed management programs. Flood zoning in urban areas is crucial for evaluating and identifying areas prone to flooding and potential damage, as well as for identifying safe routes for relief and resettlement of people. Utilizing models related to flood effects and considering the economic implications of flood damages is paramount in flood zoning in urban areas. Hence, studying floods in urban areas and preparing a risk zoning map is essential for reducing damages caused by urban floods and assisting managers in formulating better management plans. This phenomenon can be studied through flood zoning in cities, where areas prone to flooding are identified, and flood control measures are implemented accordingly. Additionally, safe routes for relief and secure settlements for affected populations have been established. Several natural factors can disrupt the balance of river flow, turning it into a destructive force. These include vegetation destruction, land conversion, rainfall intensity, as well as the degree of soil saturation, slope, and permeability of the basin. Flood risk analysis is required as a major challenge in urban areas compared to rural areas due to its greater complexity. Flood risk analysis often overlooks social and environmental impacts, focusing solely on quantifying economic damages (Kubal et al., 2009). Identifying flood-prone areas is a crucial step in managing flood impacts and classifying affected regions (Patil et al., 2008). This information guides decisions regarding land use, including the future development of cities and villages, with the aim of mitigating flood damages to some extent (Saeedi and Asiaei, 2021). There are a lot of vague ideas, variables, and systems in the real world, but fuzzy logic theory helps us think about them mathematically. It also gives us a way to make decisions and reason in uncertain situations (Zadeh, 1998). Community membership and complementary sharing, multiplication, addition, and gamma are fundamental aspects of this integration model. The hierarchical analysis process is also utilized as a decision system for multiple criteria location-based on expert knowledge, as presented by Thomas Al Saati (1990). In this method, the effective factors causing flood risk are first identified through a literature review and qualitative methods examining the characteristics of the study area.

Various factors, such as DEM, slope, distance from the river, NDVI, land use, soil, and rainfall, can affect flood risk zoning. In this regard, Rashetnia (2021) investigated flood vulnerability assessment using fuzzy rule-based indicators in Melbourne, Australia. The results of this study indicated that the distance of the river and the site of rainfall are the most significant variables in causing floods in this city. Schumann (2021) conducted a study on modeling river floods using remote sensing in Brazil. The findings of various studies and investigations revealed that variables such as distance from the river, topography, and precipitation have the greatest impact on the occurrence of floods in Brazil (Schumann, 2021). Mishra et al. (2020) evaluated flood risk in the Kosi district of India and found that this area is one of the most flood-prone regions in India and requires proper planning. Among domestic studies, we can also refer to the research by Eslaminezhad et al. (2022), Khorshidi et al. (2021), and Solaimani and Darvishi (2020). Therefore, with the growth and development of new technologies, spatial flood risk analysis methods require a more practical tool. This tool should not only provide users with more mathematical models and facilities for accurately explaining flood flow, but also offer systems with geographic information capabilities. These systems provide users with significant abilities to analyze the risk of flooding. The flood risk-zoning map can serve as an effective tool for planning the future development path of the city. It can also help identify areas where the development of flood evacuation and drainage infrastructure is necessary. Thus, in this research, a flood risk zoning map has been prepared for the Tabas catchment area.

Material and Methods

Study Area

Tabas is one of the study areas within the Lut Desert watershed, in South Khorasan Province, Iran. The total area of the Tabas study area is 12,484.85 square kilometers, comprising 4,566.73 square kilometers of plains and 7,918.13 square kilometers of highlands. Additionally, there are two alluvial aquifers in this study area, with extents of 859.81 and 389.74 square kilometers, respectively. Figure 1 below illustrates the geographical location of the study area in South Khorasan Province, Iran.

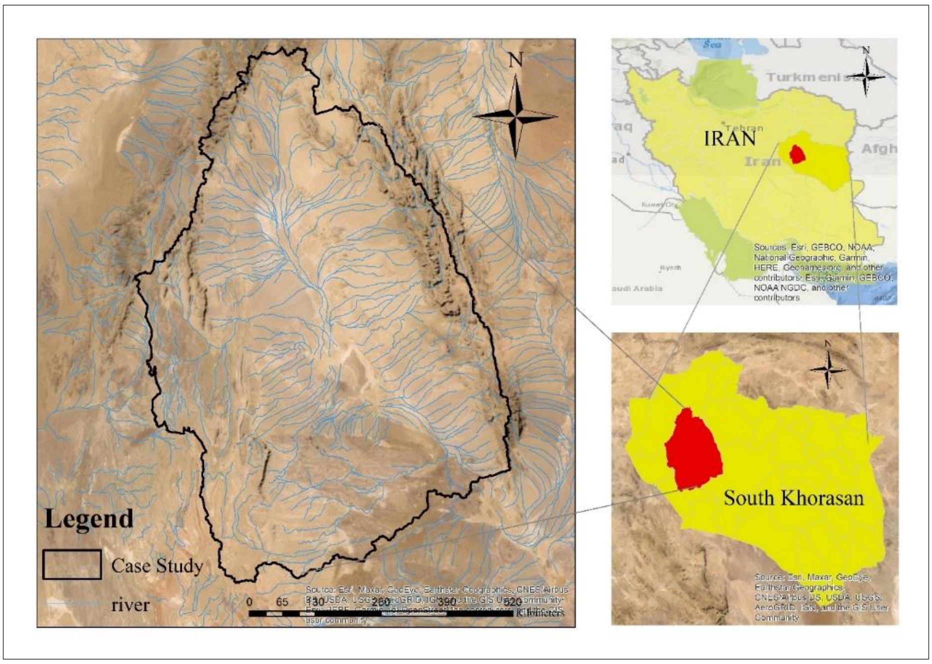

Fig 1. Geographical location of the study area.

As one of the most dangerous natural disasters that has big effects on cities, urban floods are studied in this study. To find good ways to deal with the risk of flooding and keep people safe, the Tabas watershed is used for spatial analysis of flood risk using fuzzy logic based on GIS, AHP, and spatial analysis. In this study, land use and land cover, elevation, slope, distance from the river, soil, and rainfall are considered important factors in zoning the flood phenomenon in the Tabas watershed. To compile some of the information used in this study, such as vegetation data, satellite images, including those from the Landsat 8 satellite, have been employed. An aerial image from the summer of 2022 was prepared and enhanced using ENVI 5.6.1 software and the NDVI index was subsequently extracted. The data of distance from the river, rainfall or land use were obtained from the maps received from the relevant organizations. The raster layers land use and soil were polygonal in nature and were rasterized using the feature to raster tool. The rasterization of the other layers was carried out using the Euclidean distance, interpolation, and kernel density tools. The raster maps were colored from blue to red to differentiate the values of raster cells. In this regard, the color red (in raster layers except soil, land use, NDVI, and rainfall) represents higher values. The general stages of this research include information gathering, rasterization, standardization using fuzzy membership functions, weighting using the hierarchical method, and overlaying layers using fuzzy operators. To fuzzily classify the layers, it was necessary to have a raster structure from the input information. Thus, in this research, all the information layers (excluding DEM and slope) were prepared using various tools in Arcmap 10.8.1, including a raster calculator, feature to raster, and interpolation. Here is an explanation of the types of fuzzy operators used in this research:

We define the operator of fuzzy and value as the following equation:

$$a. W_{Combination} = MIN(W_A, W_B, W_C, \dots) \quad (1)$$

where WB, WA and WC represent the fuzzy membership values of factors B, A and C in a specific situation. The effect of this operator is that the output map is controlled by the smallest fuzzy membership value that occurs at each position. fuzzy OR value is defined as the following relation:

$$b. W_{Combination} = MAX(W_A, W_B, W_C, \dots) \quad (2)$$

The effect of this operator is that the output map is controlled by the largest fuzzy membership value that occurs at each position. Product operator is defined as the following relation.

$$c. W_{Combination} = \prod_{i=1}^{n} W_i \quad (3)$$

In this method, n fuzzification controlling factors are combined, and we represent the weight of each layer. The values of fuzzy membership with this operator tend to be very small, in other words, the output value of each position is always smaller or equal to the smallest value of fuzzy membership in the corresponding positions of the input maps. Therefore, the above operator has a reduction effect. In this method, unlike fuzzy AND and OR, all membership values of the input maps affect the output map.

d- SUM operator

This operator is defined as the following relation.

$$d. W_{Combination} = 1 - \left(\prod_{i=1}^{n}(1 - W_i)\right) \quad (4)$$

By using this fuzzy operator, the fuzzy membership value of the output map in each position is always greater than or equal to the largest fuzzy membership value in the corresponding positions of the input maps. Therefore, the super operator has an increasing effect.

E- GAMMA operator

This method is a combination of algebraic multiplication and algebraic addition techniques. In this method, factors with different weights are combined according to the following relationship:

$$e.\mu_{Combination} = (Fuzzy\ Algebric\ Sum)^{\delta} * (Fuzzy\ Algebric\ Product)^{1-\delta} \quad (5)$$

In this regard, the value of γ is determined between zero and one. If we want the algebraic sum method (SUM) to be more important, the value of γ is chosen close to one, if we want the algebraic multiplication method (PRODUCT) to be more important, the value of γ is chosen close to zero. The correct and conscious choice of γ produces values in the output that have a flexible adaptation between the decreasing and increasing tendencies of the two fuzzy operators of algebraic multiplication and algebraic addition (Eastman, 2012 Consequently, Qanavati et al. (2012) employ the gamma operator to modify the algebraic multiplication and algebraic addition operators.

Today, there are different methods for zoning and flood risk estimation, For example, the use of the Google Earth Engine platform has found many applications and has provided fast and reliable results to researchers (Bagheri *et al*, 2022).

Results and Discussion

Mapping Results

Figure (2) depicts the raster layers related to seven measures: DEM, slope, distance from the river, NDVI, land use, soil, and rainfall. Among these layers, NDVI exhibits an inverse relationship with flood risk, while rainfall, DEM, slope, and distance from the river show a direct relationship with the risk of flooding (Ogato et al., 2020). After rasterizing the criteria, we standardized the rasterized layers using different fuzzy membership functions.

The results of standardization:

In the measurement of traits, a diverse range of scales is used, necessitating the conversion of values in different layers of the map into comparable units and proportions to each other. This process creates standard and comparable maps. One standardization method is the fuzzy method, in which the fuzzification operation assigns an appropriate degree to each input using the respective membership functions (Zadeh, 1965). There is no specific algorithm for obtaining the membership function; however, experience, innovation, and even the application of expert opinion can be effective in forming and defining it. At this stage, raster layers of each of the factors affecting flood risk in Tabas plain converted into fuzzy layers using linear, sigmoid, and user-defined membership functions in ARC MAP 10.8.1 software (Table 1).

The standardized layers have values between zero and one, wherein higher values indicate a higher favorability for flood risk (Figure 3). In this context, the rainfall criterion, as well as the digital elevation model of DEM and slope in the eastern part of Tabas plain exhibit the highest favorability in relation to the risk of flooding. In terms of the distance layer from the river and the soil, the predominant land

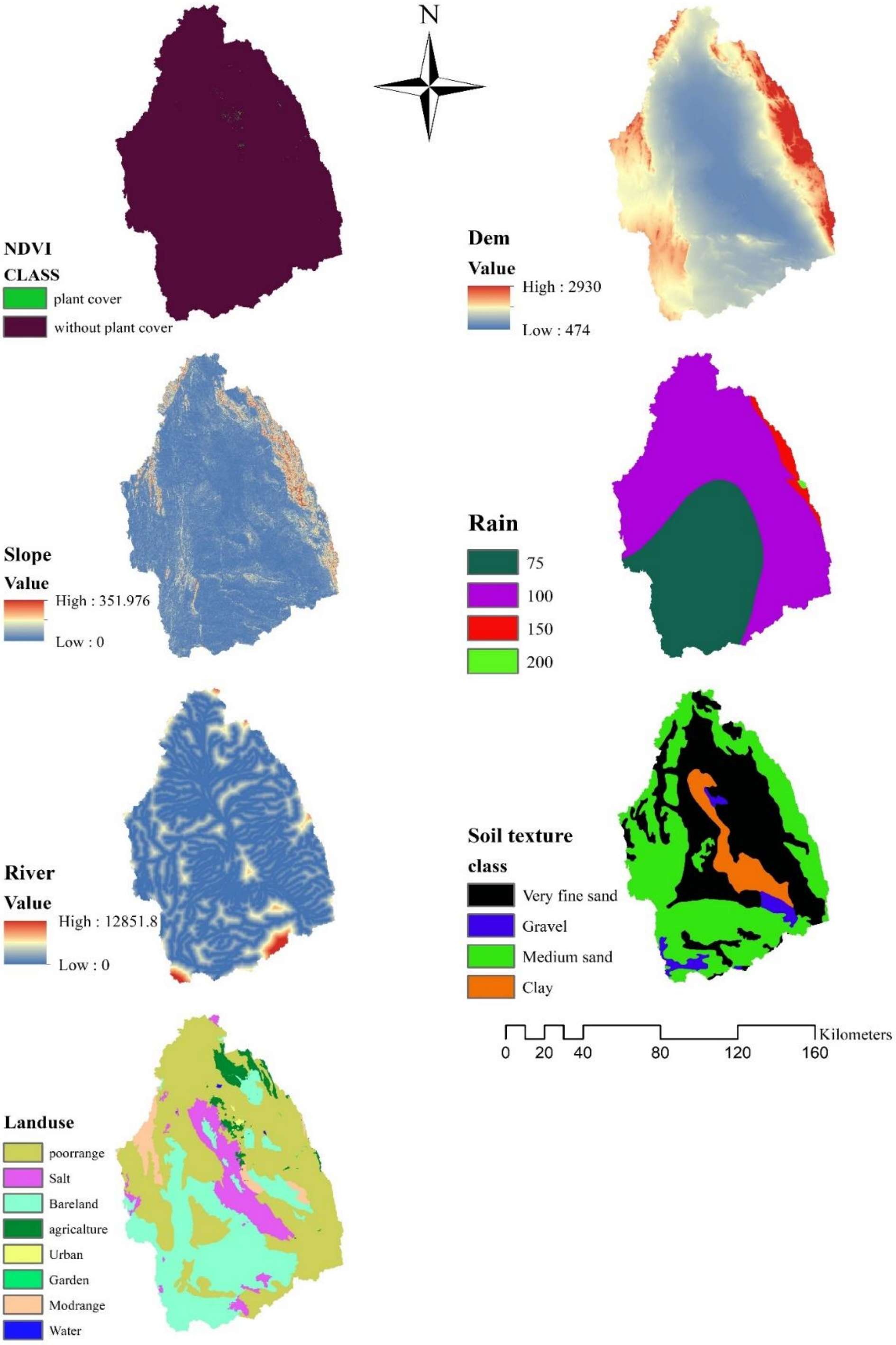

Fig 2. Raster maps of selected criteria for flood risk zoning in the study border related to 7 criteria of DEM, slope, distance from the river, NDVI, land use, soil and rainfall

Table 1. Standardization of criteria based on fuzzy membership functions

Control Points	Fuzzy Membership Function	Factor
a= 0 b=1	User defined	NDVI
Poor Pasture (0.7), Salt (1), Barren Land (0.8), Agriculture (0.3), Urban (0.9), Garden (0.1), Medium Pasture (0.2), Water (1)	User defined	Land Use
a=1000 b=2500	Sigmoid (Increasing)	Dem
a=0 b=30	Linear (Increasing)	Slope
a= 500 b=3000	Linear (Decreasing)	River
75mm= 0.25 100mm= 0.5 150mm= 0.75 200mm= 1	User defined	Rain
Sand (0), Clay (1), Medium Sand (0.33), Very Fine Sand (0.66)	User defined	Soil Pattern

use along the study boundary demonstrates a high level of favorability compared to the risk of flooding.

The use of hierarchical fuzzy method has been used in many environmental studies such as Rezaei & Roshani (2024) to prioritize parameters and prepare risk zoning maps. In this study, given that each criterion contributes differently to flooding, we utilized hierarchical analysis for weighting, ensuring that each phase layer carries its own unique value and importance. Experts and specialists assigned these values based on their judgments for the seven criteria. The AHP method comprises three main stages (Saaty, 2008). First, we analyze the decision-making problem in a hierarchical structure, determining the goal, criteria, and sub-criteria. Pairwise comparisons, the subsequent step in AHP, determine the weights for different criteria. Expert judgment guides the evaluation of paired comparisons, establishing the weight of a particular criterion by ranking its importance and suitability. The final step entails checking the consistency ratio. This ratio indicates whether the comparisons are stable or not. We can rely on the AHP results, including the calculated weights, if the consistency ratio is less than 0.1, indicating the stability of the created matrix. Table (2) presents the final weights assigned to each of the selected criteria in this analysis. The table assigns the highest weights to the criteria of distance from the river, slope, land use, precipitation, soil, DEM, and NDVI, respectively.

The results of stacking layers using fuzzy operators:

In the fuzzy method, classes and spatial units with degrees of membership between zero and one can be defined for each raster layer. Subsequently, each fuzzy layer is combined using fuzzy operators. These operators include fuzzy union (OR), fuzzy intersection (AND), fuzzy algebraic addition (SUM), algebraic multiplication (Product), and fuzzy gamma operator (Gamma). In this study, all fuzzy overlay operators have been utilized for flood risk zoning. During the overlay of fuzzified layers, the fuzzy intersection operator calculates the minimum values in the set of layer values in the output layer.

In this research, fuzzification was performed using ARC GIS software and the Fuzzy Overlay tool available in the Spatial Analysis toolbox. By utilizing this tool, all standardized and weighted layers were overlaid sequentially with all operators. It's important to note that during overlay, all raster layers must have the same correct cell size and coordinate system. Figure (4) displays the final layers resulting from overlay with five fuzzy operators; red-colored areas indicate high flood risk areas, while blue spots represent low flood risk areas.

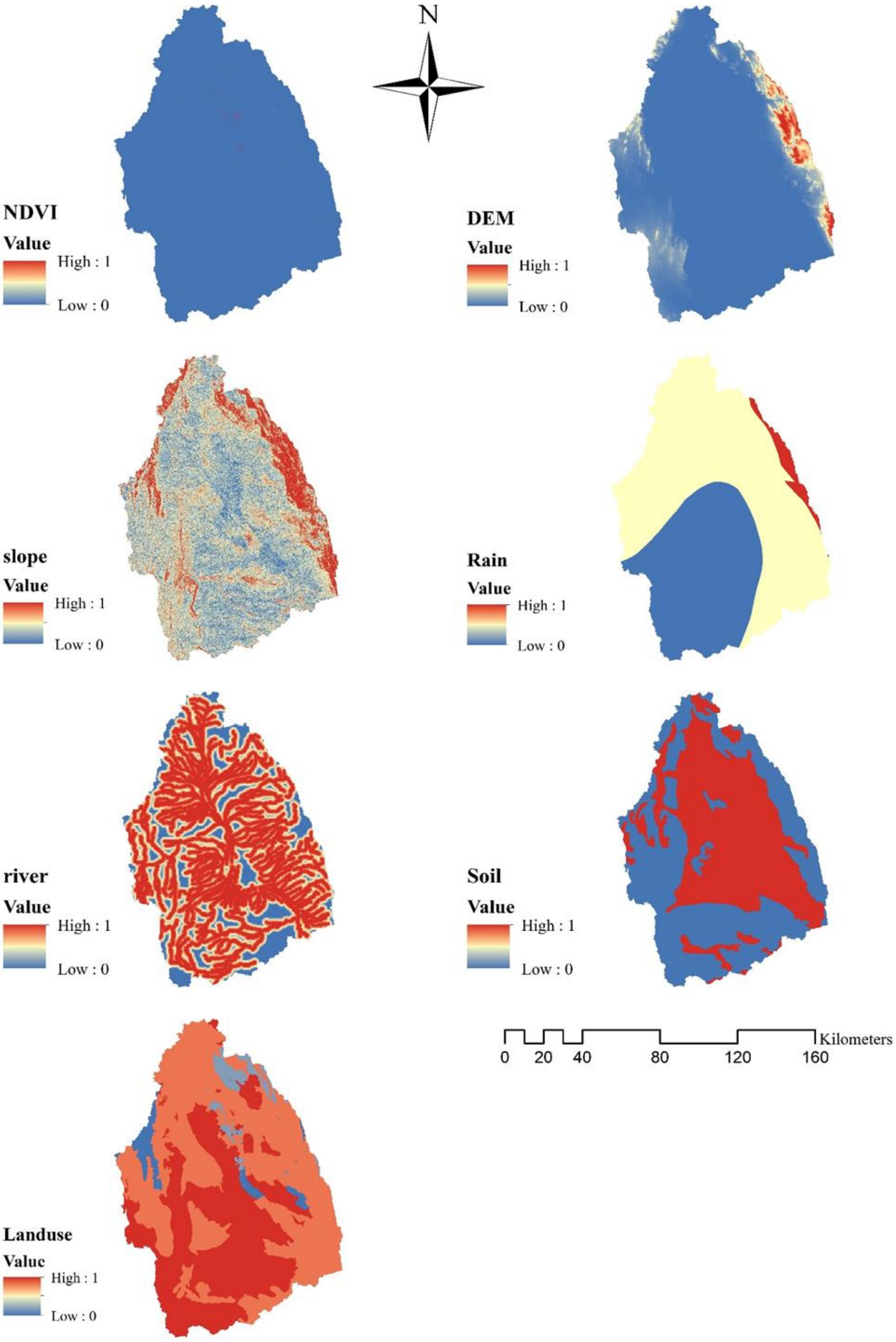

Fig3. Fuzzy maps of the raster layer for zoning the risk of flooding in the study border related to 7 parameters of DEM, slope, distance from the river, NDVI, land use, soil and rainfall

Table 2. Importance of weights of criteria and sub-criteria.

criteria	W1	sub-criteria	W2	Final weight
Hydroclimate	0.441	distance from the river	0.666	**0.2734**
		Precipitation	0.333	**0.1368**
topography	0.261	DEM	0.333	**0.0858**
		Slope	0.666	**0.1719**
Land type	0.327	land use	0.475	**0.1553**
		Soil	0.415	**0.1357**
		NDVI	0.109	**0.356**

In this research, flood risk zoning in the Tabas watershed was established based on the combination of fuzzy layers weighted with different fuzzy operators (Figure 4). According to the resulting maps, except for the OR and SUM operators, which exhibit illogical results, the rest of the operators, with slight differences, indicate the highest flood risk in the eastern part of the study area near the Tabas plain. Among these operators, the 0.9 gamma operator demonstrates the most accurate and logical result according to reality (Figure 5). Because, this map showed a more realistic result, some methods responded pessimistically and showed areas less than reality, such as Product, AND and Gamma 0.1 operators, and some operators showed much more areas, such as OR and SUM operators. In fact, this validation was done by comparing the output maps with the flood events that happened, and for this, the expert opinions of the employees of the Water and Sewerage Department as well as hydrometric data were used.

In Figure 5, the total area of high-risk areas is 15,432, 1324 ha, indicated by pixels with a value above 0.1, represented by red and orange spots. Areas with moderate risk (0.05 to 0.1) cover 97,205, 1958 ha of the Tabas Plain. The largest area corresponds to values less than 0.05, covering 926,531, 8431 ha, denoted by blue and safe spots on the map. As depicted in Figure (4), most residential areas along the study border are located in areas with low to medium flood risk.

In a study by Khorshidi et al. (2021) on prioritizing flood potential in watersheds lacking statistics using the AHP-VIKOR method in the Haji Bakhtiari watershed of Ilam province, the results indicated that the area index has the greatest effect, while the index of medium slope has the least effect on flood risk in the studied area. Similarly, in the study by Saeedi and Asiaei (2021) on flood risk zoning in Sabzevar city using fuzzy logic, slope and precipitation were identified as the most effective variables, with vegetation having the least effect in the region. Also, in relation to flood control, flood control by prioritizing flooding in sub-basins and by implementing managements to improve the coverage of pastures and build watershed structures in the river basin reduced the amount of flood discharge and prevented sudden damages (Chazgi et al., 2024).

Conclusion

In this research, flood risk zoning has been done in the Tabas watershed. Based on

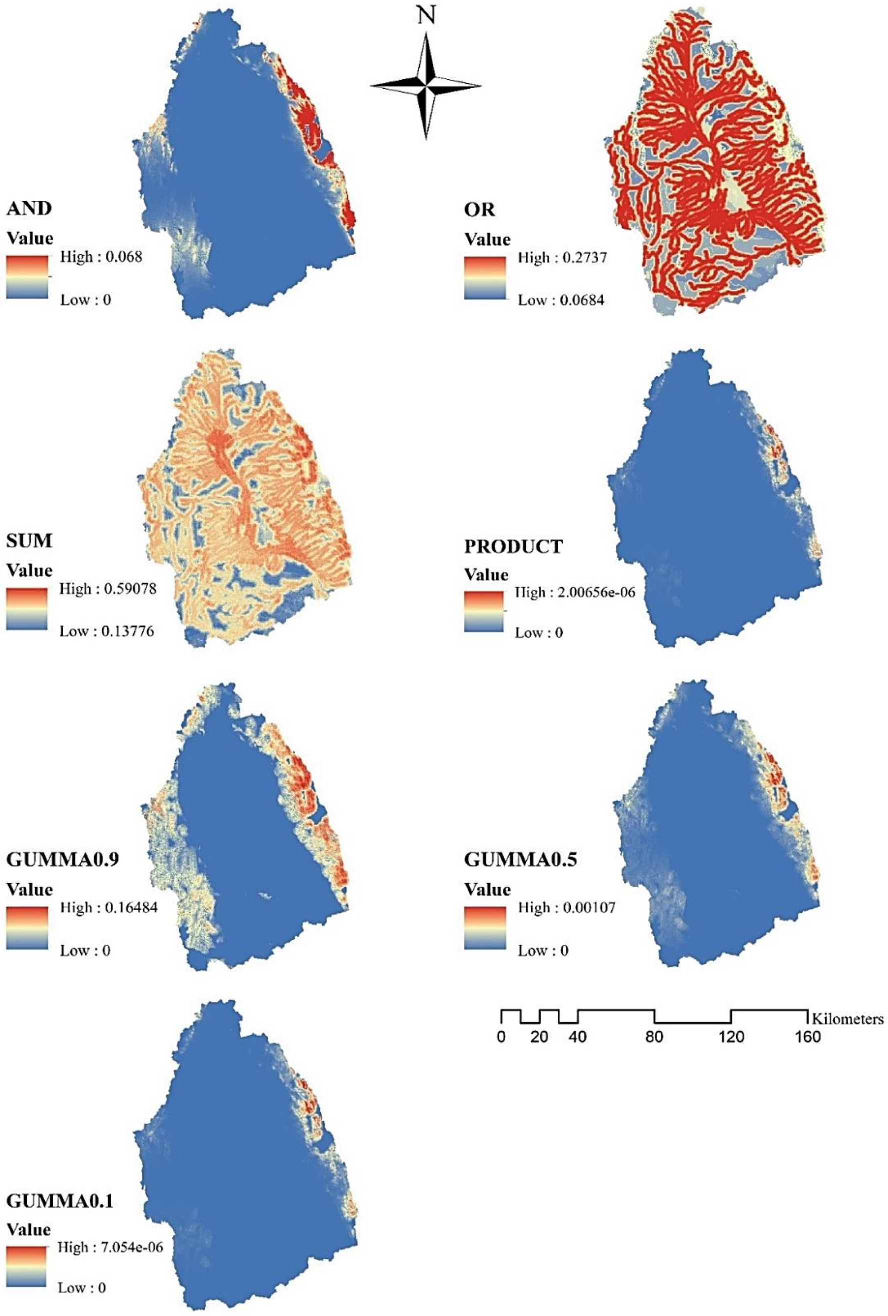

Fig4. Maps resulting from superimposing weighted fuzzy layers using fuzzy operators AND, OR, SUM, Product, Gamma0.9, Gamma0.5, Gamma0.1

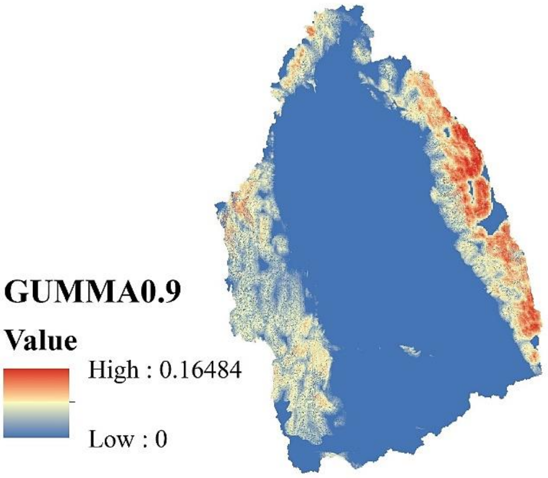

Fig5. The final map of Tabas plain flood zoning using the Gamma 0.9 operator

the range of values for each zone and the ground reality map, the Gamma operator 0.9 was chosen for the final flood risk zone. Furthermore, in this research, the prioritization and importance of different criteria in causing the flood phenomenon in the Tabas watershed were determined as follows: the criteria of distance from the river, slope, land use, rainfall, soil, DEM, and NDVI were respectively assigned the highest weights. The distance from the river, being the most influential among the variables, designates more pixels as flood risk areas than other variables. Conversely, the NDVI and DEM layers, which have fewer pixels indicating high flood risk (red color), are predominantly located in the eastern areas of the study border.

These findings align with the current research's results, recommending the distribution of land uses, specifically industrial, residential, and commercial ones, according to the flood risk potential zoning map this study generated. In potentially hazardous areas, we recommend measures like revitalizing vegetation, conducting watershed studies in basin DEM, monitoring land use changes in the upper reaches of the basin, and converting some rained and agricultural lands into gardens. Finally, it is suggested to utilize other multi-criteria methods (such as TOPSIS, etc.) to validate the flood risk potential in this area and compare their results with the findings of this research.

Reference

Bagheri, M. H., Farzaneh, M., & Rayegani, B. (2022). Development of Remote Sensing-Based Flood Estimation Methodology in Google Earth Engine. *Environment and Interdisciplinary Development*, 7(76), 12-26. https://doi.org/10.22034/envj.2022.154826

Beheshti Rad, M., Faiznia, S., Selajqa, A., & Ahmadi, H. (2009). Investigating the efficiency of landslide risk zoning model, confidence factor (CF) A case study of Moalem Kalaye watershed. *Natural Geography*, 2(5), 19-28. [In Persian].

Chezgi, J., & Hamedi, E. (2023). Flood Prioritization of Sarbaz River Sub-Basins Using SWAT Model. *Journal of Drought* *and Climate change Research*, *1*(3), 73-86. doi: 10.22077/jdcr.2023.6478.1026.

Eslaminezhad, S.A., Eftekhari, M., Akbari, M., Haji Elyasi, A., & Farhadian, H. (2022). Predicting flood prone areas using advanced machine learning models (Birjand plain), *Journal of Water and Irrigation Management*, 11(4), 885-904. 10.22059/jwim.2022.332875.934 [In Persian].

Eastman, J. R. (2012). *IDRISI Selva manual*. Clark University. Sitio web: www. Clarklabs. org.

Khorshidi , Sh., Rostami, N., & Salehpourjam, A. (2021). Prioritizing flood producing potential in ungauged watersheds using the AHP-VIKOR method (Case study: Haji-Bakhtiar Watershed, Ilam), Environmental Erosion *Researches,* 11(2), 66-92. 20.1001.1.22517812.1400.11.2.4.4 [In Persian].

Kubal, C., Haase, D., Meyer, V., & Scheuer, S. (2009). Integrated urban flood risk assessment–adapting a multicriteria approach to a city. *Natural hazards and Earth System Sciences*, 9(6), 1881-1895. https://doi.org/10.5194/nhess-9-1881-2009.

Mishra, K., & Sinha, R. (2020). Flood risk assessment in the Kosi megafan using multi-criteria decision analysis: A hydro-geomorphic approach. *Geomorphology*, *350*, 106861.https://doi.org/10.1016/j.geomorph.2019.106861

Ogato, G. S., Bantider, A., Abebe, K., & Geneletti, D. (2020). Geographic information system (GIS)-Based multicriteria analysis of flooding hazard and risk in Ambo Town and its watershed, West shoa zone, oromia regional State, Ethiopia. *Journal of Hydrology: Regional Studies*, 27, 100659. https://doi.org/10.1016/j.ejrh.2019.100659

Qanavati, E., Karam, A., & Agha Alikhani, M. (2012). Flood risk zonation in the Farahzad basin (Tehran) using Fuzzy model. *Journal of Geography and Environmental Planning Consecutive*, 48(4). 20.1001.1.20085362.1391.23.4.8.2

Ouma, Y. O., & Tateishi, R. (2014). Urban flood vulnerability and risk mapping using integrated multi-parametric AHP and GIS: methodological overview and case study assessment. *Water*, 6(6), 1515-1545. https://doi.org/10.3390/w6061515.

Patil, J. P., Sarangi, A., Singh, O. P., Singh, A.K., & Ahmad, T. (2008). Development of a GIS interface for estimation of runoff from watersheds. *Water Resources Management*, 22(9), 1221-1239. https://doi.org/10.1007/s11269-007-9222-8

Rezaei, A. R., & Roshani, A. (2024). Prioritization of Factors Affecting Drought using the Fuzzy Analytic Hierarchy Process Method (Study Case: Torbat Heydarieh City). *Journal of Drought and Climate change Research*, *2*(1), 77-92. doi: 10.22077/jdcr.2024.7255.1057

Rashetnia, S., & Jahanbani, H. (2021). Flood vulnerability assessment using a fuzzy rule-based index in Melbourne, Australia. *Sustainable Water Resources Management*, 7(2), 1-13. https://doi.org/10.1007/s40899-021-00489-w.

Saaty, T. L. (1990). How to make a decision: the analytic hierarchy process. *European Journal of Operational Research*, 48(1), 9-26. https://doi.org/10.1016/0377-2217(90)90057-I.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), 83-98. https://doi.org/10.1504/IJSSCI.2008.017590.

Saeedi, S., & Asiaei, M. (2021). Flood risk zoning in Sabzevar city using fuzzy logic, *Journal of Urban and Regional Development Planning*, 5(15), 27-49. https://doi.org/10.30473/grup.2024.55316.2554 [In Persian].

Schumann, G. J. (2021). Earth Observation for Flood Applications: Progress and Perspectives. *Earth Observation for Flood Applications*, 3-6. https://doi.org/10.1016/B978-0-12-819412-6.00001-8.

Solaimani, K., & Darvishi, Sh. (2020). Zoning and monitoring of spring 2019 Flood hazard in Khuzestan using Landsat-8 data, *Iranian Journal of Eco Hydrology*, 7(3), 647-662. 10.22059/ije.2020.302703.1333 [In Persian].

Zadeh, L. A. (1965). *Fuzzy sets. Information and control*, 8(3), 338-353. https://doi.org/10.1016/S0019-9958(65)90241-X.

Zadeh, L. A. (1988). Fuzzy logic. *Computer*, 21(4), 83-93. https://doi.org/10.1109/2.53