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Integrated Neutrosophic Best-Worst Method for Comprehensive Analysis and Ranking of Flood Risks: A Case Study Approach from Aswan, Egypt

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Abstract: This paper presents a comprehensive framework for the analysis and ranking of flood risks with respect to regional variations and data uncertainties under a Neutrosophic environment. The research introduces a novel approach to flood risk mitigation and management, bringing together the scientifically robust Best-Worst Method (BWM) and single-valued Neutrosophic set for the first time. The unique application of a single-valued Neutrosophic set allows us to better illustrate and manage uncertainty, imprecision, and vagueness in data. Additionally, we employ BWM, a multi-factor decision-making method, for discerning and ranking the most influential flood risk factors. Together, the integrated methodologies provide a balanced, comprehensive guide for decision-makers and risk handlers, showcasing efficient and effective mitigation strategies. The paper emphasizes the importance of mitigating flood risks to save lives and properties and to manage and conserve environmental resources efficiently. A case study was conducted in Aswan, Egypt, to assess flood susceptibility. The results revealed that 12.60% of the study area exhibited very high susceptibility to flooding, 18.77% showed high susceptibility, 23.94% exhibited moderate susceptibility, 22.91% registered a low susceptibility, and the remaining 21.78% showed very low susceptibility to flooding.

Keywords: Best Worst Method; Single Valued Neutrosophic Set; Flood Risks; Risk Management.

1. Introduction

Natural hazards, such as floods, pose a significant threat to communities around the globe, causing widespread socio-economic and environmental damage [1]. Increased human activity coupled with effects of climate change has led to an escalation of these hazards, placing more people and properties at risk. Flood susceptibility, in particular, plays a critical role in the burgeoning hazard scape. Particularly in regions like Egypt, the impact of flooding can be devastating due to its unique geographical features and growing population [2, 3]. Aswan, Egypt, stands as one of the areas with a growing need for effective flood risk management strategies, considering the frequent and increasing intensity of flood events in the region[4]. Despite the crucial need to manage and mitigate flood risks, this area lacks a comprehensive and in-depth analysis of flood susceptibility—a gap this study aims to fill. Understanding and managing these risks necessitates a comprehensive, nuanced, and sophisticated set of tools. This research proposes to widen the scope of traditional risk analysis by introducing a neutrosophic environment, providing a platform for analyzing and ranking flood risks based on more fluid and less precise data. The science of Neutrosophy, developed by Florentin Smarandache [5] in the late 90s, offers a potent tool for quantifying and dealing with uncertainty, imprecision, and vagueness in data. Meanwhile, the Best-Worst Method (BWM), as a versatile multi-factor decision-making technique, is particularly well-suited for discerning and ranking the most influential risk factors. Unfortunately, these analytic strategies have remained largely disparate. Thus, there's a growing need to introduce integrated strategies, unifying the robustness of BWM with the uncertainty-ridden reality as captured by Neutrosophy for improved flood risk mitigation and management. An approach which not only acknowledges the uncertainty that permeates flood risk prediction but, additionally, transforms this alleged limitation into a strategic advantage.

1.1 Problem Statement

The increasing frequency and intensity of flood events underscore the acute need for effective flood risk management [6, 7]. Currently, the application of diverse regional characteristics and data uncertainties in flood risk analysis is insufficient, leading to a significant gap in the creation of resourceful mitigation and management strategies. The disconnection between the science of Neutrosophy and the BWM further exacerbates this issue. Despite Neutrosophy's potential for precisely quantifying and handling uncertainty, imprecision, and vagueness in data, and BWM's efficiency at identifying and ranking pivotal risk factors, these two analytical strategies have scarcely been integrated in the domain of flood risk management. This overlooked integration signifies a pressing problem: the potential for improved flood risk management strategies using these methodologies remains largely untapped. This paper aims to address this specific issue. This study will propose an innovative approach that unifies the robustness of BWM with the uncertainty-ridden reality as encapsulated by Neutrosophy, hence creating a comprehensive strategy for flood risk prediction, mitigation, and management. It poses to transform the limitation of uncertainty into a strategic advantage for efficient decision-making and resource allocation in flood risk management.

1.2 Paper objectives

The objectives of this paper can be defined as follows:

1. To integrate the principles of Neutrosophy and the BWM in the field of flood risk management. This goal addresses the current lack of integration and seeks to leverage the strengths of both methodologies.
2. To create a novel strategy for efficient flood risk prediction, mitigation, and management. This strategy will be grounded in the fusion of Neutrosophy and BWM, presenting a comprehensive approach to handling the diverse regional characteristics and data uncertainties that populate flood risk analysis.
3. To transform the conceptualization of data uncertainties, viewing them not as hindrances, but as strategic advantages that can aid in robust decision-making and efficient resource allocation. This objective is tied to the distinctive ability of Neutrosophy to precisely quantify and manage uncertainty, vagueness, and imprecision in data.

Overall, this paper will make strides towards improving flood risk management by harnessing the potential of Neutrosophy and BWM.

1.3 Methodology overview

This paper employs a systematic approach for the analysis, ranking, and mitigation of flood risks, centering on the integration of the BWM and single valued Neutrosophic set for the first time in this domain.

The methodology comprises of three main stages:

1. Single Valued Neutrosophic Set: This part involves capturing and illustrating uncertainty, imprecision, and vagueness in regional characteristics and flood data. By assuming an approach rooted in Neutrosophic logic, the truth-membership degree (T), indeterminacy-membership (I), and falsity-membership degree (F) of each point or parameter in the study area can be realistically depicted [8].
2. Best-Worst Method: In this stage, using BWM—a multi-factor decision-making method—the influential flood risk factors are identified and prioritized. To conduct this, we collect expert opinions on the best and worst factor based on their judgments of which factor is the most

desirable (best) and which is the least desirable (worst). This ranking contributes to discerning the relative weight of each risk factor and contributes to the development of robust mitigation strategies.

3. Weighted Overlay: within the ArcGIS suite was incorporated as a key step in our methodology. This tool allows us to combine multiple raster datasets, representing various flood risk factors, into a single dataset with an assigned importance or weightage for each factor[9]. After applying the Single Valued Neutrosophic Set and Best-Worst Method to identify and rank flood risk factors, the Weighted Overlay process will be implemented as described below:
   - Defining input layers and weights: Each identified risk factor (such as slope, rainfall, elevation, soil type, etc.) is represented through a raster layer. Based on our BWM ranking, we assign a weight to each factor, indicating its significance in influencing flood risk.
   - Reclassification of raster layers: Each raster layer is reclassified into a common scale (for example, 1-10). This ensures that the input layers are compatible, allowing meaningful combination and comparison.
   - Application of weights: The reclassified risk factor layers are then overlaid, and a weighted sum is calculated to produce the final output raster. This final output clearly indicates regions of varying flood susceptibility, providing critical spatial understanding for risk management.

By integrating these three steps methodology, the proposed methodology constructs a balanced and detailed landscape of flood risks, facilitating improved decision making. To validate this approach, a case study was carried out in Aswan, Egypt, assessing the level of flood susceptibility. The findings confirmed the robustness and reliability of this integrated methodology in defining and treating flood risks.

1.4 Paper contributions

This paper has several meaningful contributions:

1. Methodological Contribution: This paper innovates methodologically by combining the BWM with a Single Valued Neutrosophic Set for flood risk analysis, enhancing the robustness of risk assessment.
2. Incorporation of Weighted Overlay: The integration of Weighted Overlay within ArcGIS in our proposed methodology assists in merging spatial aspects with deciding factors, which is a novelty in flood risk management research.
3. Addressing Uncertainty: This methodology addresses uncertainty, vagueness, and imprecision in flood risk factors in a significant way through Neutrosophic logic, enhancing the soundness of the resulting analysis.
4. Practical Implications: A practical testing in Aswan, Egypt presented as a case study validates the efficacy of the proposed methodology, demonstrating applied value in real-world scenarios.
5. Enabling Informed Decisions: The prioritized ranking of flood risk factors aids in the better design of flood mitigation strategies, creating the potential for more informed decision-making.

In sum, the paper contributes to both theoretical understanding and practical application in flood risk management.

1.5 Paper structure

The structure this paper is as follows:

Introduction: a brief overview of flood risks, the importance of managing them, the state of current research, and the focus of this paper (risk analysis and ranking factor for flood mitigation). **Review of Literature**: Detailed examination of existing studies on flood risk analysis and management **Methodology:** The proposed approach using a single-valued Neutrosophic Set, the best-Worst Method, and a weighted overlay within ArcGIS is explained. The reasons for method selection and their sequence are explained. **Case Study Application**: results and **Discussions:** The proposed methodology and tools are applied to a real-world scenario (e.g., Aswan, Egypt), and the process and the findings are explained. Results analysis and discussion of their implications on flood risk management are also explained. **Conclusion**: The paper's findings are summarized, the potential impact is discussed, and future research directions are laid out. **References**: Citation of all the studies and sources referred to throughout the paper.

2. Literature Review

2.1 Understanding Flood Risks

Flood risks emerge from a complex interplay of environmental, socioeconomic, and infrastructural factors [10]. At the heart of flood risk analysis lies the understanding of these risks - their sources, their potential impact, and effective strategies for their management. The primary concern regarding flood risks is their sheer unpredictability and potential to cause extensive damage to life, property, and the environment [11]. Previous case studies have shown the exacerbating effect of factors such as urbanization, climate change, and inadequate infrastructure on increasing flood risks [12]–[14]. Management strategies for flood risks also vary significantly. They range from built interventions like flood barriers and levees to natural solutions such as wetland conservation and reforestation. In recent years, scientists and policy-makers have recognized the importance of using a combination of different strategies, tailored to the specific conditions of each region, to reduce flood risks [15, 16]. Developing effective flood risk management strategies also requires understanding and integrating local community views and experiences, creating a cooperative environment for proactive preparation and response. Recent literature indicates a trend toward the development of more sophisticated tools for flood risk analysis [17, 18]. These tools incorporate probabilistic risk assessment, decision trees, and geographic information systems (GIS) to analyze flood patterns, simulate flood scenarios and devise effective risk mitigation strategies [19, 20].

2.2 Existing Methodologies in Flood Risk Analysis

The landscape of flood risk analysis is incredibly diverse, characterized by the use of various scientific methods, analytical models, and socio-economic analysis. These methodologies aim to identify, assess, and foresee flood risks, ultimately guiding the design and implementation of effective flood risk management strategies. In the interest of precision, several scientific models have been developed to quantify flood risks. Hydrological models, for example, simulate water cycle components within a defined specific area, aiding in the prediction of possible flood events [21]. Hydraulic models, conversely, are employed to understand the movement of water across landscapes during flood events [22]. In parallel, the application of GIS has revolutionized flood risk analysis [23]. This tool allows for spatial analysis of flood risks, overlays of flood scenario models over existing maps, and the creation of detailed flood risk maps, proving critical in land use planning and flood mitigation efforts. According to various case studies, climate models combined with socio-economic data have proven significantly helpful in long-term flood risk prediction and management [24, 25]. Socio-economic analysis serves in ascertaining the vulnerability and adaptability of communities to flood events, paving the way for community-specific flood risk management strategies [26]. Research indicates an increasing emphasis on integrated methodologies that blend scientific modeling, socio-economic considerations, and local knowledge to create robust and inclusive flood risk management strategies. However, these methods are not without their challenges and limitations, warranting further research and advancement in this realm.

2.3 Role of Neutrosophic Logic in Risk Mitigation

Neutrosophic logic, a branch of multi-valued logic, is a novel approach used in uncertain and indeterminate problem-solving instances, offering new avenues in flood risk mitigation [27]. Notably, it operates on the idea that every notion has its anti-notion and a degree of neutralities, ranging from truth, and indeterminacy, to falsity. Applying neutrosophic logic in flood risk mitigation involves the use of neutrosophic sets, which handle uncertainty by providing membership, non-membership, and indeterminacy functions [28]. This range of possibilities allows neutrosophic sets to capture a more comprehensive picture of the complex reality of flood risks, thereby enabling a more robust analysis. Neutrosophic logic also aids in decision-making processes relevant to flood risk mitigation. These involve crucial elements with varying degrees of certainty, ambiguity, and subjectivity. With neutrosophic multi-factor decision-making tools, such as Neutrosophic Analytic Hierarchy Process (AHP) and Neutrosophic Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), it is easier to rank and prioritize various flood mitigation strategies based on different factors [29]. Therefore, the integration of neutrosophic logic in flood risk analysis could potentially yield more precise, flexible, and adaptable flood mitigation and risk management strategies, making it a valuable tool in investigations within neutrosophic environments.

2.4 The Implementation of the Best-Worst Method in Environmental Research

The BWM technique is an increasingly popular decision-making method used in environmental research [30, 31]. It assists in identifying both the most and least significant factors among a set of alternatives. By evaluating the maximum and minimum differences together in a unified model, BWM generates more reliable and optimal results [32]. In environmental research like flood risk management, BWM is utilized in establishing a hierarchy or ranking of possible mitigation measures based on their effectiveness, economic feasibility, and environmental impact [33]. For instance, BWM could be employed to prioritize flood risk reduction strategies such as dam construction, river dredging, and floodplain zoning, considering diverse factors like cost, social consequences, ecological impact, etc. Moreover, BWM's comparative approach allows for a more objective assessment of different environmental strategies. It helps stakeholders to weigh the pros and cons of each mitigation method and make informed decisions based on systematic comparison rather than personal bias or single-factor consideration. Despite its strengths, the implementation of BWM in environmental research is not without challenges. As it involves relatively complex calculations, the process may require advanced knowledge of mathematics or the use of specific software tools. Moreover, the decision-making process can be affected by the quality of input data and requires effective communication among stakeholders. Thus, while BWM holds great potential in environmental research, its deployment must be carefully managed to ensure maximum benefits.

While previous research has applied multi-factor decision-making methods to flood risk analysis, few if any have incorporated the BWM into their analytical frameworks. In addition, while uncertainties in flood risk data are widely recognized, there is a lack of detailed methods for effectively managing these uncertainties. Furthermore, existing methods usually apply classical logic, but cannot effectively deal with the uncertainty, imprecision, and vagueness inherent in flood risk assessment data. Also, flood risk mitigation strategies are not always sufficiently tailored to specific, local risks due to lacking detailed, localized flood risk analysis. This research bridges these gaps by incorporating a single-valued Neutrosophic set in BWM for the first time, providing a novel approach to flood risk mitigation and management.

3. Methodology

3.1 Study Area

Aswan is a city located in the southern part of Egypt and is the capital of the Aswan Governorate [34]. Aswan is geographically located on the eastern bank of the Nile River at the first cataract, approximately 899 kilometers south of Cairo, Egypt's capital city. It is situated near the Tropic of Cancer, in the southernmost part of Egypt as shown in Figure 1. Latitude and longitude coordinates for Aswan are approximately 24.0889° N and 32.8998° E respectively. Aswan is surrounded by the Eastern Desert, which is characterized by hills and rugged highlands. To the southwest of the city lies Lake Nasser, one of the largest artificial lakes in the world, created by the Aswan High Dam. Aswan's geographic location and its proximity to critical natural features like the Nile River and the Eastern

Desert contribute significantly to its climate, hydrological conditions, and accordingly, its flood risk profile. It is one of the driest inhabited places in the world and is noteworthy for its significant geologic and geographic features. From the perspective of this study, important attributes of Aswan include its geographic location along the Nile River, its climate, geology, and hydrology. This city experiences high temperatures in the summer and mild winters. The Nile River has a significantly influential role in shaping the city's flood risk profile; its seasonal fluctuations, driven by the African monsoons, provide flood risks. Moreover, the Aswan High Dam, situated near Aswan city, plays a pivotal role in controlling the flow of the Nile River and subsequently affecting the flood risk in the area. The city also contains a high concentration of structures and populations, increasing potential flood vulnerability. These factors combined present the city as a suitable study area for this research.

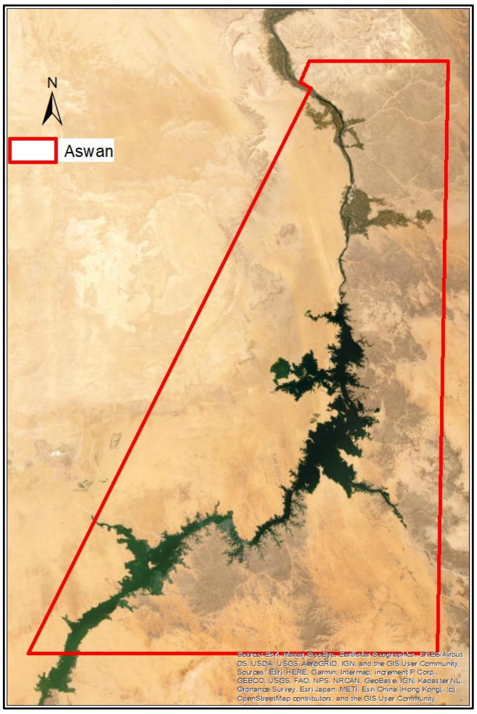


Figure 1. Study area.

3.2 Flood Susceptibility Factors

In this paper, the neutrosophic BWM method is used to utilize nine factors. These factors are instrumental in understanding and assessing the flood risks associated with the geographic and topographic characteristics of the study area. The factors for flood susceptibility in this study are detailed in Table 1 and shown in Figure 2. The spatial and attribute data used in this investigation were obtained from secondary data sources. The various data sources used are discussed in further detail in the phrases that follow. Slope and aspect were developed using ArcGIS Pro software tools and a global digital elevation model (DEM) produced by the United States Geological Survey (USGS). The FAO Soil Portal website provided the information for the soil-type map. The Egyptian National Authority for Remote Sensing and Space Sciences (NARSS) collects data on both rivers and roads. The remaining data are created with the aid of various analysis tools found in ArcGIS Pro 2.6, including the raster calculator, curvature, aspect, and slope.

Table 1. Factors for flood susceptibility assessment.

Factor	Description	Classes	Class Classification	Class Rank	Cost/ Benefit	Factor Weight (%)
		WB	Very Low	1		5

Soil Type (FRF1)	Different soil types can influence the radius and speed of floodwater. For example, sandy soil with high permeability can quickly absorb water, decreasing flood risks, while clay soil with low permeability may cause water to pool on the surface, increasing flood risks.	E	Low	2	Benefit(Maximize)	
		SCS	Moderate	3		
		SS	High	4		
		SC	Very High	5		
Slope (FRF2)	Slope can influence the speed and direction of floodwater. Steeper slopes can lead to faster water flow and could possibly aggravate soil erosion, while gentle slopes may slow water flow and decrease flood risks.	0 - 2.866623164	Very High	5	Cost(Minimize)	17
		2.866623165 - 6.775654752	High	4		
		6.775654753 - 12.76950319	Moderate	3		
		12.7695032 - 21.10877057	Low	2		
		21.10877058 - 66.45353699	Very Low	1		
Distance from Road (FRF3)	Roads can divert or block natural water courses, potentially leading to flooding. The proximity to roads can therefore determine the flood susceptibility of a region.	0 - 0.029141037	Very High	5	Cost(Minimize)	8
		0.029141037 - 0.0751532	High	4		
		0.0751532 - 0.128834057	Moderate	3		
		0.128834057 - 0.197852302	Low	2		
		0.197852302 - 0.391103387	Very Low	1		
Distance from Drainage (FRF4)	The distance from drainage can significantly affect flood risk, as locations closer to drainage channels may have higher flood risks due to potential overflow.	0 - 0.312295608	Very High	5	Cost(Minimize)	13
		0.312295608 - 0.624591216	High	4		
		0.624591216 - 0.976924722	Moderate	3		
		0.976924722 - 1.345273388	Low	2		
		1.345273389 - 2.041932821	Very Low	1		
Distance from Dams	Dams retain large volumes of water. If a dam overflows or breaches, areas downstream and close to the dam face significant flood risks.	0 - 0.562840344	Very Low	1	Benefit(Maximize)	2
		0.562840344 - 0.979759117	Low	2		
		0.979759117 - 1.427946798	Moderate	3		
		1.427946799 - 1.87613448	High	4		
		1.876134481 - 2.65785718	Very High	5		
Distance from River (FRF6)	The closer a location is to a river, the higher the flood risk, particularly in cases of river overflow.	0 - 0.110352123	Very High	5	Cost(Minimize)	13
		0.110352123 - 0.258756701	High	4		
		0.258756701 - 0.418577017	Moderate	3		
		0.418577017 - 0.605034051	Low	2		
		0.605034051 - 0.970337629	Very Low	1		

SuFRFace Curvature (FRF7)	This defines the convexity or concavity of the surface, influencing how water collects or disperses, thereby affecting flood susceptibility.	-273,456,005,100 - -8,767,064,907	Very Low	1	Benefit(Maximize)	8
		-8,767,064,906 - -2,149,841,402	Low	2		
		-2,149,841,401 - 4,467,382,103	Moderate	3		
		4,467,382,104 - 15,496,087,950	High	4		
		15,496,087,960 - 289,007,992,800	Very High	5		
DEM (FRF8)	A DEM can determine the potential flood path, as water typically flows from higher to lower areas.	60 - 190	Very High	5	Cost(Minimize)	13
		190.0000001 - 247	High	4		
		247.0000001 - 310	Moderate	3		
		310.0000001 - 389	Low	2		
		389.0000001 - 661	Very Low	1		
Aspect (FRF9)	The direction a slope faces (north, south, east, and west). This could influence the microclimate and in turn, the propensity for heavy rainfall and potential flooding.	-1 - 57.01191071	Very High	5	Cost(Minimize)	21
		57.01191072 - 136.2476912	High	4		
		136.2476913 - 211.2386977	Moderate	3		
		211.2386978 - 284.8147796	Low	2		
		284.8147797 - 359.8057861	Very Low	1		

3.3 Best Worst Mwthod

The BWM method is a multi-criteria decision-making method developed by Rezaei (2015) [35]. The key strength of this method lies in its simplicity: it only requires a small number of pairwise comparisons.

Here are the steps in applying the Best-Worst Method:

1. Identify the Factor/Alternatives: The first step involves identifying the factor or alternatives that will be used for decision-making.
2. Determine the Best and Worst Factors: Identify the best and worst factors or alternatives among those identified. The 'best' refers to that with the greatest benefit or highest importance, while the 'worst' refers to that with the least benefit or lowest importance.
3. Perform Pairwise Comparisons: Compare the best factor to all other factors, the worst factor to all other factors, and then the best to the worst. These comparisons yield a consensus estimate of the relative importance of the best and worst factors.
4. Calculate Weights: Utilizing a mathematical model, calculate the weights of all the factors. These weights offer a measure of the relative importance of each criterion compared to all the others.
5. Check Consistency: It's crucial to ensure the consistency of the responses provided in the pairwise comparisons. If the Consistency Ratio (CR) is less than 0.1, the preference weights are acceptable; if not, the pairwise comparisons need to be revised.
6. Rank Alternatives: Finally, use the calculated weights to rank the alternatives and make the decision. The alternative with the highest weight is usually considered the best choice.

3.4 Best Worst Method under Neutrosophic Set

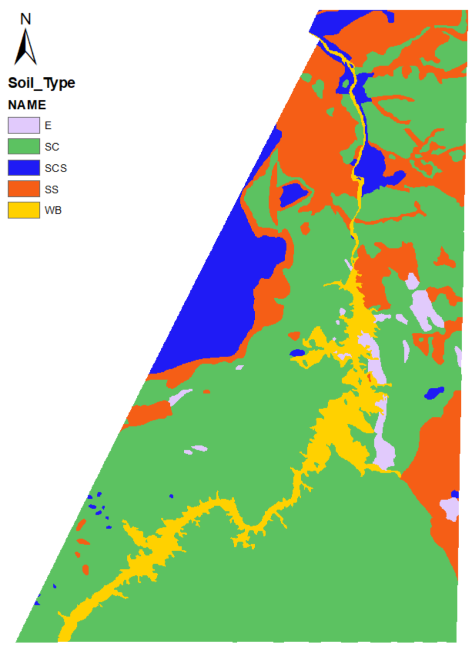
BWM's excellent consistency and data adaptability in regard to computations with the least comparability matrix has led to its widespread use [36, 37]. This section introduces the BWM under the single-valued neutrosophic set. We used the single-valued neutrosophic numbers to evaluate the factor. These numbers can deal with vague data.

Step 1. Determine the factors of flood risks

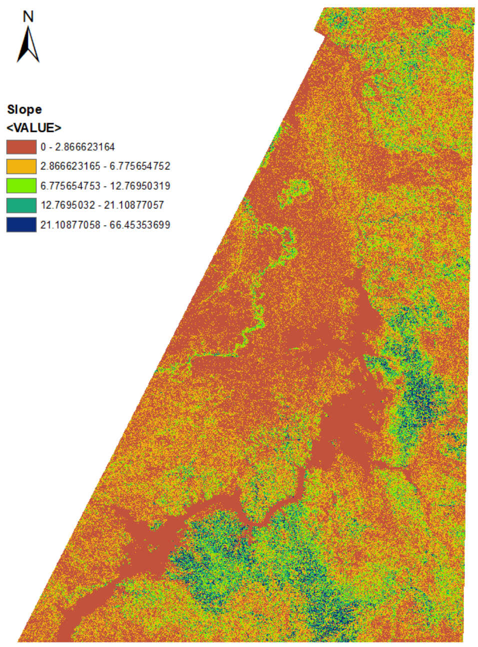
In this step, the factors used for flood susceptibility are identified as shown in Figure 3.
Step 2. Identify the most important factor and least important factors.
We pose the question, "Which factor or sub-factor is the most significant and least significant for the flood risks?" to elicit opinions on which factors are most and least relevant in this context.
Step 3. Compare the most significant factors with other factors.
After settling on the best factor (F), participants are required to assess its importance relative to the other factor on a single-valued neutrosophic scale. The final product of this process is the (FM) vector, which consists of the following values:
$X_F = (x_{F1}, x_{F2}, x_{F3} \dots \dots \dots x_{Fn})$
Step 4. Compare the rest of factors with the least important factor.
Participants are then asked to rank the remaining factor from least to most essential, with single valued neutrosophic number 1 representing the same importance as the poorest criterion (L) and single valued neutrosophic number 9 representing the utmost importance. The resulting vector, others-to-worst (FL), was calculated as follows:
$X_L = (x_{1L}, x_{2L}, x_{3L} \dots \dots \dots x_{nL})^T$
Step 5. Compute the weights of each factor.

$$\begin{cases} X_M^k | \, e^k \quad \left(\frac{1}{e^k}\right), \forall k = 1,2,3 \dots k \\ X_L^k | \, e^k \quad (e^k), \forall k = 1,2,3 \dots k \\ e^k | \, e^* \quad Dir(\alpha \times e^*), \forall k = 1,2,3 \dots k \end{cases}$$

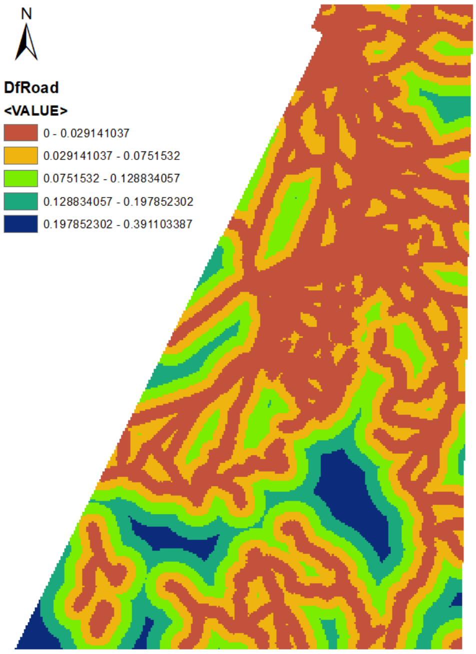
Step 6. Compute the final weights of each factor.
$G_i = \sum e_j * a_{ij}^{nor}$
j=1, a_{ij}^{nor} refers to the normalization value



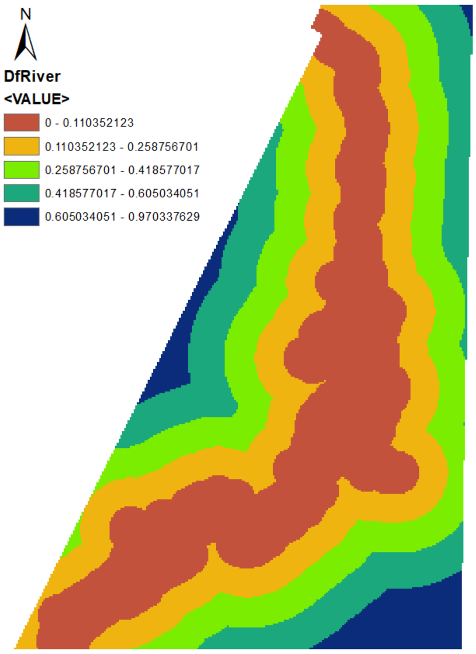
2.1 Soil_Type



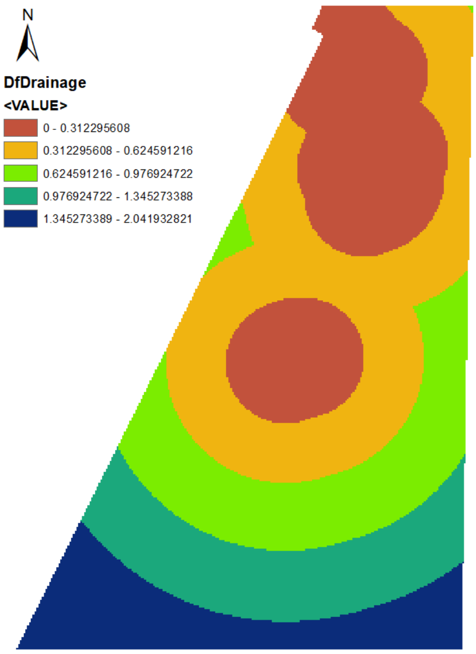
2.2 Slope



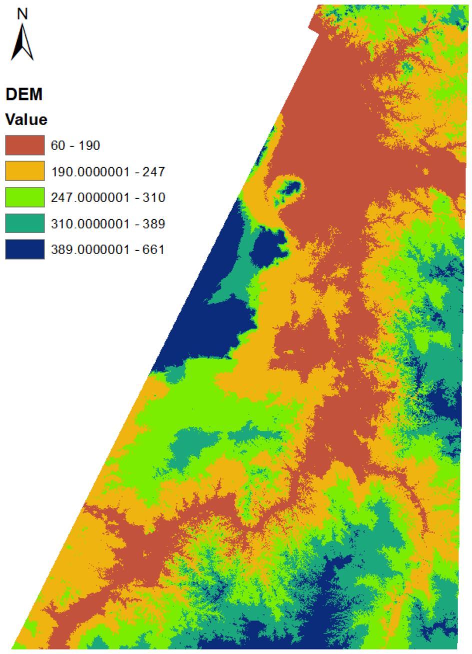
2.3 Distance from Road



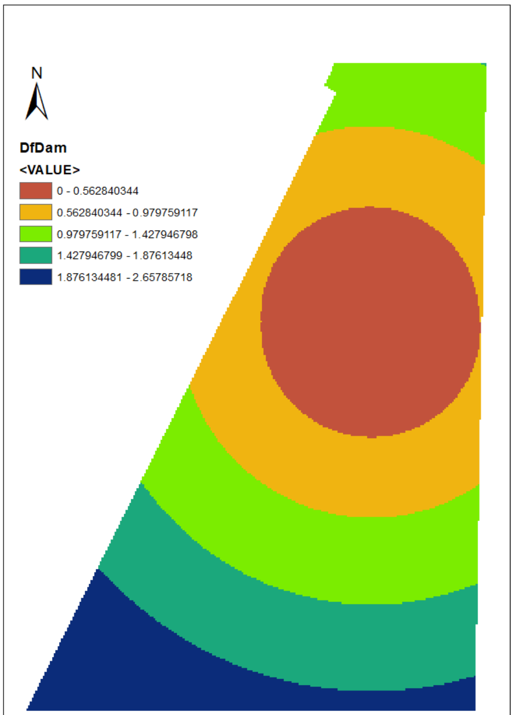
2.4 Distance from River



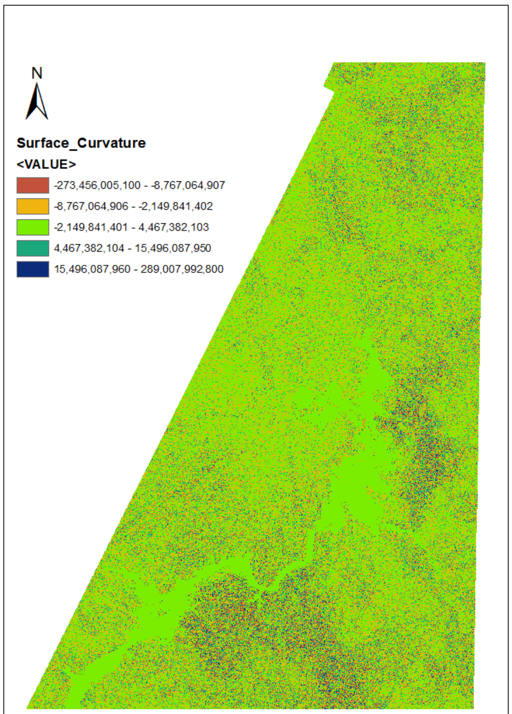
2.5 Distance from Drainge



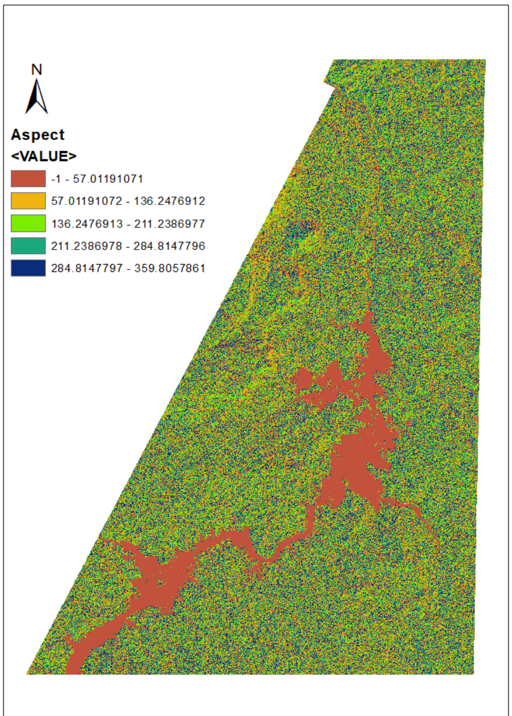
2.6 DEM



2.7 Distance from Dams



2.8 Surface_Curvature



2.9 Aspect

Figure 2. Factors map layers using ArcGIS Pro 2.9.

4. Case Study Application: Results and Discussion

The N-BWM was used to develop the weights for the factors. The main factors evaluations are exhibited in Table 2.

Table 2. Evaluation of flood risks factors using Single Valued neutrosophic numbers

	FRF_1	FRF_2	FRF_3	FRF_4	FRF_5	FRF_6	FRF_7	FRF_8	FRF_9
FRF_1	1	(0.9,0.1,0.2)	(0.8,0.2,0.3)	(0.6,0.4,0.5)	(0.7,0.3,0.4)	(0.8,0.2,0.3)	(0.3,0.75,0.65)	(0.8,0.2,0.3)	(0.9,0.1,0.2)
FRF_2	1/(0.9,0.1,0.2)	1	(0.9,0.1,0.2)	(0.25,0.75,0.80)	(0.25,0.75,0.80)	(0.25,0.75,0.80)	(0.7,0.3,0.4)	(0.6,0.4,0.5)	(0.7,0.3,0.4)
FRF_3	1/(0.8,0.2,0.3)	1/(0.9,0.1,0.2)	1	(0.9,0.1,0.2)	(0.25,0.75,0.80)	(0.7,0.3,0.4)	(0.3,0.75,0.65)	(0.3,0.75,0.65)	(0.6,0.4,0.5)
FRF_4	1/(0.6,0.4,0.5)	1/(0.25,0.75,0.80)	1/(0.9,0.1,0.2)	1	(0.8,0.2,0.3)	(0.9,0.1,0.2)	(0.6,0.4,0.5)	(0.8,0.2,0.3)	(0.8,0.2,0.3)
FRF_5	1/(0.7,0.3,0.4)	1/(0.25,0.75,0.80)	1/(0.25,0.75,0.80)	1/(0.8,0.2,0.3)	1	(0.6,0.4,0.5)	(0.3,0.75,0.65)	(0.9,0.1,0.2)	(0.7,0.3,0.4)
FRF_6	1/(0.8,0.2,0.3)	1/(0.25,0.75,0.80)	1/(0.7,0.3,0.4)	1/(0.9,0.1,0.2)	1/(0.6,0.4,0.5)	1	(0.6,0.4,0.5)	(0.7,0.3,0.4)	(0.6,0.4,0.5)
FRF_7	1/(0.3,0.75,0.65)	1/(0.7,0.3,0.4)	1/(0.3,0.75,0.65)	1/(0.6,0.4,0.5)	1/(0.3,0.75,0.65)	1/(0.6,0.4,0.5)	1	(0.8,0.2,0.3)	(0.8,0.2,0.3)
FRF_8	1/(0.8,0.2,0.3)	1/(0.6,0.4,0.5)	1/(0.3,0.75,0.65)	1/(0.8,0.2,0.3)	1/(0.9,0.1,0.2)	1/(0.7,0.3,0.4)	1/(0.8,0.2,0.3)	1	(0.9,0.1,0.2)
FRF_9	1/(0.9,0.1,0.2)	1/(0.7,0.3,0.4)	1/(0.6,0.4,0.5)	1/(0.8,0.2,0.3)	1/(0.7,0.3,0.4)	1/(0.6,0.4,0.5)	1/(0.8,0.2,0.3)	1/(0.9,0.1,0.2)	1
	FRF_1	FRF_2	FRF_3	FRF_4	FRF_5	FRF_6	FRF_7	FRF_8	FRF_9
FRF_1	1	(0.25,0.75,0.80)	(0.6,0.4,0.5)	(0.25,0.75,0.80)	(0.6,0.4,0.5)	(0.8,0.2,0.3)	(0.6,0.4,0.5)	(0.8,0.2,0.3)	(0.8,0.2,0.3)
FRF_2	1/(0.25,0.75,0.80)	1	(0.9,0.1,0.2)	(0.25,0.75,0.80)	(0.25,0.75,0.80)	(0.25,0.75,0.80)	(0.6,0.4,0.5)	(0.6,0.4,0.5)	(0.7,0.3,0.4)
FRF_3	1/(0.6,0.4,0.5)	1/(0.9,0.1,0.2)	1	(0.9,0.1,0.2)	(0.6,0.4,0.5)	(0.7,0.3,0.4)	(0.8,0.2,0.3)	(0.3,0.75,0.65)	(0.6,0.4,0.5)
FRF_4	1/(0.25,0.75,0.80)	1/(0.25,0.75,0.80)	1/(0.9,0.1,0.2)	1	(0.25,0.75,0.80)	(0.6,0.4,0.5)	(0.6,0.4,0.5)	(0.6,0.4,0.5)	(0.8,0.2,0.3)
FRF_5	1/(0.6,0.4,0.5)	1/(0.25,0.75,0.80)	1/(0.6,0.4,0.5)	1/(0.25,0.75,0.80)	1	(0.6,0.4,0.5)	(0.3,0.75,0.65)	(0.6,0.4,0.5)	(0.7,0.3,0.4)
FRF_6	1/(0.8,0.2,0.3)	1/(0.25,0.75,0.80)	1/(0.7,0.3,0.4)	1/(0.6,0.4,0.5)	1/(0.6,0.4,0.5)	1	(0.6,0.4,0.5)	(0.6,0.4,0.5)	(0.6,0.4,0.5)
FRF_7	1/(0.6,0.4,0.5)	1/(0.6,0.4,0.5)	1/(0.8,0.2,0.3)	1/(0.6,0.4,0.5)	1/(0.3,0.75,0.65)	1/(0.6,0.4,0.5)	1	(0.8,0.2,0.3)	(0.8,0.2,0.3)
FRF_8	1/(0.8,0.2,0.3)	1/(0.6,0.4,0.5)	1/(0.3,0.75,0.65)	1/(0.6,0.4,0.5)	1/(0.6,0.4,0.5)	1/(0.6,0.4,0.5)	1/(0.8,0.2,0.3)	1	(0.25,0.75,0.80)
FRF_9	1/(0.8,0.2,0.3)	1/(0.7,0.3,0.4)	1/(0.6,0.4,0.5)	1/(0.8,0.2,0.3)	1/(0.7,0.3,0.4)	1/(0.6,0.4,0.5)	1/(0.8,0.2,0.3)	1/(0.25,0.75,0.80)	1

The weights of these factors were calculated utilizing the neutrosophic Best-Worst Method (BWM). The findings are displayed in Figure 3. According to these, the weight distribution among the factors is as follows: Soil Type (FRF1) at 5%, Slope (FRF2) at 17%, Distance from Road (FRF3) at 8%, Distance from Drainage (FRF4) at 13%, Distance from Dams at 2%, Distance from River (FRF6) at 13%, Surface Curvature (FRF7) at 8%, Digital Elevation Model (DEM) (FRF8) at 13%, and Aspect (FRF9) at 21%.

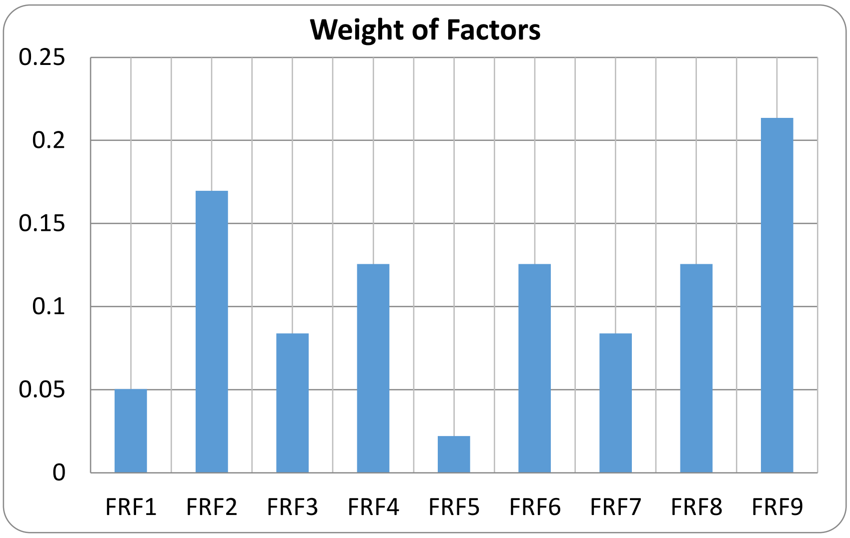


Figure 3. The weights of factors of flood risks.

The weights of these factors, calculated using the neutrosophic Best-Worst Method (BWM), were used in conjunction with the spatial layers collected via ArcGIS Pro 2.9 software's weighted overlay tool, to arrive at the flood susceptibility analysis of the study area. The results, as depicted in Figure 4, revealed that, Very Low susceptibility to flooding denotes areas that are least likely to experience flood events based on the chosen factors. These areas, constituting 21.78% of the study region, are typically situated at higher ground levels, further from bodies of water such as rivers or dams, and often exhibit favorable soil types and slopes contributing to better water runoff. It should be noted, however, that while these areas have the lowest susceptibility among the categories, it doesn't suggest they are completely immune to flooding, but rather they are less prone to flood risks compared to other regions in the study area, Areas classified as Low susceptibility to flooding represent 22.91% of the study area. These regions are more resistant to flooding compared to those in higher susceptibility categories. They typically include features such as gentle slopes that aid in water drainage, specific types of soil that absorb more water, greater distance from bodies of water like rivers or dams, and sufficient storm water management infrastructure such as roads or drainage systems. They still maintain a slight risk of flooding, particularly during severe weather events or in cases of infrastructure failure, but are generally less likely to experience flood-related problems under normal circumstances, Moderate susceptibility regions, accounting for 23.94% of the study area, are characterized by an intermediary risk of flooding. These areas neither have the most nor the least predisposition towards flooding. They often include varied slopes, soil types that have average absorption capabilities, and locations that are neither extremely close nor far from water bodies like rivers or dams. While their risk is not as heightened as in high or very high susceptibility areas, they still possess a notable risk, particularly in the event of severe weather occurrences or unexpected environmental changes. As such, continuous monitoring and effective flood mitigation measures are required in these regions, High susceptibility regions, which make up 18.77% of the study area, are more prone to flooding. These areas often have features that exacerbate flood risks, such as steep slopes which hinder effective water runoff, soil types that do not absorb water well, or proximity to water bodies like rivers or dams. Additionally, these regions could be closer to infrastructures which, when compromised, could boost the flood hazard. Incidences of flooding in these areas are more common, especially during severe weather conditions. Therefore, advanced flood monitoring and robust mitigation strategies are necessary for these areas., and The areas with Very High susceptibility to flooding, representing 12.60% of the study area, have the highest likelihood of experiencing flood events. These regions are often characterized by features such as very steep slopes reducing water absorption, soil types with poor absorption capacities, or close proximity to large water bodies like rivers or dams. These areas might also be in locations where storm water infrastructure is insufficient or compromised. Flooding is likely to occur in these places, even outside of extreme weather conditions, making continuous monitoring and aggressive flood mitigation measures a necessity for these locations. These results categories are detailed in Table 3.

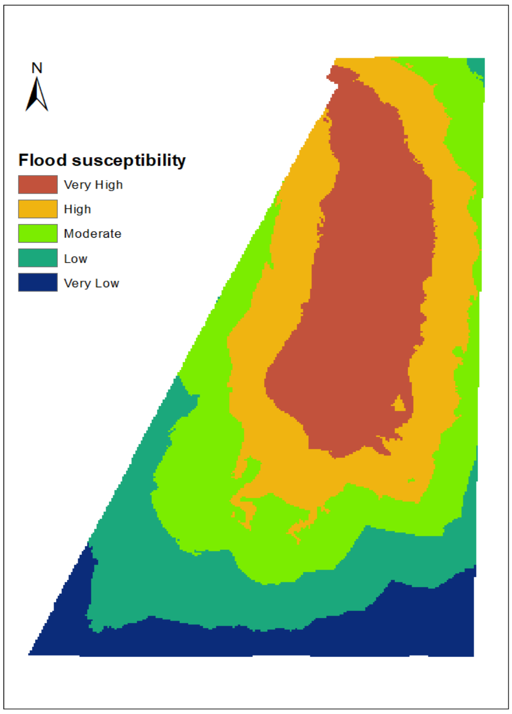


Figure 4. Flood susceptibility map.

Table 3. Flood Susceptibility classes.

Category	Interpretation	Color Scheme
Very Low	Areas that are least likely to experience flood events	
Low	Areas generally less likely to experience flood-related problems under normal circumstances.	
Moderate	Areas characterized by an intermediary risk of flooding.	
High	Areas more prone to flooding	
Very High	Areas have the highest likelihood of experiencing flood events.	

5. Conclusion

In conclusion, the analysis of flood susceptibility in the study area under the neutrosophic environment has been conducted and the areas are classified into five categories: Very Low, Low, Moderate, High, and Very High. This classification provides insights into predicting and managing flood conditions in diverse regions. Future studies could benefit from more quantifiable data, enhanced flood prediction models, and advanced flood mitigation techniques. Additionally, the integration of more layers, such as variations in climate change scenarios, could contribute to a better predictive model. The efficacy of the neutrosophic decision-making process could be further tested in various other disciplines and research fields to verify its broad applicability and robustness. Overall, a better understanding of flood patterns will aid in the strategic and targeted allocation of resources for flood risk management.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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