An Extended Neutrosophic Stepwise Weight Assessment Ratio Analysis Technique Based on GIS for Analysing Flash Floods

Nabil M. AbdelAziz*, Hassan H. Mohammed, Khalid A. Eldrandaly[3]

Department of Information Systems, Faculty of Computers and Informatics, Zagazig University, Sharqiyah, Egypt

Emails: nmabedelaziz@fci.zu.edu.eg; helfeky439@gmail.com; Khalid_Eldrandaly@zu.edu.eg

Abstract

Flash floods are a sudden natural hazard caused by successive heavy rains in a short period of time. The world suffers from heavy and frequent rains due to climate change. So, the risk assessment of flash floods is considered increasingly important and urgent. Egypt is considered one of the countries exposed to sudden floods resulting from heavy rains, especially in Upper Egypt. Multi-criteria techniques are widely used to study and analyze the causes and effects of natural hazards. In contrast to the traditional multi-criteria techniques used in the process of estimating flood problems, we applied neutrosophic logic in this study that has a great ability for simulating and reflecting uncertain human's thoughts in real world problems. Our study area sits in Southeast Sohag, and it is one of the most flash floods prone regions of Egypt's Eastern Desert. This area of Sohag has suffered from frequent flash floods, with some flood events resulting in human casualties in the last decades. This study focuses on using a neutrosophic stepwise weight assessment ration analysis (N-SWARA) technique with remotely sensed data and geographical information system (GIS) for producing a flash floods hazard map. The N-SWARA technique is applied to determine the weights of various factors that related to flash flooding, including elevation, slope, topographic wetness index, distance from the stream, flow accumulation, aspect, and flow direction. The obtained weight of selected criteria used then to produce the flood hazard map (FHM) using a raster calculator tool in geographic information system. The weight of each factor calculated by using the N-SWARA multi criteria analysis method and obtained the following results: 0.39 for slope, 0.21 for elevation, 0.12 for distance, 0.08 for flow direction, 0.05 for flow accumulation, 0.09 for TWI and 0.03 for aspect.

Keywords: Neutrosophic Set; Multi-Criteria Decision-Making Technique (MCDM); Stepwise Weight Assessment Ratio Analysis (SWARA); Geographic Information System (GIS); Flood Hazard Map.

1. Introduction

The occurrence of extreme weather changes around the world has a significant impact on the frequency of flood occurrence, as well as its dynamics, speed and destruction. Flash floods are considered as one of the most common natural disasters worldwide which cause serious harm to humans the environment and socioeconomic all over the world. Climate changes, as well as other geographical factors such as topography and geomorphology, greatly affect the amount of surface runoff and, accordingly, the intensity of floods. Therefore, the increase in flash floods and the increase in their damages all over the world needs continuous studies and continuous updating in identifying and mapping the risks of flash floods.

Flash flood risk maps provide information about potential damage and help in decision-making on how to prevent potential disasters. Geographic information system (GIS) and remote sensing (RS) technologies have made significant contributions to the analysis of natural hazards. There are many factors that used for

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

producing flash flood susceptibility maps and depends on the effect and importance of each independent factor and varies between different areas, including elevation, slope, topographic wetness index, distance from the stream, flow accumulation, aspect, and flow direction.

Multi-criteria decision-making analysis is a broad term that used to describe several models that facilitate decision making and considering many criteria within a defined system. There have been a large number of studies that combine remotely sensed data and geographical information system (GIS) with multi-criteria decision-making techniques for producing a flash flood hazard map and planning and formulating more flexible and accurate risk decisions [1-9].

In literature there does not exist any model which combined neutrosophic SWARA technique with GIS for analyzing flash floods problems. The SWARA was introduced in 2010 in the MCDM field with a different paradigm. It was created for the processes of decision-making which highlights making policy more than classical decision-making process [10-13]. SWARA technique have several advantages as follows: (1) it is a simple and straightforward technique, (2) experts can work together easily, (3) it is useful in gathering and coordinating data from experts, and (4) it can assess expert judgment on the relative importance of criteria in the weight determination process [14]

Our study focuses on extending the SWARA technique under neutrosophic environment and combining it with remotely sensed data and geographical information system (GIS) for producing a flash flood hazard map.

The structure of this research is planned as follow: Section 2 describes the study area and flash flood influencing factors with details. Section 3 describes some basics of neutrosophic theory. Section 4 describes the proposed method of neutrosophic SWARA based GIS. The application of the proposed method is described in section 5. Section 6 describes results and discussions of study area using proposed method. Section 7 summarizes research and conclusions of this study.

2. STUDY AREA AND FLASH FLOOD INFLUENCING FACTORS

The study area is situated in Upper Egypt in the southeast of Sohag governorate and is located between 26° 15′ 09" – 27° 11′ 37″ N and 31° 59′ 40" – 32° 35′ 40″ E (Figure . 1). Physiographically, we can divide the drainage basins of Sohag province into two sectors, one on the western side of the Nile River and another on the eastern side.

Our study area is on the eastern of the Nile River. There is a limestone plateau on both sides of the Nile. Cultivated land and Urban areas in the basin outlets remarkably dominate and the area is characterized by elevations and undulating surfaces. Semi-arid and arid conditions are prevalent in Egypt [8]. Rainfall in the Sohag region is very variable and can happen at high rates and unexpectedly. Susceptibility to floods increases when the rate of rainfall is higher than the ability of the soil to absorb water and is higher than the rate of water evaporation. [15] Mentioned in his research that the average annual rainfall on the eastern part of the Sohag is $2.25\ mm$. More than 11 floods occurred from 1950 to 2000, with a range of 2 to 9 years between floods occurring [8]. Regarding to temperature, the maximum recorded temperature was in August (47.3 °C) and the minimum recorded temperature was in January (14–30.8 °C) [8]. The average temperature in the area is 23.2 °C as appears in Table 1.

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

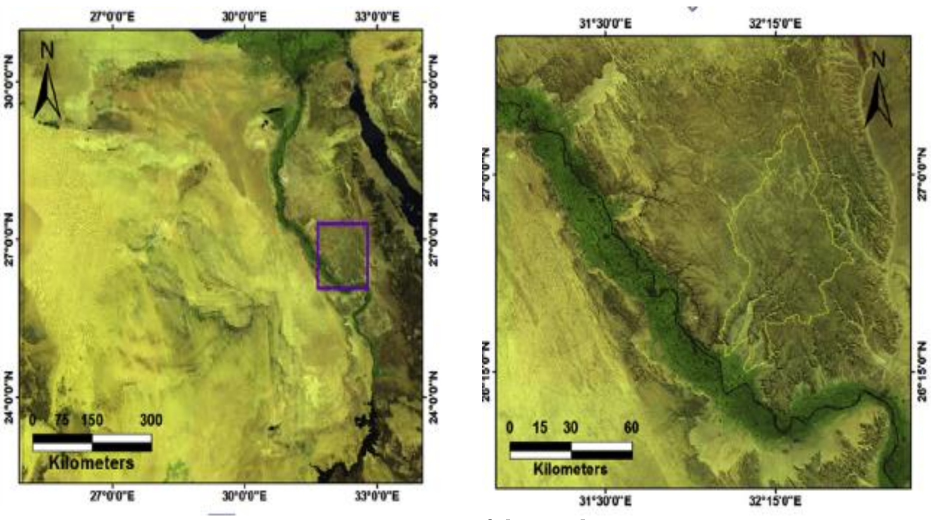


Figure 1: Location of the Study area

Table 1: Climatic conditions in the Sohag region (EMA, 2000)

Maximum Temp.	**Minimum Temp.**	**Average Rainfall**	**Maximum Rainfall**	**Average Humidity**	**Average Evaporation**
47.3 C ^{O}	0.4 C ^{O}	4.1 m/yr	17.8 mm	41$\%/yr$	7.2 mm/yr

Susceptibility mapping and flood hazard mapping focus on determining influencing factors. To determine the factors causing and influencing flash floods, the opinions of experts in the field are relied upon and the use of previous studies. The choice of spatial criteria or factors is very important in decision-making analysis [16]. [17] Used slope, elevation, distance from stream, and hydrologic units to implement a multi-hazard approach hazard so as to ultimately evaluate and specify the appropriate locations for urban development. While [18] assumed factors as follows: slope, cover type, elevation, land use, population density and distance from river and mainstream for estimating areas prone to flood risk, and help water resources planners and decision makers to focus on specific areas in order to perform a further detailed assessment of flood risk. Also, [19] used lithology, slope, drainage network, wetness index of topographic, elevation and curvature as influencing factors to establish a flood susceptibility map for the study area. As said by [20] , geological, hydrogeological, and physio-geographical factors that affect flash floods include slope, soil type, precipitation, catchment area and land use. Also,[8] used the following six flood causative factors: digital elevation model (DEM), slope, distance from stream, topographic wetness index (TWI), lithological units, and land use (LULC) and reclassify these based on their contribution and their effect on flood probability. Both elevation and slope have the highest values in terms of susceptibility of flooding, while the area of low slopes and low ground elevation are more susceptible to flash floods [8, 19, 20, 21].

From reviewing relevant literature, we selected the following seven flash flood factors for our study area as follows:

2.1 Elevation

According to a DEM downloaded from the United State Geological Survey (USGS). The elevation of the study area was categorized into five categories (Figure . 2), which each category weighted according to its effect on the occurrence of floods. The lower areas are more prone to flooding [23], whilst higher areas are less prone to flooding. According to [24] areas of lower elevation are more susceptible to flooding as water is flow into the lower areas more than the higher areas.

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

2.2 Slope

Slope refers to the rate of change in elevation values and is very important factor in determining vulnerability to flash floods because it determines the stream water flows and runoff. Areas with gentle slopes are more affected by flooding, as it's the first areas to be inundated when a flood enters an area [23]. The slope of our study area was divided into five slope classes (Figure . 3). The lower slope given the highest rating.

2.3 Topographic Wetness Index (TWI)

TWI is an indicator that determines the ability of the Earth's surface to be saturated with water and could determine overland flow output. Many researchers have used TWI as an input to develop predictive maps regarding hazard risk of wildfire landslide susceptibility and soil sensitivity [25, 26].

The TWI (Figure . 4) was calculated using the following equations for our study area:

Fd = flow direction (DEM) (1)
Fa = flow accumulation (Fd) (2)
Slope $= (slope\ (DEM)\ * \ 1.570796)\ /\ 90$ (3)
Tan_ slope = $con\ (slope\ >\ 0\ , tan(Slope)\ , 0.001)$ (4)
Fa_scaled = $(Fa\ +\ 1\ )\ *$ cell size (5)
TWI = ln (Fa_scaled / Tan_ slope) (6)

2.4 Drainage Network

We used the DEM to extract the drainage network. Several network buffer zones

($0\ -\ 0.002247371;\ 0.002247371\ -0.005158307;\ 0.005158307\ -\ 0.008368898;$ $0.008368898\ -\ 0.011237027;$ and > 0.011237027) were applied and created five drainage network classes (Figure . 5). The closer we are to the drainage network system, the greater the effect of flooding.

2.5 Aspect

Aspect is the orientation of slope, measured clockwise in degrees from 0 to 360, where 0 is north-facing, 90 is east-facing, 180 is south-facing, and 270 is west-facing. Aspect is related to the directions of water flow affecting flash flood occurrence. It governs evapotranspiration, soil moisture retention and vegetation development, thereby determining the flow direction and infiltration-to-runoff ratio. In our study, aspect was classified into four classes directions (Figure . 6).

2.6 Flow Direction and Flow Accumulation

Flow direction means the direction the stream flows in each cell. The flow direction value for each pixel is the direction in which water is flowing over that pixel as it makes its way downstream. The flow accumulation value for each pixel is the sum of all flows from upstream of that pixel that is the accumulated value or magnitude of the stream that flows over that pixel. Flow accumulation is one of the most important criteria in determining areas vulnerable to flood hazard. It calculates the number of cells that flow to each cell. High values of flow accumulation indicate potential high flood hazard, whereas low values indicate low flood hazard. Flow direction raster (Figure . 7) and Flow accumulation raster (Figure . 8) both were classified into five classes.

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

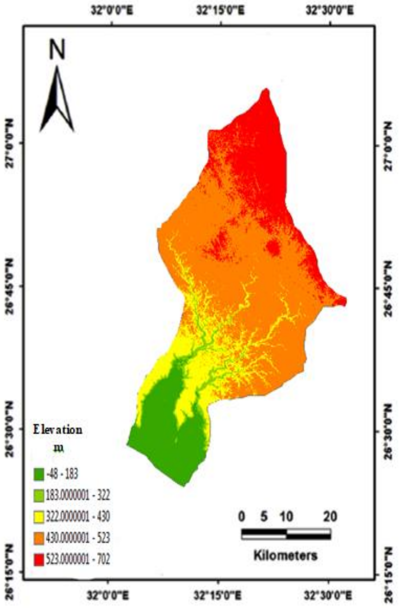


Figure 2: Elevation

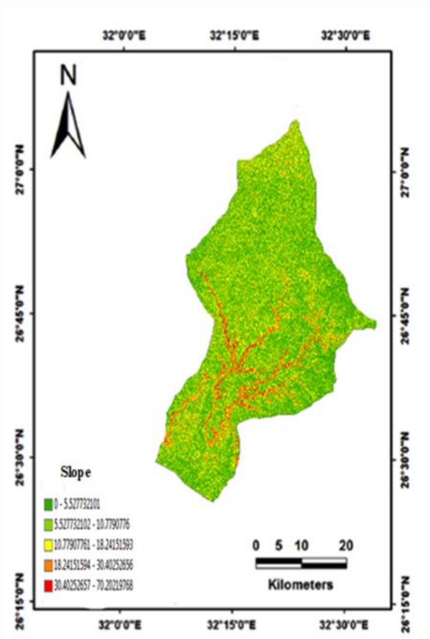


Figure 3: Slope

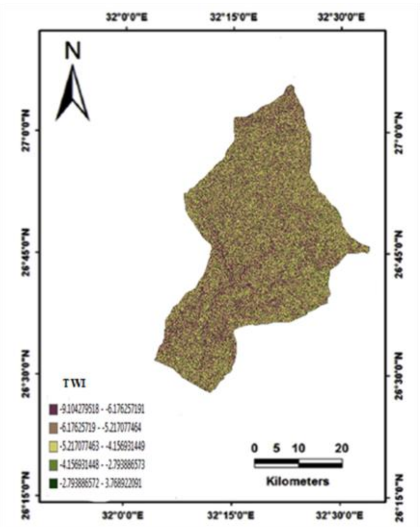


Figure 4: TWI

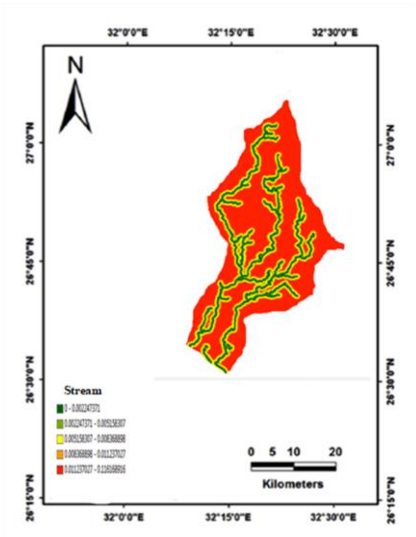


Figure 5: Stream

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

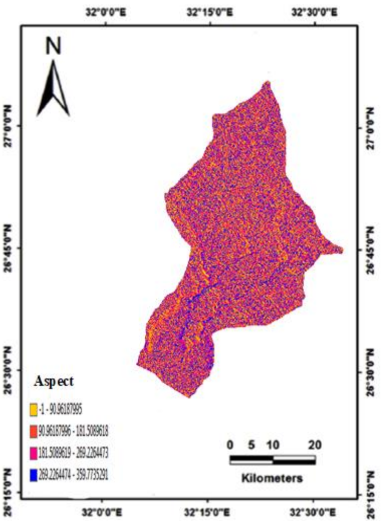


Figure 6: Aspect Classes

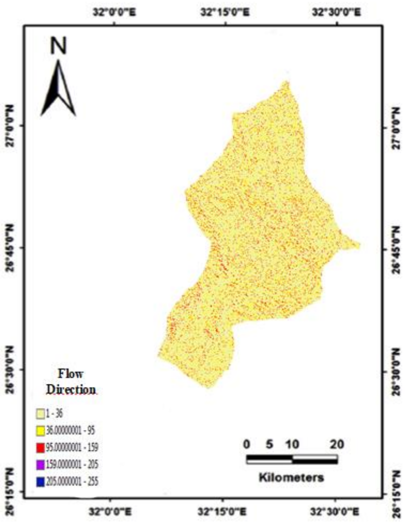
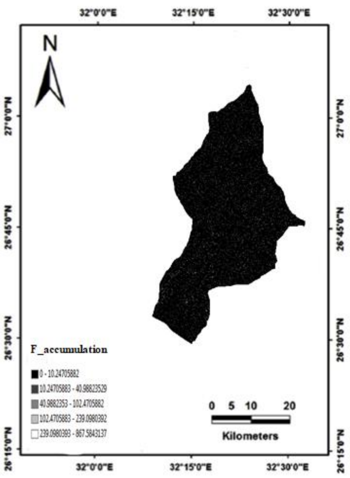


Figure 7: Flow



\

Figure 8: Flow accumulation

3. NEUTROSOPHIC PRELIMINARIES

In this part, some significant definitions of neutrosophic set are presented [27]. The neutrosophic set N has three membership functions which are truth $T_{Ne}(x)$, indeterminacy $I_{Ne}(x)$ and falsity $F_{Ne}(x)$ membership functions, where $T_{Ne}(x)$:X→$]^-0, 1^+[$, $I_{Ne}(x)$:X→$]^-0, 1^+[$ and $F_{Ne}(x)$:X→$]^-0, 1^+[$. This set is free from restriction on the sum of $T_{Ne}(x)$, $I_{Ne}(x)$ and $F_{Ne}(x)$, so $0^- \leq \sup T_{Ne}(x) + \sup I_{Ne}(x) + \sup F_{Ne}(x) \leq 3^+$.

A single valued neutrosophic set Ne over X has the following form $A=\{\langle x, T_{Ne}(x), I_{Ne}(x), F_{Ne}(x)\rangle : x \in X\}$, where $T_{Ne}(x)$:X→[0,1], $I_{Ne}(x)$:X→[0,1] and $F_{Ne}(x)$:X→[0,1] with $0 \leq T_{Ne}(x) + I_{Ne}(x) + F_{Ne}(x) \leq 3$ for all $x \in X$.

A single valued triangular neutrosophic number, $\tilde{a} = \langle (a_1, a_2, a_3); a_{\tilde{a}}, q_{\tilde{a}}, b_{\tilde{a}} \rangle$ is a neutrosophic set whose

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

membership functions are as follows:

$$T_{\tilde{a}}(x) = \begin{cases} a_{\tilde{a}}\left(\frac{x-a_1}{a_2-a_1}\right)(a_1 \le x \le a_2) \\ a_{\tilde{a}} \quad (x = a_2) \\ a_{\tilde{a}}\left(\frac{a_3-x}{a_3-a_2}\right)(a_2 < x \le a_3) \\ 0 \quad \text{otherwise} \end{cases}, \tag{7}$$

$$I_{\tilde{a}}(x) = \begin{cases} \frac{(a_2-x+q_{\tilde{a}}(x-a_1))}{(a_2-a_1)}(a_1 \le x \le a_2) \\ q_{\tilde{a}} \quad (x = a_2) \\ \frac{(x-a_2+q_{\tilde{a}}(a_3-x))}{(a_3-a_2)}(a_2 < x \le a_3) \\ 1 \quad \text{otherwise}, \end{cases} \tag{8}$$

$$F_{\tilde{a}}(x) = \begin{cases} \frac{(a_2-x+b_{\tilde{a}}(x-a_1))}{(a_2-a_1)}(a_1 \le x \le a_2) \\ b_{\tilde{a}} \quad (x = a_2) \\ \frac{(x-a_2+b_{\tilde{a}}(a_3-x))}{(a_3-a_2)}(a_2 < x \le a_3) \\ 1 \quad \text{otherwise}. \end{cases} \tag{9}$$

Where $a_{\tilde{a}}$,$q_{\tilde{a}}$ and $b_{\tilde{a}}$, represent the greatest degree of truth membership, least degree of indeterminacy and falsity memberships, respectively. Basic operations of single valued triangular neutrosophic numbers are as follows:

Let $\tilde{a}=\langle(a_1, a_2, a_3); a_{\tilde{a}}, q_{\tilde{a}}, b_{\tilde{a}}\rangle$ and $\tilde{b}=\langle(b_1, b_2, b_3); a_{\tilde{b}}, q_{\tilde{b}}, b_{\tilde{b}}\rangle$ be two single valued triangular neutrosophic numbers and g$\neq 0$ be any real number. Then,

1. Addition of $\tilde{a}$ and $\tilde{b}$:

$\tilde{a}+\tilde{b}=\langle(a_1+b_1, a_2+b_2, a_3+b_3); a_{\tilde{a}} \wedge a_{\tilde{b}}, q_{\tilde{a}} \vee q_{\tilde{b}}, b_{\tilde{a}} \vee b_{\tilde{b}}\rangle$

2. Inverse of $\tilde{a}$:

$\tilde{a}^{-1} = \langle\left(\frac{1}{a_3}, \frac{1}{a_2}, \frac{1}{a_1}\right); a_{\tilde{a}}, q_{\tilde{a}}, b_{\tilde{a}}\rangle$,Where$(\tilde{a} \neq 0)$

3. Multiplication of $\tilde{a}$ by constant value:

$$g\tilde{a} = \begin{cases} \langle(ga_1, ga_2, ga_3); a_{\tilde{a}}, q_{\tilde{a}}, b_{\tilde{a}}\rangle \ if\,(g > 0) \\ \langle(ga_3, ga_2, ga_1); a_{\tilde{a}}, q_{\tilde{a}}, b_{\tilde{a}}\rangle \ if\,(g < 0) \end{cases}$$

4. Division of $\tilde{a}$ by constant value:

$$\frac{\tilde{a}}{g} = \begin{cases} \langle\left(\frac{a_1}{g}, \frac{a_2}{g}, \frac{a_3}{g}\right); a_{\tilde{a}}, q_{\tilde{a}}, b_{\tilde{a}}\rangle \ if\,(g > 0) \\ \langle\left(\frac{a_3}{g}, \frac{a_2}{g}, \frac{a_1}{g}\right); a_{\tilde{a}}, q_{\tilde{a}}, b_{\tilde{a}}\rangle \ if\,(g < 0) \end{cases}$$

5. Division of $\tilde{a}$ and $\tilde{b}$:

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

$$\frac{\tilde{a}}{\tilde{b}} = \begin{cases} \langle \left(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1}\right); a_{\tilde{a}} \wedge a_{\tilde{b}}, q_{\tilde{a}} \vee q_{\tilde{b}}, b_{\tilde{a}} \vee b_{\tilde{b}} \rangle & if (a_3 > 0, b_3 > 0) \\ \langle \left(\frac{a_3}{b_3}, \frac{a_2}{b_2}, \frac{a_1}{b_1}\right); a_{\tilde{a}} \wedge a_{\tilde{b}}, q_{\tilde{a}} \vee q_{\tilde{b}}, b_{\tilde{a}} \vee b_{\tilde{b}} \rangle & if (a_3 < 0, b_3 > 0) \\ \langle \left(\frac{a_3}{b_1}, \frac{a_2}{b_2}, \frac{a_1}{b_3}\right); a_{\tilde{a}} \wedge a_{\tilde{b}}, q_{\tilde{a}} \vee q_{\tilde{b}}, b_{\tilde{a}} \vee b_{\tilde{b}} \rangle & if (a_3 < 0, b_3 < 0) \end{cases}$$

6. Multiplication of $\tilde{a}$ and $\tilde{b}$:

$$\tilde{a}\tilde{b} = \begin{cases} \langle (a_1 b_1, a_2 b_2, a_3 b_3); a_{\tilde{a}} \wedge a_{\tilde{b}}, q_{\tilde{a}} \vee q_{\tilde{b}}, b_{\tilde{a}} \vee b_{\tilde{b}} \rangle & if\ (a_3 > 0, b_3 > 0) \\ \langle (a_1 b_3, a_2 b_2, a_3 b_1); a_{\tilde{a}} \wedge a_{\tilde{b}}, q_{\tilde{a}} \vee q_{\tilde{b}}, b_{\tilde{a}} \vee b_{\tilde{b}} \rangle & if\ (a_3 < 0, b_3 > 0) \\ \langle (a_3 b_3, a_2 b_2, a_1 b_1); a_{\tilde{a}} \wedge a_{\tilde{b}}, q_{\tilde{a}} \vee q_{\tilde{b}}, b_{\tilde{a}} \vee b_{\tilde{b}} \rangle & if\ (a_3 < 0, b_3 < 0) \end{cases}$$

4. Proposed Neutrosophic Extended Stepwise Weight Assessment Ratio Analysis (N-Swara) Technique

There are various methods for evaluating the weights of decision attributes as AHP [28], FARE [29], and entropy [30]. The SWARA [10, 11] is a new technique that has an interesting framework that is completely varied from other techniques as BWM, FARE, ANP or AHP. Regarding to SWARA technique, the most significant factor is ranked as the best and takes rank 1, but the least important factor is ranked as the last. The whole ranks are represented according to the average value of all ranks based on the experts [31, 32]. This technique also provides experts an important role in calculating the weights of factors. The advantage is that each expert determines the importance of each factor exclusively. Subsequently, they can sort the factors from first to last by taking into consideration the general outcome. The information, experience and implicit knowledge are the main factors which help experts in decision-making process.

The main disadvantage of traditional SWARA technique is incapability of simulating and handling uncertainty of human's thoughts. Since neutrosophic logic has a great ability for simulating human's thoughts and increasing flexibility of expert's preferences, we applied it in this part with SWARA technique. So, we can say that the neutrosophic SWARA (N-SWARA) technique will be able to deal with uncertainties in input data or when decision makers are not entirely sure about their suggestions.

The procedure for determination of weights by N-SWARA is stated in the steps below:

Step 1: Let decision makers begin to evaluate criteria according to their expected significances using the neutrosophic scale as appears in Table 2. In this part, we used triangular neutrosophic numbers to represent values of linguistic variables.

Table 2: The linguistic values and its corresponding neutrosophic values for evaluation process

Linguistic Ranking of Criteria	**Corresponding Neutrosophic Values (NV_s)**	**Linguistic Rating for Relative Importance of Criteria**	**Corresponding Neutrosophic Values (NV)**
Very Low (VL)	(0.0, 0.0, 0.25)	Low Importance (LI)	(0.0, 0.25, 0.5)
Low(L)	(0.0, 0.25, 0.5)	Medium Importance (MI)	(0.25,0.5,0.75)
Medium(M)	(0.25,0.5,0.75)	Important (I)	(0.5,0.75,1)
High (H)	(0.5,0.75,1)	Very Important (VI)	(0.75, 1,1)
Very High (VH)	(0.75, 1,1)	Equally Important	(0.5, 0.5,0.5)

The previous linguistic variables are used by decision makers to clear their preferences.

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

Step 2: Let decision makers determine their confirmation degrees of linguistic variables as follows:

Absolutely Sure (AS)$=(1,0,0)$; the first parameter (1) is the truth degree, second parameter (0) is indeterminacy degree and finally the falsity degree. Very Strongly Sure (VSS)$=(0.9,0.1,0.1)$, Equally Sure (ES) $=(0.5,0.5,0.5)$, Absolutely Not Sure (ANS) $=(0.0,0.0,1)$, Very Strongly Not Sure (VSN) $=(0.3,0.75,0.7)$ and Strongly Not Sure $(SNS)=(0.4,0.65,0.6)$.
Step 3: Calculate $\widetilde{c_{jk}}$ values which obtained by interviewing the decision makers. After then, calculate the average rank value of criteria $\tilde{\tilde{c}}_j$ using this formula:

$$\tilde{\tilde{c}}_j=\frac{\sum_{k=1}^{d}\widetilde{c_{jk}}}{d} \quad (10)$$

where $\widetilde{c_{jk}}$ is the neutrosophic ranking of the j criteria by the k decision maker and d is the number of decision makers.

Step 4: Make the final ranking of criteria based on their score functions as follows:

Let $\tilde{A}_1=\langle(a_1,a_2,a_3);\mu_{\tilde{A}_1},\gamma_{\tilde{A}_1},\lambda_{\tilde{A}_1}\rangle$ be triangular neutrosophic number then the score function equals:

$$S(\tilde{A}_1)=\frac{1}{12}(a_1+2a_2+a_3)*[2+\mu_{\tilde{A}_1}-\gamma_{\tilde{A}_1}-\lambda_{\tilde{A}_1}] \quad (11)$$

From obtained score function of criteria, if $S(\tilde{C}_1)>S(\tilde{C}_2)$ then $\tilde{C}_1>\tilde{C}_2$. Also, if $S(\tilde{C}_1)<S(\tilde{C}_2)$ then $\tilde{C}_1<\tilde{C}_2$, and if $S(\tilde{C}_1)=S(\tilde{C}_2)$ then $\tilde{C}_1=\tilde{C}_2$.
Step 5: Begin to determine the comparative importance of the average value $\widetilde{coi}_j$, which starts with the second criterion since the decision maker states the relative importance of criterion j in relation to the previous $(j-1)$ criterion, for each criterion. The decision maker will use the determined scale in Table 2 for determining coi_j. Besides the pervious scale the decision makers must also use the predefined confirmation degree.

Step 6: Begin to calculate coefficient $\tilde{k}_j$ as follows:

$$\tilde{k}_j=\begin{cases}(1,1,1;1,0,0) & j=1\\ \widetilde{coi}_j+(1,1,1;1,0,0) & j>1\end{cases} \quad (12)$$

Step 7: The recalculated weight $\widetilde{wr}_j$ is determined as follows:

$$\widetilde{wr}_j=\begin{cases}(1,1,1;1,0,0) & j=1\\ \frac{\tilde{k}_{j-1}}{\tilde{k}_j} & j>1\end{cases} \quad (13)$$

Step 8: Calculate relative weights of the estimation criteria as follows:

$$\widetilde{w}_j=\frac{\widetilde{wr}_j}{\sum_{j=1}^{n}\widetilde{wr}_j} \quad (14)$$

Step 9: Use the predefined score function (i.e., Eq. (11)) to transform each neutrosophic weight value to its crisp value.

5. Neutrosophic Swara Analysis For Weighting Flood Influencing Factors

The SWARA technique has been used in various applications areas [10, 11, 31, 32]. But there exists only two research which integrated SWARA with other MCDM techniques in neutrosophic environment. The first research integrated SWARA with VIKOR technique in neutrosophic environment for assessment of eco-industrial thermal power plants [33] and in this research the steps of estimating criteria are as in classical SWARA and the role of neutrosophic appears exactly in the calculations of best and worst degrees. The second research integrated classical SWARA with neutrosophic TOPSIS and EDAS techniques [34].
In our study, we are the first to propose a new extended neutrosophic SWARA technique based on GIS for analyzing flash floods. The N-SWARA used to obtain weights of flood influencing factors and combined into the GIS - environment to create flood susceptibility maps. The integration of GIS-environment with

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

neutrosophic SWARA analysis provides more flexibility for to assess the causative agents of flooding. The general framework of proposed model for analyzing flash floods appears in Figure .9.

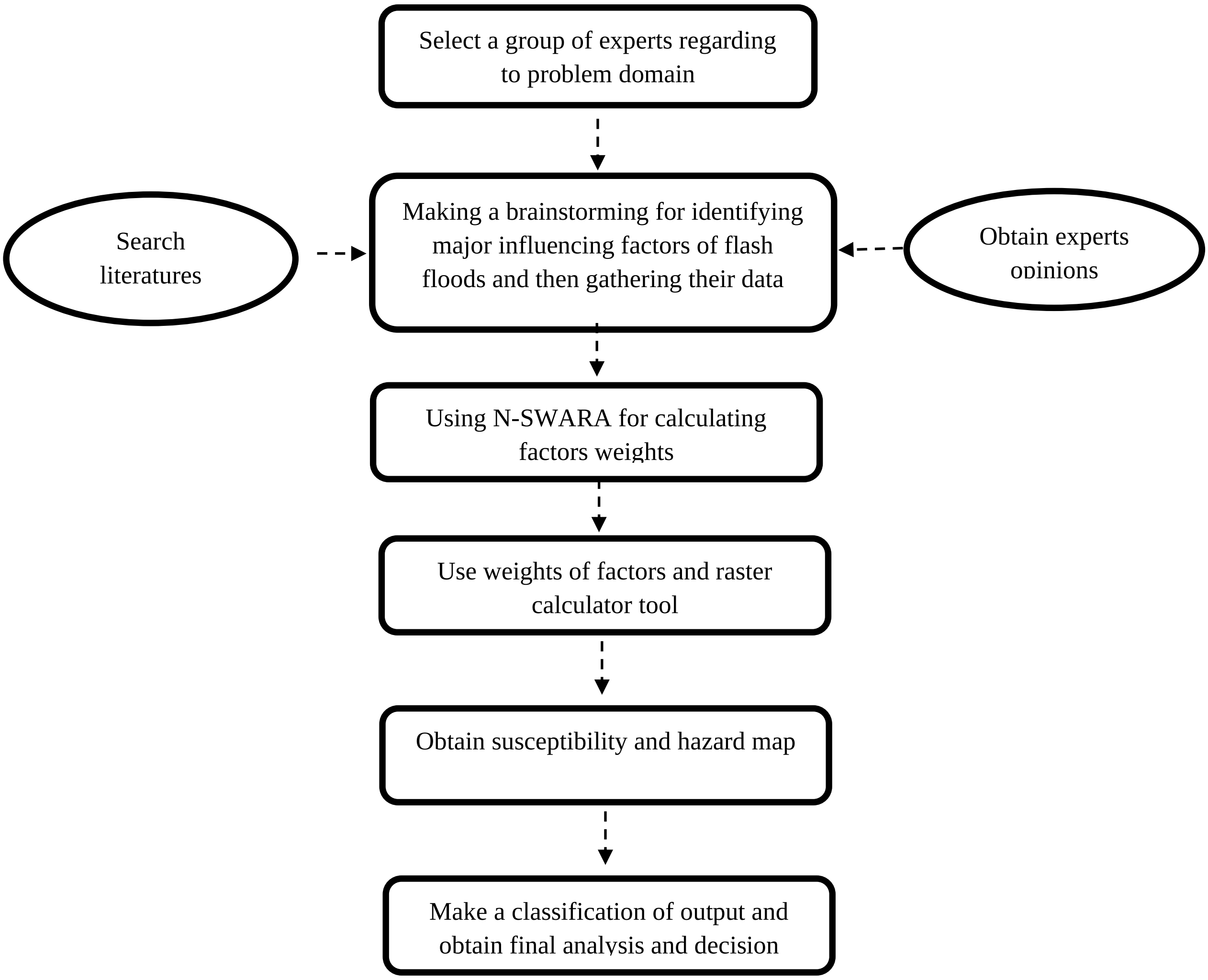


Figure 9: Study methodology

Since in our study area we discuss various factors related to flash flooding as slope, distance from stream network, elevation, TWI, aspect, flow direction and flow accumulation. So, let us now use proposed algorithm for calculating its weights and then make analysis of flash floods as follows:

Step 1: The decision makers begin to evaluate criteria based on their expected significances using neutrosophic linguistic variables which presented in Table 2 and beside each neutrosophic linguistic variable the decision makers presented their confirmations degrees. Here in our study, we have five decision makers and by interviewing them we obtained data which presented in Table 3.

Table 3: The neutrosophic values for evaluating criteria

Experts	Slope (C1)	Elevation (C2)	TWI (C3)	Distance(C4)	Flow Accumulation(C5)	Flow Direction(C6)	Aspect (C7)
1	VH; AS	H;VSS	M;ES	VH;AS	M;ES	L;ES	VL;ES
2	VH; AS	H;VSS	L;ES	H;VSS	M;VSS	M;ES	L;ES
3	H; VSS	VH;AS	M;ES	H;VSS	L;ES	M;VSS	VL;ES
4	H; VSS	H;AS	M;VSS	M;VSS	H;ES	M;ES	M;VSS
5	H; VSS	H; VSS	L; ES	M; VSS	L; ES	H; VSS	M;VSS

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

The calculation for making the final rank of criteria presented in Table 4.

Step 2: The comparative importance of the average value $\widetilde{co\iota}_j$ using predefined scale in Table 2 and the suitable confirmation degree presented in Table 5.

Table 4: The neutrosophic computations of criteria for ranking process

Computations	**Criteria**						
	Slope (C1)	Elevation (C2)	TWI (C3)	Distance (C4)	Flow Accumulation (C5)	Flow Direction (C6)	Aspect (C7)
Sum of criteria ranks $\sum_{k=1}^{5}\widetilde{c_{jk}}$	(3,4.25,5 0.9,0.1,0.	(2.75,4,5 ; 0.9,0.1,0.1)	(0.75,2,3.25 0.5,0.5,0.5)	(2.25,3.5,4 0.9,0.1,0.1	(1,2.25,3.5; 0.5,0.5,0.5)	(1.25,2.5,3. 0.5,0.5,0.5)	(0.5,1.25,2 0.5,0.5,0.5)
Average rank of criteria $\tilde{\tilde{c}}_j = \frac{\sum_{k=1}^{5}\widetilde{c_{jk}}}{5}$	(0.6,0.85, 0.9,0.1,0.	(0.55,0.8,1 0.9,0.1,0.1)	(0.15,0.4,0. 0.5,0.5,0.5)	(0.45,0.7,0 0.9,0.1,0.1	(0.2,0.45,0. 0.5,0.5,0.5)	(0.25,0.5,0. 0.5,0.5,0.5)	(0.1,0.25,0 0.5,0.5,0.5)
Score value of average rank	0.742	0.708	0.200	0.619	0.225	0.250	0.137
Final rank of criteria	1	2	6	3	5	4	7

Table 5: The relative importance assessment of criteria with neutrosophic linguistic variables

Experts	**C1⟷C2**	**C2⟷C4**	**C4 ⟷C6**	**C6 ⟷C5**	**C5 ⟷C3**	**C3 ⟷C7**
1	VI;VSS	I;AS	MI;VSS	EI;AS	MI;VSS	EI;AS
2	VI;AS	I;AS	I;AS	MI;AS	EI;AS	MI;AS
3	I;AS	EI;VSS	EI;VSS	I;VSS	LI;AS	LI;VSS
4	I;VSS	VI;VSS	EI;AS	MI;VSS	I;VSS	MI;VSS
5	VI; VSS	VI; VSS	I; VSS	I; VSS	EI;VSS	LI; VSS

Step 3: Calculate coefficient $\tilde{k}_j$ using Eq. (12).

Step 4: The recalculated weight $\widetilde{wr}_j$ is determined using Eq. (13).

Step 5: Calculate weights of the estimation criteria using Eq. (14).

The previous calculations from steps 3 to step 5 appears in Table 6.

Table 6: The weights of criteria using N-SWARA technique

Criteria	$\widetilde{co\iota}_j$	$\tilde{k}_j$	$\widetilde{wr}_j$	$\tilde{w}_j$
1	-	(1,1,1;1,0,0)	(1,1,1;1,0,0)	(0.37,0.43,0.49;0.9,0.1,0.1)

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

2	(0.65,0.9,1;0.9,0.1,0.1)	(1.65,1.9,2;0.9,0.1,0.1)	(0.5,0.526,0.61;0.9,0.1,0.1)	(0.19,0.23,0.29;0.9,0.1,0.1)
4	(0.6,0.8,0.9;0.9,0.1,0.1)	(1.6,1.8,1.9;0.9,0.1,0.1)	(0.26,0.29,0.38;0.9,0.1,0.1)	(0.09,0.13,0.18;0.9,0.1,0.1)
6	(0.45,0.6,0.75; 0.9,0.1,0.1)	(1.45,1.6,1.75;0.9,0.1,0.1)	(0.15,0.18,0.26;0.9,0.1,0.1)	(0.06,0.08,0.12;0.9,0.1,0.1)
5	(0.4,0.6,0.8;0.9,0.1,0.1)	(1.4,1.6,1.8;0.9,0.1,0.1)	(0.08,0.11,0.18;0.9,0.1,0.1)	(0.03,0.05,0.09;0.9,0.1,0.1)
3	(0.35,0.5,0.65;0.9,0.1,0.1)	(1.35,1.5,1.65;0.9,0.1,0.1)	(0.05,0.1,0.13;0.9,0.1,0.1)	(0.02,0.04,0.06;0.9,0.1,0.1)
7	(0.2,0.4,0.6;0.9,0.1,0.1)	(1.2,1.4,1.6;0.9,0.1,0.1)	(0.03,0.1,0.11;0.9,0.1,0.1)	(0.011,0.04,0.05;0.9,0.1,0.1)

Step 6: Use the predefined score function (i.e., Eq. (11)) to transform each neutrosophic weight value to its crisp value as presented in Table 7 and Figure .10.

Table 7: The relative weights for each criterion using N-SWARA technique

Criteria	Weights
C1	0.39
C2	0.21
C4	0.12
C6	0.08
C5	0.05
C3	0.09
C7	0.03

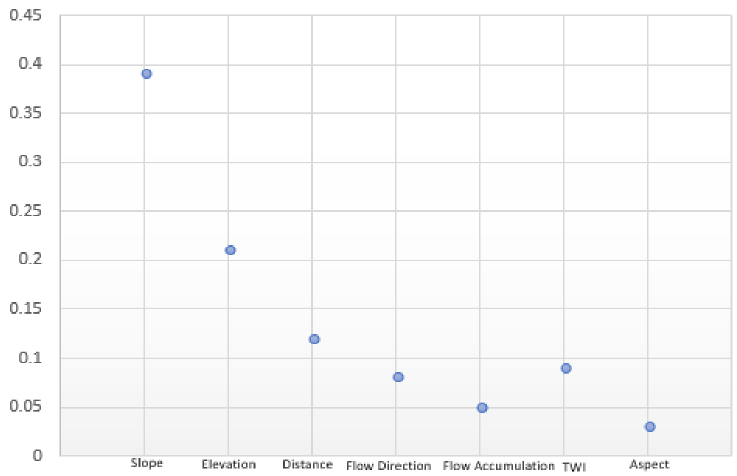


Figure 10: Weights of flash floods controlling factors

6. Results and Discussion

The applications of a multi-criteria decision-making analysis in our study area was used for evaluating the relative weights of flood controlling factor. The weights of the flood variables were calculated using N-SWARA model through evaluating criteria based on their expected significances. For determining the importance of each criterion, the decision maker used the suggested neutrosophic linguistic variables and their confirmations degrees. The integration of GIS-environment with N-SWARA technique provides more flexibility to assess the causative agents of flooding.

We identified flood influencing factors and by using these factors in multi-criteria analysis we developed a flood susceptibility map of the study area. Regarding to our flood influencing factors, the elevation factor

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

was classified into the five classes: less than 183 m; 183 – 322 m; 322– 430 m; 430– 523 m, and above 523 m. From our results, the class of less than 183 m was assigned with the highest rating. as presented in Figure .11

The slope factor was classified into the five classes: less than 5.5°, 5.5 – 10.8°, 10.8– 18.24°, 18.24– 30.4°, and above 30.4°. From our results, the class of the lowest slope had the highest rating. as presented in Figure .12

The TWI factor was classified into the five classes: less than $-6°$, (-6)– $(-5°)$, (-5) – $(-4°)$, (-4) – $(-2°)$, and above $-2°$.The class ' $< -6°$ ' had the highest rating. as presented in Figure .13

The distance factor was grouped into five classes : $0 - 0.002247371$; $0.002247371 - 0.005158307$; $0.005158307 - 0.008368898$; $0.008368898 - 0.011237027$; and > 0.011237027, according to buffer distance. From our results, closer to the stream, the more susceptibility to flooding as presented in Figure .14

The aspect factor was grouped into four classes: < 90 ; $90 - 18$; $181 - 269$; and > 269 as presented in Figure .15. The flow accumulation factor was grouped into five classes: < 10 ; $10 - 40$; $40 - 102$; $102 - 239$ and > 239 as presented in Figure .16. The flow direction factor was grouped into five classes: < 36; $36 - 95$; $95 - 159$; $159 - 205$ and > 205. as presented in Figure .17

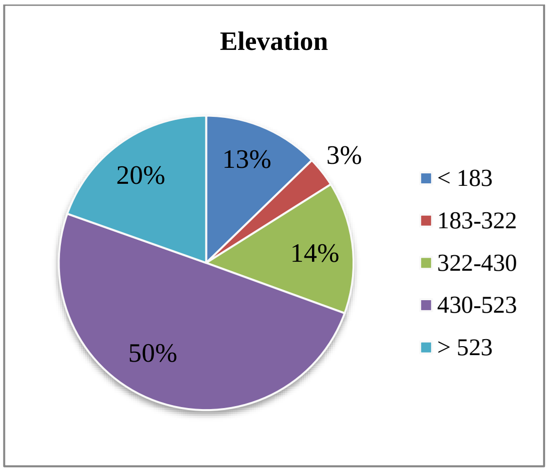


Figure 11: classification of Elevation factor

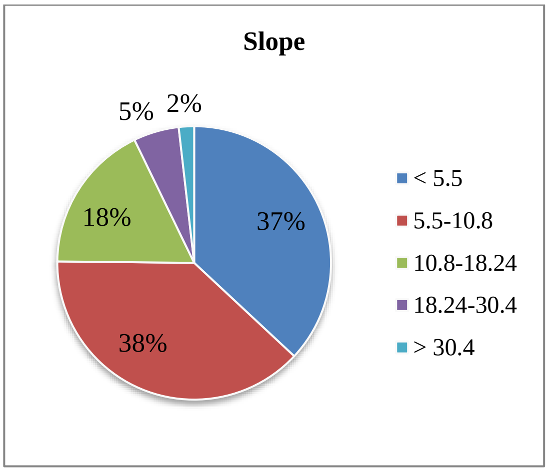


Figure 12: classification of Slope factor

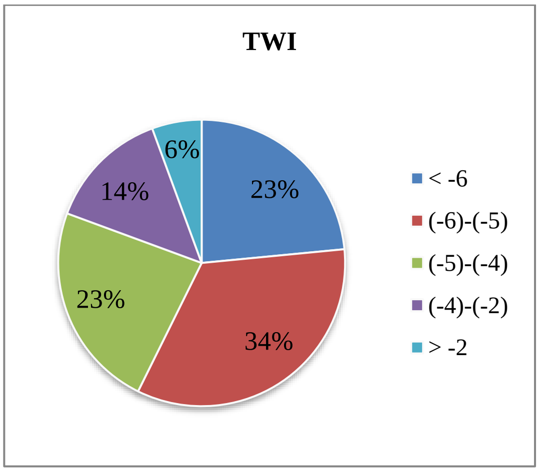


Figure 13: classification of TWI factor

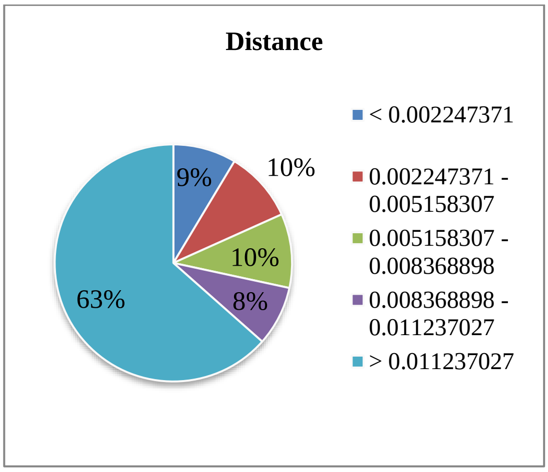


Figure 14: classification of Distance factor

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

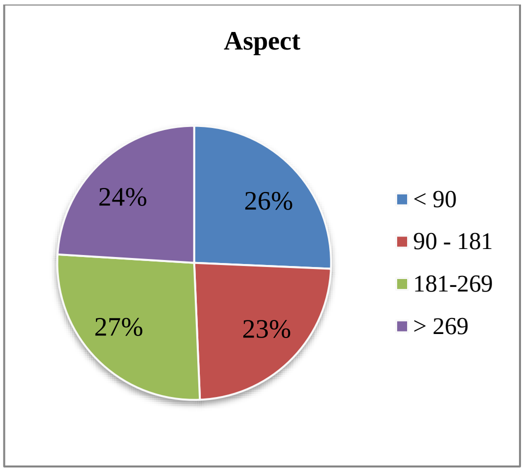


Figure 15: classification of Aspect factor

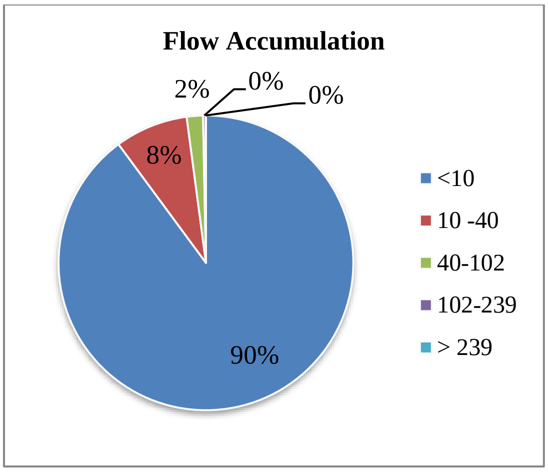


Figure 16: classification of Flow Accumulation factor

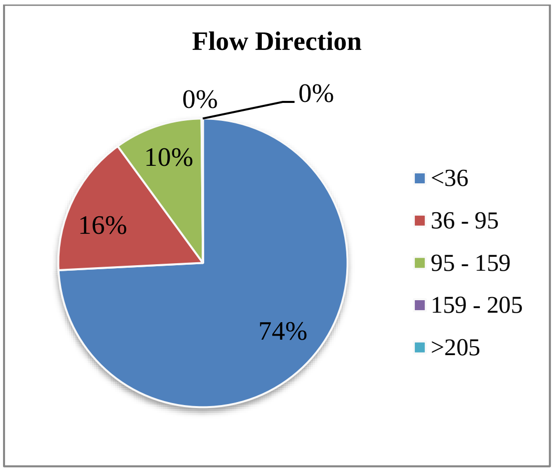


Figure 17: classification of Flow Direction factor

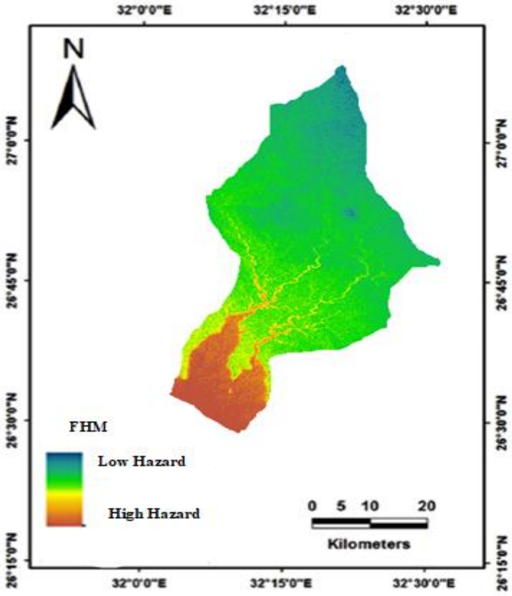
By using the N-SWARA multi-criteria analysis method, the weight of each factor calculated and obtained the following results: 0.39 for slope, 0.21 for elevation, 0.12 for distance, 0.08 for flow direction, 0.05 for flow accumulation, 0.09 for TWI and 0.03 for aspect. Flood hazard map and flood susceptibility map was generated using the following equation:

$$FHM = \Sigma\,(C1Wj1 + C2Wj2 + C3Wj3 + CnWjn), \qquad (15)$$

Where, Wj is the weight of each factor; n is the number of factors, $C1$, $C2, C3$, and Cn are the respective factors. In our study, five classes were identified: very high, high, moderate, low, and very low.

The resulting hazard map reveals that 'very high' susceptibility category reflects approximately 12%. whilst the 'high' susceptibility class reflects approximately 4% and the 'moderate' susceptibility category covers approximately 21%. Furthermore, the 'low' susceptibility category reflects approximately 39% and the 'very low' susceptibility class reflects approximately 24% of our study area. (see Figure .18 , Figure . 19 & Figure . 20).

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023



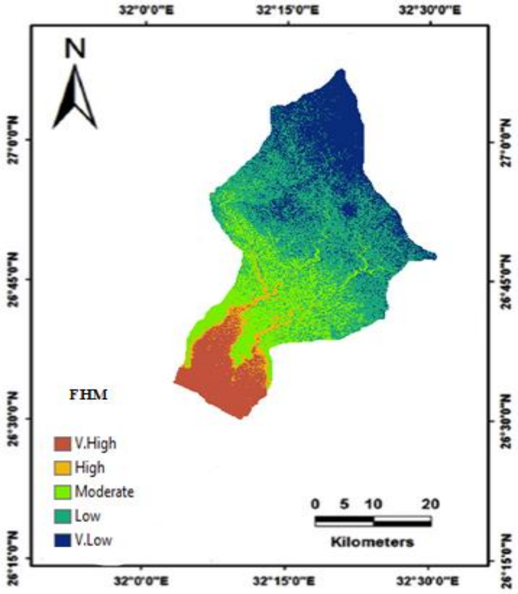


Figure 18: Susceptibility Figure 19: Hazard classes

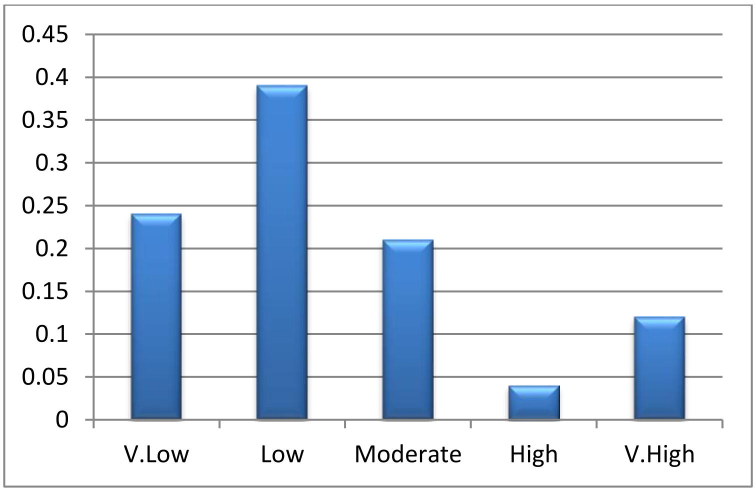


Figure 20: classification of Hazard map

7. Concluding Remarks

Flood susceptibility map provides valuable data for decision-makers and the planners dealing with flood hazards and susceptibility. Flood susceptibility map provides residents with information about probable damages and how to prevent potential disasters. Our study area is in Upper Egypt in the southeast of Sohag governorate. To analyze the influence of flash floods on study area, seven influencing factors such as elevation, slope, topographic wetness index, distance from the stream, flow accumulation, aspect and flow direction were determined. The weight of each factor calculated by using the N-SWARA multi criteria analysis method and obtained the following results: 0.39 for slope, 0.21 for elevation, 0.12 for distance, 0.08 for flow direction, 0.05 for flow accumulation, 0.09 for TWI and 0.03 for aspect. Our results reveal that 'very high' susceptibility category reflects approximately 12%. whilst the 'high' susceptibility class reflects approximately 4% and the 'moderate' susceptibility category covers approximately 21% . Furthermore, the 'low' susceptibility category reflects approximately 39% and the 'very low' susceptibility

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

class reflects approximately 24% of our study area. From our study we concluded that the integration of remotely sensed data and geographical information system (GIS) with neutrosophic SWARA is a valuable and an appropriate tool to assess flash flood susceptibility.
In the future, we will analyze the influence of flash floods on various study areas using various neutrosophic MCDM techniques and geographical information system.

Limitation of Proposed Research: More involvements from more companies will make our research better.

Competing Interests

The authors announce that there is no discrepancy of interests concerning the publication of this research.

Acknowledgments
The authors would like to thank the anonymous referees for their insightful and constructive comments and suggestions.

References

[1] Chen, H., Ito, Y., Sawamukai, M., & Tokunaga, T. (2015). Flood hazard assessment in the Kujukuri Plain of Chiba Prefecture, Japan, based on GIS and multicriteria decision analysis. Natural Hazards, 78, 105-120.
[2] Fernández, D. S., & Lutz, M. A. (2010). Urban flood hazard zoning in Tucumán Province, Argentina, using GIS and multicriteria decision analysis. Engineering Geology, 111(1-4), 90-98.
[3] Kourgialas, N. N., & Karatzas, G. P. (2017). A national scale flood hazard mapping methodology: The case of Greece–Protection and adaptation policy approaches. Science of the Total Environment, 601, 441-452.
[4] Sanyal, J., & Lu, X. X. (2006). GIS‐based flood hazard mapping at different administrative scales: A case study in Gangetic West Bengal, India. Singapore Journal of Tropical Geography, 27(2), 207-220.
[5] Wang, G., Liu, Y., Hu, Z., Zhang, G., Liu, J., Lyu, Y., ... & Liu, L. (2021). Flood Risk Assessment of Subway Systems in Metropolitan Areas under Land Subsidence Scenario: A Case Study of Beijing. *Remote Sensing*, *13*(4), 637.
[6] Akay, H., & Koçyiğit, M. B. (2020). Flash flood potential prioritization of sub-basins in an ungauged basin in Turkey using traditional multi-criteria decision-making methods. *Soft Computing*, 1-13.
[7] Ajjur, S. B., & Mogheir, Y. K. (2020). Flood hazard mapping using a multi-criteria decision analysis and GIS (case study Gaza Governorate, Palestine). *Arabian Journal of Geosciences*, *13*(2), 1-11.
[8] El-Magd, S. A. A., Amer, R. A., & Embaby, A. (2020). Multi-criteria decision-making for the analysis of flash floods: A case study of Awlad Toq-Sherq, Southeast Sohag, Egypt. *Journal of African Earth Sciences*, *162*, 103709.
[9] El-Magd, S. A. A. (2019). Flash Flood Hazard Mapping Using GIS and Bivariate Statistical Method at Wadi Bada'a, Gulf of Suez, Egypt. *Journal of Geoscience and Environment Protection*, *7*(8), 372-385.
[10] Hashemkhani Zolfani, S., & Bahrami, M. (2014). Investment prioritizing in high tech industries based on SWARA-COPRAS approach. *Technological and Economic Development of Economy*, *20*(3), 534-553.
[11] Keršuliene, V., Zavadskas, E. K., & Turskis, Z. (2010). Selection of rational dispute resolution method by applying new step‐wise weight assessment ratio analysis (SWARA). *Journal of business economics and management*, *11*(2), 243-258.
[12] Kouchaksaraei, R. H., Zolfani, S. H., & Golabchi, M. (2015). Glasshouse locating based on SWARA-COPRAS approach. *International Journal of Strategic Property Management*, *19*(2), 111-122.
[13] Zolfani, S. H., & Saparauskas, J. (2013). New application of SWARA method in prioritizing sustainability assessment indicators of energy system. *Engineering Economics*, *24*(5), 408-414.
[14] Zolfani, S. H., Yazdani, M., & Zavadskas, E. K. (2018). An extended stepwise weight assessment ratio analysis (SWARA) method for improving criteria prioritization process. *Soft Computing*, *22*(22), 7399-7405.

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023

[15] Moneim, A. A. A. (1992). *Numerical simulation and groundwater management of the Sohag aquifer, the Nile Valley, Egypt* (Doctoral dissertation, University of Strathclyde).
[16] Malczewski, J. (1996). A GIS-based approach to multiple criteria group decision-making. *International Journal of Geographical Information Systems*, *10*(8), 955-971.
[17] Skilodimou, H. D., Bathrellos, G. D., Chousianitis, K., Youssef, A. M., & Pradhan, B. (2019). Multi-hazard assessment modeling via multi-criteria analysis and GIS: a case study. *Environmental earth sciences*, *78*(2), 47.
[18] Rincón, D., Khan, U. T., & Armenakis, C. (2018). Flood risk mapping using GIS and multi-criteria analysis: A greater Toronto area case study. *Geosciences*, *8*(8), 275.
[19] Youssef, A. M., & Hegab, M. A. (2019). Flood-hazard assessment modeling using multicriteria analysis and GIS: a case study—Ras Gharib area, Egypt. In *Spatial modeling in GIS and R for earth and environmental sciences* (pp. 229-257). Elsevier.
[20] Ganová, L. (2011). Integrating multicriteria analysis with geographical information system for evaluation flood vulnerable areas. *International Multidisciplinary Scientific GeoConference: SGEM*, *2*, 433.
[21] Rahmati, O., Zeinivand, H., & Besharat, M. (2016). Flood hazard zoning in Yasooj region, Iran, using GIS and multi-criteria decision analysis. *Geomatics, Natural Hazards and Risk*, *7*(3), 1000-1017.
[22] Bui, D. T., Pradhan, B., Nampak, H., Bui, Q. T., Tran, Q. A., & Nguyen, Q. P. (2016). Hybrid artificial intelligence approach based on neural fuzzy inference model and metaheuristic optimization for flood susceptibilitgy modeling in a high-frequency tropical cyclone area using GIS. *Journal of Hydrology*, *540*, 317-330.
[23] Bathrellos, G. D., Skilodimou, H. D., Soukis, K., & Koskeridou, E. (2018). Temporal and spatial analysis of flood occurrences in the drainage basin of pinios river (thessaly, central greece). *Land*, *7*(3), 106.
[24] Tang, Z., Zhang, H., Yi, S., & Xiao, Y. (2018). Assessment of flood susceptible areas using spatially explicit, probabilistic multi-criteria decision analysis. *Journal of Hydrology*, *558*, 144-158.
[25] Frazier, B. E., Rodgers, T. M., Briggs, C. A., & Rupp, R. A. (2009). Remote area soil proxy modeling technique. *Soil Horizons*, *50*(2), 62-67.
[26] Chuvieco, E., & Congalton, R. G. (1989). Application of remote sensing and geographic information systems to forest fire hazard mapping. *Remote sensing of Environment*, *29*(2), 147-159.
[27] Shimaa Said,Mahmoud M. Ibrahim,Mahmoud M. Ismail, An Integrated Multi-Criteria Decision-Making Approach for Identification and Ranking Solar Drying Barriers under Single-Valued Triangular Neutrosophic Sets (SVTNSs), Neutrosophic and Information Fusion, Vol. 2 , No. 1 , (2023) : 35-49 (Doi : https://doi.org/10.54216/NIF.020103)
[28] Abedallah Z. Abualkishik,Rasha Almajed, Triangular Neutrosophic Multi-Criteria Decision Making AHP Method for Solar Power Site Selection, International Journal of Advances in Applied Computational Intelligence, Vol. 2 , No. 2 , (2022) : 08-15 (Doi : https://doi.org/10.54216/IJAACI.020201).
[29] Ginevičius, R. (2011). A new determining method for the criteria weights in multicriteria evaluation. *International Journal of Information Technology & Decision Making*, *10*(06), 1067-1095.
[30] Shannon, C. E. (1948). A mathematical theory of communication. *The Bell system technical journal*, *27*(3), 379-423.
[31] Bitarafan, M., Zolfani, S. H., Arefi, S. L., Zavadskas, E. K., & Mahmoudzadeh, A. (2014). Evaluation of real-time intelligent sensors for structural health monitoring of bridges based on SWARA-WASPAS; a case in Iran. *The Baltic Journal of Road and Bridge Engineering*, *9*(4), 333-340.
[32] Shereen Zaki,Mahmoud M. Ibrahim,Mahmoud M. Ismail, Interval Valued Neutrosophic VIKOR Method for Assessment Green Suppliers in Supply Chain, International Journal of Advances in Applied Computational Intelligence, Vol. 2 , No. 1 , (2022) : 15-22 (Doi : https://doi.org/10.54216/IJAACI.020102)
[33] Nada A. Nabeeh,Alshaimaa A. Tantawy, A Neutrosophic Model for Blockchain Platform Selection based on SWARA and WSM, Neutrosophic and Information Fusion, Vol. 1 , No. 2 , (2023) : 29-43 (Doi : https://doi.org/10.54216/NIF.010204).
[34] Supciller, A. A., & Toprak, F. (2020). Selection of wind turbines with multi-criteria decision-making techniques involving neutrosophic numbers: A case from Turkey. *Energy*, *207*, 118237.

DOI: https://doi.org/10.54216/IJNS.210302
Received: January 25, 2023 Revised: April 14, 2023 Accepted: June 12, 2023