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Exploring Flood Susceptibility Mapping Using ArcGIS Techniques Integrated with Analytical Hierarchy Process under Multi-Criteria Decision Analysis in Kanakarayan Aru River Basin, Sri Lanka

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Abstract: Floods are one of the natural disasters causing economic, social, and environmental damage around the world, including in Sri Lanka. Flood susceptibility mapping is essential for flood prevention and mitigation measures. This study aimed to develop and validate a flood susceptibility map for the Kanakarayan Aru River Basin in Sri Lanka. Primary data were collected from water professionals and experts from Provincial Irrigation-Northern Province, Provincial Irrigation-Eastern Province, Disaster Management Centre, and Irrigation Department to decide the significance of flood causative factors. Secondary data of rainfall, digital elevation model, and GIS-based thematic data layers were collected from different agencies. GIS-based spatial multi-criteria decision analysis and analytical hierarchy process method were used for the study. A total of eight flood causative factors, i.e., elevation, slope, precipitation, land use and land cover, river proximity, drainage network density, topographic wetness index, and soil types were identified. Results show that the three most-relevant factors of flood risk were precipitation (33%), drainage density network (17%), and surface slope (11%). The very high, high, and moderate flood risks occupy 12.5%, 23.4%, and 27.1% of the river basin areas, respectively. The validation process is executed based on the map's comparison of the historical flood locations of the different flood-susceptible zones and it provides a significant accuracy.

Keywords: Flood Susceptibility, Kanakarayan Aru, Flood Susceptibility Mapping, Precipitation, Sri Lanka

1. Introduction

Sri Lanka is a lower middle-income island with a total population of 23 million. This island has faced many natural disasters, including floods, landslides, tsunamis, droughts, and cyclones. Flood susceptibility means a potential likelihood of a dangerous event occurring in an area on the basis of local terrain conditions due to a flood. Floods have become a common natural disaster that lead to not only devastating destruction to the infrastructure and natural environment but also destroying people's lives around the world including in Sri Lanka. It is estimated by Feng & Lu [1] that, of the total economic losses from all disasters, 40% are caused by floods. Seasonal flooding occurs frequently in Sri Lanka, particularly during the southwest and northeast monsoons. The most common types of floods in this river basin are fluvial and pluvial. Fluvial flooding occurs when intense precipitation causes rivers to overflow. Pluvial flooding may occur when rainwater accumulates beyond the absorptive capacity of the soil. Sri Lanka faces massive fatal and economic losses by a flood. In May 2017, 15 districts in Sri Lanka experienced flash flooding and landslides causing 210 fatalities, and affected around 630,000 people. In the subsequent year, a more intense monsoon flood caused 24 fatalities, displaced 6,000 people, and affected 170,000 Sri Lankans [2].Climate change and climate variability in terms of rainfall are also causational factors for floods in Sri Lanka. Flood susceptibility mapping is an essential tool to produce a crucial map for decision-makers to identify effective options for mitigation measures including early warning signals. Flood risks are defined in terms of inundation depth, and accordingly, up to 0.05 meters of inundation depth is defined as very low risk, 0.05–0.15 meters low risk, 0.15–0.5 meters moderate risk, 0.5–1.5 meters high risk and above 1.5 meters very high risk [3].

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Researchers have used criteria such as rainfall, slope, elevation, topographic wetness index, drainage network density, distance from the river, land use and land cover, and soil type in their studies for flood susceptibility analysis [4], [5]. Abeysiriwardana and Wijesekera [6] produced a flood susceptibility map for the Nilwala river basin in Sri Lanka using logistic regression and GIS tools that give useful insights to researchers.
This study aimed to develop and validate a flood susceptibility map for the Kanakarayan Aru River Basin in Sri Lanka using the research methodology of Weighted Linear Combination Method using Overlay of ArcGIS techniques with an Analytical Hierarchy Process (AHP) under Multi-Criteria Decision Analysis (MCDA). This methodology has not been explored in this catchment area so far and gives innovative novel value to this paper.

2. Study Area

The Kanakarayan Aru river basin in Sri Lanka, situated between latitude 9.2573° and longitude 80.4592°, covers an area of 906 km^2 along Vavuniya, Mullaitivu, and Kilinochchi districts. It is 86km in length and originates from Chemamadu in the Vavuniya district and ends at Chundikulam Lagoon close to Elephant Pass in the Kilinochchi district. The slopes, which are generally mild, vary a few degrees (0° and 1.5°). The average annual rainfall is 1380 mm and the main rainfall gauge station is in Iranaimadu. The average temperature is 26 $^{\circ}$C, with a maximum of 38 $^{\circ}$C and a minimum of 12 $^{\circ}$C. The hydrographic network is dense. The soil complex is characterized by dominantly reddish Brown Earth and Low Humic Gley Soils, Red Yellow Latosols, and Solodized Solonetz and Solonohaks flat terrain.

Four climatic seasons exist in the study area, viz., North East Monsoon Season, South West Monsoon Season, First Inter Monsoon Season, and Second Inter Monsoon Season. However, rainfall is not evenly distributed over the four seasons as only the two seasons, namely, Second Inter Monsoon Season (October to November) and North East Monsoon Season (December-February), have adequate rainfall in the basin.

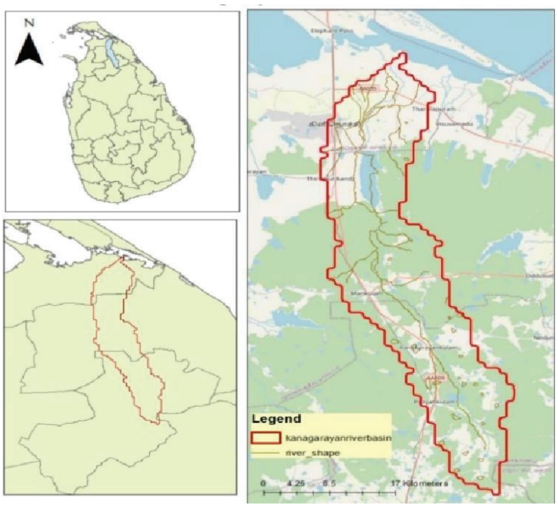

Figure 1 – Location map of Kanakarayan Aru River Basin and Study Area

3. Materials and Methods

3.1 Data Sets, Sources and Data Collection

The secondary data for this study was obtained from several open sources, through an extensive literature review, and primary data was collected by expert opinions and a questionnaire survey from experts in the field of water resources, and the Irrigation sector in the Northern Province of Sri Lanka. These data sets and sources are shown in the following Table 1.

Table 1 - Description of Primary and Secondary Data Sources

No	Data Category	Data Type	Data Source
1	Land cover	Land use and Land cover data	United State Geological Survey (USGS)
2	GIS data	Road Network shapefile River shapefile	United State Geological Survey (USGS)
3	Hydro-meteorological data (Precipitation)	Rainfall data (1982-2018) Stream Flow data (1968- 2018	Metrological Department and Provincial Irrigation, Northern Province
4	Geomorphologic data	Soil data (2020)	Digital World Soil Map (FAO)
5	Ancillary data	Other relevant information	Verbal interviews and field surveys

3.2 Applicable Methodology

The applicable methodology for flood susceptibility map for Kanakarayan Aru River Basin in this paper was the integration of Weighted Linear Combination Method using Overlay of ArcGIS techniques with an Analytical Hierarchy Process under Multi-Criteria Decision Analysis. To identify the flood vulnerable areas, Multi Criteria Decision Analysis was used. The Analytical Hierarchy Process was selected as the criteria weighting method in the context of Multi-Criteria Decision Analysis. The criteria used for determining the flood susceptibility were based on the parameters that most contribute to river floods, based on expert survey and literature. The comprehensive methodology with an overall schematic diagram is illustrated in Figure 2.

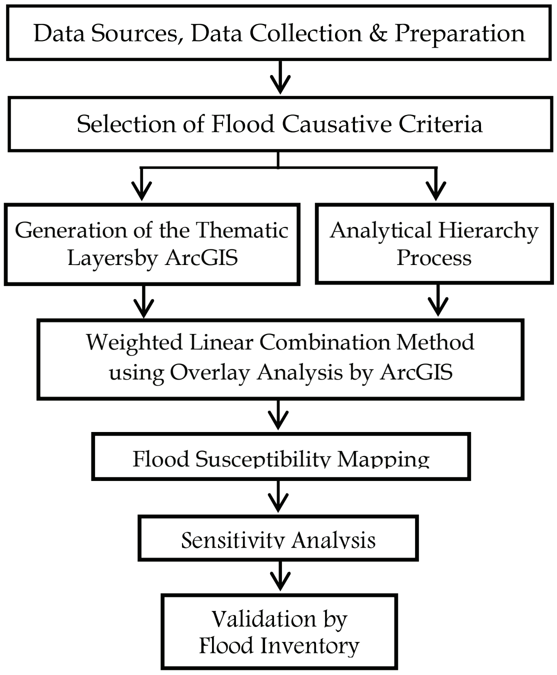

Figure 2 - Schematic Diagram for the Research

3.3. Analytical Hierarchy Process (AHP)

Saaty [7]developed a sturdy and useful device for dealing with multi-criteria elements involved in selection-making behavior called Analytical Hierarchy technique (AHP) that is primarily based on a hierarchical structure.AHP is a mathematical and psychological approach to tackling complicated problems in the philosophy of decision-making. Using a hierarchical model with a goal, criteria (sub-criteria), and alternatives, the AHP is used to make decisions. Pairwise comparison judgments are made regarding the dominance of groups of elements in a level below with respect to the element from which they are connected in the level above. To rank the options, the priorities of all the components are ultimately combined. The AHP system concerned defining the problem, developing of AHP hierarchy, pairing sensible comparison, assigning weights to standards, figuring out the priority variable, and checking consistency and final judgment.

3.4 Selection of Flood Causative Criteria

Eight criteria were determined to be critical for mapping the flood-susceptible areas within the Kanakarayan Aru River Basin based on a literature review and expert opinions. They are illustrated below.

3.4.1 Precipitation (Rainfall)

Rainfall pattern performs a main role in flooding, with areas receiving high rainfall, the more flood- runoff will be produced. Rainfall intensity is also critical in causing flooding.

For this analysis, at least thirty years of continuous rainfall records was used. The average annual rainfall for the study area is 1381mm.

3.4.2 Drainage Network Density

Drainage network density is considered as one of the major parameters for flooding. It was estimated as the ratio between the total length of river segments to the total area of drainage basin. According to Magesh et al. [8], drainage density expresses the length of rivers per unit of area (km/km^2).In a basin with high drainage density, the contribution of surface runoff to stream discharge will be high.

3.4.3 Slope

The slope is the degree of inclination to the horizontal plane. It is also considered one of the predominant flood hazard contributing parameters of this study area. The slope of any basin affects surface runoff and water infiltration capacity. Besides, the opportunity of a flood increases because the slope of an area decreases[9].

3.4.4 Topographical Wetness Index

The Topographic Wetness Index (TWI) becomes advanced and introduced by Beven & Kirkby [10], combining local upslope contributing area through a certain point per unit contour length and slope. Therefore, regions with better TWI values are in all likelihood to be wetter relative to areas with lower values. The TWI is an outstanding terrain-derived parameter that assesses topographic results on some hydrological procedures, especially flood activities [11].

3.4.5 Distance from the River (Drainage)
One of the primary criteria used to evaluate flood susceptibility map technology in the study area is the distance from the river. Areas that can be close to a river commonly have higher potential by flooding than areas far away from the rivers [12].In their study, González-Arqueros et al.[13] claimed that surplus water from the river first reaches the banks and distance from the river indicates primary pathways for flood discharge and growth.

3.4.6 Land Use and Land Cover
Land use and land cover map is one of the elements in determining susceptibility to floods and represents the current usage of the land, its sample size, and its type. It influences infiltration rates and the interaction of surface and groundwater of the watershed. As mentioned by Nuissl et al. [14], land use and land cover map represents the main factor to perceive regions that are at risk of being submerged through flooding.

3.4.7 Elevation
It is a common phenomenon that flood situations are probably created in lower elevated flat areas compared to higher elevations and has a considerable influence on the propagation of floods. Argaz et al. [15] mentioned that flooding was less of an issue for higher elevations, and vice versa.

3.4.8 Soil Type
The type of soil has a massive impact on the rate of infiltration (drains), permeability, and the water-conserving capability of the location. In their study, Hammami et al. [16]claimed that soil type maps are used to symbolize permeability conditions and ability of soil to keep and deliver water. The highest weight value is assigned to the sand class to the soil type[17].

3.5Analysis by Weighted Linear Combination (WLC) Method for Producing Flood Susceptibility Maps

One of the most popular GIS-based decision rules is a Weighted Linear Combination (WLC), an analytical technique that may be employed when dealing with multi-attribute decision-making. WLC is based on combining weighted averages of a number of parameters selected by the expert. The WLC technique permits complete tradeoffs between each of these variables. However, a factor's weight determines how much it can make up for another. Any GIS with overlay capabilities can be used to operationalize it. The attribute map layers (input maps) can be combined using overlay techniques to create the composite map layer (output map).

For flood susceptibility mapping, eight thematic layers were created by performing spatial analysis tools in ArcGIS in relation to the selected criteria. After reclassifying the maps, using the weights derived from the AHP technique under multi-criteria decision analysis and using the weighted linear combination method under the Weighted Overlay Tool of ArcGIS, flood susceptibility maps shall be developed and categorized into five classes from very low to very high for the entire Kanakarayan Aru River Basin.

3.6 Sensitivity analysis and validation of the model

The model's validation and sensitivity analysis come last. Lowry et al. [18] provide examples of sensitivity analysis. This study used sensitivity analysis to examine changes in the flood susceptibility map area relative to the original model by adding and subtracting 10% from each criterion weight. Model validation can be carried out by comparing model output to observable data. By comparing the flood susceptibility map with the Flood Inventory, the validation process will be carried out.

4. Results and Discussion

4.1 Generation and Reclassification of Thematic Layers (Maps) by ArcGIS
This study applied GIS techniques integrated with AHP under multi-criteria decision analysis for generating a flood susceptibility map. The 30 m-resolution of a Digital Elevation Model (DEM) was processed in ArcGIS Software version 10.8 for the thematic layers. These are shown in the illustrations below.

4.1.1 Precipitation (Rainfall) Layer
The rainfall in the research area was classified into five categories based on its impact on food risk: very low (1429.0–1490.0 mm), low (1491.0–1541.0 mm), moderate (1542.0–1577.0 mm), high (1578.0–1607.0 mm) and very high (1608.0–1669.0 mm and above).These classifications are based on rainfall intensity in terms of flood risks (magnitude). In addition to average annual

rainfall, average rainfall of November and December was also developed. The average annual precipitation map is shown in Figure 3.

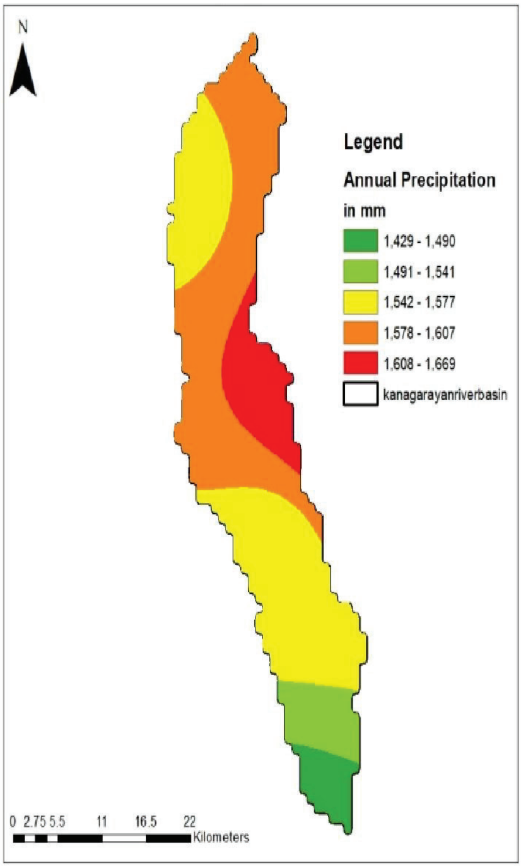

Figure 3 - Precipitation Map of Kanakarayan Aru River Basin

4.1.2 Drainage Network Density Layer

The drainage density map was produced employing the line density analysis tool in the ArcGIS software environment. The density of the study area is grouped into five classes, which is illustrated in Figure 4.They are 0–57.7 km/km^2, 57.8– 115.0 km/ km^2, 116.0–173.0 km/km^2, 174.0–231.0 km/km^2, and 232.0–289.0 km/km^2. After that, a reclassification into five categories was made based on flood hazard, i.e., very low, low, moderate, high, and very high, and weights were assigned to them as 2, 4, 6, 8, and 10, respectively, because a standardization procedure of the raw data was required through weighted-linear scale transformation to make the various criterion maps comparable.

Moreover, the terrain of the study area with a higher drainage density of (232.0 -289.0 km/km^2) was recorded while a low drainage density of (0–57.7 km/km^2) was identified.

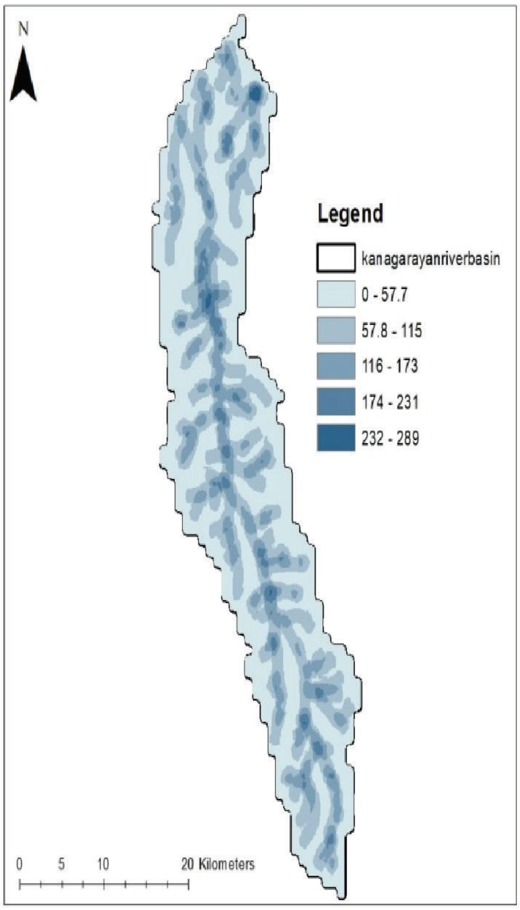

Figure 4 - Drainage Network Density Map of Kanakarayan Aru River Basin

4.1.3 Slope Layer

The digital elevation model with a resolution of 30 meters and the spatial analysis tool in ArcGIS 10.8was used to construct the slope percent map for the study region. The slope of the basin in the study region was divided into five categories: very low (0.999–1.293%), low (0.665–0.998%), moderate (0.457–0.664%), high (0.249–0.456%) and very high (0.0–0.248%). When it comes to slope, the regions with the highest slope values (> 1.29%) were categorized as having a very low flood hazard slope angle and given a class 1 ranking. Figure 5 shows them in detail and the re-classification of the surface slope into five categories of Kanakarayan Aru River Basin is illustrated in Figure 6.

On the upstream side of this basin, the higher slope areas are concentrated. As a result, the research area had a very low level of flood risk.

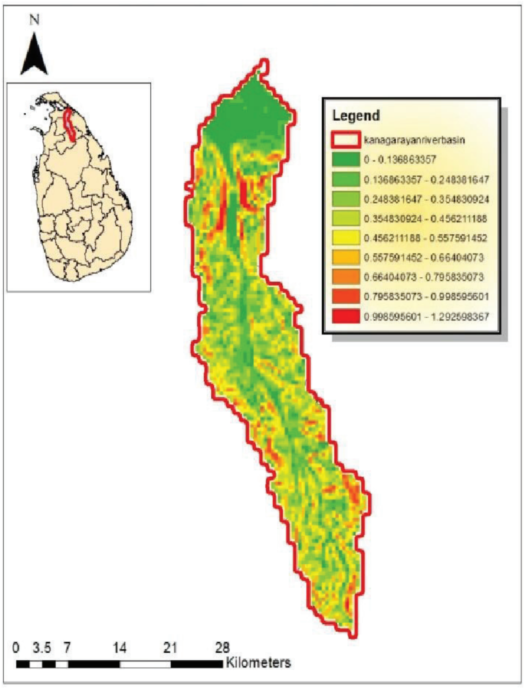

Figure 5 - The Surface Slope of Kanakarayan Aru River Basin

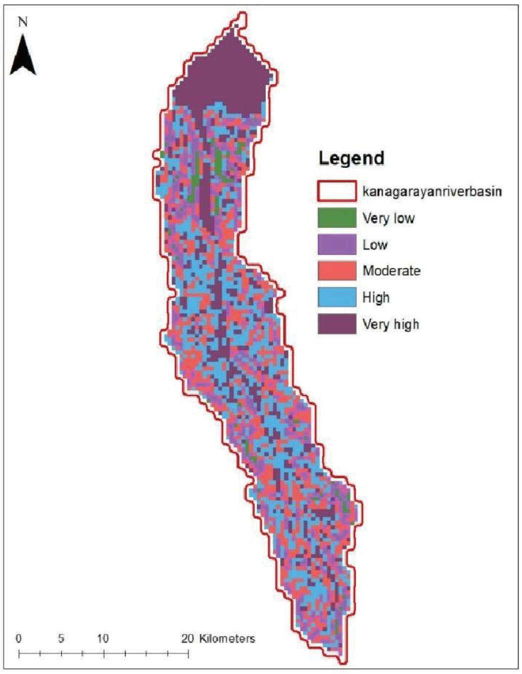

Figure 6 – The Re-classification of the Surface Slope of Kanakarayan Aru River Basin

4.1.4 Topographical Wetness Index (TWI) Layer

TWI of the study area was derived from the Shuttle Radar Topography Mission (SRTM) and Digital Elevation Model (DEM) data set and was computed using the following equation (Beven and Kirkby, 1979) and spatial analyst tools with ArcGIS software.

$$TWI = \ln(\alpha/\tan\beta) \qquad \dots(1)$$

where α is the specific catchment area A/L (catchment area (A) divided by contour length (L)), and β is the local slope.

The present study classified the TWI map into five classes as very low (-6.55 to -4.05), low (-4.04 to -2.54), moderate (-2.53 to-0.591), high (-0.59 to -2.06), and very high (2.07 to -6.22) susceptible groups based on TWI as shown in Figure 7. This study confirms the fact that the areas affected by frequent floods in the study area are characterized by the highest TWI (2.07-6.22).

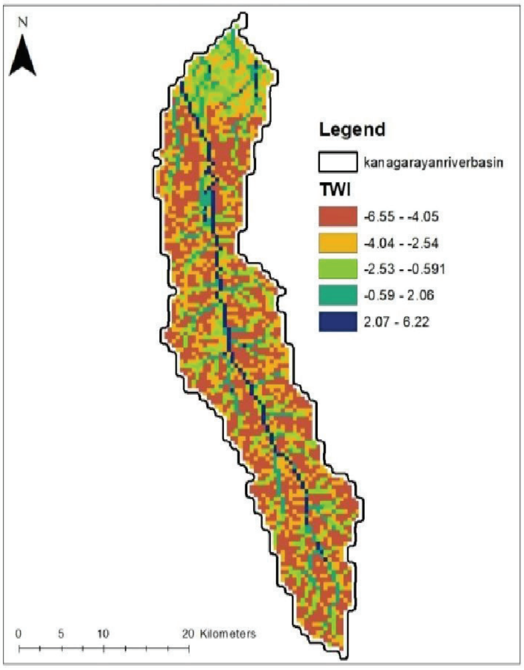

Figure 7 - Topographical Wetness Index Map of Kanakarayan Aru River Basin

4.1.5 Distance from the River (Drainage) Layer

Distance from the river network (Drainage network) map (layer) was produced using the "Euclidean" distance tool and techniques with a vector layer in the ArcGIS software environment. Areas with a high distance from the river were ranked with the lowest rate value while those with low river distance were ranked with the highest rate value, as illustrated in Figure 7. In this study, the class was divided into five categories based on their effect on flood risks, namely, very high (0–988.51 m), high (988.52–1977.00 m), moderate (1977.00–2965.60 m), low (2965.6–3954.00 m) and very low (3954.10–4942.50 m) which is derived from the watershed river network as shown in Figure 8.

Further, the re-classification of the distance from the river network (Drainage network) into five categories of Kanakarayan Aru River Basin is illustrated in Figure 9.

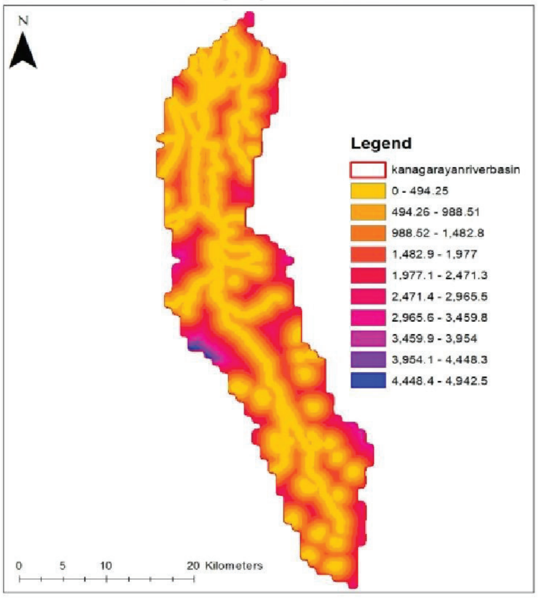

Figure 8 - Distance from the River Map of Kanakarayan Aru River Basin

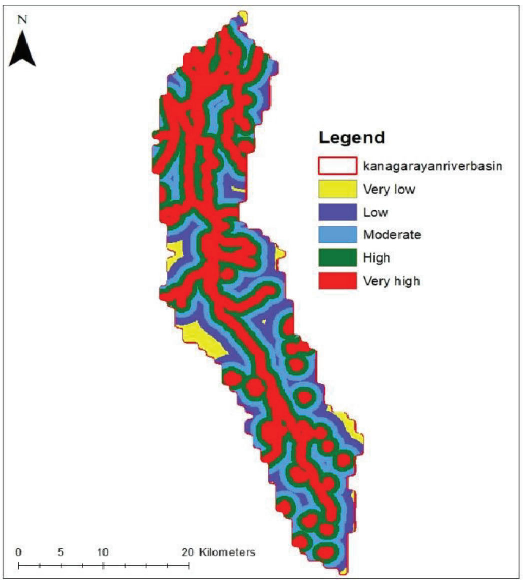

Figure 9 – Re-Classification of Distance from the River Map of Kanakarayan Aru River Basin

4.1.6 Land Use and Land Cover layer (LULC)

The data for land use and land cover was obtained from ESRI latest land cover 2021 determined from the satellite images. Land use affects infiltration rate with forest and vegetated areas favoring infiltration and vice versa. In the land use map, six classes were identified, namely, water bodies, trees, floating vegetation, crops, building, and bare land. The class was reclassified into five categories, namely, very high (10), high (8), moderate (6), low (4), and very low (2), based on their effect on flood risks and their ability to increase or decrease the rate of floods. This is shown in Figure 10 given below.

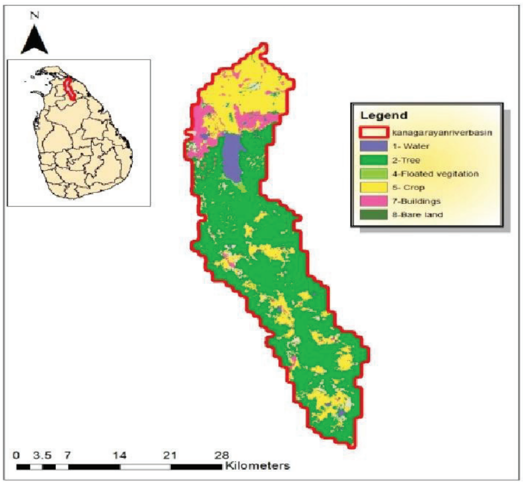

Figure 10 - Land Use and Land Cover Map of Kanakarayan Aru River Basin

4.1.7 Elevation Layer

The research area's elevation raster layers were categorized and grouped into five groups using the reclassification tool in the ArcGIS environment as very low (5.0-15.0 m), low (15.1-25.0 m), moderate (25.1-35.0 m), high (35.1-80.0 m), and very high (80.1 -121.0 m), based on its effect on food susceptibility. Each class covers approximately 54.8%, 28.3%, 8.4%, 7.2 %, and 1.3% of the total area of the watershed, respectively. This is shown in Figure 11. Higher elevation is found in the Southern part and lower elevation is in the Northern part of the study area.

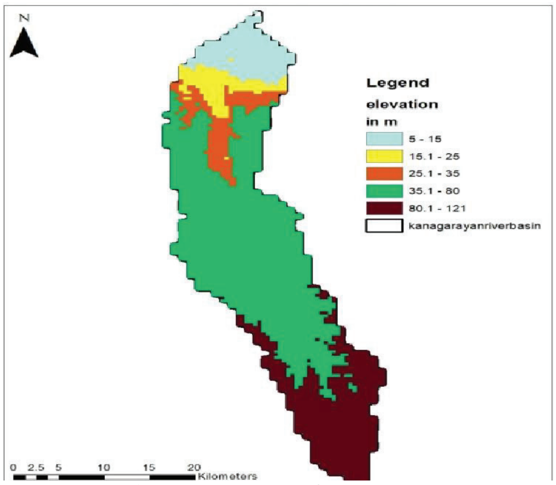

Figure 11 - Elevation Map of Kanakarayan Aru River Basin

4.1.8 Soil Type Layer

The thematic soil type map in the current study was displayed in a GIS layer that ranked soils according to their textures and structures. By assigning weights to each soil class, the weighted soil map was created. For the research area, soil types were classified into five broad categories, namely, very low-(Nil), low (Zg-Gleyic solonchaks), moderate (Jc-Calcaric fluvisols), high (Fr-rhodic ferralsols), and very high (Lc-Chromic luvisols). These are illustrated in Figure 12.

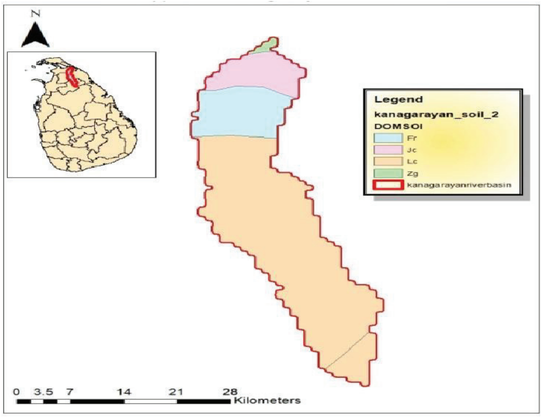

Figure 12 - Types of Soil Map of Kanakarayan Aru River Basin

4.2 Analytical Hierarchy Process under Multi-Criteria Decision Analysis for Flood Susceptibility Analysis

4.2.1 Assigning Values to Subjective Judgments and Calculating the Relative Weights of Each Criterion

The weights of the factors applied in the Kanakarayan Aru river basin were determined using the Analytical Hierarchy Process (AHP) pairwise comparison by experts' judgment method for identifying relative weights of criteria. The relative importance of each factor was determined by one to nine(1-9) numerical scales, as shown in Table 2.

Table 2 - Relative Weights of Criteria of Analytical Hierarchy Process

Factors (Criteria)		Indicate More Importance A or B	Scale
A	B		(1-9)
Topographic Wetness Index	Elevation	A	1
	Surface Slope	A	1
	Precipitation	B	3
	Land Use and Land Cover	B	1
	Distance from River	A	2
	Drainage Network Density	B	3
	Soil Type (Permeability)	A	3
Elevation	Surface Slope	B	2
	Precipitation	B	3
	Land Use and Land Cover	A	2
	Distance from River	A	1
	Drainage Network Density	B	4
	Soil Type (Permeability)	A	1
Surface Slope	Precipitation	B	2
	Land Use and Land Cover	A	1
	Distance from River	A	3
	Drainage Network Density	B	2
	Soil Type (Permeability)	A	1
Precipitation	Land Use and Land Cover	A	5
	Distance from River	A	7
	Drainage Network Density	A	4
	Soil Type (Permeability)	A	4

Land Use and Land Cover	Distance from River	B	2
	Drainage Network Density	A	1
	Soil Type (Permeability)	A	2
Distance from River	Drainage Network Density	A	1
	Soil Type (Permeability)	A	1
Drainage	Soil types (Permeability)	A	3

4.2.2 Determination of Pair-wise Comparison Matrix under Analytical Hierarchical Process

The proposed methodology suggests a pairwise comparison, using an 8 × 8 matrix, where diagonal elements are equal to 1. The values of each row characterizes the importance between two parameters. The first row of Table 3 illustrates the importance of the TWI with regards to the other parameters which are placed in the columns. The entire process is shown in Table 3.

Table 3 – Pairwise Comparison Matrix for Flood Causative Criteria under Analytical Hierarchy Process

Parameter	TWI	Elevation	Surface Slope	Precipitation	Land Use and Land Cover	Distance from River	Drainage Network Density	Soil Type (Permeability)
TWI	1	1	1	1/3	1	2	1/3	3
Elevation	1	1	1/2	1/3	2	1	1/4	1
Surface Slope	1	2	1	1/2	1	3	1/2	1
Precipitation	3	3	2	1	5	7	4	4
Land Use and Land Cover	1	1/2	1	1/5	1	1/2	1	2
Distance from River	1/2	1	1/3	1/7	2	1	1	1
Drainage Network Density	3	4	2	1/4	1	1	1	3
Soil Types (Permeability)	1/3	1	1	1/4	1/2	1	1/3	1
Total	**10.83**	**13.5**	**8.83**	**3.01**	**13.50**	**16.50**	**8.42**	**16.00**

4.2.3 Assessment of Normalized Parameter Matrix under Analytical Hierarchical Process

4.2.3.1 Basic Theory Behind Analytic Hierarchy Process (AHP)

The theory of Measurement and the Theory of relative measurement are basic theories.

The philosophical explanation of how measurements are made in science is known as measurement theory. It is an effort to comprehend scientific measurement and the thinking process and related body of knowledge that serves as the foundation for reliable measurements. The theory of ratio-scale measures was developed by psychophysicist, Stanley S. Stevens (1946), in the middle of the last century is also applicable. Independent of research of other researchers, Rasch (1960) also established measurement theory and a measurement model applicable to AHP.

The natural values were normalized by adding the column values and dividing the value of each cell by the total of column values from the pairwise comparison matrix for flood causative criteria under the Analytical Hierarchy Process from Table 3. Calculation of the normalized parameter matrix that is given in the following Table 4.

Table 4 - Normalized Parameter Matrix under Analytical Hierarchy Process

Parameter	TWI	Elevation	Surface Slope	Precipitation	Land Use and Land Cover	Distance from River	Drainage Network Density	Soil Type (Permeability)	Total	Average	Weighted %
TWI	0.09	0.07	0.11	0.11	0.07	0.12	0.04	0.19	0.80	0.10	10
Elevation	0.09	0.07	0.06	0.11	0.15	0.06	0.03	0.06	0.63	0.08	7
Surface Slope	0.09	0.15	0.11	0.17	0.07	0.18	0.06	0.06	0.89	0.11	11
Precipitation	0.28	0.22	0.23	0.33	0.37	0.42	0.48	0.25	2.64	0.33	33
Land Use and Land Cover	0.09	0.04	0.11	0.07	0.07	0.03	0.12	0.13	0.66	0.08	8
Distance from River	0.05	0.07	0.04	0.05	0.15	0.06	0.12	0.06	0.67	0.08	8
Drainage Network Density	0.28	0.30	0.23	0.08	0.07	0.06	0.12	0.19	1.30	0.16	17
Soil Type(Permeability)	0.03	0.07	0.11	0.08	0.04	0.06	0.04	0.06	0.50	0.06	6
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	100

4.2.4 Consistency Ratio Assessments and Judgment

The consistency of the created eigenvector matrix needs to be evaluated for accuracy and reliability. CR= CI/RI, where CR is the consistency ratio, CI the consistency index and RI the specific Random Index. The eigenvalue (λ max) was computed using the methodology adopted by Ogato et al. [19], in which, λmax (Maximum eigenvalue of the matrix) represents the sum of the products between the sum of each column of the comparison matrix and the relative weights the criteria. In this study,

λmax = (10.83 x 0.10+13.50 x 0.08+8.83 x0.11 +3.01 x0. 33+13.50 x0.07 +16.50 x0.08+8.42 x0.16 +16.00 x0.06) = 8.70, λmax =8.70

CI is calculated using Eq.(1)

$$CI = (\lambda max - n)/(n-1) = (8.70 - 8)/7 = 0.10$$

RI values are given in a specific table proposed by Ogato et al.[14].This is shown in Table 5.

Table 5 - Specific Random Index (RI) Table used to compute consistency ratio

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.55	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Source: Ogato et al.(2020)

From Table 5, RI= 1.40

CR = CI/RI= 0.10/1.40= 0.07 ≤ (0.1)- Acceptable.

In real-world scenarios, it is impossible to obtain a judgmental matrix that is entirely consistent after pairwise comparison. The consistency index, which is a numerical value, indicates separation from the consistent matrix. The consistency index can be defined mathematically as a function from a set of judgmental matrices to a set of real values. Saaty[7] decided the threshold of 0.10 for the consistency ratio(CR).

Accordingly, CR for the flood-contributing factors in the Kanakarayan Aru River Basin is 0.07, which is less than the standard 0.1 and 10% (Saaty, 1980) and acceptable.

4.3 Results of Flood Susceptibility Analysis by Weighted Linear Combination (WLC) Method Using Overlay Analysis by ArcGIS

By using the spatial analysis tool in ArcGIS, eight thematic layers for flood susceptibility zoning were produced. After reclassifying the layers, an analysis was conducted and the flood susceptibility risks for the entire Kanakarayan

Aru River Basin were classified into five classes, ranging from very low to very high, using the weights derived from the AHP technique under multi-criteria decision analysis and using the weighted linear combination method under the Weighted Overlay Tool of ArcGIS. Since precipitation accounted for 33% of all factors in accordance with Table 4, three scenarios—average annual precipitation, average precipitation for the month of November, and average precipitation for the month of December—were created in order to identify critical risks. Maximum precipitation occurs in November and December each year for this basin. These are shown in Figure 13.

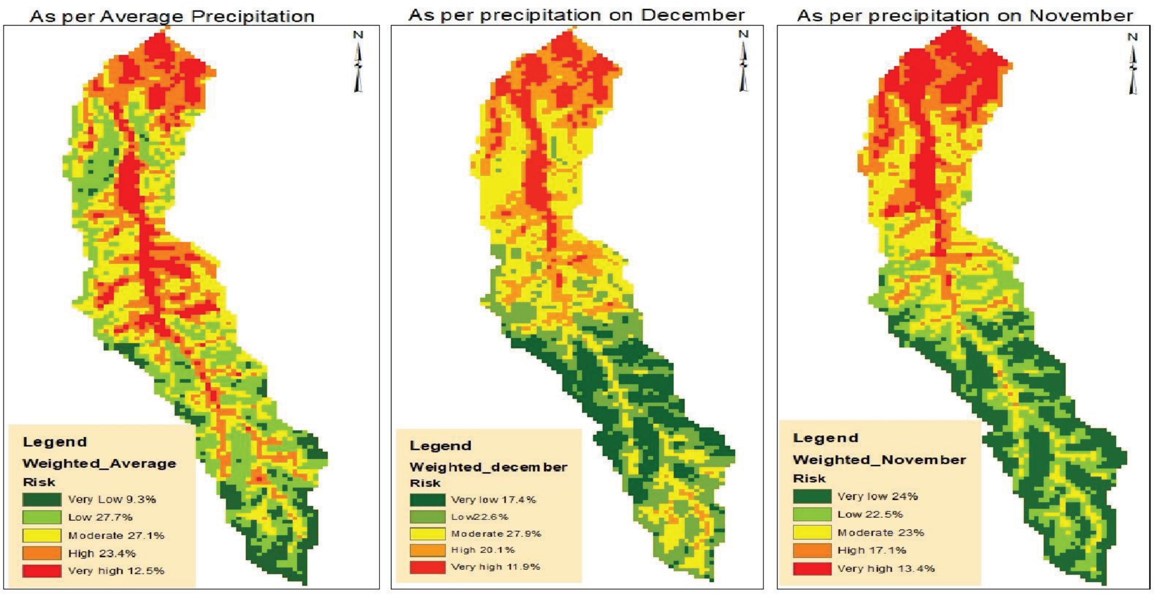

Figure 13 - Flood Susceptibility Mapping for Kanakarayan Aru River Basin for Average Annual Precipitation, and Average Precipitation for the month of November, and December

Analysis of the results obtained from the linear combination of the selected factors showed that the three most-relevant factors for the determination of flood risk were precipitation (33%), drainage density network (17%), and surface slope (11%).

Five flood risk classes, varying from very low to very high, were defined according to the flood risk map of the Kanakarayan Aru river basin. The respective areas corresponding to the different degrees of flood risks are shown in Table 6 for three different scenarios.

Table 6 – Degree of Flood Susceptibility Classification System and the Area Coverage in Kanakarayan Aru River Basin in Sri Lanka

Degree of Flood Susceptibility class	**Area & coverage as per average annual precipitation**		**Area & coverage as per average precipitation for the month of December**		**Area & coverage as per average precipitation for the month of November**	
	Area (km^2)	**Area coverage (%)**	**Area (km^2)**	**Area coverage (%)**	**Area (km^2)**	**Area coverage (%)**
Very Low	84.26	9.30	157.64	17.4	217.44	24.0
Low	250.96	27.7	204.76	22.6	203.85	22.5
Moderate	245.53	27.1	252.77	27.9	208.38	23.0
High	212.00	23.4	183.02	20.2	154.93	17.1
Very High	113.25	12.5	107.81	11.9	121.4	13.4
Total	**906.00**	**100.0**	**906.00**	**100.0**	**906.00**	**100.0**

According to Table 6, comparing the three scenarios, very high-risk categories are below 13.4 % of the total catchment areas of 906km². Considering the average annual rainfall, risk varied from 12.5% (very high risk), 23.4% (high risk), 27.1% (moderate risk), 27.7% (low risk), and 9.30% (very low risk). Most flood areas were located on the flood plains toward Kilinochchi and downstream of the catchment area and were the most vulnerable to high flood occurrences.

4.4 Sensitivity Analysis

This study used sensitivity analysis to examine changes in the flood susceptibility map area relative to the original model by adding and deleting 10% from each criterion weight. In the original map, significant changes were seen for the precipitation-related flood causes. The percentage change in areas with very high and high flood susceptibility increased by 3.54% when 10% of the initial precipitation was added, whereas it decreased by 4.16% when 10% of the initial precipitation was subtracted. Moreover, a decline has a considerably greater impact on the prediction than an increase does. Some change scenarios are not regarded as essential since they include very low and low classes or a little (less than 5%) change. The remaining flood-causing characteristics of the slope, elevation, distance from the river, land use, and land cover and soil types appear to be unaffected by modifications in the model. The Kanakarayan Aru River Basin's flood susceptibility map is satisfactory in terms of sensitivity analysis.

4.5 Model Validation of the Flood Susceptibility Map

To validate the flood susceptibility map of Kanakarayan Aru River Basin, flood susceptibility map results were tested for validation with the satellite-based historical inundation map with field observations. The comparison shows that about 22% and 13% area of the total inundation situated in high and very high susceptibility zones, respectively, while about 26% and 24% area of inundation come under low and moderate zones, respectively. Only 15% of the inundated area lies in the very-low susceptibility zone. Moreover, the validation process was carried out based on the map's comparison with the sites of previous floods, and it provides a significant level of accuracy with field observations of 93.8%.The validation map is shown below in Figure 14.

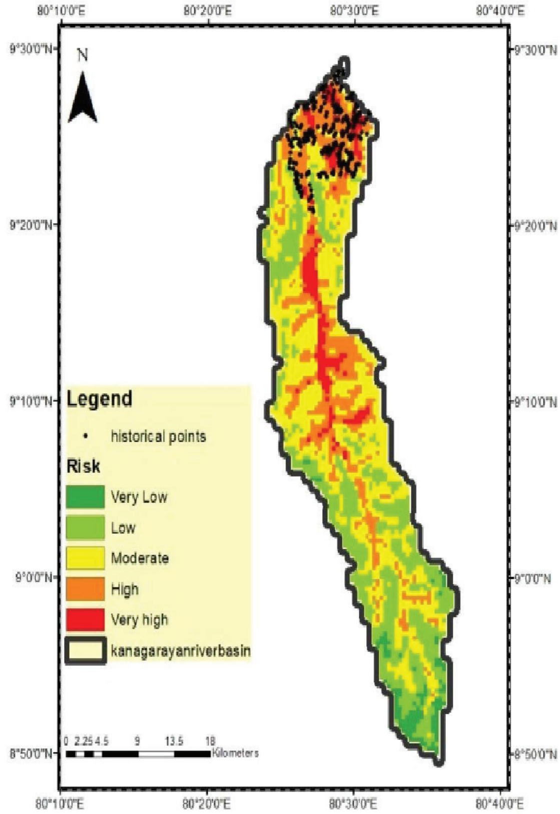

Figure 14 - Validation of the Flood Susceptibility Map by Comparing Historical Flood

4.6 Conclusions

Eight criteria have been determined as the flood-causative factors for flood susceptibility mapping. Out of these factors, the highest normalized weight in the study was precipitation (33%) which was the most flood susceptibility affecting factor among considered flood causative factors, followed by drainage network density (17%), surface slope (11%), topographic wetness index (10%), elevation (8%), river proximity (8%), land use and land cover (7%), and soil type (6%). The fluvial flood is a dominant flood type. The results of the flood susceptibility map as per average annual precipitation reveal that 12.5 percent (113km²) of the total study area (906km²) has been identified as a very high flood zone along with 23.40 percent (212km²) of a high flood susceptibility regions of Kanakarayan Aru River Basin. These maps are helpful for water resources planners, engineers, hydrologists, and decision-makers to reduce the flood risk for mitigation measures. The validation process was executed based on the map's comparison of the historical flood locations and it gives a significant accuracy of 93.8% with observations in the field.

4.7 Limitations of the Study, Implications of the Findings, and Future Research

One limitation of this study is the lack of a suitable hydraulic method or hydrodynamic model for calculating flood inundation depths. Hydrodynamic modeling could be used in future studies to calculate inundation depth. Moreover, further studies could also be done by using modern techniques of basic machine learning models such as Random Forest (RF) and Support Vector Machine (SVM) on Flood susceptibility mapping to this River Basin.

The implications of the findings can be used by the Ministry of Disaster Management, Irrigation Department, Provincial Irrigation - Northern Province, Local Authorities, Divisional Secretaries, and Universities. They can use the study's findings to reduce the harm to lives and infrastructure by taking flood susceptibility mapping into account in their detailed plans and land use programs.

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