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Flood Susceptibility Modelling Using GIS-Based Analytical Hierarchy Process (AHP) in Benin City, Nigeria

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Abstract

Flooding is a major hazard in both urban and rural areas today. There are several factors that determine the susceptibility of an area to flooding, and the problem of flooding cannot be solved if the flood susceptible areas are unidentified. Flood susceptibility mapping is an important way of controlling floods because it identifies the flood prone regions within an area of interest. This study aims to present a method of determining the flood susceptible zones for a watershed area in Benin City using the Multi-Criteria Decision Analysis (MCDA) approach, particularly the Analytical Hierarchy Process (AHP) and Geographic Information System (GIS). Six flood conditioning factors were selected for the study: slope, drainage density, distance from rivers, flow accumulation, elevation, and curve number. These factors were presented as raster datasets. The factors were ranked based on their potential contribution to flooding and given factor weights according to the AHP technique. The combination of these flood conditioning factors with their corresponding weights in the QGIS software was used to produce the flood susceptibility map. From the flood susceptibility map, it was observed that 26.1% of the watershed area was characterized by very high and high susceptibility to flooding.

1.0. Introduction

Flooding is one of the most serious, common, and dangerous natural disasters that many countries face. It is one of the natural disasters that cause damage worldwide, [1]. Flood is the second deadliest of all weather-related hazards and has been detrimental to many other societies in most parts of the world. Floods can be local, impacting a neighborhood or a community, or even as large as affecting regions, plains, and valleys. This extreme climatic event has the potential to cause a serious impact on human health, security, livelihood, and poverty. [2]. Urban regions generally have a high risk of flash flooding because of the presence of enormous impervious regions and sometimes inefficient drainage systems, [3] [4]. Increased urbanization in flood-prone regions has exacerbated challenges around resilience and vulnerability to recurrent flooding.

In Nigeria, aside from droughts, floods cause almost 90 percent of the damages resulting from natural hazards [5]. Floods that occur in Nigeria are as a result of extensive rainfall, drainage blockages, and dam failures [6]. The main cause of flooding according to [7], is excessive rainfall, but however, there are many other causes resulting from human activities, for example: land degradation, deforestation of catchment areas, sprawl and increased population density along riverbanks, poor land use planning, zoning, and control of flood plain development; inadequate drainage, particularly in cities, and inadequate management of discharges from river reservoirs, [8, 9, 10, 11], poor land use planning, zoning, and control of flood plain development; inadequate drainage, particularly in cities, and inadequate management of discharges from river reservoirs.

Floods are also triggered by climate change, and this threatens environmental sustainability, economies, and ecological cycles, [23].

Identification of potential flood risk areas through mapping is crucial to reducing flood damage, and this risk map will guide policymakers to easily identify the vulnerable areas for flood hazards and suitable areas for development activities necessary to attain sustainable development, [12]. This approach provides valuable insights into the spatial distribution of flood risk, thereby, assisting policymakers and decision-makers in formulating effective flood risk reduction strategies through targeted flood vulnerability and risk reduction measures. [13].

The assessment of floods requires knowledge of flood-risk areas in order to develop prevention as well as mitigation measures. Flood risk maps are essential tools in the identification of flood-vulnerable areas, [14]. The flood susceptibility map is a comprehensive resource for forecasting and preventing floods worldwide, particularly where floods occur on a regular basis, which is missing in numerous developing-country basins [15]. A flood hazard maps is an essential tool to assess the susceptibility of flood prone areas. [16]. Flood susceptibility and risk mapping has proven to be a critical tool in modern natural hazard analysis as it provides geospatial representations of hazard susceptibility and risk, which has become vital in land use management and planning, [17].

Flash floods in cities lead to high levels of water in the streets and roads, causing many problems such as bridge collapse, building damage, and traffic problems. It is impossible to avoid the risks of floods or prevent their occurrence, however, it is plausible to work on reducing their effects and the losses that they may cause. Flash flood mapping to identify sites in high risk flood zones is one of the powerful tools for this purpose, [18].

It has been reported that identification of flood-susceptible areas and taking necessary structural and non-structural measures in the identified areas can effectively reduce property damage, fatalities, and economic losses. Therefore, mapping flood-prone areas is considered the most important step in flood management and mitigation. The objective of flood hazard mapping is to classify a region into different zones according to their susceptibility to floods, [19].

Numerous techniques have been proposed for multi-criteria decision making, and the Analytic Hierarchy Process (AHP), developed by [20], is going to be adopted for this study.

Flooding is a recurrent and severe natural hazard in Benin City, exacerbated by climate change, and poses significant threats to human lives and livelihoods by affecting its inhabitants and disrupting socio-economic activities as have been the case during previous flooding events in this area. In this study, a GIS-based approach was utilized to delineate flood-prone zones within the watershed area using Digital Elevation Models (DEMs). DEM-derived features, including slope, drainage density, distance from rivers, flow accumulation, and elevation, were developed using QGIS. While previous research works on flood susceptibility mapping in Benin City have not taken into account the curve number of the catchment, this research considers curve number of the catchment as one of the flood causative factors, as the catchment hydrological soil group and land use are also important factors affecting flooding. The AHP was used in the study to assign ranks to the classes of each causative flood factor. The result of the study provides a simplified method of mapping and assessing flood susceptible areas, which can be used as a reference for flood mitigation, prevention, and reduction of natural disasters within the study area.

2.0.Materials and Method

2.1. Study Area

The study area, which is represented by a watershed, is located in Oluku, Benin City, Edo State, Nigeria, and covers specific places such as Oluku Market, Terminal Resort and Park, Sacred Heart Nursery and Primary School, Iguosa Housing Estate, Oluku Bypass, and others. The watershed (catchment) area covers an area of 28.82 km^2 as shown in Figure 3.1. The coordinates of the study area are enclosed in the bounding box: 5.5667^{o}E, 5.6339^{o}E, 6.5000^{o}N, 6.4167^{o}N. The study area lies within the Ikpoba river basin, and all the rainfall in the study area flows and ultimately discharges into Ikpoba River in Benin City. The calculated area of the watershed was found to be 28.82 km^2. Annual precipitation in Benin City is around 190 mm and there are 274.89 rainy days (75.31% of the year).

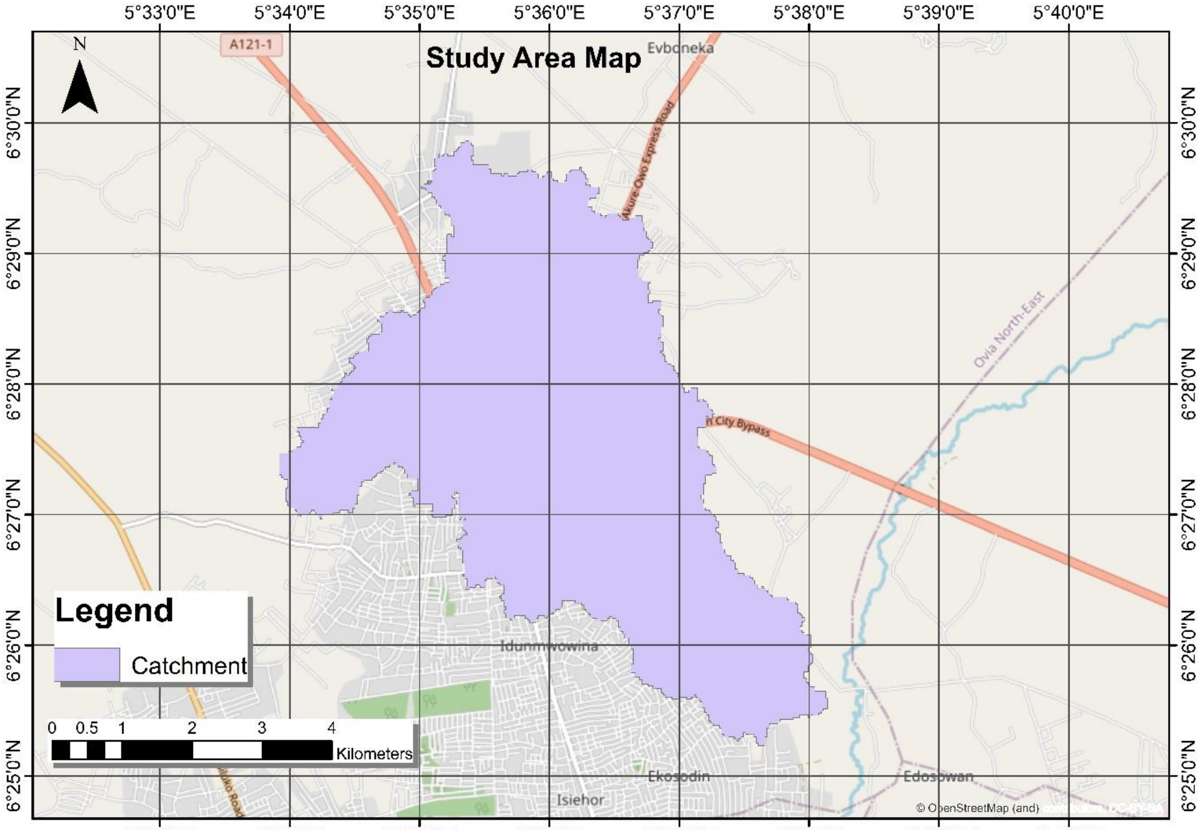


Figure 1. Study Area for Flood Susceptibility Mapping

2.2.Flood Conditioning Factors and Methods of Processing

Flood susceptibility mapping requires various input data that was collected from different sources and processed in QGIS. The original data, which were used to process flood conditioning factors, and their sources are reported in Table 1.

Table 1. Data sources used for the processing of flood conditioning factors

Data	Format	Source	Resolution(m)
Digital elevation model (DEM)	Raster file	United States Geological Survey (USGS)	30
Land use/ land cover	Raster file	Environmental Systems Research Institute (ESRI)	307
Global hydrologic soil groups	Raster file	NASA EARTH DATA	230

Due to their relevance to flooding [21], six flood conditioning factors were selected for the spatial modeling. They are: slope (˚), river network density (km/km^2), distance from rivers (m), flow accumulation (pixels), elevation (m), and curve number. All of the flood conditioning factors were processed in the GIS software and are summarized below.

2.2.1. Map of elevation

Elevation usually affects flooding in an inverse way, i.e., flooding increases with lower elevation, meaning that lower elevations are more susceptible to flooding. The map of elevation was simply obtained from the Digital Elevation Model (DEM).

2.2.2. Map of slope

Another significant physical factor in flooding is slope. Areas with a steep slope tend to have more runoff and less infiltration into the ground. This increased overland flow can cause flooding. The slope degree map was generated from the DEM in QGIS by going to Raster > Analysis > Slope.

2.2.3. Map of flow accumulation

The accumulated flow is based on the number of cells flowing into each cell in the output raster. The current processing cell is not considered in this accumulation. Output cells with higher flow accumulation are areas of concentrated flow. In this sense, an increase in flow accumulation should reflect an increase in flood susceptibility. Convert the DEM to PCRaster format and calculate the flow direction map; the flow accumulation was derived from the flow direction raster.

2.2.4. Map of distance from rivers

Distance from rivers is another important conditioning factor since rivers and their adjacent lands are the main pathways for flooding. In order to generate the distance from rivers/distance from streams map, the streams were first delineated in the DEM. This map in ArcGIS was generated by going to Geoprocessing ArcToolbox > Spatial Analyst Tools > Distance > Euclidean Distance Tool.

2.2.5. Map of river network density

As for the river network density, a higher density generally means increased surface runoff and thus an increased probability of flooding, while a lower density means reduced surface runoff and hence a lower probability of flooding. The surface area of the catchment was calculated in the open field calculator of the attribute table by going to geometry > $area, and the total length of the stream network was also calculated by going to Vector > Geoprocessing Tools > Dissolve. This river network density map was generated from the “LineDensity” tool in the QGIS processing toolbox with the dissolved file as the input layer

2.2.6.Map of curve numbers

Curve numbers are a measure of the rainfall-runoff coefficient of the area, and the ease of runoff of the soil is also a factor that determines flooding. High curve number values indicate low permeability and, therefore, a high likelihood of flooding. Hydrologic soil groups and land use/ land cover data represented the inputs for the calculation of curve numbers. The curve numbers were calculated using the GDAL raster calculator in QGIS by querying each cell of the input raster and assigning a curve number value based on the published curve number tables by the Natural Resources Conservation Service (NRCS).

2.3. Classification of Flood Conditioning Factors

In order for the conditioning factors to be comparable, they were reclassified into five susceptibility classes (5—very high, 4—high, 3—moderate, 2—low, and 1—very low) based on their potential contributions to flooding and other criteria mentioned earlier. This classification is shown in Table 2.

Table 2. Classes of conditioning factors estimated ratings, and relative importance.

Factor	Class	Rating	Relative importance
Slope (˚)	0.0-2.5	5	6
	2.5-5.0	4	
	5.0-15.0	3	
	15.0-30.0	2	
	>30	1	
River network density (km/km^2)	0-0.00152	1	5
	0.00152-0.00216	2	
	0.00216-0.00271	3	
	0.00271-0.00328	4	
	0.00328-0.00521	5	
Distance from rivers (m)	0-30	5	4
	30-90	4	
	90-200	3	
	200-500	2	
	500-1070	1	
Flow accumulation(pixels)	0-70	1	3
	70-150	2	
	150-900	3	
	900-6000	4	
	6000-30600	5	
Elevation (m a.s.l.)	<70	5	2
	70-90	4	
	90-125	3	
	125-150	2	
	150-183	1	
	71-78	1	
	78-81	2	

Curve number	81-83	3	1
	83-86	4	
	>86	6	

The classes for the flood conditioning factors were adjusted according to the natural break (Jenks) grading method.

2.4.Multi-Criteria Decision Analysis: Analytical Hierarchy Process (AHP)

The parameter weights were calculated through the AHP technique. The pairwise comparison process is the main part of the AHP technique, which determines each parameter weight. The values and criteria of the parameters are given to indicate their relative importance between two parameters. The relative importance of the selected conditioning factors was assigned based on empirical knowledge of hydrology as some of the flood conditioning factors will have a greater influence on flooding than others, and also similar approach have been used in recent studies like [21]. It ranges from 6 (highest importance) to 1 (lowest importance). In order to estimate the weights for each criterion (flood conditioning factor), the technique of pairwise comparisons known as the AHP was used. The relative weights were derived by taking the principal eigenvector of a square reciprocal 6 × 6 matrix of pairwise comparison between the criteria. The pairwise comparison matrix is shown in Table 3.

Table 3. Pairwise comparison matrix

Factors	**Slope**	**River network density**	**Distance from rivers**	**Flow accumulation**	**Elevation**	**Curve numbers**
Slope	1	2	3	4	5	6
River network density	0.5	1	2	3	4	5
Distance from rivers	0.33	0.5	1	2	3	4
Flow accumulation	0.25	0.33	0.5	1	2	3
Elevation	0.2	0.25	0.33	0.5	1	2
Curve numbers	0.167	0.2	0.25	0.33	0.5	1

The normalized factor weights and final weights (W_i) were calculated by the approximation method and are shown in Table 4.

Table 4. The normalized factor weights and final weights (W_i)

Factors	**Slope**	**River network density**	**Distance from rivers**	**Flow accumulation**	**Elevation**	**Curve numbers**	**Weight (W_i)**
Slope	0.408	0.467	0.423	0.369	0.323	0.286	**0.379**
River network density	0.204	0.233	0.282	0.277	0.258	0.238	**0.249**

Distance from rivers	0.136	0.117	0.141	0.185	0.194	0.191	**0.161**
Flow accumulation	0.102	0.078	0.071	0.092	0.129	0.143	**0.102**
Elevation	0.082	0.058	0.047	0.046	0.065	0.095	**0.065**
Curve numbers	0.068	0.051	0.035	0.031	0.032	0.048	**0.044**

After completing the AHP, the consistency ratio (CR) was calculated in order to examine the consistency of the developed ratings. The formula for calculating the consistency ratio is shown in equation 1:

$$\mathrm{CR}=\frac{CI}{RI} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where RI is the random index, which depends on the number of conditioning factors used, and CI is the consistency index, which is given by equation 2:

$$\mathrm{CI}=\frac{\lambda_{max}-n}{n-1}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where n is the number of conditioning factors and λ_{max} is the average value of the consistency vector. According to Saaty (1980), the average value of the consistency vector should be less than 0.1 for the AHP to be consistent.
In this case, our value of λ_{max} was calculated to be 6.122, and therefore, CI was calculated using equation 2.

$$\mathrm{CI} = \frac{\lambda_{max}-n}{n-1} = \frac{6.122-6}{6-1} = 0.0244$$

From equation (1),

$$\mathrm{CR} = \frac{CI}{RI}$$

Table 5 shows the RI values.

Table 5. Various numbers of factors and their corresponding Random Index RI

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

(Saaty, 1980).

The value of the random index (RI) for six factors is 1.24. Then, CR was calculated using equation 1 as

$$\mathrm{CR} = \frac{0.0244}{1.24} = 0.01968$$

This value of CR is less than 0.1, so this confirms the consistency of the ratings used.

2.5.Generation of the Flood Susceptibility Map

After each flood conditioning factor had been generated into separate raster files and successfully classified into 5 classes, the weights of each factor as obtained earlier were multiplied by the corresponding flood conditioning factor map in the raster calculator in the QGIS software to get the final flood susceptibility map. The raster calculator expression is shown below:
SlopeRaster * 0.379 + StreamdensityRaster * 0.249 + DistancefromriversRaster * 0.161 + FlowaccumulationRaster * 0.102 + ElevationRaster * 0.065 + CurvenumberRaster * 0.044.

After the flood susceptibility map had been created, the natural breaks (Jenks) grading method was used to classify the final flood susceptibility map into 5 different classes, which were: very high, high, moderate, low and very low susceptibility to flooding.

3.0.Results and Discussion

3.1.Slope

This represents the rate of change in elevation. For this work, this is the factor that is taken to have the most contribution to flooding. For our catchment area, the slope ranges from 0° to 33.69°. Zero degrees is the portion with the lowest slope and hence most likely to be flooded, and 33.69 degrees is the portion with the highest slope and hence less likely to be flooded. The processed map of the slope of our catchment area is shown in Figure 2.

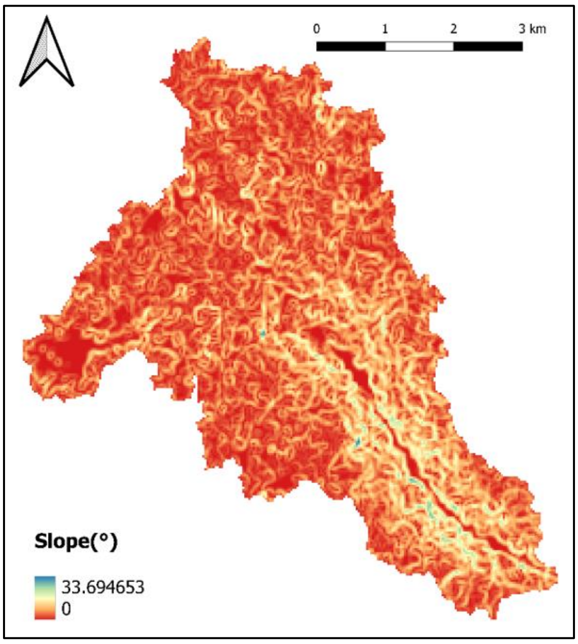


Figure 2. Slope of catchment

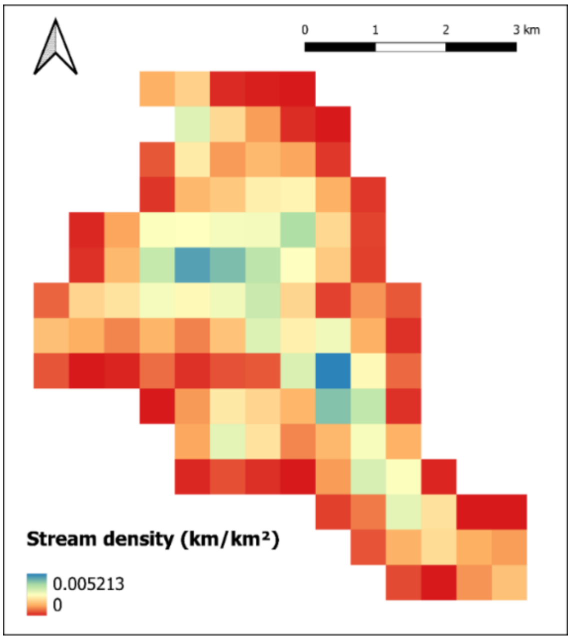


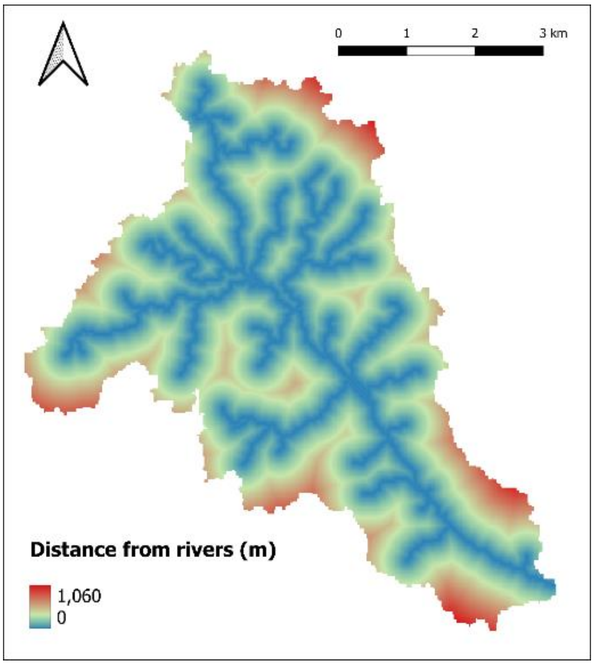
Figure 3. River network density of catchment

3.2. River Network Density

River network density is taken to have the second highest contribution to flooding. The drainage density of our catchment area ranged from 0 km/km^2 to 0.00521 km/km^2. Where 0 km/km^2 represents the region with the lowest river network density, hence giving the least contribution to flooding, and 0.00521 km/km^2 represents the region with the highest river network density, hence giving the most contribution to flooding. This is shown in Figure 3.

3.3.**Distance from Rivers**

This is the factor that is considered to have the third highest contribution to flooding. This is the distance in meters from each cell in the raster data to the nearest stream network. From Figure 4, 0 m indicates the portion of our catchment that is exactly at streams, while the farthest distance, which is 1060 m, indicates the portion that is relatively far from the streams.



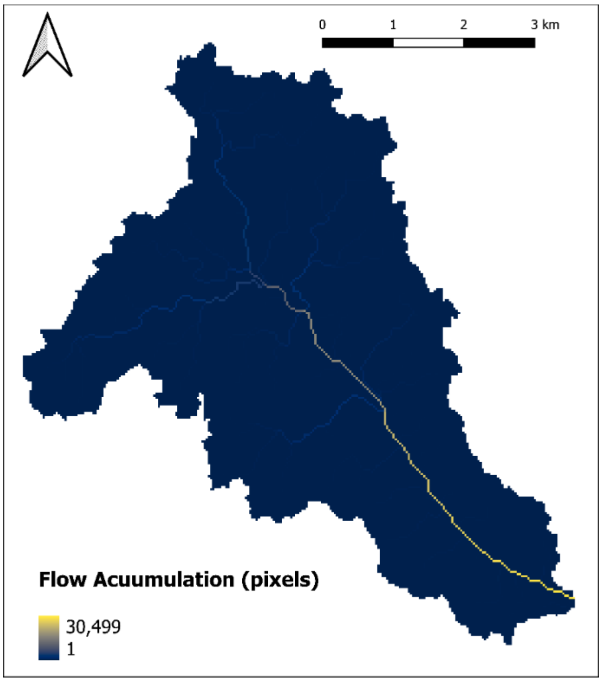


Figure 4. Distance from rivers of catchment   Figure 5. Flow accumulation of catchment

3.4. Flow Accumulation

The result of flow accumulation is a raster of accumulated flow to each cell, as determined by accumulating the weight of all cells that flow into each downslope cell. Output cells with a high flow accumulation are areas of concentrated flow and can be used to identify stream channels. Flow accumulation is usually measured in pixels; the higher the pixel value, the higher the flow accumulation at that point. From the flow accumulation of our catchment area, a 1 pixel value represents the region with the least flow accumulation, while a 30499 pixel value represents the region with the highest flow accumulation. This is shown in Figure 5.

3.5.**Elevation**

This is the DEM of our catchment area. It is measured in meters above mean sea level (m a.m.s.l.). This distance ranges from 52 m to 183 m above mean sea level. The region with the lowest elevation is more susceptible to flooding, while the region with the highest elevation is less susceptible to flooding. This is shown in Figure 6.

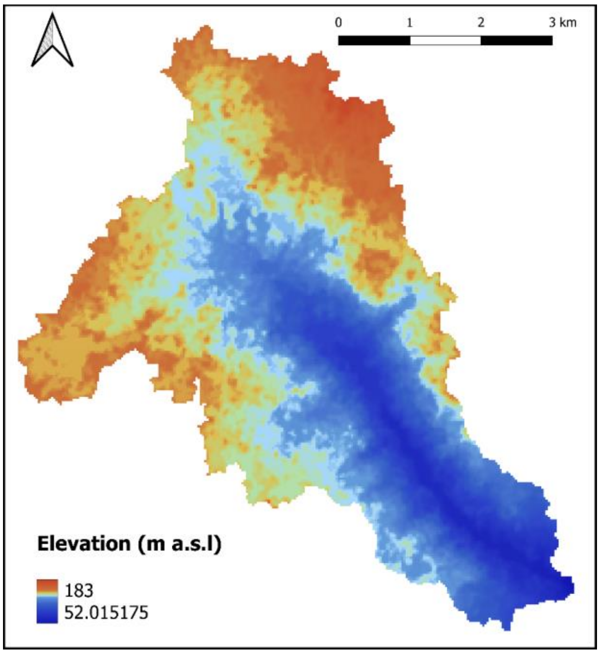


Figure 6. Elevation of catchment

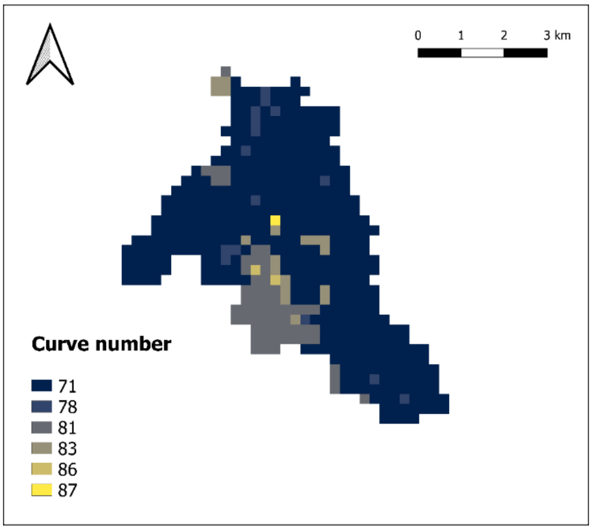


Figure 7. Curve Number of catchment

3.6.Curve number

Curve number (CN) is a hydrological parameter used to describe the stormwater runoff potential for our catchment area. A high curve cumber (such as 98 for impervious pavement) indicates low infiltration and high runoff, while a low curve number (such as 30 for certain wooded areas) indicates high infiltration and low runoff. The curve number for our catchment area ranges from 71 to 87, as shown in Figure 7.

3.7. Analysis of the Flood Susceptibility Map

With regard to the AHP method, this natural breaks (Jenks) grading method is considered to be the most appropriate for classifying the flood susceptibility zones [21]. The reclassified flood susceptibility map is shown in Figure 8.

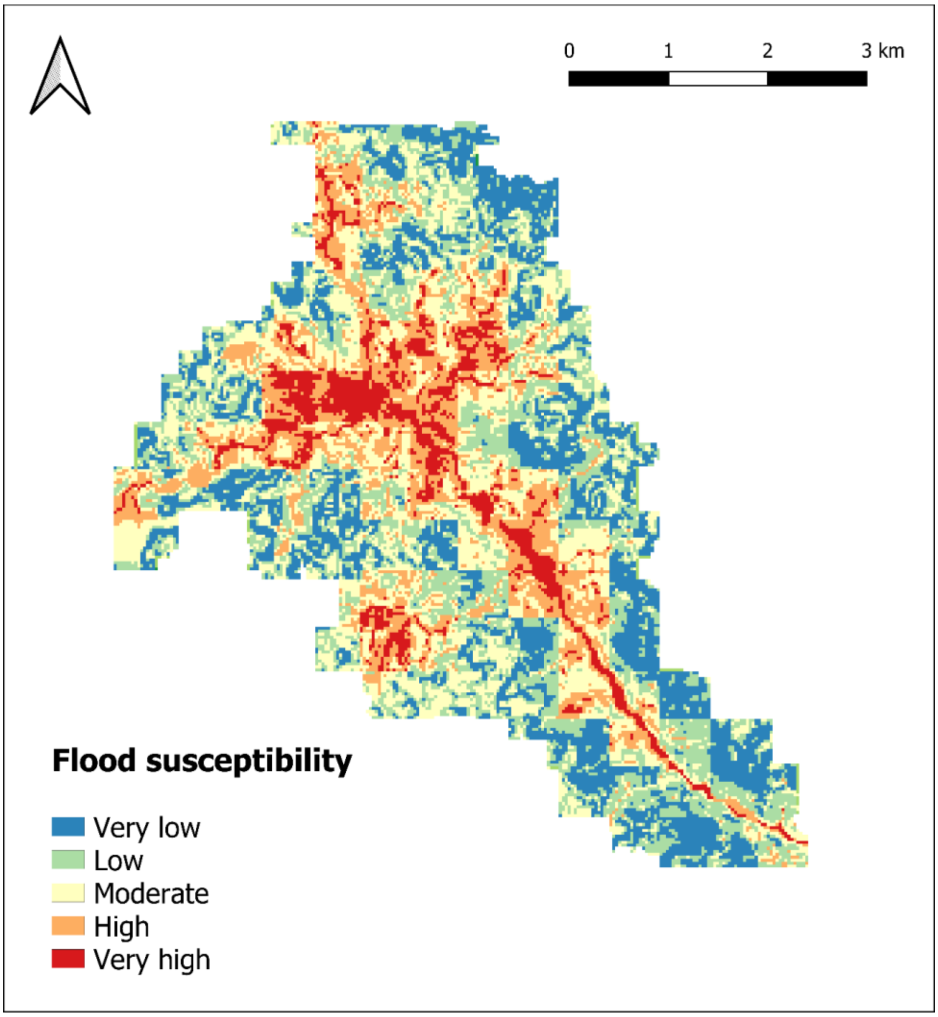


Figure 8. Flood Susceptibility Map

The areas occupied by each of these five flood susceptibility zones were then calculated, and the data is presented in Table 6.

Table 6. Area coverage of flood susceptibility classes.

Flood Susceptibility	**Area(km^2)**	**Area (%)**
Very low	5.594	22.4
Low	6.028	24.1
Moderate	6.834	27.4
High	4.497	18
Very High	2.034	8.1

As for the share of flood susceptibility classes (area percentage), the lowest share was recorded in the very high (8.1%) class, and the high flood susceptibility class covers an area of 18%, while the low susceptibility class recorded the share of 24.1% and the very low susceptibility class recorded the share of 22.4%. The highest share (27.4%) occurred in the moderate flood susceptibility class.

3.8. Discussion

Although the AHP method was successfully applied for the flood susceptibility mapping in our study, as confirmed by its good accuracy, there could be remarks, sources of uncertainty, and possible limitations that need to be addressed for the study.

The first possible issue is a number of flood conditioning factors and also the question of what order the flood conditioning factors should be selected for the AHP analysis in order to best characterize the physical characteristics that determine the susceptibility of the study area to flooding, as it is an adjustment by the experts. There are various numbers of parameters used in different studies of flood susceptibility determination using AHP, but in this study, six conditioning factors have been selected, as in similar studies like [22, 23]. Some studies have used as low as four flood conditioning factors, such as, [24, 25]. Others have used seven, for example [26], while some have also used as many as ten, [27, 28] and twelve [29] flood conditioning factors. This goes to show that no exact agreement exists on which factors should be applied for flood susceptibility analysis. However, it is generally recommended to use not less than six factors in order not to produce unrepresentative weights dominated by a single weight, which may increase the possibility of over-rating some of the flood contributing factors, [28].

Furthermore, some flood conditioning factors recur in multiple studies and thus can be considered as basic factors, indicating their important relevance for flood susceptibility mapping. These basic factors are represented by slope, elevation, land use/land cover, and distance from rivers/river network density. In this study, the flood-causative parameters can be grouped into categories as follows: (1) hydrography factors: river network density, distance from rivers; (2) hydrological factors: flow accumulation; (3) morphometric factors: elevation, slope; and (4) permeability factors: curve numbers. In this research, six flood conditioning factors were selected that involved only the physical characteristics of the catchment area. In this respect, the exclusion of causal rainfall factors from the set of flood conditioning factors might also be considered one of the possible limitations. However, rainfall is a factor that has been excluded in the study since it is considered a dynamic parameter that can change rapidly over time. As mentioned before, the purpose of this study was to show the physical properties (static parameters), which are not changeable or likely to change through time, that influence flood susceptibility. This approach was also presented in other studies, such as [24, 18, 25, 30, 21].

Another important issue in determining the flood susceptibility zones using the MCDA is the process of assigning relative importance to the selected conditioning factors. For this study, slope has been assigned the highest relative importance, indicating that slope is considered the most important conditioning factor for finding areas susceptible to flooding. The relative significance of the rest of the conditioning factors used in this study decreases as follows: river network density, distance from rivers, flow accumulation, elevation, and curve number. A similar approach to prioritizing the flood conditioning factors was also used and verified in other studies, such as [31].

4.0. Conclusion

The study aimed to determine the flood susceptibility zones for the study area using the Analytical Hierarchy Process (AHP) technique and GIS. The watershed area, which represented our area of interest, was successfully delineated with QGIS, and six flood conditioning factors were chosen in order to capture the complexity of the physical characteristics of the study area. In order not to underestimate or overestimate some category of factors, the following factors were selected: two hydrography factors—river network density and distance from rivers; one hydrological factor—flow accumulation; two morphometric factors—elevation and slope; and one permeability factor—curve number.

The flood conditioning factors were ranked, and the AHP technique was used to calculate the factor weights. The relative importance of the selected conditioning factors prioritized the slope as the most important factor for finding areas susceptible to flooding, followed by river network density, distance from rivers, flow accumulation, elevation, and curve number. The aggregation method was used to combine the reclassified factors and produce the resulting flood susceptibility map, which contains five classes: very low, low, moderate, high, and very high susceptibility. Finally, the presented approach for flood susceptibility analysis can provide a suitable alternative for the review of preliminary flood risk assessment and the identification of potential significant flood risk zones.

References

[1] S. Vorogushyn, K.-E. Lindenschmidt, H. Kreibich, H. Apel and B. Merz, "Analysis of a detention basin impact on dike failure probabilities and flood risk for a channel-dike-floodplain system along the river Elbe, Germany," *Journal of Hydrology,* vol. 436, pp. 120-131, May 2012.

[2] A. Ramamurthy, F. A. Chundeli and R. Srikonda, *OIDA International Journal of Sustainable Development,* vol. 17, no. 3, pp. 47-66, 3 May 2024.

[3] J. Chen, A. A. Hill and L. D. Urbano, "A GIS-based model for urban flood inundation," *Journal of Hydrology,* vol. 373, no. 1-2, pp. 184-192, 2009.

[4] K. Sowmya, C. John and N. Shrivasthava, "Urban flood vulnerability zoning of Cochin City, southwest coast of India, using remote sensing and GIS," *Natural Hazards,* vol. 75, pp. 1271-1286, 2015.

[5] N. O. Adeoye, N. Ayanlade and O. Babatimehim, "Climate change and menace of floods in Nigerian cities: socio-economic implications," *Advances in Natural and Applied Sciences,* vol. 3, no. 3, pp. 369-377, September 2009.

[6] D. N. Jeb and S. P. Aggarwal, "Flood inundation hazard modelling of the river Kaduna using remote sensing and geographic information systems," *Journal of Applied Sciences Research,* vol. 4, no. 12, pp. 1822-1833, December 2008.

[7] B.-S. Kim and H.-S. Kim, "Evaluation of flash flood severity in Korea using the modified flash flood index (MFFI)," *Journal of Flood Risk Management,* vol. 7, no. 4, pp. 344-356, 2014.

[8] A. S. Prasad, B. W. Pandey, W. Leimgruber and R. M. Kunwar , "Mountain hazard susceptibility and livelihood security in the upper catchment area of the river Beas, Kullu Valley, Himachal Pradesh, India," *Geoenvironmental Disasters,* vol. 3, no. 3, pp. 1-17, 2016.

[9] P. Billi, Y. T. Alemu and R. Ciampalini , "Increased frequency of flash floods in Dire Dawa, Ethiopia: Change in rainfall intensity or human impact?," *Natural Hazards,* vol. 76, pp. 1373-1394, 2015.

[10] C. Mbow, A. Diop, A. Diaw and C. Niang, "Urban sprawl development and flooding at Yeumbeul suburb (Dakar-Senegal)," *African Journal of Environmental Science and Technology,* vol. 2, no. 4, pp. 75-88, 2008.

[11] E. K. Forkuo and V. A. Tsawo, "The use of digital elevation models for water-shed and flood hazard mapping," *International Journal of Remote Sensing & Geoscience,* vol. 2, no. 2, pp. 56-65, March 2013.

[12] S. S. Rana, A. S. Habib, M. N. H. Sharifee, N. Sultana and H. S. Rahman, "Flood risk mapping of the flood-prone Rangpur division of Bangladesh using remote sensing and multi-criteria analysis," *Natural Hazards Research,* vol. 4, no. 1, pp. 20-31, March 2024.

[13] Q. D. Ikram, A. R. Jamalzi, A. R. Hamidi, I. Ullah and M. Shahab, "Flood risk assessment of the population in Afghanistan: A spatial analysis of hazard, exposure, and vulnerability.," *Natural Hazards Research,* vol. 4, no. 1, pp. 46-55, March 2024.

[14] P. C. Mmom and A. Ayakpo, "Spatial analysis of flood vulnerability levels in Sagbama Local Government Area using geographic information systems (GIS)," *International Journal of Research in Environmental Studies,* vol. 1, pp. 1-8, July 2014.

[15] K. Sakmongkoljit, N. Homtong, N. Surakotra and N. Silaratana, "Multi-criteria Flood Susceptibility Assessment Using Remote Sensing and GIS-based Approaches in Chi River Basin, Thailand.," in *IOP Conference Series: Materials Science and Engineering,* 2021.

[16] K. Seejataa, A. Yodyinga, T. Wongthadama, N. Mahavika and S. Tantaneeb, "Assessment of flood hazard areas using Analytical Hierarchy Process over the Lower Yom Basin, Sukhothai Province," *Procedia Engineering,* vol. 212, pp. 340-347, 2018.

[17] R. Roopnarine, J. Opadeyi, G. Eudoxie, G. Thong and E. Edwards, "GIS-based Flood Susceptibility and Risk Mapping Trinidad Using Weight Factor Modeling," *Caribbean Journal of Earth Science,* vol. 49, pp. 1-9, 2018.

[18] I. Elkhrachy, "Flash Flood Hazard Mapping Using Satellite Images and GIS Tools: A case study of Najran City, Kingdom of Saudi Arabia (KSA)," *The Egyptian Journal of Remote Sensing and Space Science,* vol. 18, no. 2, pp. 261-278, December 2015.

[19] A. M. Al-Abadi, S. Shahid and A. K. Al-Ali, "A GIS-based integration of catastrophe theory and analytical hierarchy process for mapping flood susceptibility: a case study of Teeb area, Southern Iraq," *Environmental Earth Sciences,* vol. 75, pp. 1-19, 2016.

[20] T. Saaty, "The Analytic Hierarchy Process (AHP) for Decision Making," *In Kobe, Japan,* vol. 1, pp. 1-69, 1980.

[21] M. Vojtek and J. Vojteková, "Flood Susceptibility Mapping on a National Scale in Slovakia Using the Analytical Hierarchy Process," *Water,* vol. 11, no. 2, p. 364, 2019.

[22] N. N. Kourgialas and G. P. Karatzas, "Flood management and a GIS modelling method to assess flood-hazard areas—a case study," *Hydrological Sciences Journal,* vol. 56, no. 2, pp. 212-225, 2011.

[23] D. Chaulagain , P. R. Rimal, S. N. Ngando, B. E. K. Nsafon, D. Suh and J.-S. Huh, "Flood susceptibility mapping of Kathmandu metropolitan city using GIS-based multi-criteria decision analysis," *Ecological Indicators,* vol. 154, p. 110653, October 2023.

[24] O. Rahmati, H. Zeinivand and M. Besharat, "Flood hazard zoning in Yasooj region, Iran, using GIS and multi-criteria decision analysis," *Geomatics, Natural Hazards and Risk* , vol. 7, no. 3, pp. 1000-1017, 2016.

[25] S. Samanta, C. Koloa, D. K. Pal and B. Palsamanta, "Flood Risk Analysis in Lower Part of Markham River Based on Multi-Criteria Decision Approach (MCDA)," *Hydrology* , vol. 3, no. 3, p. 29, 2016.

[26] M. M. Msabi and M. Makonyo, "Flood susceptibility mapping using GIS and multi-criteria decision analysis: A case of Dodoma region, central Tanzania," *Remote Sensing Applications: Society and Environment,* vol. 21, p. 100445, January 2021.

[27] A. Haghizadeh, S. Siahkamari, A. H. Haghiabi and O. Rahmati , "Forecasting flood-prone areas using Shannon's entropy model," *Journal of Earth System Science,* vol. 126, no. 39, pp. 1-11, 2017.

[28] S. H. Mahmoud and T. Y. Gan, "Multi-criteria approach to develop flood susceptibility maps in arid regions of Middle East," *Journal of Cleaner Production,* vol. 196, pp. 216-229, September 2018.

[29] G. Zhao, B. Pang, Z. Xu, J. Yue and T. Tu, "Mapping flood susceptibility in mountainous areas on a national scale in China," *Science of The Total Environment,* vol. 615, pp. 1133-1142, February 2018.

[30] R. Costache, "Flash-Flood Potential assessment in the upper and middle sector of Prahova river catchment (Romania). A comparative approach between four hybrid models," *Science of The Total Environment,* vol. 659, pp. 1115-1134, April 2019.

[31] S. V. R. Termeh , A. Kornejady, . H. R. Pourghasemi and S. Keesstra, "Flood susceptibility mapping using novel ensembles of adaptive neuro fuzzy inference system and metaheuristic algorithms," *Science of The Total Environment,* vol. 615, pp. 438-451, 2018.