MAKERERE UNIVERSITY

COLLEGE OF ENGINEERING DESIGN ART AND TECHNOLOGY

SCHOOL OF THE BUILT ENVIRONMENT

DEPARTMENT OF GEOMATICS AND LAND MANAGEMENT

TOPIC: FLOOD MAPPING USING ANALYTICAL HIERACHCY PROCESS AND FUZZY LOGIC (CASE STUDY KAMPALA CITY)

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DECLARATION

I **AMANYA SAPHRA**, hereby declare that the information presented in this report is originally my work and it has never been submitted to any other university or institution for the award of a bachelor's degree in Land surveying and Geomatics or its equivalent academic qualification.

Signature:

Supervisor: Prof Anthony Gidudu

Signature: ....

Date 23rd December 2021

ACKNOWLEDGEMENT

First, I thank God, by his Grace, I was able to complete this project report (Psalms 116:7).

Secondly, I extend thanks to my supervisor Prof. Anthony Gidudu for his guidance.

Lastly, I extend sincere thanks to the project coordinator, Mr. Mugumya Vincent.

ABSTRACT

Kampala city has experienced floods on a number of occasions after a downpour, causing damage to people's homes, water pollution, disruption of traffic and economic activities. This study aims at flood susceptibility mapping using analytical hierarchy process, fuzzy criteria and a combination of two algorithms AHP and fuzzy in Kampala city Uganda. Flood maps are generated based on six flood influencing factors (rainfall intensity, LULC, soil moisture index, soil type and drainage density). Thematic maps for each of the six flood conditioning factors were generated, and the generated thematic maps were used to develop flood maps using AHP, fuzzy criteria and a combination of both algorithms AHP and fuzzy. Using AHP the weight derived for the factors were Rainfall 59%, Slope 7.514%, Drainage density 14.291%, Soil type 5.243%, LULC 11.002%, Soil moisture 2.95%. The generated flood susceptible maps were assessed based on the area under the curve as shown by the receiver operating curve, AHP had an accuracy of 56.16%, fuzzy criteria had an accuracy of 81.42% and the combination of both algorithms had an accuracy of 71.98%.

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List of Abbreviations

AHP	Analytical Hierarchy Process
ROC	Receiver Operating Curve
LULC	Land Use Land Cover
SMI	Soil Moisture Index
PV	Proportion of Vegetation
BT	Satellite Brightness Temperature
LST	Land Surface Temperature
NDVI	Normalized Difference Vegetation Index
CR	Consistency Ratio
USGS	United States Geological Survey
SRTM	Shuttle Radar Topography Mission
DEM	Digital Elevation Model
KCCA	Kampala Capital City Authority
NARO	National Agricultural Research Organization
UNMA	Uganda National Meteorological Authority
UNRA	Uganda National Roads Authority
FEMA	Federal Emergency Management Agency
EPA	Environmental Protection Agency
NRCS	National Resources Conservation Service

TOA	Top of Atmosphere
IDW	Inverse Distance Weighting

1.0 INTRODUCTION

1.1 BACKGROUND

Kampala city has experienced floods on a number of occasions after a downpour, the city is drained by 8 main drainage systems with a total catchment area of 278.71 km^2, the natural and constructed drainage channels along the flood plains and low-lying areas are regularly over topped by floodwaters, causing damage to people's homes, water pollution, disruption of traffic and economic activities. The frequency of flooding is attributed to increased runoff caused by climate-related and land use changes in the catchments, reduction of the buffer capacity of wetlands due to encroachment, frequent disposal of solid waste in storm water channels leading to blockage, inadequately design and constructed road side drainage channels and culverts among others.

Kampala Capital City Authority (KCCA) has also carried out a risk assessment and identified the most dangerous or risky roads that are vulnerable to floods during rainy season. Flood hotspots in Kampala, Nakawa division; Jinja road (Game-Shoprite, Banda-Moil, BandaYoshino), Lugogo By-pass (Cricket Oval), Kyambogo Junction (UNRA), Katogo-Mbuya, Kasokoso Bridge. Central division; Clock Tower, Seventh Street, Makindye division, Gaba road (Sunga Soya), Kibuli road (Police station), Mukwano Road, Cape Road Munyonyo, Bukejje-Mayanja Drain, Gapco Nsambya. Kawempe Division; Nsooba Road (Motegil section), Bombo Road, Mulago Roundabout. (Draku, 2021). In 2017 the Kampala Capital City Authority (KCCA) announced the Kampala drainage master plan where the authority aimed to prioritize improvement of main channels in the city in order to ease water flow and also curb flooding in the area. (News, 2020). Apart from the Kampala Capital City Authority (KCCA) drainage master plan, risk assessment and identification of most risky roads vulnerable to floods during rainy season, other studies have been made on floods in Uganda, (Jacobs, et al., 2016), (Musoke, 2011), (Mhonda, 2013), (Habonimana, 2014), however all the studies that have been done, analytical hierarchy process and fuzzy criteria hasn't been applied using GIS to carry out flood mapping in Kampala.

1.2 PROBLEM STATEMENT

It is estimated flooding damages caused by prevailing extreme rainfall regime in Kampala will increase from US$ 1-7 million (2013) to between US$ 33-102 million by 2050. (CDKN, 2015). Because of rapid urban development coupled with the emerging impacts of climate change and variability, there is always need to update flood susceptible maps so as to provide a more accurate reference document that would guide in flood management and consequently reduce flooding impacts and consequences. Flood susceptibility is a critical task for emergency preparedness and management strategies on prevention and mitigation of floods.

1.3 JUSTIFICATION

Kampala has in recent years experienced rapid urbanization trends that have led to very high increase urban imperviousness levels (Mugume, 2015). It is estimated that between 1989 and 2010, the built-up area in Kampala quadrupled and will continue to present a significant challenge to flood management if left unchecked (Vermeiren, et al., 2012). Flood susceptibility mapping provides accurate information used in flood management activities that is flood forecast and warning. Fuzzy analytical hierarchy process will be used for this research, since each model performance is centered on the data used, accuracy and the structure. Besides, there is no evidence that a particular model should be used for a particular scenario or study area.

(Nachappa, et al., 2020).

1.4 OBJECTIVES Main objective

Flood susceptibility mapping using analytical hierarchy process and fuzzy criteria in Kampala city

Specific objectives

1. To develop thematic maps for flood conditioning factors
2. To develop flood susceptible maps using analytical hierarchy process, fuzzy criteria and a combination of both algorithms.
3. To evaluate flood susceptible maps.

1.5 STUDY AREA

Kampala is the capital city of Uganda, the city covers a total area of 73 square miles, comprising 68 square miles of land and 5 square miles of water.

Kampala is a hilly place with its valleys filled with sluggish rivers/swamps, the highest point in the city proper is the summit of Kololo hill at 4,301 feet located in the center of the city and the lowest point at the shores of Lake Victoria south of the city center at altitude of 3724 feet.

Kampala's weather features two wetter seasons, while the city does not have a true dry season month, it experiences heavier precipitation from August to December and from February to June. However, it is between February and June that Kampala sees substantially heavier rainfall per month, with April typically seeing the heaviest amount of precipitation at an average of around 169 millimeters (6.7 in) of rain.

The city is divided into the five divisions of Kampala central division, Kawempe division, Makindye division, Nakawa division and Rubaga division.

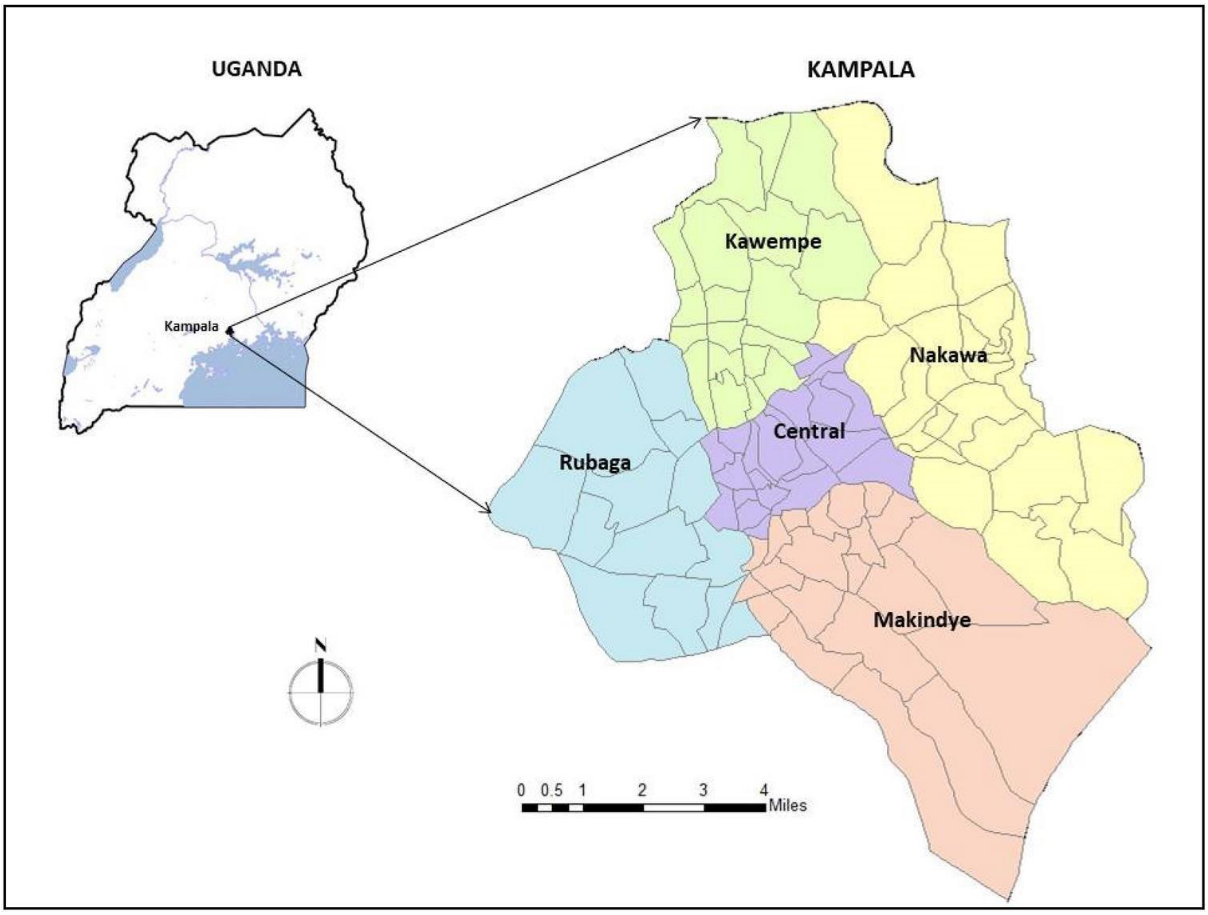


Figure 1 Map of Kampala, showing the five divisions.

2.0 LITERATURE REVIEW

2.1 FLOODS

A flood is an overflow of water that submerges land that is usually dry (dictionary, 2009), say a situation in which water temporarily covers land where it normally doesn't (site, 2008). Flooding occurs when water bodies such as rivers, lakes, and oceans overflows or overtops or breaks levees escaping its usual boundaries (Crawls, 2007). Water overflows usually occur due to an accumulation of rainwater on saturated ground in Areal flood. (Fgnievinski, 2021)

2.2 EFFECTS OF FLOODS

The flood effects can be categorized as primary or secondary effects. The primary effects of flooding include loss of life and damage to buildings and other structures, including bridges, sewerage systems, roadways and canals, power transmission and generation. The secondary effects include; Economic hardship due to a temporary decline in tourism, rebuilding costs, or flood shortages leading to price increases is a common after effect of severe flooding. The impact on those affected may cause psychological damage to those affected, in particular where deaths, serious injuries and loss of property occur. (Fgnievinski, 2021)

2.3 TYPES OF FLOODS.

There are two basic types of floods; flash floods and the more widespread river floods. Flash floods generally cause greater loss of life and river floods generally cause greater loss of property. (USGS, 2018)

2.3.1 River flooding (Fluvial)

A river flood occurs when a river overspills its banks; that is, when its flow can no longer be contained within its channel (Shaw, 2019). The water level rise could be due to excessive rain or snowmelt. (Zurich, 2020).

2.3.2 Flash floods

Flash floods are caused by heavy rainfall or rapid snow melt. They can happen almost out of nowhere sometimes and occur within few minutes of rainfall but generally last for no longer than 6 hours.

2.3.3 Coastal floods

Coastal floods are caused by extreme sea level, which arise as combinations of four main factors: waves, astronomical tides, storm surges and relative mean sea level. (Rareloop, 2016)

2.3.4 Ponding (Pluvial floods)

Pluvial flooding can be broadly defined as flooding that results from rainfall generated overland flow and ponding before the runoff enters any watercourse, drainage system or sewer, or cannot enter it because the network is full to capacity. Pluvial flooding is distinguished from flash flooding which may also be associated with high intensity rainfall but usually arises from a water course. (Falconer, et al., 2009)

2.4 FLOOD PRONE AREAS

Flood prone areas according to the dictionary on law insider means any land area susceptible to being inundated by water from any source (Insider, 2018). A land area is susceptible to being inundated by water; when it lies in an elevation lower than the land water boundary along a watercourse or when water is twice or three times the maximum depth at bank full level, if the soils as classified by the national soils department as soils subject to flooding, if an area is classified by the National meteorological Authority department as exposed to heavy rains, if an area is designated by city councils and environmental authorities as an area prone to floods, or acknowledged by community as being susceptible to being inundated by water from any source, say from water bodies or rain storm water. (Insider, 2018)

Flood-prone areas may include, but are not limited to, the floodplain, the floodway, the flood fringe, wetlands, riparian buffers, or other areas adjacent to the main channel. (Insider, 2018)

According to the national geographic, a flood plain is a generally flat area of land next to a river or stream. (Geographic, 2016)

According to Federal Emergency Management Agency (FEMA), a flood way means the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height. (FEMA, 2020)

Flood fringe means the portion of the floodplain outside of the floodway covered by floodwaters during a flood. (LawInsider, 2019)

According to Environmental Protection Agency (EPA), Wetlands are areas where water covers the soil, or is present either at or near the surface of the soil all year. (EPA, 2018)

According to Natural Resources Conservation Service (NRCS), A riparian buffer or stream buffer is a vegetated area near a stream, usually forested, which helps shade and partially protect the stream from the impact of adjacent land uses. (NRCS, 2006)
Flood prone areas have been described however the reliability of identification of these areas and extents remain not identified in Kampala city Uganda. One of the ways to identify flood prone areas is through flood susceptibility mapping which is a crucial task for emergency preparedness and management strategies on prevention and mitigation of floods hence reducing risks and losses. (Nachappa, et al., 2020)

2.5 FLOOD INFLUENCING FACTORS

Floods are influenced by various factors these are not limited to but include; elevation, slope, rainfall, soil types, land use land cover, drainage density and distance to the main channel.

2.5.1 Elevation.

Water has a tendency of flowing from a high altitude to low elevation therefore areas of low elevations are easily saturated if there’s a continuous flow of rainwater or river overflows but river overflows also affect areas of high elevation in situations where the river level is twice or three times beyond the normal level. (Pham, et al., 2020)

2.5.2 Slope.

The likelihood of a flood increases as the amount of water at a location increases, (Elkhrachy, 2015) thus higher surface run off, in case of steeper slopes, infiltration will be less and the excessive runoff will cause flooding of the down slope flat areas. (Pham, et al., 2020)

2.5.3 Rainfall.

Rainfall is the primary source of water, high rainfall intensities for longer durations, would increase the river level, saturated soils, and result into high surface run off hence flooding.

2.5.4 Soil types.

Soil is one of the important factors affecting infiltration and runoff and thus has a great impact on flooding. Soils rich in clay are mostly impermeable and cause more runoff and thus cause flooding of the area. (Pham, et al., 2020)

2.5.5 Land use land cover.

Land use land cover affect the degree of frequency of floods in an area, infiltration in an area do depend on land use land cover patterns. Change of land use land cover such as encroachment on wetlands, deforestation can influence flooding. (Pham, et al., 2020)

2.5.6 Drainage density.

Drainage density is the length of all channels within the basin divided by the area of the basin. If the drainage network is dense at any area, it will be a good indicator to high flow accumulation path and more likely to get flooded. (Elkhrachy, 2015)

2.5.7 Distance to the main channel.

Areas located close to the main channel and flow accumulation path are more likely to get flooded. (Elkhrachy, 2015)

2.6 ASSESSMENT OF FLOOD CONDITIONING FACTORS

2.6.1 Fuzzy logic

Fuzzy logic. Initially a theory, today fuzzy logic has become an operational technique. Used alongside other advanced control techniques. Its advantages stem from its ability to; formalize and simulate the expertise of an operator or designer in process control and tuning, provide a simple answer for processes which are difficult to model, continually take into account cases or exceptions of different kinds, and progressively incorporate them into the expertise, take into account several variables and perform “weighted merging” of influencing into variables (CHEVRIE & GUELY, 1998).

2.6.2 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a decision support method developed to complete problem by breaking the solution problems, grouping them, and then arranging them into a hierarchical structure. To obtain priority criteria, this method uses a comparison of criteria paired with a measurement scale that has been determined (Putra, et al., 2018).

2.7 FLOOD SUSCEPTIBILITY MAPPING

Fuzzy analytical hierarchy process

Fuzzy analytical hierarchy process, combines two the fuzzy and the analytic hierarchy process (AHP) algorithm. Fuzzy analytic hierarchy process is a method of Analytic hierarchy process developed with fuzzy logic theory. The fuzzy analytic hierarchy process method sets the AHP scale into the fuzzy triangle scale to be accessed priority (Putra, et al., 2018).

3.0 METHODOLOGY

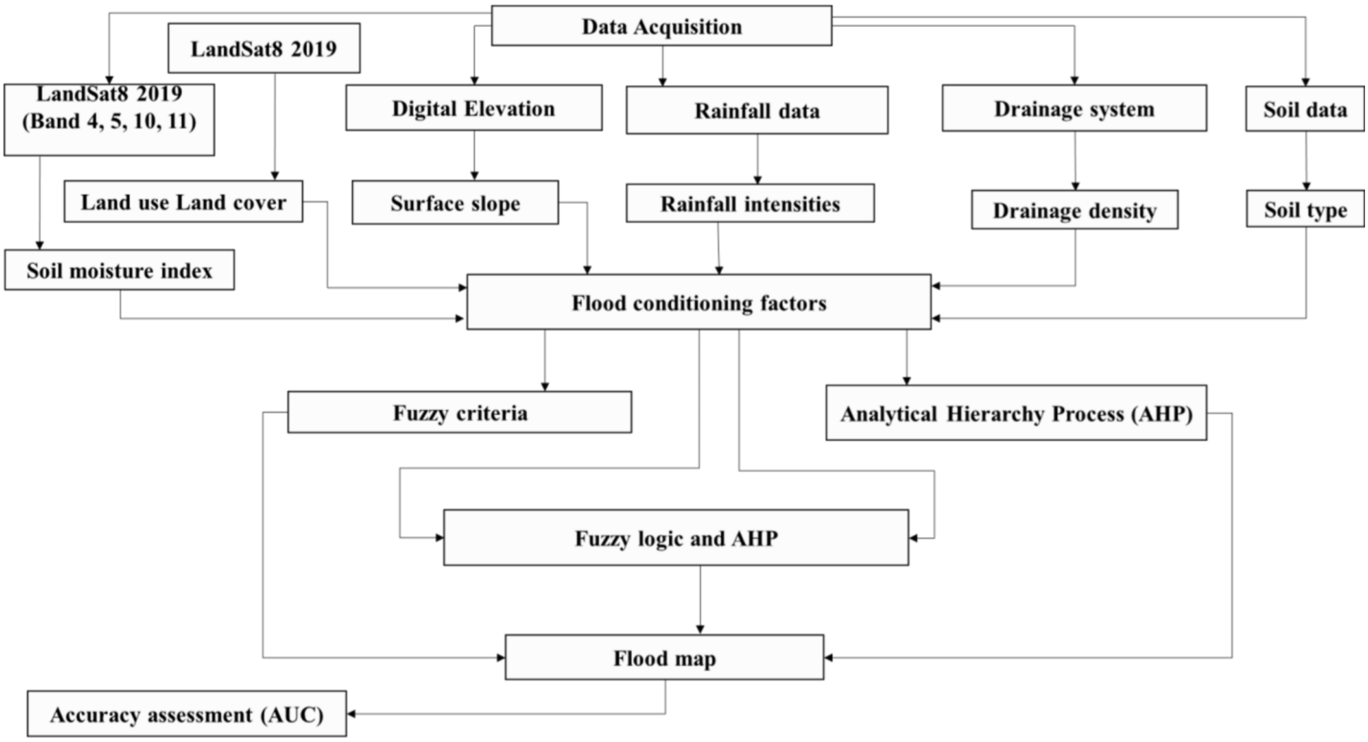


Figure 2 flow chart of methodology

3.1 DATA ACQUISITION

3.1.1 Satellite images.

A Landsat image in particular band 4, 5, 10 &11 for 29th May 2019 was downloaded from USGS, the acquired image was used to create a thematic map of soil moisture index. 29th May 2019, was downloaded because on the 26th may 2019 a flood occurred.

A Landsat image within the month of January was downloaded from USGS, the acquired image was used to create a thematic map of land use land cover. An image from January was downloaded because January is a dry season of the year.

3.1.2 Digital Elevation Model (DEM)

An SRTM Digital Elevation Model was downloaded from USGS, the acquired DEM was used to create a thematic map of surface slope.

3.1.3 Rainfall.

Rainfall amounts were obtained from Uganda National Meteorological authority (UNMA), the acquired rainfall amounts were used to create a thematic map of rainfall intensity. 2019 yearly rainfall was acquired because 2019 had a flood in May and December.

3.1.4 Soil.

Soil data was obtained from the National Agricultural Research Organization (NARO) laboratories. The obtained data was used to develop a thematic map of soil type.

3.1.5 Drainage system.

Drainage system information was acquired from the Kampala Capital City Authority (KCCA), the acquired information was used to create a thematic map of drainage density.

3.2 DATA PROCESSING

The acquired Landsat8 bands 4,5, 10 & 11, were processed to generate a soil moisture index(SMI) map.

NDVI = (B5-B4)/ (B5+B4).

TOA Radiance ($L\lambda$) = MI*Qcal + AL

Where; MI - Radiance multi band

Qcal - Quantized and calibrated standard product value

AL – Radiance add band

Satellite Brightness temp (BT) = $K2/Ln(K1/ L\lambda)+1) – 272.15$

Proportion of Vegetation (PV) = $(NDVI – NDVImin)/(NDVImax – NDVImin)^2$

E = 0.004 * PV + 0.986

Land Surface Temp LST = $BT/ (1+\lambda*BT/\rho)*In (E))$ Where;

$\rho = h*c/s = 1438\mu mk$

h planks constant

c velocity of light s

Boltzmann constant λ

wave length

SMI = (LSTmax - LST)/ (LSTmax-LSTmin)

Where; LSTmax = a1 *NDVI + b1

LSTmim = a2 *NDVI + b2 Where;

a Present Slope

b Present intercept

The downloaded Landsat8 image was classified first using supervised classification, where training samples were generated and a signature file created. Using the generated signature file unsupervised classification in particular maximum likelihood was used to generate a LULC in ArcMap.

The downloaded SRTM DEM was used to generate a slope map using the slope tool in ArcMap.

The acquired precipitation data was used to generate a rainfall intensity map using IDW interpolation technique in ArcMap.

The acquired data from the NARO was in a feature format the acquired feature map was classified according to soil types to generate the soil type thematic map in ArcMap.

The acquired drainage information was used to generate a drainage density map using a raster calculator, based on the formula stated below;

Drainage density = Total length of stream / surface area of catchment.

Using the generated thematic maps of the six conditioning factors (surface slope, soil type, rainfall intensity, drainage density, soil moisture index and LULC), AHP tool was used to generate consistency ratio and AHP values.

	Soil Type	Drainage Density	Soil Moisture	Surface Slope	Land Use Land Cover	Rainfall Intensity
Soil Type	1	0.333	3	0.5	0.4	0.125
Drainage Density	3	1	4	3	2	0.125
Soil Moisture	0.333	0.25	1	0.2	0.2	0.125
Surface Slope	2	0.333	5	1	0.4	0.125
Land Use Land Cover	2.5	0.5	5	2.5	1	0.125
Rainfall Intensity	8	8	8	8	8	1

Table1: Preference matrix
Consistency Ratio (CR) = Consistency index/ Random index

Consistency index = (λmax – n)/(n-1)

Where; n- Criteria number

λmax- weight sum value

Random index <0.10

AHP results

Rainfall 59%, Slope 7.514%, Drainage density 14.291%, Soil type 5.243%, LULC 11.002%, Soil moisture 2.95%, CR = 0.09.

The obtained AHP values were used as weights while using the weighted sum overlay tool in ArcMap and a flood map was generated.

Using the generated thematic maps of the six conditioning factors (surface slope, soil type, rainfall intensity, drainage density, soil moisture index and LULC), a fuzzy membership map was generated for each factor using the fuzzy membership overlay tool in ArcMap. The generated fuzzy membership maps were overlaid using the fuzzy overlay tool and a flood map was generated.

Using the generated fuzzy membership maps of the six conditioning factors (surface slope, soil type, rainfall intensity, drainage density, soil moisture index and LULC), the weighted sum overlay tool was used to generate a flood map while taking AHP values as weights.

3.3 DATA ANALYSIS Accuracy Assessment

The generated flood maps were evaluated against historical flood points and flood lines to assess their accuracy. And using the receiver operating curve (ROC), which is a plot against true positive and false positive the Area under the Curve (AUC) indicated the accuracy level.

4.0 RESULTS

The various steps as discussed in the methodology were followed and yielded various results as discussed and analyzed in this chapter. The results are represented inform of maps and graphs.

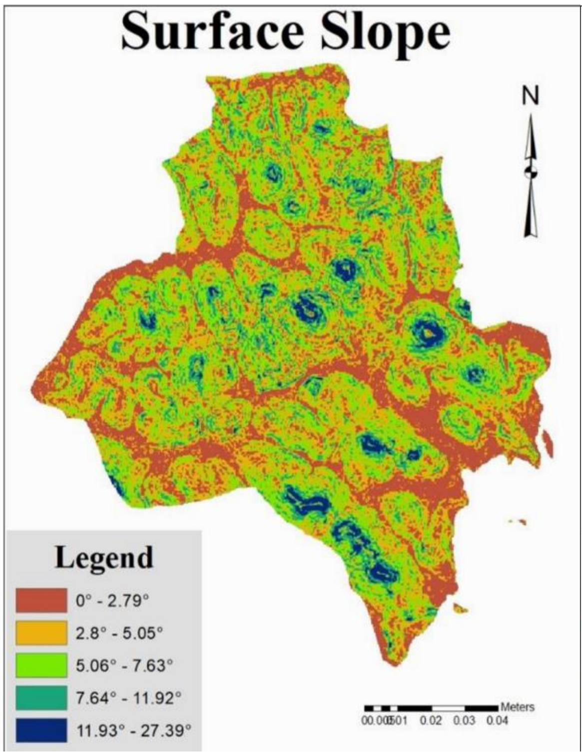


Figure 3: Thematic map showing surface slope

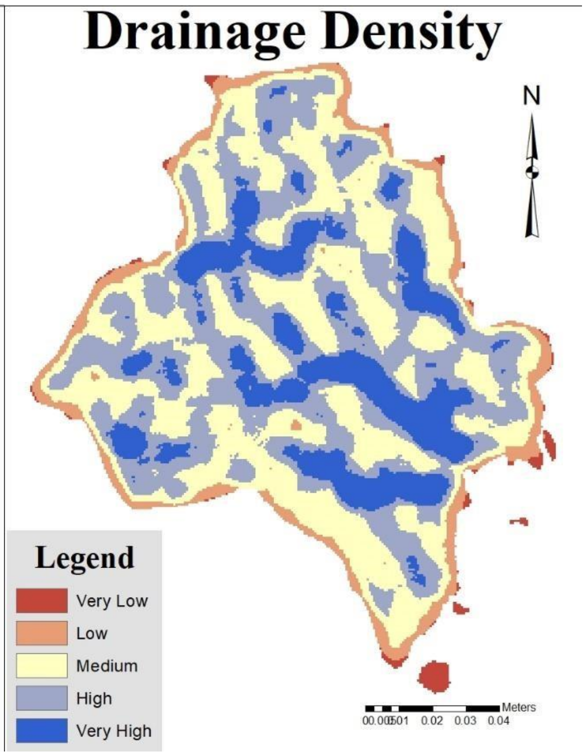


Figure 4: Thematic map showing drainage density

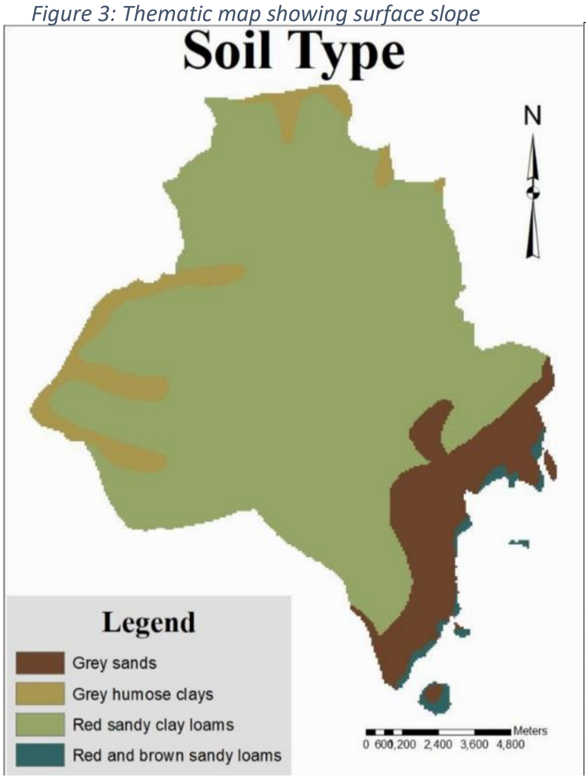


Figure 5: Thematic map showing soil type

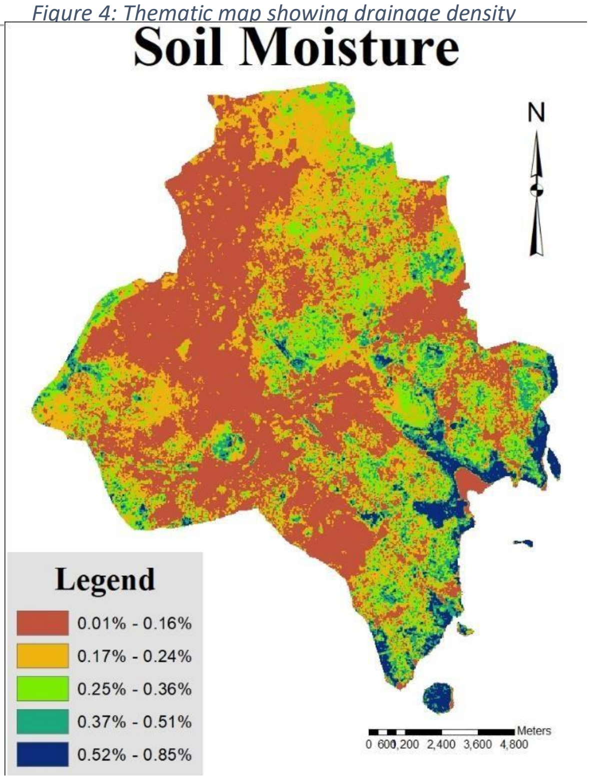
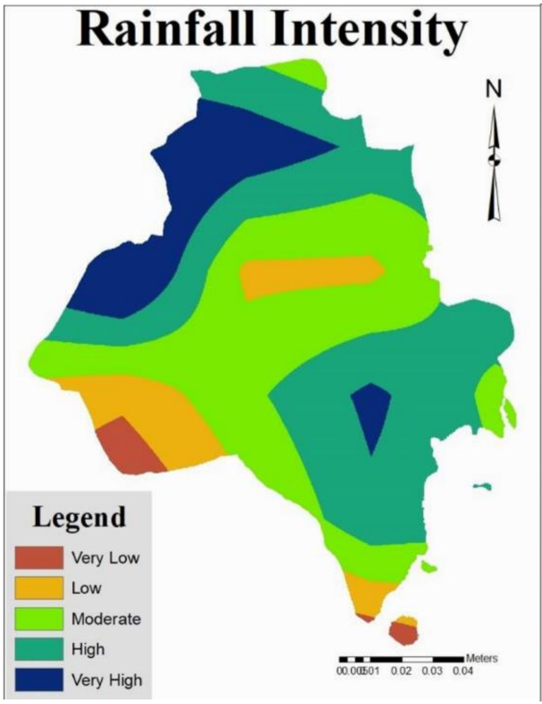


Figure 6: Thematic map showing soil moisture



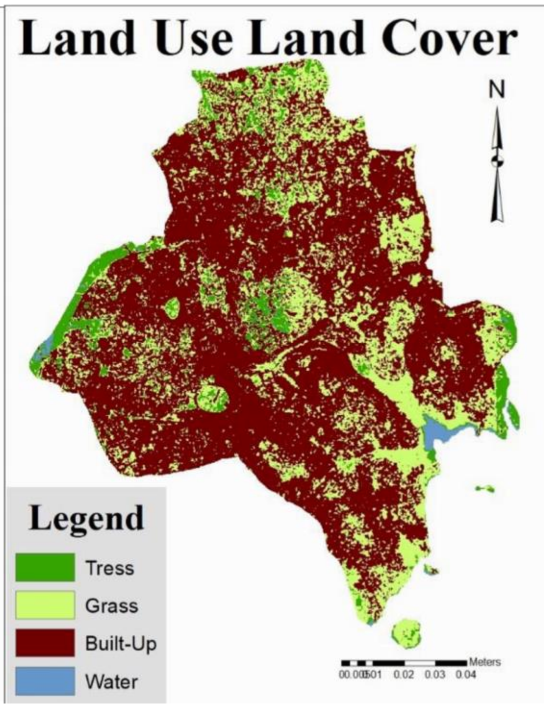
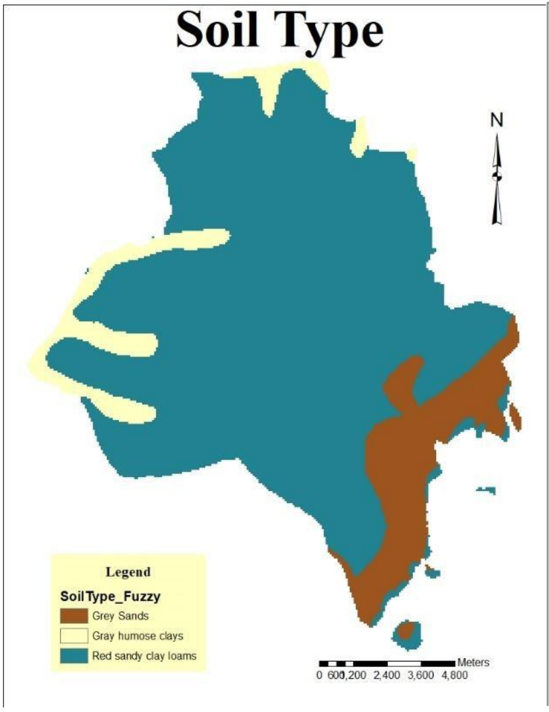


Figure 7: Thematic map showing rainfall intensity

Figure 8: Thematic map showing LULC



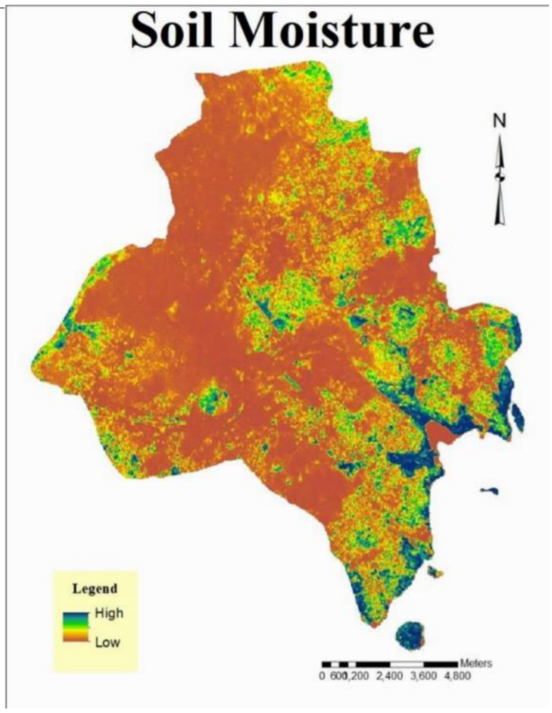
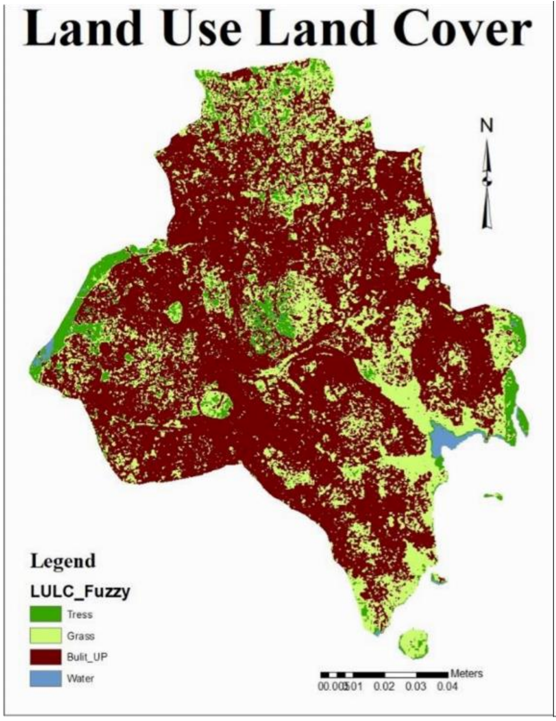


Figure 9: Fuzzy membership soil type map

Figure 10: Fuzzy membership soil moisture map



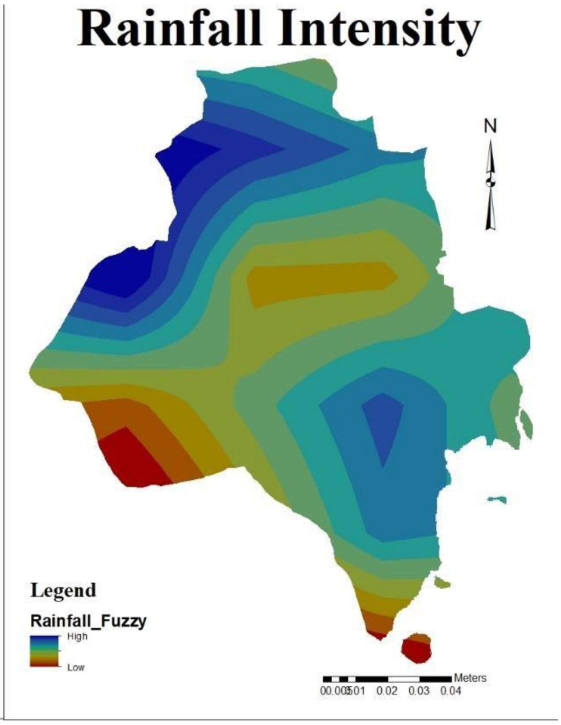
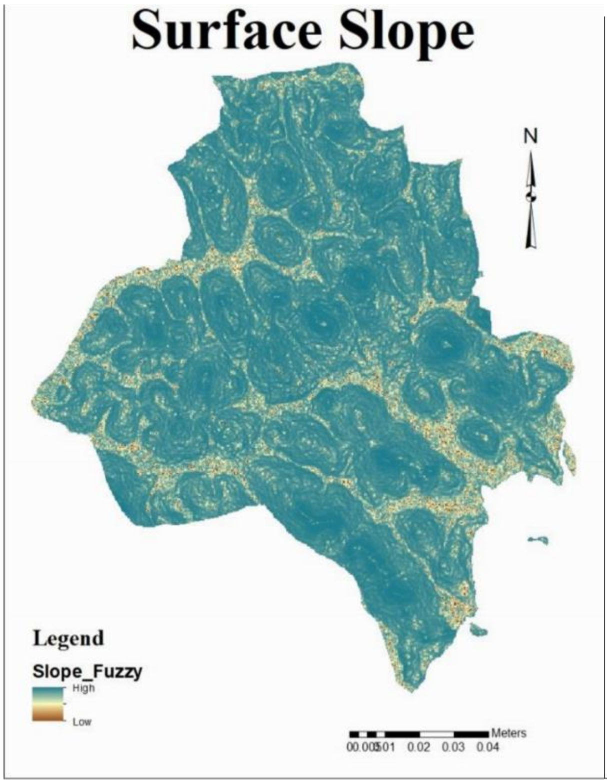


Figure 11: Fuzzy membership LULC map

Figure 12: Fuzzy membership rainfall intensity map



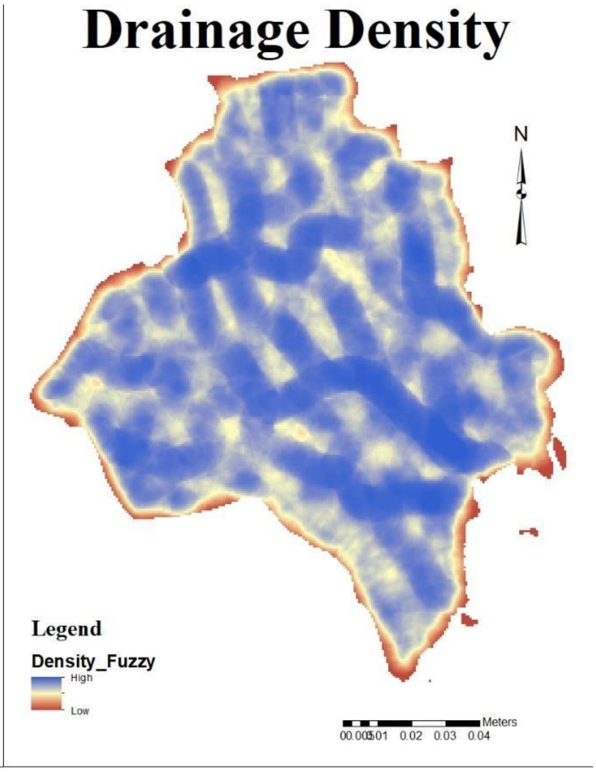


Figure 13: Fuzzy membership surface slope map

Figure 14: Fuzzy membership drainage density map

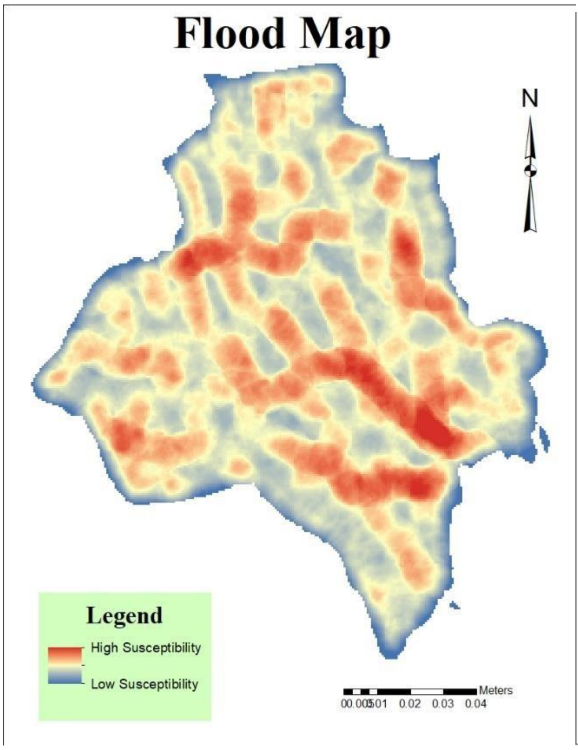


Figure 15: flood map generated using AHP

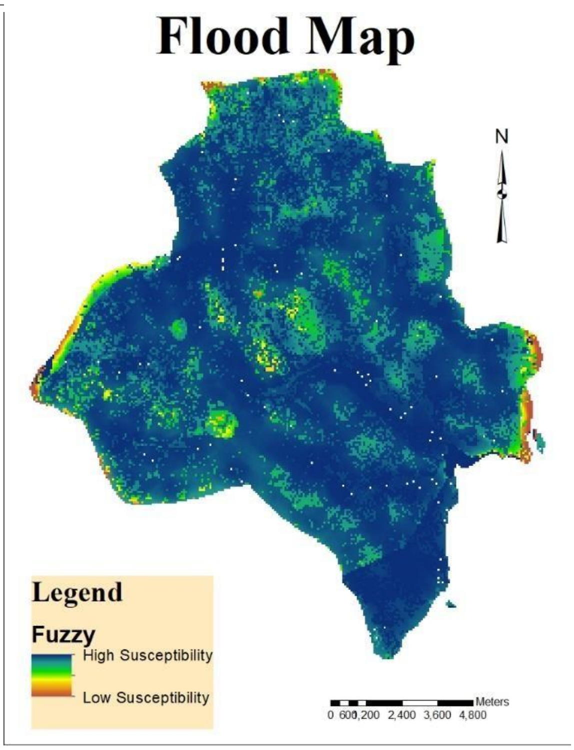


Figure 16: flood map generated using fuzzy criteria

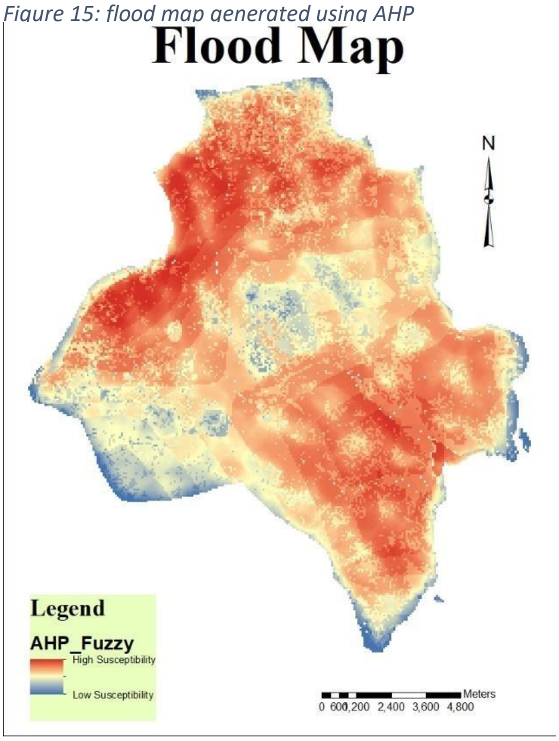


Figure 17: flood map generated using AHP and fuzzy criteria

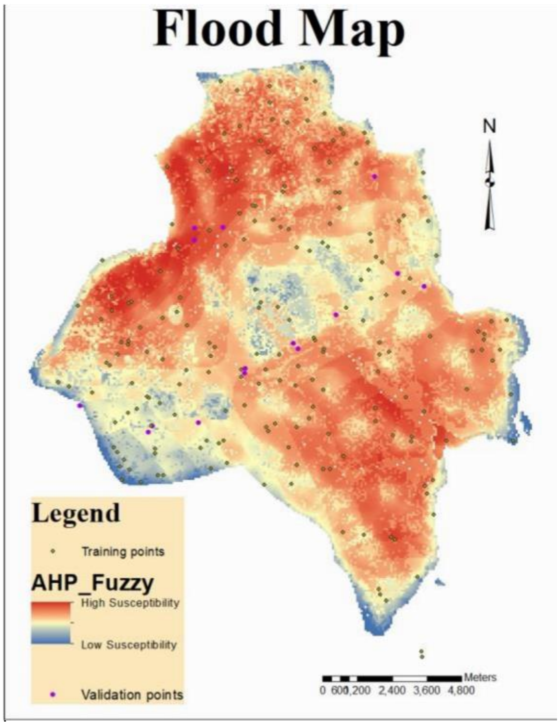


Figure 18: Points used to assess a fuzzy_AHP flood map

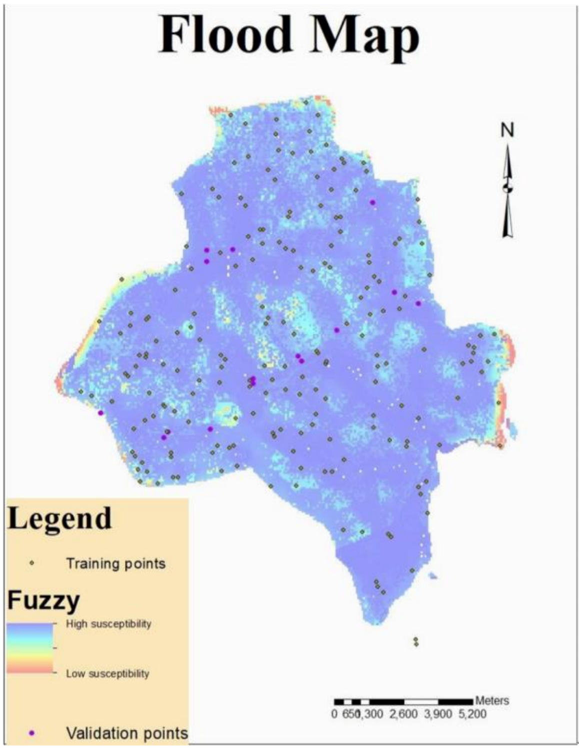


Figure 19: Points used to assess a fuzzy flood map

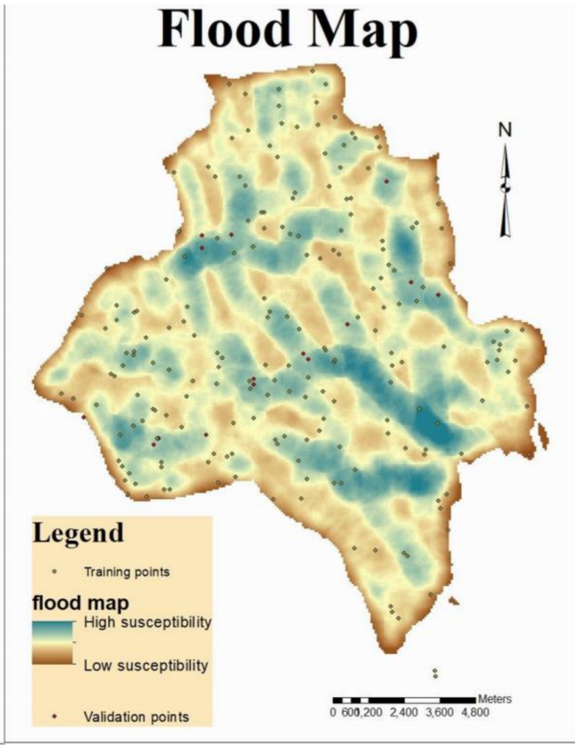


Figure 20: Points used to assess an AHP flood map

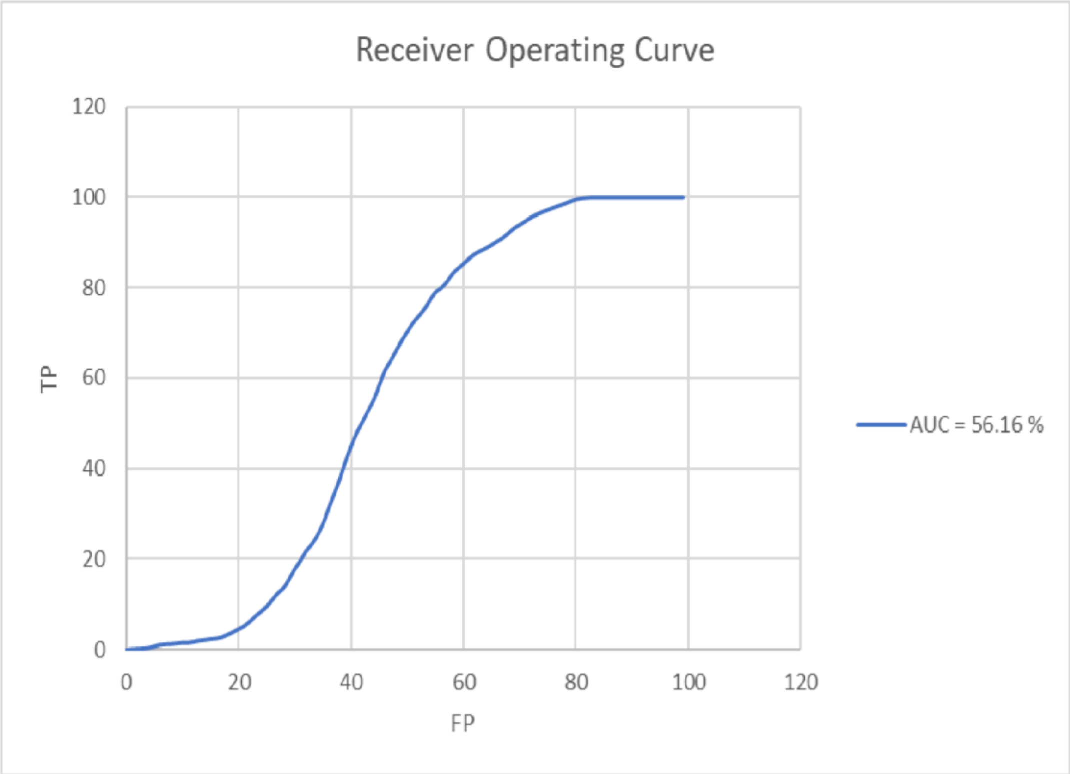


Figure 21: ROC used to assess an AHP flood map accuracy level

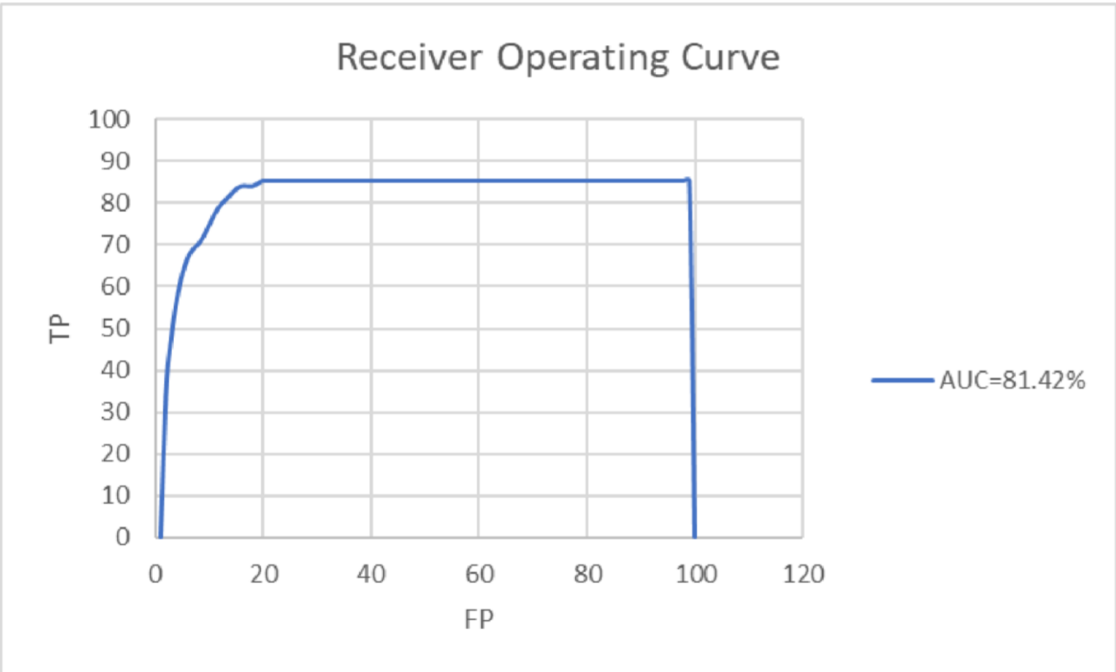


Figure 22: ROC used to assess a fuzzy criteria flood map accuracy level

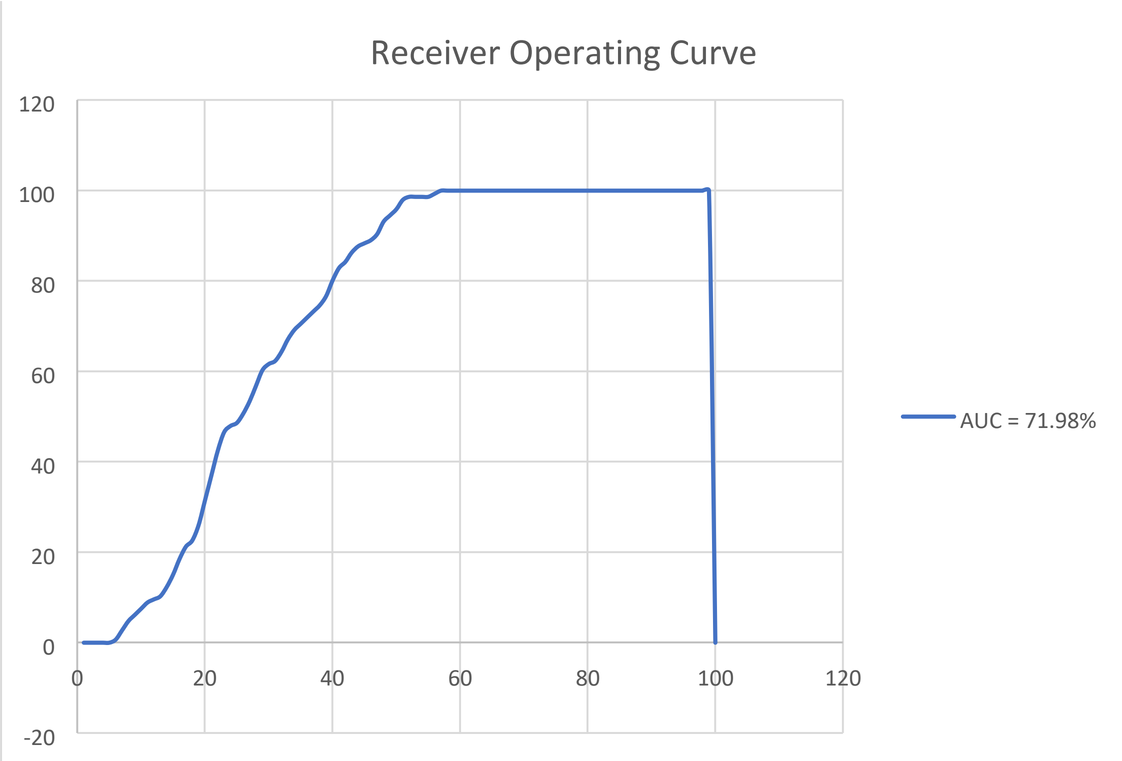


Figure 23: ROC used to assess a fuzzy_AHP flood map accuracy level

5.0 CONCLUSION AND RECOMMENDATION

CONCLUSIONS

This study used AHP, fuzzy criteria and combined the two algorithms Fuzzy and AHP, to create a flood susceptibility map by using flood conditioning factors which has indicated that soil moisture index, Rainfall intensity, drainage density, LULC, slope degree, and soil type were the most influential factors in flood susceptibility mapping. The study shows the important role of GIS in the decision making-process.

AHP had an accuracy of 56.16%, fuzzy criteria had an accuracy of 81.42% and the combination of both algorithms had an accuracy of 71.98%.

RECOMMENDATION

This research could be used to other zones to help managing, manipulating, and lowering of flood harm in regions vulnerable to flooding.

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