

GIS-Based Identification of Flood Conditioning Factors and Hazard Rating in Yola North Local Government Area, Adamawa State, Nigeria

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Abstract: This research aimed at identifying flood conditioning factors and hazard rating in Yola North Local Government Area, Adamawa State, Nigeria with geospatial technology. The data used include ASTER with 30m spatial resolution, Landsat 9 OLI multispectral data (2023), and flood and non-flood points. This research was achieved by preparing flood conditioning factors and assessed flood hazard rating in the study area. The data used for this research includes; the satellite imageries covering the study area of 1980-2021, Digital Elevation Model, Curvature, Aspect, Slope, Topographic Roughness Index (TRI), Topographic Wetness Index (TWI), Stream Power Index (SPI), Sediment Transport Index (STI), Land Use/Land Cover (LULC) measurements, Distance To The River, Soil, Rainfall, Total Flow Accumulation, Flood Points and Non-Flood Points to achieve the stated objectives. The data were used as an input for Geospatial analysis. The study analyzed land use, aspect values, distance to streams, flow accumulation, and other factors to assess flood risk. Built-up areas (33%), farmland (25%), and bare land (18%) were identified as significant land use types. Aspect values ranged from low (-1 to 63) to high (289 to 358). Distance to streams ranged from 250m to over 2000m. Areas with high flow accumulation and direction values are prone to flooding. Rainfall ranged from 0mm to 348.1mm in August. River basin values indicated larger catchment areas in some areas. Slope values ranged from 0.76 (low) to 13 (high). Soil characteristics and SPI, STI, TRI, TWI, and NDWI values also indicated varying levels of flood risk. The study's results can be used to inform flood mitigation strategies. The results showed that 58% of the area has a low degree of hazard, while 18% has an extreme hazard, 17% has a significant hazard, and 6% has a moderate hazard. The study identified areas prone to flooding, including those with low elevation, proximity to water bodies, and poor drainage. The findings suggest that land use patterns, topography, and soil characteristics significantly influence flood risk rating in the study area. Therefore, the results of this study are useful in flood mitigation strategies, such as identifying flood-prone areas for targeted interventions, designing drainage systems and flood protection infrastructure, and planning evacuation routes and emergency response plans.

Keywords: flood, conditional factor, hazard rating, GIS, Yola North.

INTRODUCTION

Flood is commonly defined as an overflow of water onto lands that are used or are usable by man, and are not normally covered by water. Floods have two essential characteristics: the inundation of land is temporary; and the land is adjacent to and inundated by overflow from a river, stream, lake, or ocean (Pyaskovskyi and Pomeranets, 1982). Another, more general definition states that flood is determined as a general and temporary condition of partial or complete inundation of normally dry land areas from overflow of inland or tidal waters, or from the unusual and rapid accumulation or runoff of surface water from any source (Pyaskovskyi and Pomeranets, 1982). A river channel is formed by the forces of nature to be able to convey the flow that is found most of the time. When the volume exceeds this, the water level rises above the banks and spreads in to the adjacent lands. This area is usually called the flood plain of the river e.g. when rainfall exceeds absorption capacity of the soil, which in turn causes significant environmental consequences (Nwachukwu *et al.*, 2018).

Flood disaster is generally defined as the function of hazard, the probability of a flood event; exposure, the population and value of assets subject to flooding; and vulnerability, the capacity of a society to deal with the event (IPCC, 2012). While the understanding of hazard and exposure has greatly improved over the years, knowledge of vulnerability remains one of the biggest hurdles in flood risk assessment to date (Mechler *et al.*, 2014; Visser *et al.*, 2014). Traditionally, studies assessing flood disaster and the feasibility of flood risk management (FRM) policies include the physical vulnerability of structures and goods as an indicator of flood risk (Filatova, 2014; Jongman *et al.*, 2014a).

Flooding as one of the most common and destructive natural disasters has caused approximately 7 million deaths and more than \$US 700 billion losses around the world since 1900 (EMDAT, 2020). Worse still, some studies have declared that flooding events may increase in many coastal regions in the future due to global and regional climate change that will cause rising sea levels (Li *et al.*, 2020). There are many events happenings around the world every day, some of which become natural disasters (Pal *et al.*, 2020). Natural disasters are a disaster or disaster caused by a high-risk natural phenomenon such as floods, droughts, earthquakes, landslides, hurricanes or volcanoes that cause extensive damage to human communities, but in areas where direct contact with humans These events do not turn into natural disaster (Yariyan *et al.*, 2020a; Chen *et al.*, 2021). Floods are the most destructive catastrophe worldwide and cause the highest number of deaths and injuries (Nachappa *et al.*, 2020a). In recent years, assessments and estimates of floods have increased significantly due to increased urbanization and the concentration of residential areas around rivers and floodplains. Rentschler and Salhab (2020) estimate that ‘1.47 billion people, or 19% of the world population, are directly exposed to substantial risks during 1-in-100year flood events. In developing countries, flooding results from climate change, excessive precipitation, building on waterways, sea-level rise, soil moisture regime, dam operations, especially along borders,

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uncontrolled rapid population growth, inadequate preparedness, and lack of political will (Olanrewaju *et al.*, 2019; MacLeod *et al.*, 2021). MacLeod *et al.* (2021) identified excessive levels of precipitation as the main natural cause of flooding, caused by climate change.

Flooding as one of the most common and destructive natural disasters which has caused approximately 7 million deaths and more than \$US 700 billion losses around the world. Along with rapid urbanization and industrialization in recent decades, the increasing population and property exposure has greatly exacerbated losses. In the year 2023, the National Emergency Management Agency (NEMA, 2023) issued an alert over the threat of rapid flooding along the River Niger and River Benue Basin, owing to the release of water from the Lagdo Dam in the Republic of Cameroon, calling for the immediate activation of an emergency response plan in the following states: Adamawa, Benue, Taraba, Nasarawa, Kogi, Anambra, Edo, Delta, Rivers, and Bayelsa. Also, in 2022, heavy rainfall and overflowing rivers in the past months have affected 4.4 million people across Nigeria, including 2.6 million children, as the country experienced the worst floods in a decade. The water damaged not only people's homes and farmlands, but also put public health facilities, water systems, and sanitation facilities out of service, increasing the risk of waterborne diseases, such as cholera, diarrhoea, and malaria (UNICEF, 2022). Some 2.4 million people were displaced and took temporary refuge in makeshift internally displaced people (IDP) sites, such as schools and health facilities, which impinged on the continuity of basic services (UNICEF, 2022).

The Nigeria Hydrological Services Agency, (NIHSA) has in its prediction of the 2022 Annual Flood Outlook, (AFO), predicted that 233 Local Government Areas (LGAs) in 32 States of the Federation and the FCT fall within the Highly Probable Flood Risks Areas, while 212 LGAs in 35 States of the Federation including FCT fall within the Moderately Probable Flood Risks Areas. The remaining 329 LGAs fall within the probable flood Risks Areas. The Highly Probable Flood Risk States are; Adamawa, Abia, Akwa-Ibom, Anambra, Bauchi, Bayelsa, Benue, CrossRiver, Delta, Eboyin, Ekiti, Edo, Gombe, Imo, Jigawa and Kadunna, others are, Kano, Kebbi, Kogi, Kwara, Lagos, Nasarawa, Niger, Ogun, Ondo, Osun, Oyo, Rivers, Sokoto, Taraba and Yobe, as well as Zamfara and FCT (NIHSA, 2022). Worse still, some studies have revealed that flooding events may increase in many river and coastal regions in the future due to global and regional climate change that will cause rising water and sea levels. From this view, flood control and disaster reduction comprise a major theme for humans whether in the past, present, or future and Adamawa State is not exceptional from these effects.

Within the last two decades, the most widely used approaches in modelling flooding in Nigeria include geospatial techniques and Geographic Information Systems (GIS), and hydrological modelling and fitting of probability distributions. Komolafe *et al.* (2020) using GIS techniques to describe vulnerable areas prone to flooding close to the Ogun River basin, Nigeria, concluded that the combined mapping of multi-criteria analysis and the Height Above Nearest Drainage (HAND) terrain model generated a better result than the individual models. The vulnerability map indicates

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that part of Lagos state is extremely vulnerable to flooding, because of its closeness to the Ogun River. Komolafe *et al.* (2021) in related work on the Ogunpa River basin, Ibadan, Oyo state, combined three methods, viz., the HAND model, GIS-based multi-criteria decision analysis and event-based flood simulation using the FLO-2D model, to develop flood hazard maps. Hence the need of this research in identification of flood conditioning factors and hazard rating in Yola North Local Government Area, Adamawa State, Nigeria with the aid of geospatial technology.

MATERIALS AND METHODS

Yola-North LGA is one of the largest cities in Adamawa state, Nigeria, situated at a height of 215 meters Above Mean Sea Level and located between Latitudes 9° 12' 0." and 9° 21' 0" North of the Equator and Longitudes 12° 19' 12" and 12° 30' 0" East of the Greenwich Meridian. The area is located at the bank of River Benue and is bounded by Giere in the North and East, and in South and West by Yola-South local government area. Yola-North Local Government is composed of eleven Wards namely; Yelwa, Nasarawo, Jambutu, Luggere, Alkalawa, Doubeli, Limawa, Rumde, Karewa, Ajiya and Gwadabawa. It has an estimated area of approximately 112.74Km². Yola North Local Government area experiences a tropical sub humid climate, the wet and dry seasons. Over the course of the year, the temperature typically varies from 17° Celsius (C) to 39° Celsius (C) and is rarely below 14°Celsius (C) or above 42° Celsius (C) (Weather spark, 2021).

The study area is underlain by Bima Sandstone which marks the base of the sedimentary succession in the Upper Benue Trough. It varies in thickness from 100m to 300m and has a maximum thickness at the Lamurde anticline where it exceeds 3000m. The differing degree of sediment accumulation in the trough and the irregular relief of the underlying crystalline basement on which the sediments accumulated are probably responsible for the variation in thickness. The Bima Sandstone rocks in the Upper Benue Basin have been sub-divided from base to top into three sandstone members. These include the lower Aptian/Albian Bima, the Middle Albian Bima Sandstone and the late Albian/Cenomanian Upper Bima Sandstone (Carter *et al.*, 1963). Like most areas in northern Nigeria, the soil of Yola-North is derived from the basement complex rock, however, there is some alluvial soil along the Benue flood plains. The soil of the study area is loamy and it drains easily when it rains. The vegetation consists of short, medium and shrubs, more especially in the months of August and September during which the area records higher amount of rainfall. The population of the area is approximately the projected Population as at the year 2022 is 307,900 based on exponential growth model with an annual growth rate of 2.7 percent. The city is clearly stratified in terms of population densities such as low, medium and high-density areas.

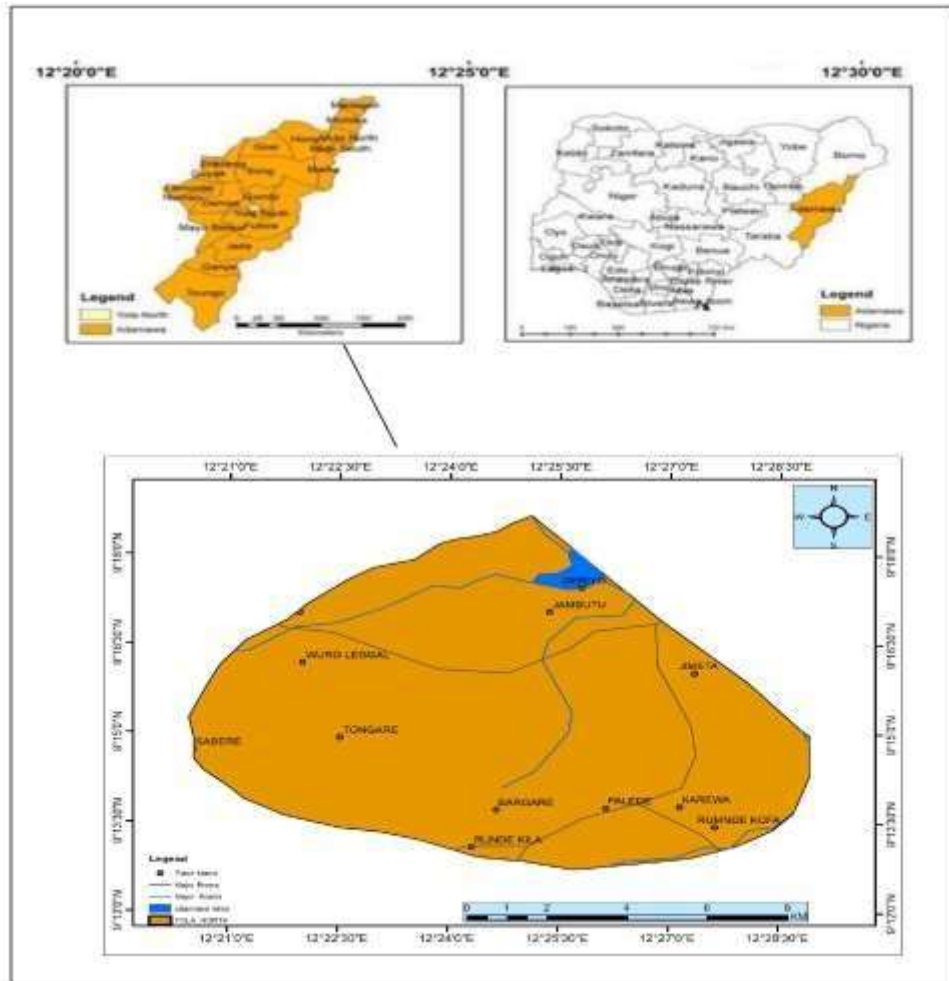


Figure 1: Map of Yola North (Study Area)

Source: Ministry of Land and Survey, Yola North, 2025

Reconnaissance Survey

The survey was carried out to get acquainted with the study area for data sources and to aid in the method of field observation and generation/taking coordinate of floodable and non-floodable areas.

Types and Sources of Data

Tables 1 show the type and sources of data and the parameters to be used as input for this research.

Table	Type of Data	Source of Data
1: Types and Sources of Data		
S/NO		
1	Digital Elevation Model	ASTER with 30m spatial resolution, Global Landcover
2	Curvature	wusgs
3	Aspect	wusgs
4	Slope	wusgs
5	Topographic Roughness Index (TRI)	wusgs
6	Topographic Wetness Index (TWI)	wusgs
7	Stream Power Index (SPI)	Wusgs
8	sediment transport index (STI)	wusgs
9	Land Use/Land Cover (LULC)	Wusgs
10	Distance To The River	wusgs
11	Soil	Wusgs
12	Rainfall	NIMET
13	Total Flow Accumulation	Wusgs
14	Flood Points and Non-Flood Points	Historical data sources, Fieldwork, Perception of local residents, and Google Earth Engine

Source: Thlakma, 2024.

Data Analysis

The data was assessed and examined based on the stated objectives as follows: Flood conditioning factors were prepared in the study area. The preparation of a flood inventory map of the research area was the preliminary stage for creating the flood susceptibility map. Based on the training datasets, the 'extract values to point' tool in ArcGIS 10.8 software was used to derive data from flood conditioning parameters (spatial datasets). The datasets were then imported into the ArcGIS

10.8 software and all the modeling was performed there. The accessible technologies of GIS were used to achieve and investigate the normal state at the flooded sites. The DEM was used for the preparation of the flood disaster inventory map, where flood points location of the study area was collected. Non-flood points were allocated to 0. Subsequently, non-flood points were split arbitrarily into point categories. Validation datasets were designed to test the final models, including both flood and non-flood points as 1 and 0. Both the datasets for training and validation were presented in the form of a map. The development of the susceptible spatial flood model was typically very complex and precise, as many geospatial topographical and hydrological variables were needed as baseline data. Recognition of variables driving the flood was thus a critical activity, and the scientifically selected parameters validated the accuracy of the flood susceptibility analysis. The flood influencing parameters selected were elevation, curvature, aspect, slope, topographic roughness index (TRI), topographic wetness index (TWI), stream power index (SPI), sediment transport index (STI), land use/land cover (LULC), distance to the river, soil type, and rainfall. A Digital Elevation Model (DEM) was prepared from ASTER with 30m spatial resolution for the study area in ArcGIS 10.10.8 environment. The topographic factors were derived from DEM, such as slope, curvature, aspect, topographic wetness index (TWI), stream power index (SPI), sediment transport index (STI), and topographic roughness index (TRI) in ArcGIS 10.8 environment. All the influencing factors were transformed into raster format with 30m spatial resolution. Topographic Wetness Index:

This index shows the amount of water contained in every pixel size of the region and that is computed using the Eq. (1): $TWI = \ln(A_s) / \tan \beta$ Eq. (1).

The specific catchment area (m^2m^{-1}) and the slope gradient (in degrees) are indicated by A_s and β , respectively.

Stream Power Index (SPI): The SPI is computed using Eq. (2). $SPI = A_s \tan \beta$ Eq. (2).

Where, A_s and the slope gradient represent the specific catchment area is indicated by β (radians) The sediment transport capacity and the erodibility of its bed are referred to as total SPI.

Sediment Transport Index: Sediment transport index (STI).

The STI is derived from DEM using Eq. (3). $STI = (A_s / 22.13)^{0.6} (\sin \beta / 0.0896)^{1.3}$ Eq. (3).

Eq. (3). Where, each pixel of the slope is represented by β , and the area of upstream is indicated as A_s (Based on hydro-climatic and geomorphologic attributes of the area, the STI is calculated.

Land use/Land Cover:

This study used a 2023 Land Use/Land Cover (LULC) map, derived from 30m-resolution Landsat imagery and classified using an Artificial Neural Network (ANN) in ArcGIS 10.8. The classification process employed supervised learning with maximum likelihood algorithms. The LULC map was categorized into five classes (Table 2), adapted from Anderson et al. (1976) and tailored to Yola North's characteristics. Additionally, a distance-to-river map was prepared from a topographic map in ArcGIS 10.8.

Table 2: Land Use Land Cover Classification Scheme

LULC Class	Description
Built-up Area	Residential, commercial, industrial, transportation, and other constructed areas
Vegetation	Trees, shrubs, grasslands, and other vegetated areas
Bare Land	Exposed soil, sand, rocks, and areas with little or no vegetation
Farmland	Cultivated areas and agricultural fields
Water Bodies	Rivers, streams, ponds, and other surface water features

Source: Adapted from Anderson et al. (1976)

This study utilized a supervised classification approach with the Maximum Likelihood Classifier (MLC), a widely recognized method for accurate land cover mapping (Belgiu & Drăguț, 2016). Training samples for each Land Use/Land Cover (LULC) class were carefully selected from high-resolution imagery and validated with ground truth data. For historical images without ground observations, samples were derived from areas with well-documented land uses. The MLC was optimized and applied to generate LULC maps. A majority filter was used to refine the maps, reducing noise and improving coherence. Accuracy assessment was performed using independent validation points, evaluating metrics such as overall accuracy, user's accuracy, producer's accuracy, and the Kappa coefficient to ensure reliable results.

Flood Hazard Rating

Two-dimensional numerical analysis was performed to calculate inundation and flow velocity maps for training the random forest, which was used to generate a map of the predicted flood hazard rating of grid units given the total accumulative overflow of the target area. To confirm the goodness of fit, the proposed model was used to predict a flood disaster rating map for a rainfall event observed in August 2023. The 3D flood analysis results were used to generate the maximum flood depth and flow velocity for each grid. The flood rating for each grid was calculated according to two types of data. Various formulas are available for calculating the flood disaster rating based on numerical analysis or observation; the one from DEFRA (2006) was used in this study because of its clarity. Table 3 presents the hazard rating criteria of DEFRA. The flood hazard rating is an important factor that indicates the level of damage impact to human life. Flood disaster rating maps are important foundational data for flood responses and measures. The debris factor (DF) can be

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$$\text{Hazard Rating} = d \times (v + 0.5) + \text{DF}, \quad \text{Eq.4}$$

where d is the flood depth (m), v is the flow velocity (m/s) in the event of a flood, and DF is 0, 0.5, or 1 based on its impact. Thus, the flood hazard rating is the sum of the flood depth and flow rate function and the DF. As given in Table 5, the DF value may vary depending on the land use, flood depth, and flow rate.

Table 3. Disaster/Hazard to People as a Function of Velocity and Depth

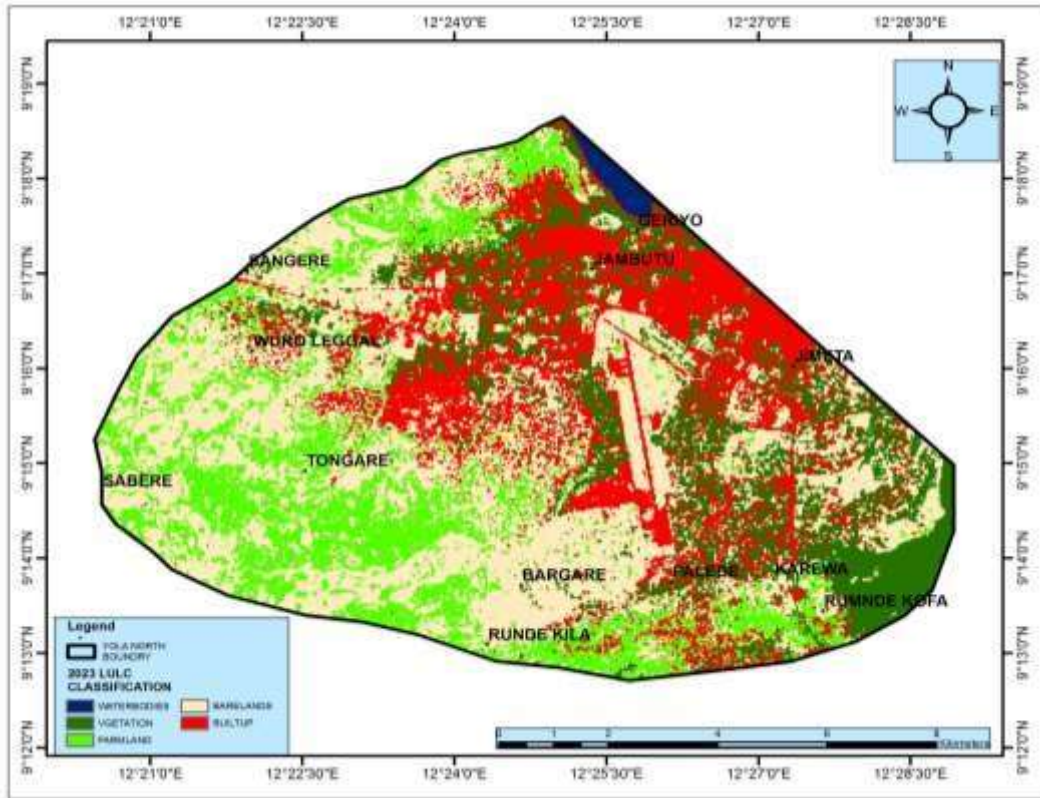
$d \times (v + 0.5)$	Degree of flood hazard	Description
< 0.75	Low	Caution Flood zone with shallow flowing water or deep standing water
0.75 – 1.25	Moderate	Dangerous for some (i.e., children) Danger: Flood zone with deep or fast flowing water
1.25 – 2.5	Significant	Dangerous for most people Danger: Flood zone with deep fast flowing water
> 2.5	Extreme	Dangerous for all Extreme danger: flood zone with deep fast flowing water

Source: DEFRA, (2006)

RESULTS AND DISCUSSION

Prepare flood conditioning factors in the study area:

Land Use Map of Yola North: The result for the land use map of Yola North is presented on Figure 2 and Table 4.

**Figure 2: Land Use Map of Yola North**

Source: Author's Analysis, 2025

Table 4. Land Use Land Cover of 2023

Land Use	Years 2023 (%)
Buildup	33.32
Bare land	18.22
Vegetation	14.57
Farmland	24.84
Water Bodies	9.06
Total	100%

Source: Authors Analysis (2025)

The 2023 Land Use Land Cover (LULC) analysis (Figure 1 and Table 3) reveals the study area's land use distribution, with significant implications for flood risk. Key findings include the Builtup Area (33%) this shows that high urbanization and impervious surfaces increase stormwater runoff and flood risk by altering hydrological processes. Farmland (25%) revealed soil compaction and crop management practices contribute to runoff and soil erosion, exacerbating flood risk. Bare Land (18%) indicates lack of vegetation cover increases runoff and erosion, vegetation (15%) helps mitigate flood risk by absorbing rainfall and stabilizing soil while waterbodies (9%) clearly indicates that only small proportions of the area regulate flood flows and provide ecosystem services like habitat provision and water filtration. The LULC analysis suggests that land use patterns significantly influence flood risk susceptibility in the study area, consistent with previous research (Lin et al., 2020; Tate, 2021; Bui, 2019). These studies emphasize that flood risk is closely tied to land use and land cover characteristics.

Aspect Map:

The Aspect of the study area is resented on Figure 3.

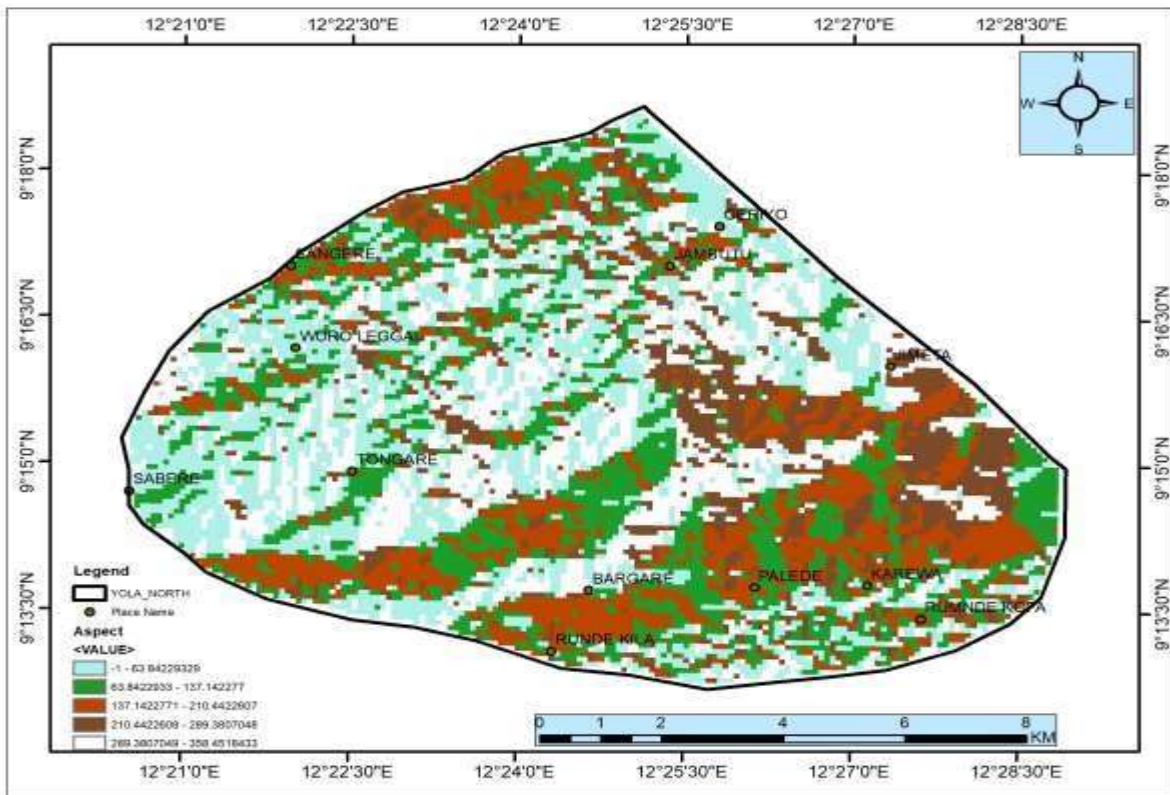


Figure 3: Aspect Map of Yola North

Source: Author's Analysis, 2025

The aspect values in the study area range from -1 to 63 low, 137 to 210 medium and 289 to 358 high across the study area.

The aspect values indicate the direction of slopes in the study area, ranging from -1 (flat) to 358° (all directions). From Figure 3, Low Aspect Values (-1 to 63) areas with low aspect values are likely to have slopes facing north to northeast, potentially receiving less direct sunlight and having slower runoff. Medium Aspect Values (137 to 210) areas with medium aspect values are likely to have slopes facing southeast to southwest, potentially receiving moderate direct sunlight and having moderate runoff. Additionally, high aspect values (289 to 358) areas with high aspect values are likely to have slopes facing northwest to north, potentially receiving more direct sunlight and having faster runoff. More so, areas with medium to high aspect values (137-358°) may be more prone to flooding, as they may have faster runoff and more direct sunlight. Aspect values can influence runoff direction, with slopes facing watercourses potentially contributing to flood risk. Areas with high aspect values may experience more soil erosion, exacerbating flood impacts. Aspect value range flood risk level -1 to 63, low-moderate, 137 to 210, moderate-high and 289 to 358 respectively.

Digital Elevation Model (DEM):

The Digital Elevation Model (DEM) Map of the study area is presented on Figure 4.

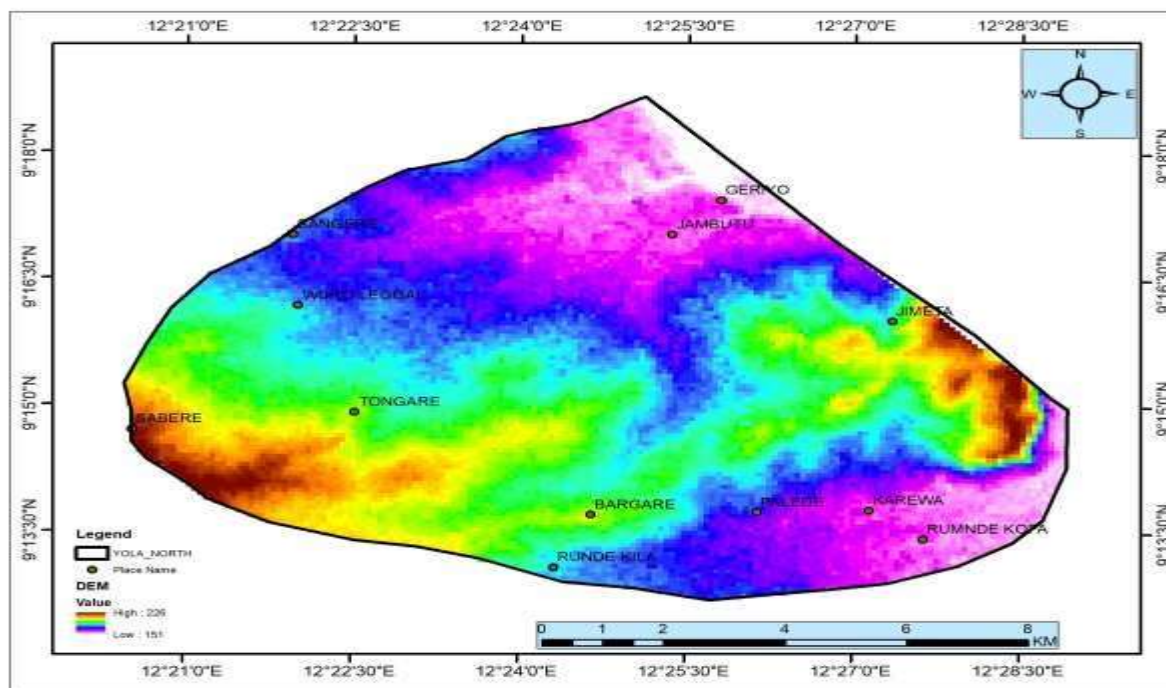


Figure 4: Digital Elevation Model (DEM) Map of Yola North

Source: Author's Analysis, 2025

The DEM values in the study area range from 226m to 151m. The higher values of about 226m were found in areas like Sabre, Togare, BArgage, Karewa, and Jalingo, while the lower values of 151m are found in areas like Jambutu, Gugumayo, Jerngel Mayo, Rumindekofa, and Dolabe Barre. The DEM (Digital Elevation Model) results indicate significant elevation variations in the study area, ranging from 226m in higher grounds to 151m in lower-lying areas. Areas with lower elevations (e.g., Jambutu, Gugumayo, Jerngel Mayo, Rumindekofa, and Dolabe Barre) are more prone to flood disasters due to their topography, as water naturally flows and accumulates in these areas. Lower-elevation areas fund to be areas with higher risk of flooding, especially during heavy rainfall or river overflow. Communities in Jambutu, Gugumayo, Jerngel Mayo, Rumindekofa, and Dolabe Barre may face increased flood risk, impacting lives, infrastructure, and livelihoods. Understanding elevation patterns can inform flood mitigation strategies, such as dentifying flood-prone areas for targeted interventions. Designing drainage systems and flood protection infrastructure, planning evacuation routes and emergency response plans.

Distance to Stream:

The distance to stream of the study area is resented on Figure 5.

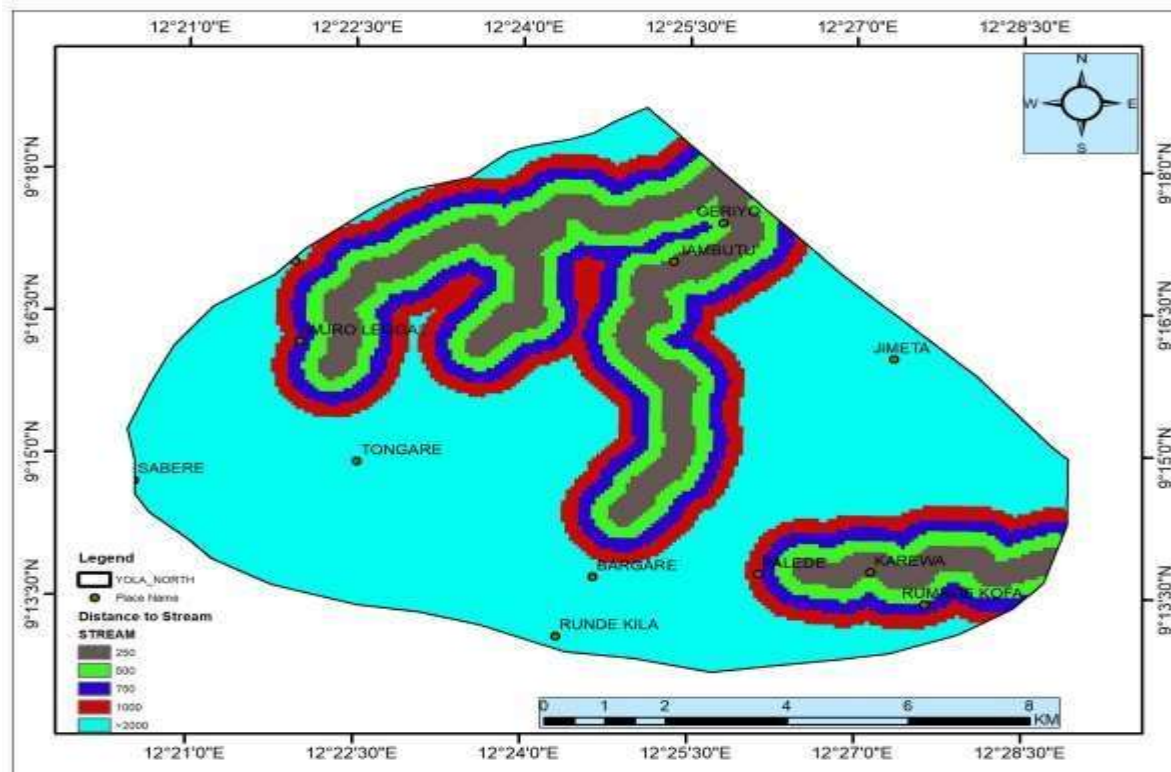


Figure 5: Distance to Stream Map of Yola North

Source: Author's Analysis, 2025

The Distance to stream l values in the study area ranges from 250m, 500m, 750m, 1000m and more than 2000 across the study area.

The Distance to Stream values indicates the proximity of areas in the study area to streams or rivers, ranging from 250m to more than 2000m. it was revealed that low distance (250m) areas with low distance to streams are likely to be more prone to flooding, as they are closer to water sources. High Distance (>2000m) areas with high distance to streams may be less prone to flooding, as they are farther away from water sources. Areas with low distance to streams (250m-500m) may be more prone to flooding, requiring prioritized flood mitigation measures. Areas with high distance to streams (>1000m) may have lower flood risk, but may still be affected by other factors like rainfall and topography. More so, distance to stream data can inform buffer zone management, helping to protect areas prone to flooding and maintain ecosystem services. Based on general flood risk classification, research has shown that areas with distance to stream flood risk level 250m - 500m high, 500m - 1000m moderate, 1000m - 2000m low-moderate And 2000m low respectively.

Floodable and Non-Floodable Map of Yola North:

The floodable and non-floodable map of the study area is resented on Figure 6.

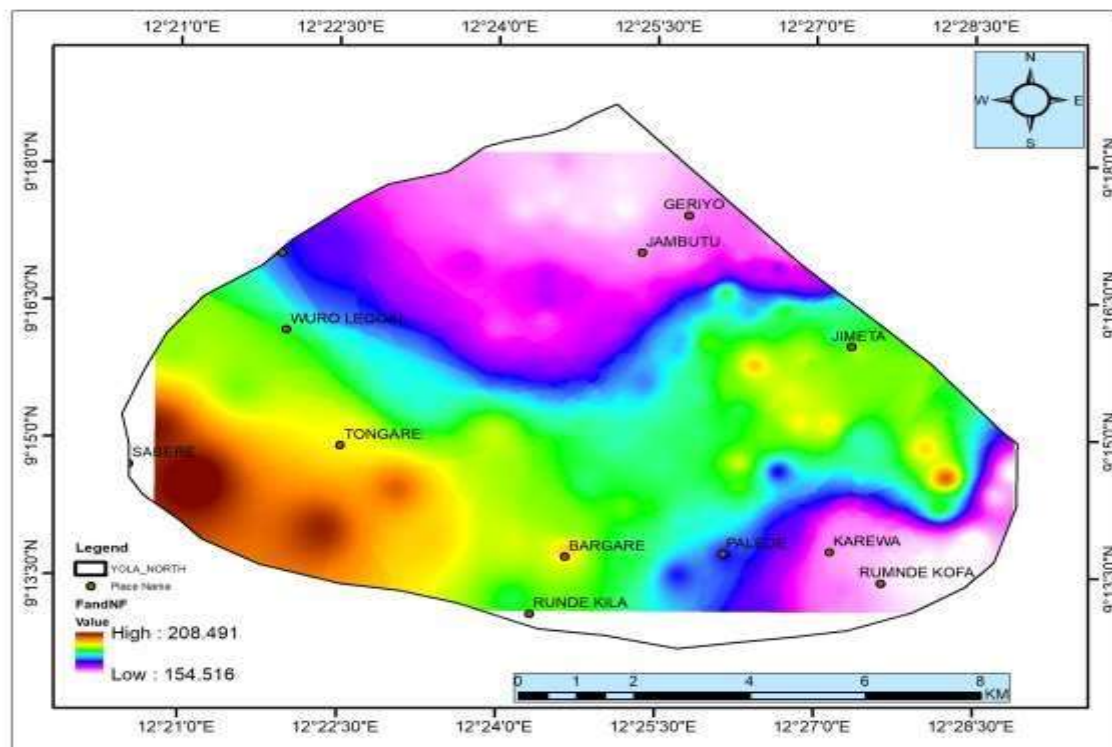


Figure 6: Floodable and Non-Floodable Map of Yola North

Source: Author's Analysis, 2025

The values on Figure 6 indicate the study area's flood risk, ranging from 208.491 (high) to 154 (low). High Values (208.491) areas with high values are likely to be flood-prone, with low elevation, proximity to water bodies, or poor drainage. Low Values (154) areas with low values are likely to be non-flood-prone, with higher elevation, better drainage, or farther from water bodies. Areas with high values may experience frequent flooding, requiring prioritized mitigation measures. Areas with low values may have lower flood risk, but may still be affected by extreme events or climate change. Flood risk data can inform land use planning, ensuring development avoids high-risk areas.

Flow Accumulation:

The flow accumulation of the study area is resented on Figure 7.

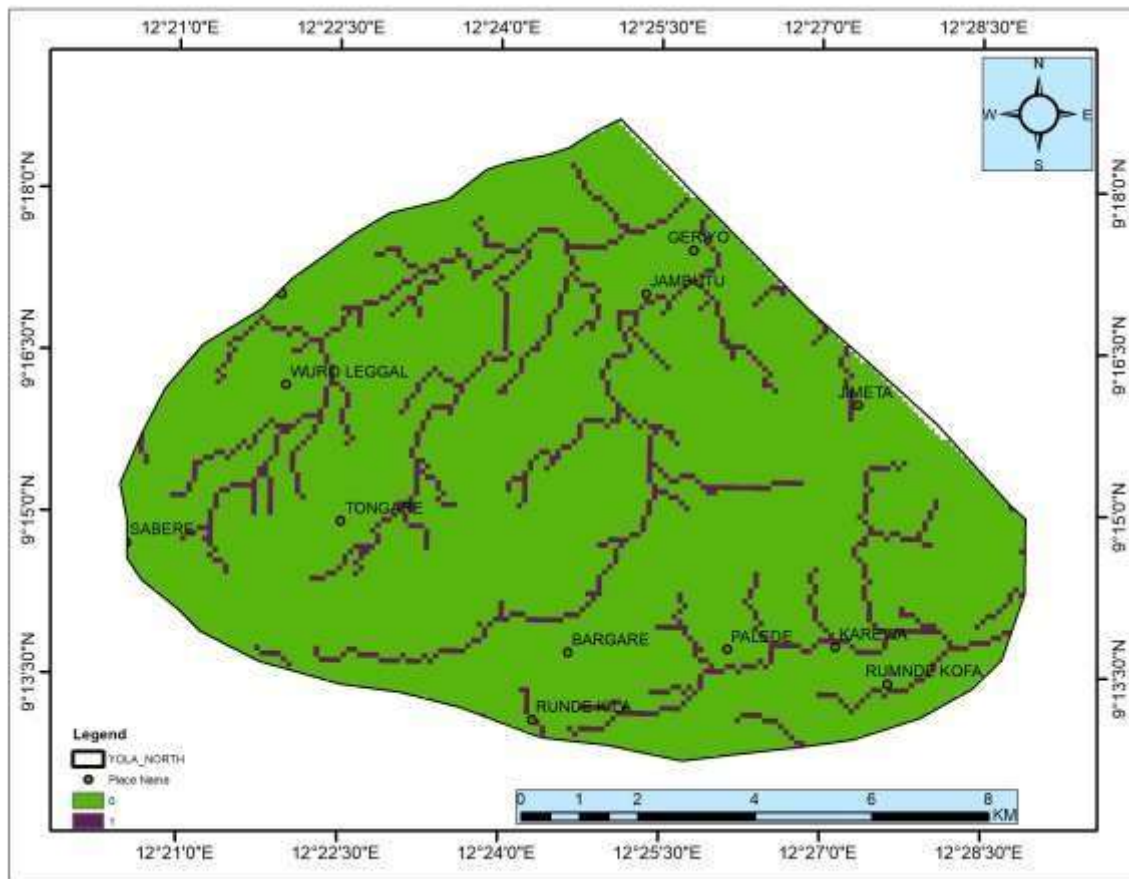


Figure 7: Flow Accumulation Map of Youla North

Source: Author's Analysis, 2025

From Figure 7, the flow accumulation ranges from 0 to 1 in the study area. The flow accumulation values indicate the amount of water flowing through each cell, ranging from 0 to 1. Areas with high flow accumulation (1) likely represent concentrated flow paths, such as streams or rivers, while areas with low values (0) indicate minimal or no flow. Additionally, areas with high flow accumulation are more prone to flooding, as they concentrate water flow from surrounding areas. Flow accumulation patterns can identify natural drainage paths, which may be vulnerable to flooding or erosion. Flow accumulation data can inform flood risk assessments, helping prioritize areas for mitigation measures.

Flow Direction:

The flow direction of the study area is resented on Figure 8. Figure 8 shows that, the direction of flow values in the study area ranges from 128 to 1. The hower values of about 1 were found in areas like Sabre, Togare, Bargage, Karewa, and Jalingo, while the higher values of 128 are found in areas like Jambutu, Gugumayo, Jerngel Mayo, Rumindekofa, and Dolabe Barre.

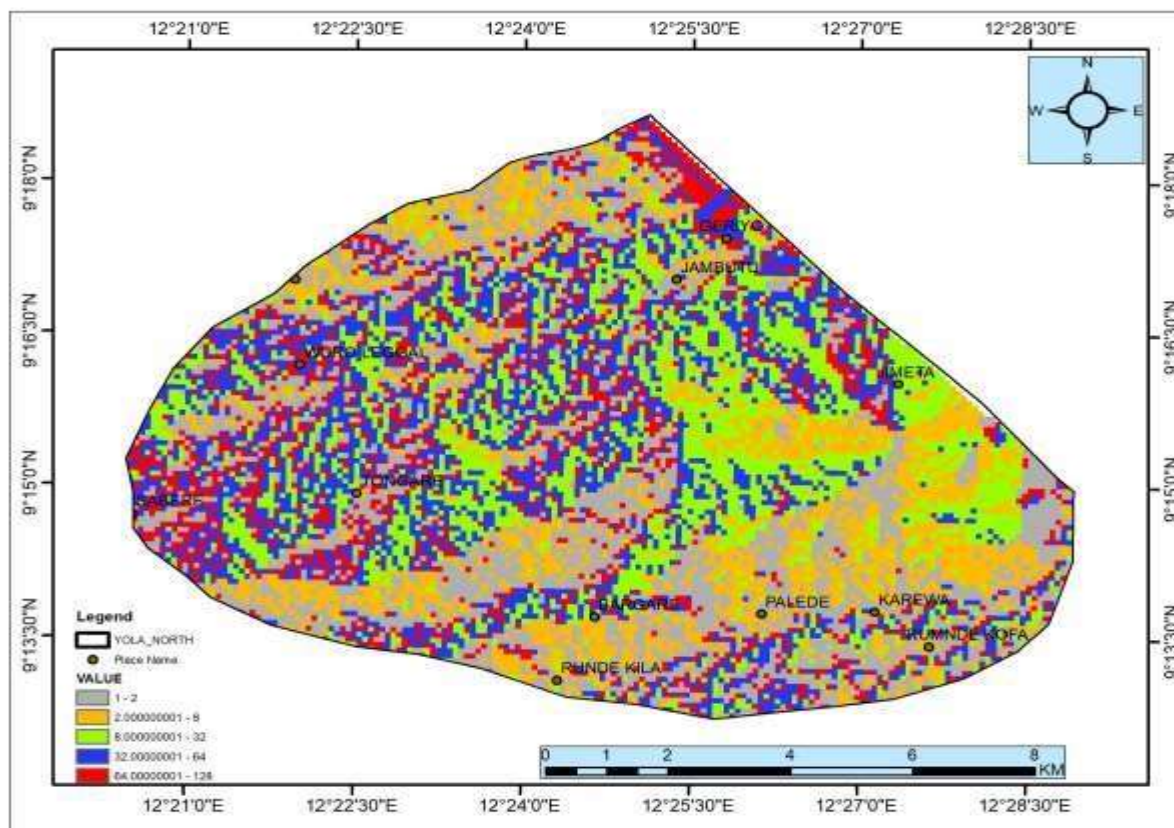


Figure 8: Flow Direction Map of Youla North

Source: Author's Analysis, 2025

The Flow Direction values indicate the direction of water flow in the study area, ranging from 1 to 128. Lower values (1) in areas like Sabre, Togare, Bargage, Karewa, and Jalingo suggest flat or high-elevation areas where water flow is minimal or divergent. Higher values (128) in areas like Jambutu, Gugumayo, Jerngel Mayo, Rumindekofa, and Dolabe Barre indicate concentrated water flow, likely in low-lying areas or channels. More so, areas with high Flow Direction values (Jambutu, Gugumayo, Jerngel Mayo, Rumindekofa, and Dolabe Barre) are likely to accumulate water, increasing flood risk. These areas may serve as natural drainage channels, but may also overflow during heavy rainfall or excessive water flow. Flow Direction patterns can help predict flood propagation paths and identify areas that may be affected by upstream flooding.

Rainfall:

The rainfall of the study area is resented on Figure 9. The rainfall values on Figure 9 indicate the study area's precipitation patterns, ranging from 0mm (low) to 348.1mm (high) in August. The area of Low Rainfall (0mm) areas with low rainfall values indicates minimal precipitation, potentially reducing flood risk

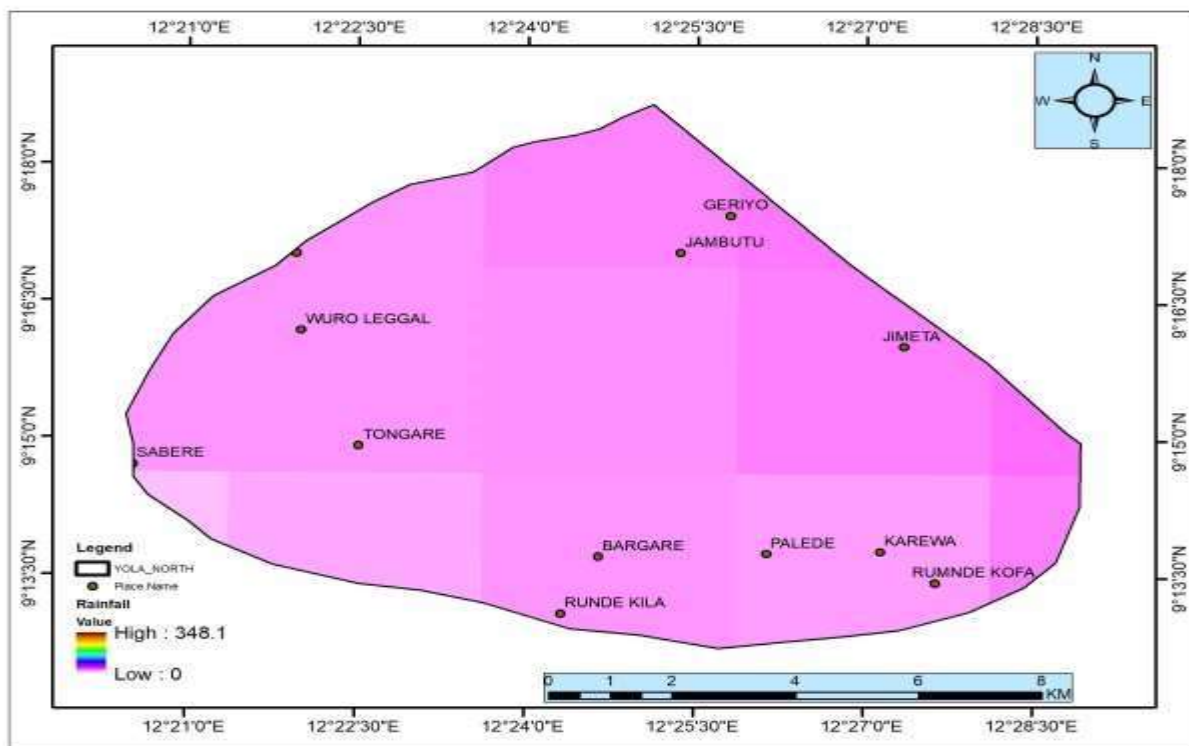


Figure 9: Rainfall Map of Youla North

Source: Author's Analysis, 2025

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High Rainfall (348.1mm) areas with high rainfall values indicate intense precipitation, increasing flood risk and potential damage. High rainfall areas may be more prone to flooding, requiring prioritized flood mitigation measures. Intense rainfall may lead to increased runoff and erosion, exacerbating flood impacts. High rainfall areas may experience soil saturation, increasing flood risk and potential landslides. Research has shown that rainfall rangedetermine flood risk level as 0mm - 100mm indicates low flood risk level, 100mm - 200mm moderate and area with rainfall ranges from 200mm - 348.1mm connotes high flood risk level. As supported by MacLeod *et al.* (2021) that excessive levels of precipitation is one of the main natural cause of flooding, caused by climate change.

River Basin:

The river basin of the study area is resented on Figure 10. From Figure 10, the river basin values in the study area range from 134 to 1. The higher values of about 134 were found in areas like Palade, Jambutu, Gugumayo, Jalingo, Rumindekofa and Jeringel while the lower values of 1 are found in areas like Bargage, Karewa, Wauroolegal and Dolabe Barre. The river basin values revealed the contributing area or watershed size, ranging from 1 to 134. Higher values (134) in areas like Palade, Bargage, Karewa, Jalingo, Rumindekofa, and Jeringel suggest larger catchment areas, likely indicating main river channels or significant tributaries.

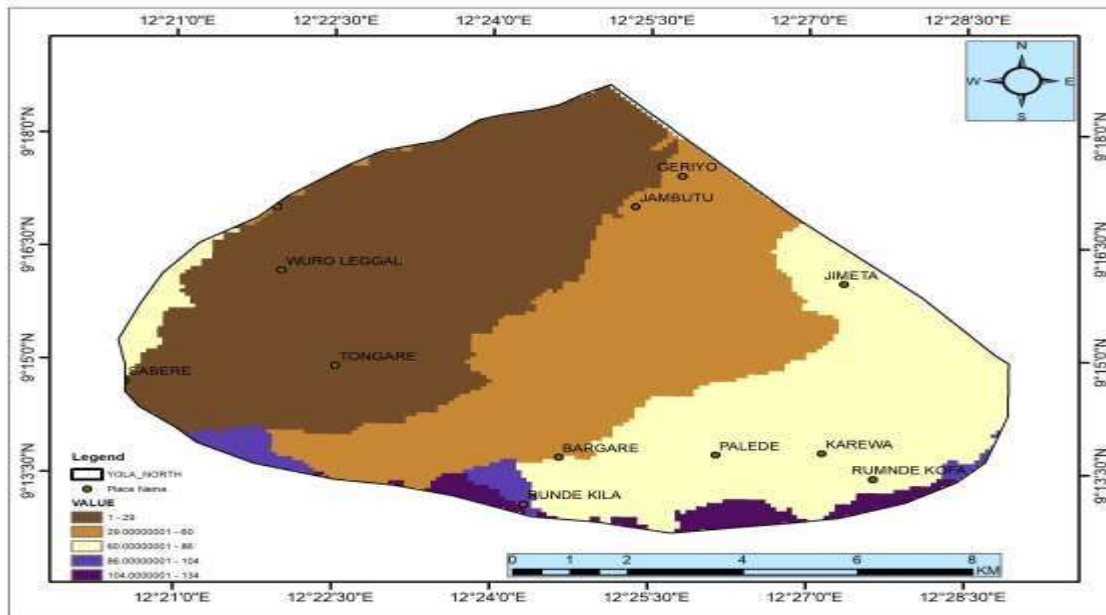


Figure 10: River Basin Map of Youla North

Source: Author's Analysis, 2025

Lower values (1) in areas like Jambutu, Gugumayo, Wauroolegal, and Dolabe Barre indicate smaller or no contributing areas, possibly representing upland or headwater areas. The areas with

high river basin values are more likely to experience significant water flow and flooding, especially during heavy rainfall or upstream runoff. Jambutu, Gugumayo, Palade, Jalingo, Rumindekofa, and Jeringel may be main river channels or significant tributaries, requiring flood management attention. Bargage, Karewa, Wauroolegal, and Dolabe Barre may be less prone to flooding from large river basins but may still experience localized flooding or runoff.

Slope:

The slope of the study area is presented on Figure 11. The Figure 11 shows the slope values in the study area range from 0.76 low, 3.8 medium and 13 high across the study area. The value ranges from 0 to 1.6 constitute about 82% of the study area. The slope values indicate the study area's terrain steepness, with values ranging from 0.76° (low) to 13° (high). Most of the area (82%) has gentle slopes (0-1.6°).

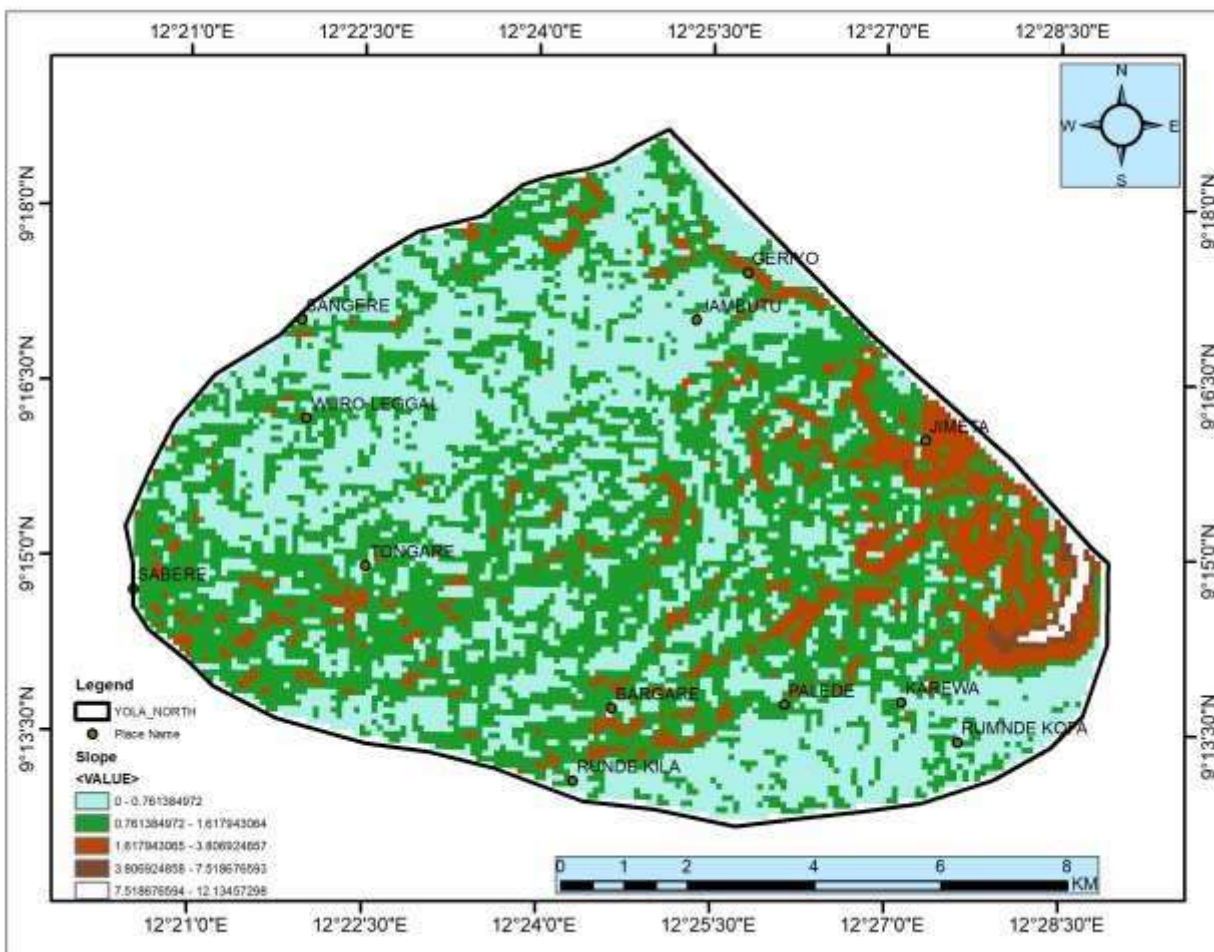


Figure11: Slope Map of Youla North

Source: Author's Analysis, 2025

Gentle slopes ($0-1.6^\circ$) may increase flood risk due to slow drainage and potential ponding. Steeper slopes (13°) may experience rapid runoff, increasing flood risk downstream. Flat areas may be more susceptible to inundation, especially during heavy rainfall or river overflow.

Soil:

The soil of the study area is resented on Figure 12. From Figure 12, soil values indicate the study area's soil characteristics, with the following ranges: Low: 2 - 9,262. Medium: 19,091.0 - 29,849 and High: 38,120.0 - 49,830. These values represent soil types or properties, here's the analysis: Low Soil Values (2-9,262) areas may have sandy or loamy soils, which can be prone to erosion and have moderate to high permeability. Medium Soil Values (19,091.0-29,849) areas may be characterized as those with have clay-loam or silty soils, which can have moderate permeability and be susceptible to waterlogging. High Soil Values (38,120.0-49,807) areas have clay-rich or impermeable soils, which can have low permeability and increase flood risk. More so, areas with medium to high soil values (19,091.0-49,807) may be more prone to flooding, requiring prioritized flood mitigation measures while those with high soil values may experience rapid soil saturation, increasing flood risk and potential landslides

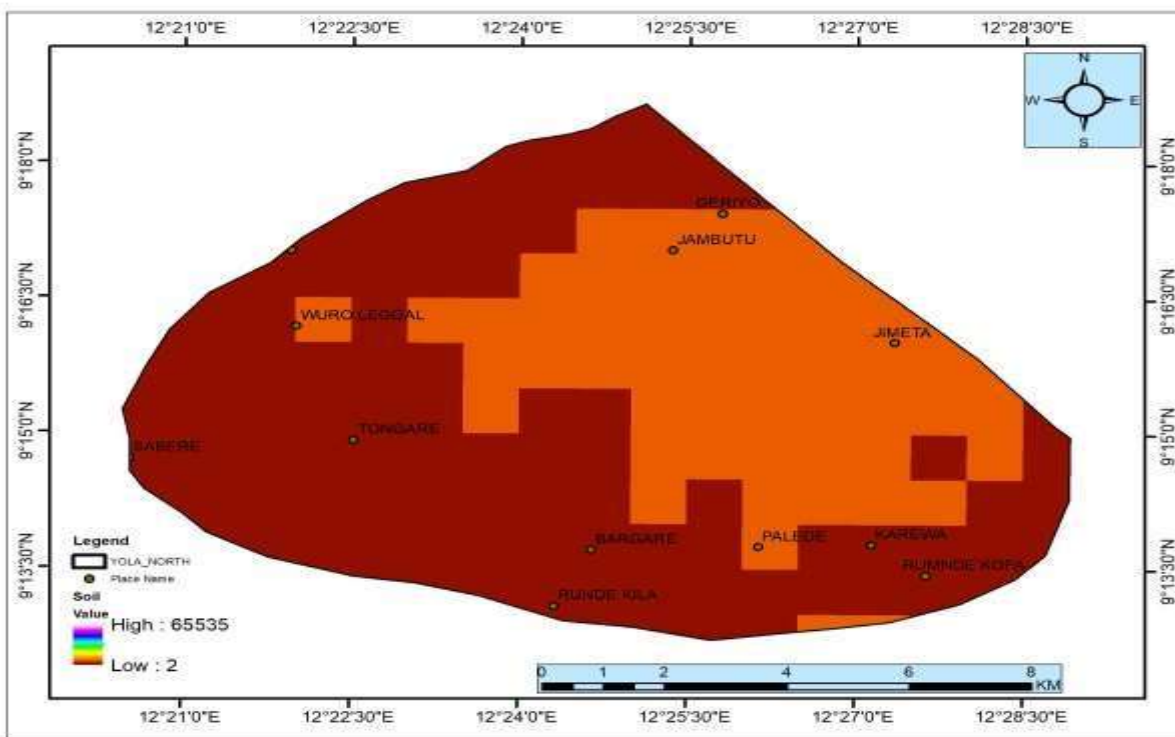


Figure 12: Soil Map of Youla North

Source: Author's Analysis, 2025

Areas with low soil values may be susceptible to erosion, exacerbating flood impacts. Soil value range 2 - 9,262 indicates moderate, 19,091.0 - 29,849 high, and those between 38,120.0 - 49,807 indicates very high flood risk levels.

Stream Power Index (SPI):

The Stream Power Index (SPI) of the study area is presented on Figure 13. Stream Power Index (SPI) analysis from Figure 13 shows that the SPI values in the study area range from 0 low and 120.48 high across the study area. The SPI values indicate the study area's potential for erosion and sediment transport, ranging from 0 (low) to 120.48 (high). Low SPI (0) areas are likely to have minimal erosion and sediment transport potential. These areas may be less prone to flood-related erosion. High SPI (120.48) areas indicate high erosion and sediment transport potential. These areas are more likely to experience flood-related erosion, sedimentation, and channel instability. Furthermore, high SPI areas may experience significant erosion, sedimentation, and channel instability, exacerbating flood impacts. Areas with high SPI values are more susceptible to flood-related damage, requiring prioritized flood mitigation measures. High SPI areas may experience channel instability, increasing flood risk and potential damage to infrastructure.

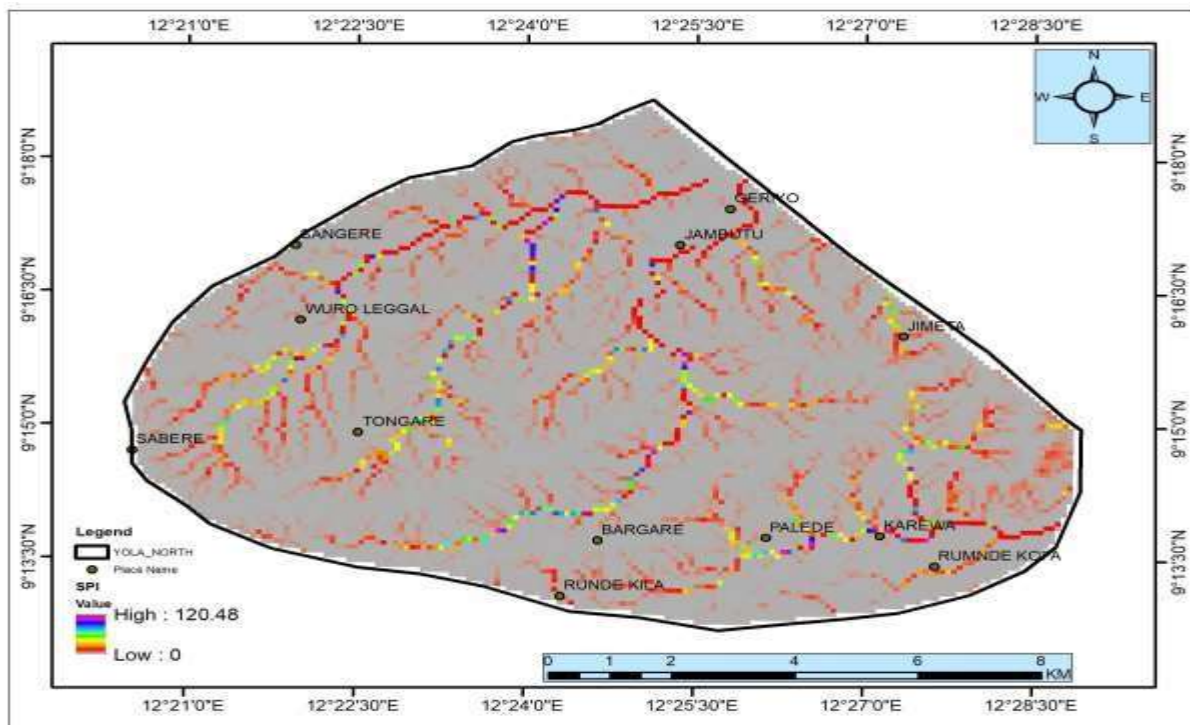


Figure 13: Stream Power Index (SPI) Map of Youla North

Source: Author's Analysis, 2025

Sediment Transport Index (STI):

The Sediment Transport Index (STI) of the study area is resented on Figure 14. Sediment Transport Index (STI) result presented on Figure 13 revealed that the STI values in the study area range from 0 to 0.8 low, 3.5 to 8.2 medium and 17 to 29 high across the study area. The STI values indicate the study area's potential for sediment transport and deposition, ranging from 0 to 29. However, low STI (0-0.8) areas are likely to have minimal sediment transport and deposition. These areas may be less prone to flood-related sedimentation. Medium STI (3.5-8.2) areas indicate moderate sediment transport and deposition potential. These areas may experience some flood-related sedimentation. High STI (17-29) areas indicate high sediment transport and deposition potential. These areas are more likely to experience significant flood-related sedimentation, erosion, and channel instability. The high STI areas may experience significant sedimentation, increasing flood risk and potential damage to infrastructure. Areas with high STI values may experience erosion, exacerbate flood impacts and increase sediment load. High STI areas may experience channel instability, increasing flood risk and potential damage to infrastructure.

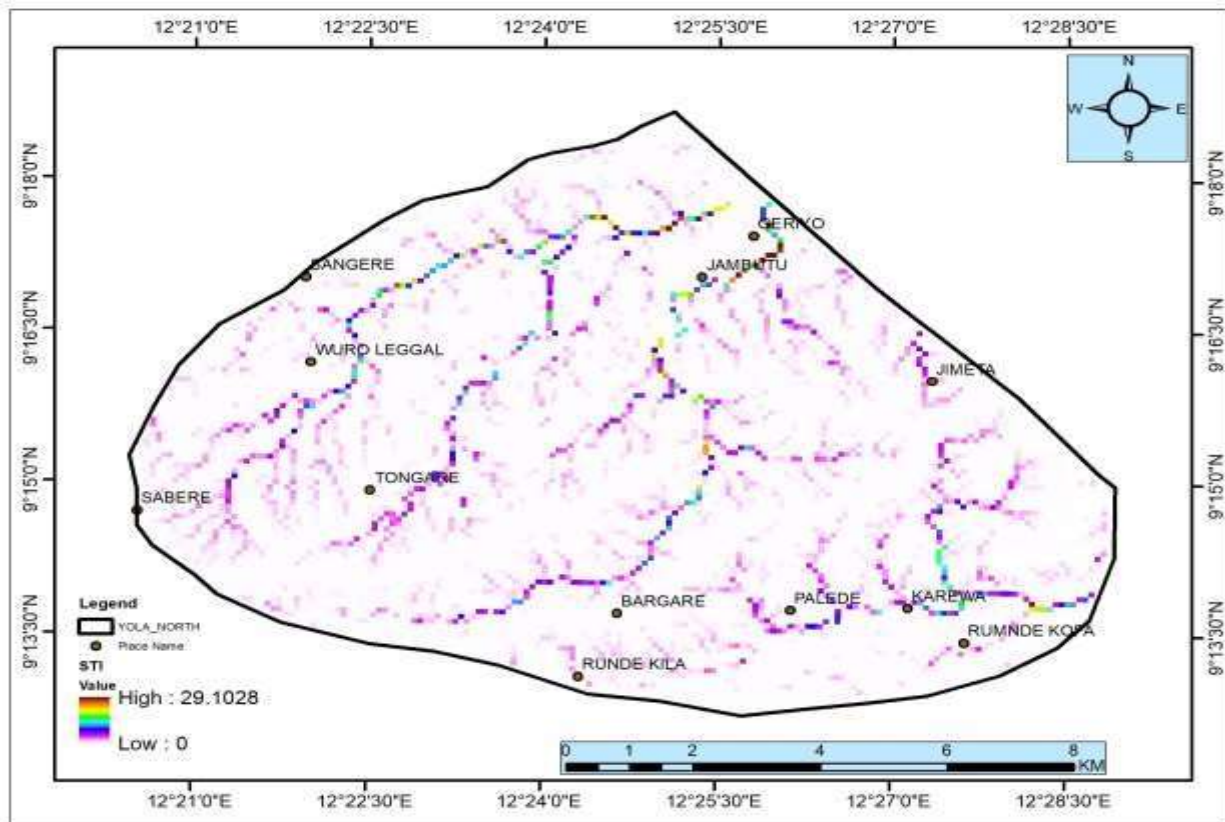


Figure 14: Sediment Transport Index (STI) Map of Youla North

Source: Author's Analysis, 2025

Terrain Ruggedness Index (TRI):

The Terrain Ruggedness Index (TRI) of the study area is resented on Figure 15. The TRI values in the study area range from 0.11 low, 0.48 medium and 0.89 high across the study area as indicated in Figure 15. The Terrain Ruggedness Index (TRI) values indicate the study area's topographic complexity, with values ranging from 0.11 (low) to 0.89 (high). Those areas with high TRI values (0.89) may experience rapid runoff, increasing flood risk downstream. Low TRI areas (0.11) may be prone to water ponding, increasing flood risk locally. Medium to high TRI areas (0.48-0.89) may be susceptible to erosion, exacerbating flood impacts.

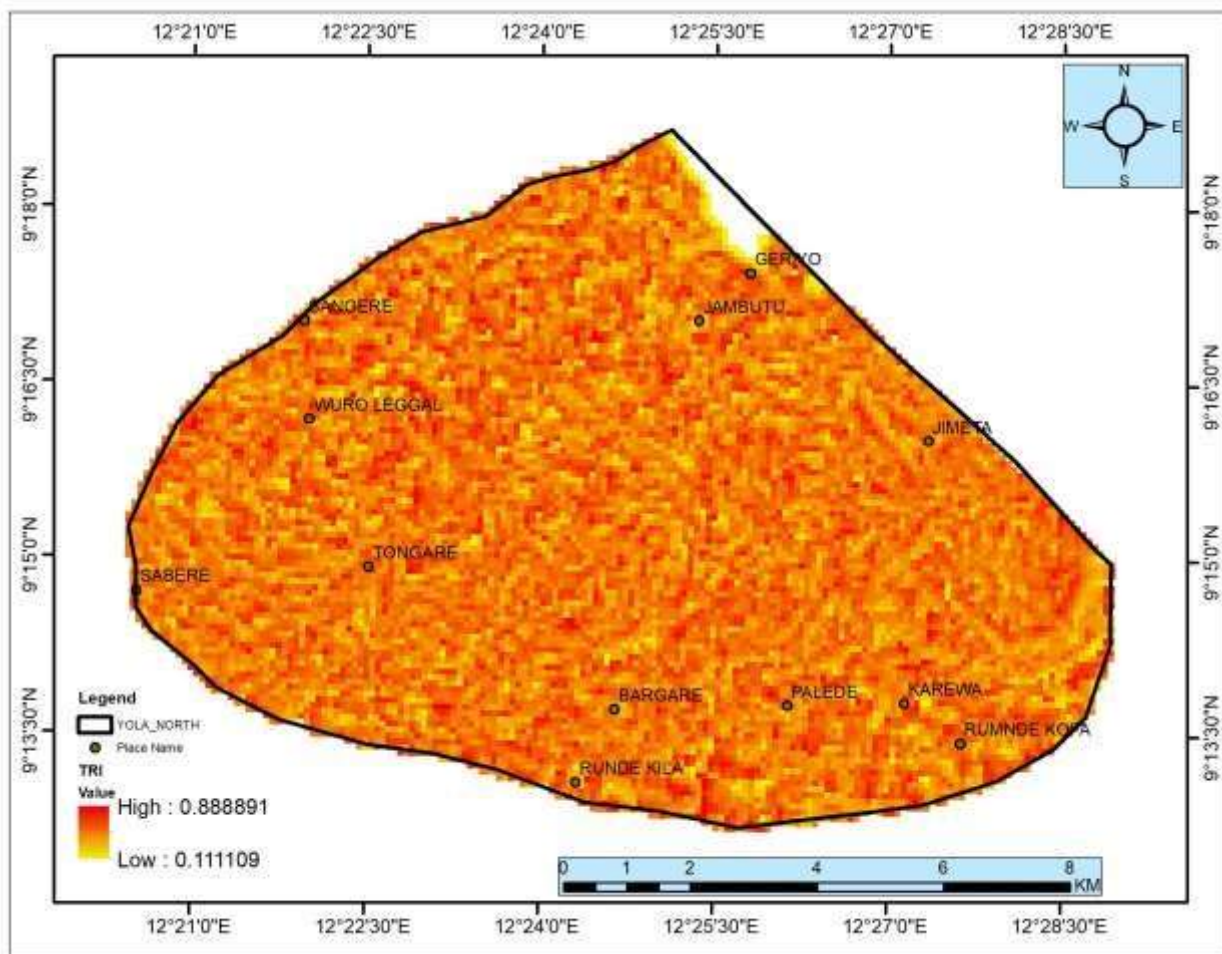


Figure 15: Terrain Ruggedness Index (TRI) Map of Youla North

Source: Author's Analysis, 2025

Topographic Wetness Index (TWI):

The Topographic Wetness Index (TWI) of the study area is resented on Figure 16.

The Topographic Wetness Index (TWI) values on Figure 16 indicate the study area's propensity for water accumulation and flow, ranging from 6.11967 (low) to 19.9592 (high). Low TWI (6.11967) areas are likely to be well-drained, with minimal water accumulation. These areas may be less prone to flooding. High TWI (19.9592) areas indicate potential water accumulation and flow paths. These areas are more likely to experience flooding, especially during heavy rainfall or river overflow. Also, high TWI values (19.9592) indicate the direction of flood flow, helping identify areas that may be affected by flooding. Areas with high TWI values are more susceptible to flooding, requiring prioritized flood mitigation measures. The high TWI areas may experience water accumulation, increasing flood risk and potential damage.

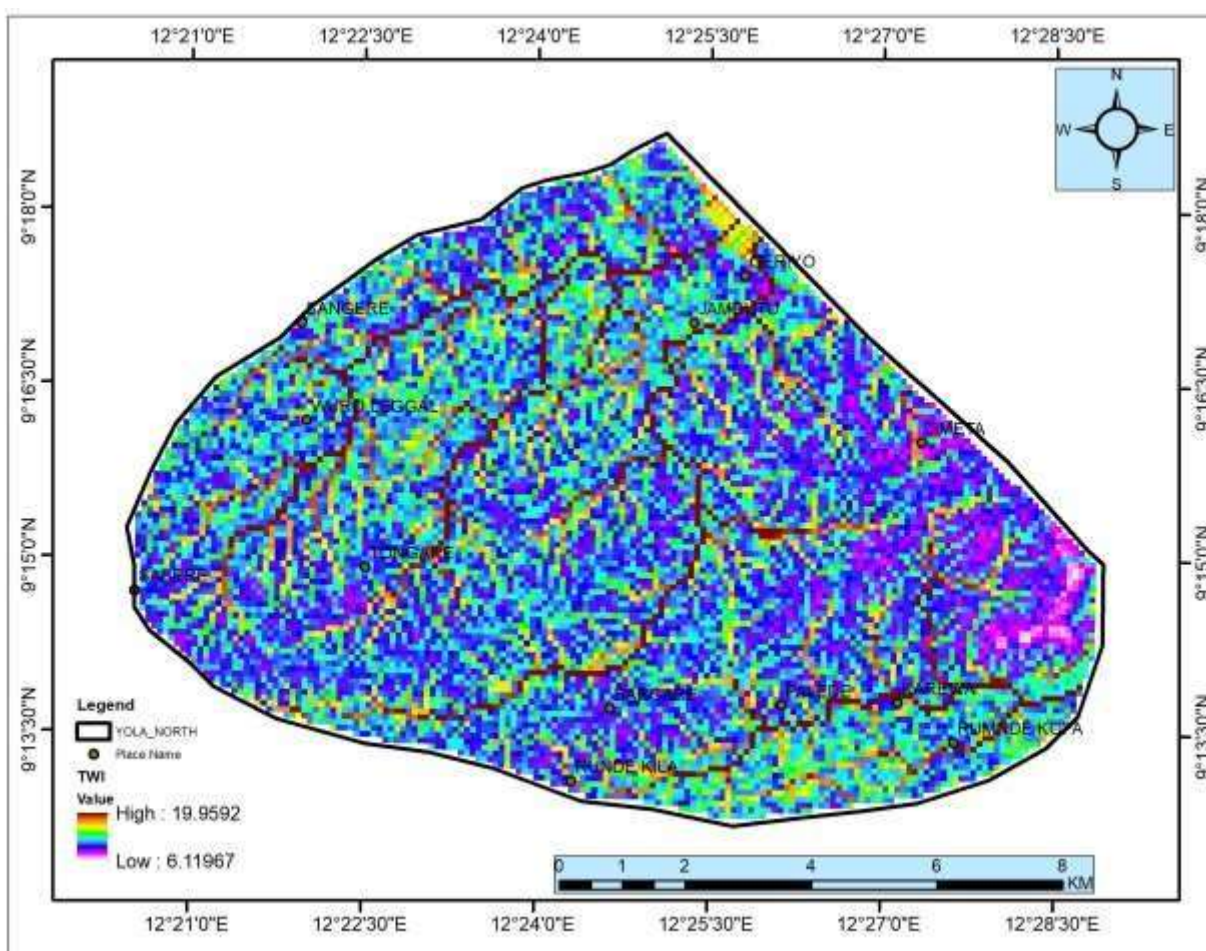


Figure 16: Topographic Wetness Index (TWI) Map of Youla North

Source: Author's Analysis, 2025

Normalized Difference Water Index (NDWI):

The Normalized Difference Water Index (NDWI) of the study area is resented on Figure 17. Normalized Difference Water Index (NDWI) analysis as presented on Figure 17 revealed that the NDWI values in the study area range from 0 to -0.362027 low and 0.0524681 high across the study area. The NDWI values indicate the study area's water presence and moisture levels, ranging from -0.362027 (low) to 0.0524681 (high). Also, low NDWI (-0.362027) areas with low NDWI values indicate minimal water presence and dry conditions. These areas may be less prone to flooding. High NDWI (0.0524681) areas with high NDWI values indicate higher water presence and moisture levels. These areas may be more susceptible to flooding, especially during heavy rainfall or river overflow. The implication of this result is that areas with high NDWI may be more prone to flooding, requiring prioritized flood mitigation measures. Areas with high NDWI values may experience water accumulation, increasing flood risk and potential damage.

High NDWI areas may have saturated soils, increasing runoff and flood risk. Low NDWI (-0.362027) areas indicate minimal water presence and dry conditions. These areas may be less prone to flooding and high NDWI (0.0524681) areas connotes higher water presence and moisture levels.

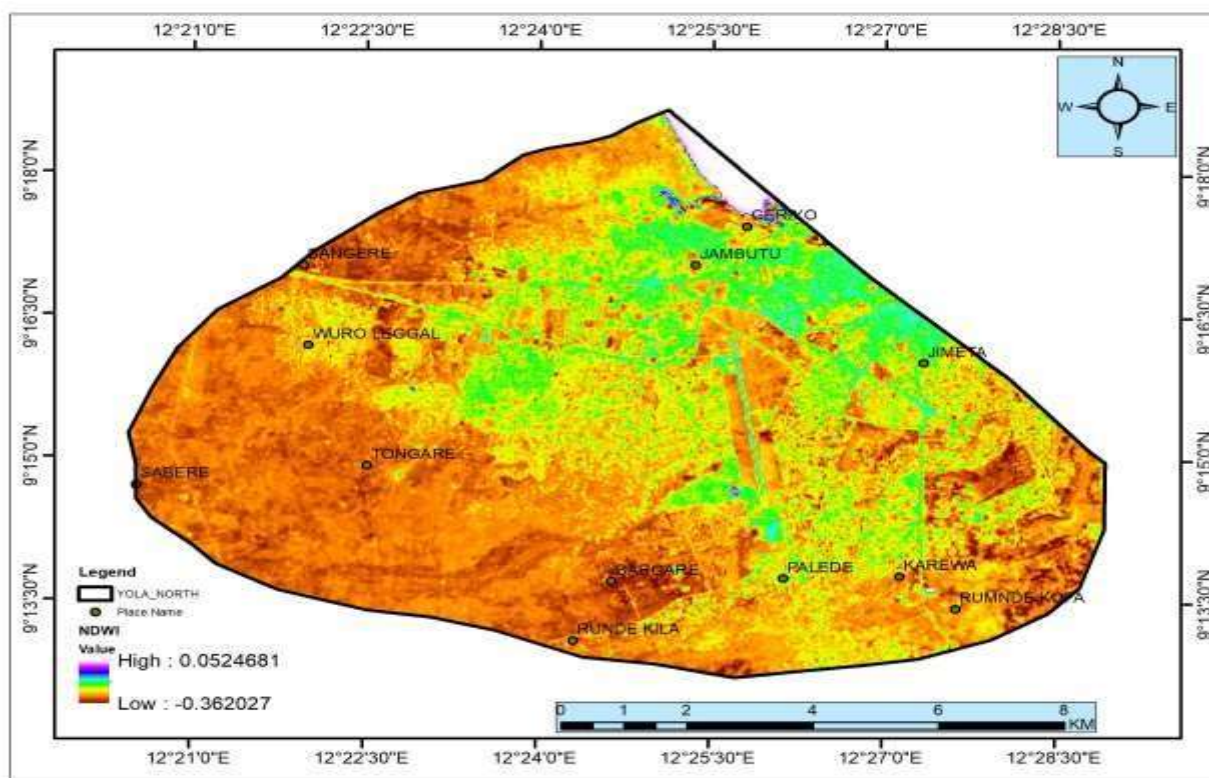


Figure 17: Normalized Difference Water Index (NDWI) Map of Youla North

Source: Author's Analysis, 2025

These areas may be more susceptible to flooding, especially during heavy rainfall or river overflow. More so, high NDWI areas may be more prone to flooding, requiring prioritized flood mitigation measures. Areas with high NDWI values may experience water accumulation, increasing flood risk and potential damage. High NDWI areas may have saturated soils, increasing runoff and flood risk. Areas with NDWI range -0.362027 - 0 low flood risk level, 0 - 0.0524681 moderate to high.

FLOOD HAZARD RATING

The flood hazard rating of Youla North is presented on Figure18 and Table 5. The results indicate the flood hazard rating distribution in the study area. From the Figure and Table 5, the largest areas of low degree of hazard constituted about 58%, follow by extreme with 18% coverage, significant 17% and moderate 6% which constituted the least area coverage of the study. Low Hazard (58%) show that majority of the study area is at relatively low risk of flooding.

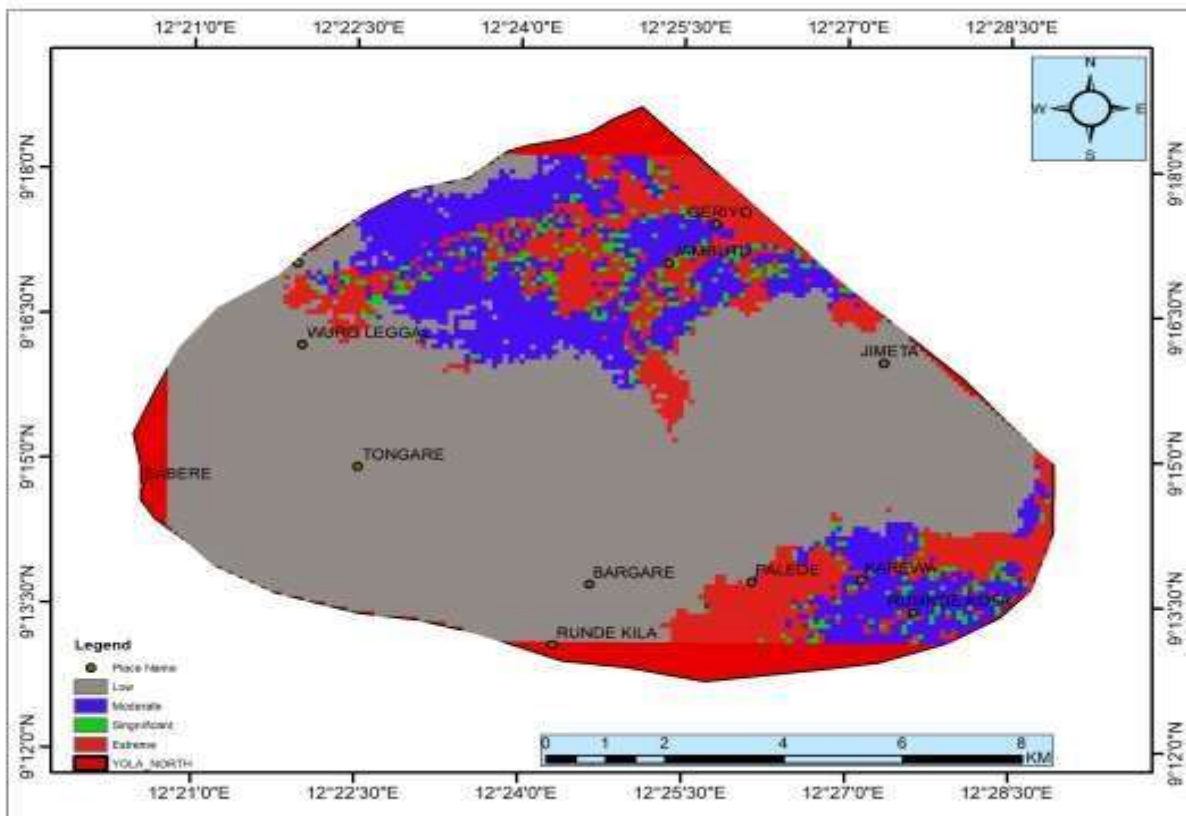


Figure 18: Flood Hazard Rating Map of Youla North

Source: Author's Analysis, 2025

Table 5: Flood Hazard Rating

S/No	Degree of Hazard	Percentage
1	Low	58.2%
2	Moderate	6.4%
3	Significance	17.3%
4	Extreme	18.1%
Total		100%

Source: Author's Analysis, 2025

These areas due to higher elevations, better drainage systems and lower probability of flood events. The extreme hazard (18%) shows that a significant portion of the area is at high risk of flooding, indicating high probability of flood events, potential for severe damage to infrastructure and livelihoods and the need for prioritized mitigation measures as supported by NIHSA, (2022). This area is usually called the flood plain of the river e.g. when rainfall exceeds absorption capacity of the soil, which in turn causes significant environmental consequences (Nwachukwu *et al.*, 2018). More so, significant hazard (17%) of the study areas with notable flood risk, requiring. Attention and planning, flood risk reduction measures and a consideration in land use planning (IPCC, 2012; Filatova, 2014; Jongman *et al.*, 2014a). Moderate Hazard (6%), the least area coverage, but still requiring consideration in flood management plans, monitoring and preparedness measures

CONCLUSSION AND RECOMMENDATIONS

The findings of this indicated that the study area is prone to flooding due to various factors, including land use patterns, topography, soil characteristics, and rainfall. The results show that built-up areas, farmland, and bare land are more susceptible to flooding due to increased runoff and erosion. Areas with low elevation, proximity to water bodies, and poor drainage are more prone to flooding. Soil characteristics, such as clay-rich or impermeable soils, can increase flood risk. Rainfall patterns, including intensity and duration, play a significant role in flood risk. Also, flow accumulation, flow direction, and stream power index are important factors in determining flood risk. More so, The study's results also show that 58% of the study area has a low degree of hazard, while 18% has an extreme hazard, and 17% has a significant hazard. The remaining 6% has a moderate hazard.

Based on the major findings, the researchers recommend the need to consider slope in urban planning and infrastructure development to minimize flood impacts implement flood protection infrastructure in high TWI areas, consider TWI in land use planning and urban development to minimize flood impacts, the NDWI values indicate the study area's water presence and moisture

Publication of the European Centre for Research Training and Development UK levels, ranging from -0.362027 (low) to 0.0524681 (high), implement flood mitigation measures, such as flood control structures, drainage systems, and flood-resistant construction, in areas with high flood risk, encourage land use planning that takes into account flood risk, such as avoiding development in high-risk areas, establish flood early warning systems to alert communities of potential flooding, educate communities on flood risk and provide training on flood preparedness and response and conduct further research on flood risk assessment and mitigation measures, including the impact of climate change on flood risk.

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