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EVALUATING MORPHOLOGICAL AND HYDROLOGICAL FACTORS INFLUENCING FLOODING DYNAMICS IN IBAJI LGA, KOGI STATE, NIGERIA

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Abstract

This study, Evaluating Morphological and Hydrological Factors Influencing Flooding Dynamics in Ibaji LGA, Kogi State, Nigeria, investigates how physical characteristics such as elevation, slope, and terrain wetness influence flooding in the region. The primary objective is to identify and analyze factors that contribute to flood vulnerability and propose data-driven strategies for mitigation. The study used both primary data, including field surveys and questionnaires, and secondary data, such as satellite imagery (ASTER DEM and Landsat), to evaluate morphologic and hydrologic properties. Advanced GIS tools like ArcGIS and ILWIS were employed to analyze these factors. The findings reveal that low-lying areas, with elevations ranging from (9m to 54m), and flat slopes, between 0° and 1.57°, are the most flood-prone. High terrain wetness index (TWI) values further indicate areas with a high likelihood of water accumulation, exacerbating flood risks. The study also highlights that significant land-use changes, including deforestation and agricultural expansion, have intensified these vulnerabilities by reducing natural drainage and increasing surface runoff. The study concludes that understanding the interplay of morphologic and hydrologic factors is critical for effective flood management. It recommends reforestation, sustainable land-use practices, and the integration of GIS-based flood mapping for planning and disaster response. These findings provide a framework for mitigating flood impacts and promoting sustainable development in Ibaji Local Government Area.

Keywords: Morphologic, Hydrologic, Floods, Elevation, Slope, Terrain, Vulnerability

1. Introduction

Floods can be quite beneficial. Actually, nature benefits are more from natural floods than from not having them at all. What makes natural floods a disaster is when flood waters occur in area populated by humans and in areas of significant human development. Otherwise when left in its natural state, the benefits of floods outweigh the adverse effects (Bradshaw *et.al*, 2007). The major approach to flood mitigation has been the structural approach. Non-structural mitigation strategies such as land use planning, forecast and the application of Geographic Information System (GIS) and Remote Sensing are however crucial and are gaining attention (Faisal *et.al*.,2000). In Nigeria and elsewhere, GIS and remote sensing techniques have been applied in the assessment of flood vulnerability and risks. Advancement in RS and GIS with computer applications are very useful in flood management particularly in the mapping of flood risk areas (Opolot, 2013). In recent time, Vulnerability assessment has been done using GIS and remote sensing in addition to socio economic surveys (Cutter *et.al*.2001).

Vulnerability has environmental and socioeconomic dimensions implies (Fusel, 2007 and Alcantara, 2002) liability to suffer loss and increases with decreasing ability to cope with, resist, and recover from or adapt to imposed stress factors such as flood disasters (Samarasinghe*et.al*.2010, Cutter 2013). Flooding is one of the most serious environmental problems in Ibaji Local Government, It is also one of the most devastating environmental hazards in the Area, claiming more lives and causing damages to properties and infrastructure more than any other natural phenomena. (Onwuka*et.al*, 2015). Other problems resulting from flooding in the area include forced migration of people, destruction of household properties, destruction of farm produce which threatens food security, causing hunger to the victims, over-crowding, spread of communicable disease and water born disease, crime rate and conflict increases as people resort to different social vices to survive.

In the contemporary times, Geographical Information System (GIS) is emerging as apowerful tool for the assessment of risk and management of Natural Hazards. With the adoption of GIS techniques, natural hazard maps can be prepared to delineate risk prone areas. Such kinds of maps will help the civil authorities in the quick assessment of potential impact of a natural hazard and initiation of appropriate measures for reducing the impact (Islam and Sadu, 2002).

The huge losses sustained from floods throughout the World have stimulated actions to deal with flood problem as a priority issue, thereby reducing the impact of flooding and flood liability on individual owners and occupiers of flood prone properties and to reduce private and public losses resulting from flood. Flood damage has been extremely severe in recent decades and it is evident as both the frequency and intensity of floods are increasing (Nyomo and Aggarwal, 2008). In the past ten years, losses amounting to more than 250 billion dollars have had to be borne by societies all over the world to compensate for the consequences of floods. Trend analyses reveal that major flood disasters and the losses generated by them have increased drastically in recent years (Nyomo and Aggarwal, 2008).

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Keinth(1996),observed that floods occur due to human and physical causes, in which human cause’s results from deforestation and poor water management while the physical causes are caused by excessive rainfall, snow melt, landslide, Dam failure, storm surges and tsunami. In most cases, ‘flooding’ is caused by a river over-spilling its banks. This can be due to excessive precipitation, combined with inadequate channel capacity. Over-spilling can also occur due to obstruction in or aggradations of the river bed. Flooding can also result from inadequate waterway a trial and road crossings, or when there are encroachments in the flood plain. Flooding can also occur at confluences of streams when the main river is in high stage and backs up into the tributaries and areas there about (Khanna, Agrawal and Pravin, 2008). Flood can also occur due to Dam discharges as a result of high volume of water.

Accurate and current floodplain maps can be the most valuable tools for avoiding severe social and economic losses from floods, accurately updated flood plain maps also improve public safety.

Early identification of flood-prone properties during emergencies allows public safety organizations to establish warning and evacuation priorities. Armed with definitive information, government agencies can initiate corrective and remedial efforts before disaster strikes (Chapman and Canaan, 2001). It is therefore necessary to use scientific methodology such as flood risk modeling to provide a basis for concerted action-plans to be carried out in flood plainplanning, flood structures or hazard mitigation, warning systems and rescue operations by either government or nongovernmental agencies as applicable

Floods are part of the hydrological cycle and a natural hydrological feature of most river systems (Campion and Venzke, 2013). In recent years, however, flood events have drastically increased both in terms of frequency and severity due to a variety of reasons such as climate change (Liu, et al., 2018) and urbanization (Hollis, 1975; Zhang et al. 2008), hence, flood events are regarded mostly in negative terms. Floods have not just become the most frequent natural hazard worldwide (Jongman, et al., 2012), it appears to be one of the deadliest natural disasters and often kills the most people, for instance, in 2016, flood killed the most people (4731), (Guha-Sapir, et al., 2016). According to Loster (1999), a ten-year comparative study of the world's great flood disasters from 1950 to 1998 showed a three-fold increase in the number of flood events, while the economic losses from flood events from the 1990's were ten times as high as in the 1950's, amounting to $250 billion globally. Further, UNISDR (2015) notes that since 1995, floods have accounted for 47% of all weather-related disaster and that flood affects Asia and Africa more than other continents, for example, 560,000 people were affected by floods on average each year between 1995 and 2004. Di Baldassarre et al. (2010) notes that in the last decades, there has been an increased incidence of severe flooding due to a variety of reasons, however, the capacity of most of the affected parties to anticipate and mitigate flood damages is very poor. While flood affects every part of the society, the most vulnerable groups are usually the indigent (Chan and Parker, 1996) and marginalized who enjoy little protective mechanisms against disasters, especially in the developing nations where the main source of income is agriculture. People can experience the same type of hazards and yet have different degrees of vulnerability as a result of variations in exposure, sensitivity and adaptive capacity.

The river basin has become increasingly accepted as the most appropriate hydro-geomorphic and climatic unit of analyses by many researchers such as Desale (2015), ICRAF (2006), ADB (2016) and Hardy (2005). The rationale stems from the concept of a river as an organic system, where interference with or modification of any part of it will be felt elsewhere in the system (Gordon, et al., 2004). Gregory and Walling (1973) define a drainage basin as an area that contributes water to a particular channel or sets of channels. Peckham (2003) goes further to describe a river basin as a physical, ecological, biological and climatic entity, where a hydrological balance can be struck when one considers inflow and outflow of moisture and energy. In other words, it provides an essential geomorphic unit for analysing hydrological input and output.

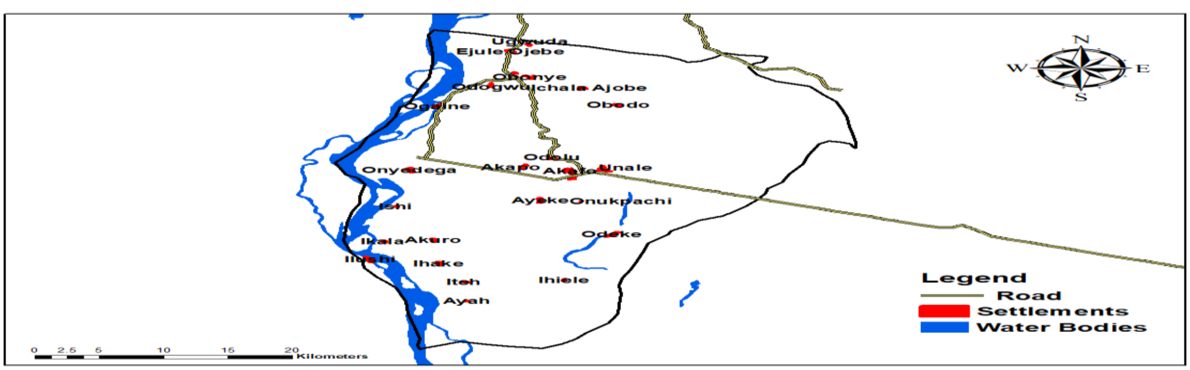
Meteorological conditions and land use pattern are necessary, but not sufficient conditions for flood occurrence in an area. Flood intensity and frequency does not only depend on land cover system and precipitation (Şen, 2018), but also physical characteristics such as topography, geology, soil, geomorphology and morphometric characteristics such as stream order, drainage density, stream frequency, and elongation ratio of a watershed, which influences the hydrological response of a watershed and have a significant influence on the incidence and magnitude of floods (Chow, 1964; Strahler, 1964). Topography plays a key role in flood behavior through a fundamental interaction that involves the elevation of the landscape across multiple spatial and temporal scales (Tucker and Whipple, 2002). According to Şen (2018), "topographic conditions such as high-exposure (steeply sloping) high land terrains, narrow valleys, or ravines hasten the runoff and increase the likelihood of flash flood occurrence. Saturated soil or shallow watertight geological layers increase surface runoff. Urbanization processes and affiliated construction with watertight materials are thought to make runoff 2–6 times greater in comparison to terrains with natural such as coverage, fields, meadows, forests". Topography is considered by several authors such as Bajabaa, et al. (2014), Sande et al. (2012), Brasington and Richards (1998) and Bates and Roo (2000) to be one of the most important controlling factors concerning the hydrological response to flood. From the hydrological standpoint, floods occur when the land surface is inundated and the soil no longer has the capacity to absorb water. Therefore, the excess water flows over the land surface. The overflow is due to either of two reasons. The first is explained by Horton's overland flow (Knighton, 1998) where the infiltration capacity of the soil is exceeded while the 53 second is the result of saturated overland flow. In the second case, the water table rises as more water is received and then the excess water is discharged as overland flow. Evidently, surface hydrological behaviour is one of the main drivers behind floods; it is rapid or delayed hydrological response, which often makes a watershed vulnerable to flooding (Meraj, et al., 2014). Morphological characteristics such as stream order, drainage density, channel slope, relief, stream frequency etc., are important in understanding the hydrology of the watershed since the hydrologic behavior of a catchment depends on these characteristics (Gupta, et al., 1980). Morphological characteristics of a basin can help show the extent of inundated areas, the direction of flood flows, and changes in river channel which promotes understanding of the nature, characteristics and probability of flood occurring in the future. Diakakis (2010), mentions that the importance of morphological characteristics becomes even more significant when studying runoff reaction to intense rainfall, especially in the case of ungauged, flash flood prone basins. The application of geomorphic principles to understand and quantify environmental hazards such as flooding has led to a significant amount of research focused on identifying the relationships between basin morphometric and stream flooding (Patton, 1988). Building on earlier studies, this thesis addresses the fundamental scientific question of assessing the morphometric and topographical factors that makes the Ibaji more prone to flooding. In this research, an integrated analysis of the hydrological, morphological and morphometric properties of Ibaji is attempted in order to facilitate a better understanding of the flooding problem and its associated processes.

Lately, researchers have used a suite of satellite-based geospatial datasets with cost-effective detection methods to assess flood hazards in ungauged regions, but to date, the estimation of current and predicted flood effects is poor in Ibaji Local Government. In this regard, a comprehensive approach was used to analyze morphologic and hydrologic properties and evaluate their effects on the flooding processes in the study area. Furthermore, there is a generally low level of knowledge and understanding of how hydrological responses in the basin affect flood events, characteristics and behavior in the study area The aim of this study is to assess the effects of changing land use and land cover on the flood events in the study area.

2. Material and Methods

Study Area

The study area is Ibaji Local Government Area of Kogi State, Nigeria. It is located between Latitude 06° 52'00"N 06°87'00"N of the equator, and Longitude 06° 48'00"E06°80'00"E of the Greenwich meridian. It is located in eastern part of Kogi state (Figure 1) and covers approximately 1, 377km². It is bordered by Edo state to the west by the river Niger, and Delta state to the south. The Headquarter of Ibaji local government is Onyedega.



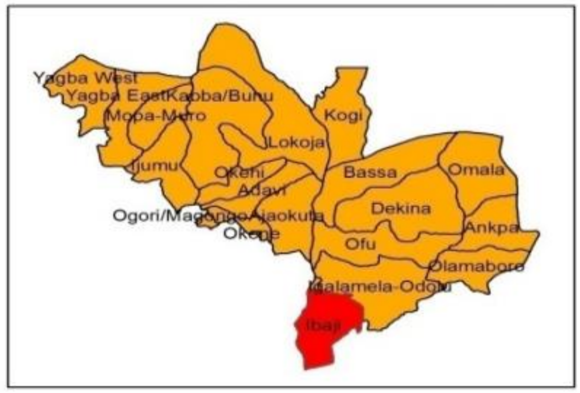


Figure 1: The Study Area

Reconnaissance Survey

A two weeks exploratory survey was conducted in the study area to get familiar with the terrain and the people and this informed the choice of data and methodology used in this research. The administrative maps, satellite image along with a native field assistant serves as a guide**.**

Source of Data

The data sources for this study were drawn from both primary and secondary sources.

a. **Primary Sources**

This involves direct measurements and investigations as well as questionnaire administration on the field. This research employs the use of field survey/questionnaire administration, personal observation and interview with respondents drawn from various sampled neighborhoods.

b. **Secondary Sources**

These are data generated from documents of various kinds and retrieved from the original sources. They include reports, Journals, statistical handbooks, text books. Published and unpublished thesis/dissertation. The Secondary data used in this research includes; Satellite Imagery, Topographic maps, Textbooks, Internet materials, Research journals and thesis (both published and unpublished).

Data Types

The data types used in this research as well as the hardware and software include the following:

(a) Satellite Imagery. The satellite imagery utilized in this research includes, Aster Digital Elevation Model (DEM), 2022 and LANDSAT Imagery of 2002, 2012 and 2022 respectively. The two-satellite imagery were obtained from the official website of Global Land Cover Facility (GLCF) and Gloves.

(b) Ground Positioning System (G.P.S): A Garmin 97 hand help GPS was used for the ground trothing and coding of various points of references (GPS Coordinates).

(c) Topographic Map: Topographic maps of the study area was used and aid the production of a new digitized map of the area. It was obtained from the National Centre for Remote Sensing (NCRS) Jos.

(d) Softwares Used: The softwares used in this study includes; Idrisi Selva, ILWIS 3.3 and ArcGIS 10.1 were used for all GIS analysis involving spatial and attribute data, map productions and calculations and general model development and implementation. Microsoft word and Excel were used in result presentation and general write up.

Evaluating the Flood Vulnerability Factors

Flood vulnerability factors are chosen to help fuse direct analysis of the both the flood behaviors and the surrounding characteristics of the study area. The flood vulnerability factors that were selected for analysis are Elevation (DEM), Slope, Terrain Wetness Index, Topographic Power Index (TPI) and Land use/Land cover.

a. **Elevation(DEM)**

The global digital elevation model(GDEM) was used to depict various height in the study araea using ArcGIS 10.1 .Elevation explains the height above the sea level.

The height above the mean sea level of a particular place helps determine the level of vulnerability of an area to flood occurrences. This factor was chosen because it relates that, Areas with low elevation are more vulnerable to flooding than high areas.

b. **Proximity to Rivers/drainage**

The derived land use and river maps were used to generate proximity maps using DISTANCE operation algorithm in ArcGIS 10.1.Buffer zones (5m, 10m) was created along the rivers and overlaid on the land use/cover maps. The land use areas that falls within the buffer zones were mapped to show the level of vulnerability and impacts during flood events.

c. **Terrain Wetness Index (TWI).**

The terrain wetness index map was derived from ASTER Elevation data using the compound index operation in ILWIS 3.3 software.The rational behind the selection of this factor is to determine the soil water capacity, that is the saturation level of the soil. The higher the soil wetness values the higher the vulnerability and vice versa.This factor was chosen to check the level of soil wetness in the study area and the relative reaction if there is an addition at a given time.

d. **Slope**

The slope of the study area was derived using the "Surface analysis" tool in ArcGIS 10.8 using the Digital Elevation Model (DEM) as input. The slope was generated in degrees. The choice of slope as one of the indicators of flooding is due to its influences on the velocities of overland flow and the concentration of flow. The probability of a flood increases as the slope of a region decreases, making it a solid indicator for flood vulnerability evaluation (Rahman*et al*. 2019). A high slope supports quick water drainage, whereas low slope results in stagnation of water, and promoting flooding (Dash and Sar2020).

e. **Computation of Topographic Power Index:**

The SPI has been employed in several flood risk studies (Cao et al. 2016; Khosravi et al. 2016). The TPI is considered a "measure of the erosive power of flowing water based on the assumption that discharge is proportional to specific catchment area (As)" (Wilson and Gallant, 2000). As specific catchment area and slope steepness increase, the amount of water contributed by upslope areas and the velocity of water flow increase, hence stream power and potential erosion increase (Gruber and Peckham, 2009). The TPI is calculated as As * tanb. Whereas is the specific catchment area (m2/m), and b (radian) is the slope gradient (in degrees). On the other hand, low Topographic power index is the sign of wider floodplains and collapsed basins. For the purpose of this study, the Stream Power Index (SPI) was computed using the "Spatial Analyst Tool" within the ArcGIS 10.5 environment with the Digital Elevation Model (DEM) raster serving as the primary data for deriving other relevant indices.

Statistical Data Analysis Methods

The Spatial analyst tool in ArcGIS 10.1 was used in extracting the areas covered by various land use, TWI, TPI and elevation in the study area. It was also used to determine the area covered by the different of flood vulnerability categories.

3. Result and Discussions

4.2 Morphometric Flood Risk

This section focused on assessing flood risk and were analysed using land use and morphometric analysis. The Digital Elevation Model was used in extracting the morphological parameters used in identifying the potentially flood-prone areas by creating a map of four classes of flood vulnerability (Low, Moderate, High and Very High). This study considered elevation, slope, Terrain Wetness Index (TWI) and Topographic Potential Index (TPI) as flooding factors in the Study Area. These factors were qualitatively combined using the weighted overlay tool in ArcGIS.

4.2.1 Elevation

Low lying zones and flat topography are some of the possible biophysical triggers for LULC change mainly in Africa, Latin America and Asia. (Lambin, et al., 2003). The DEM shows that a substantial part of the study area is moderately low and therefore potentially flood-prone. The elevation of the study area ranges between 9m to 54m (Figure 2).

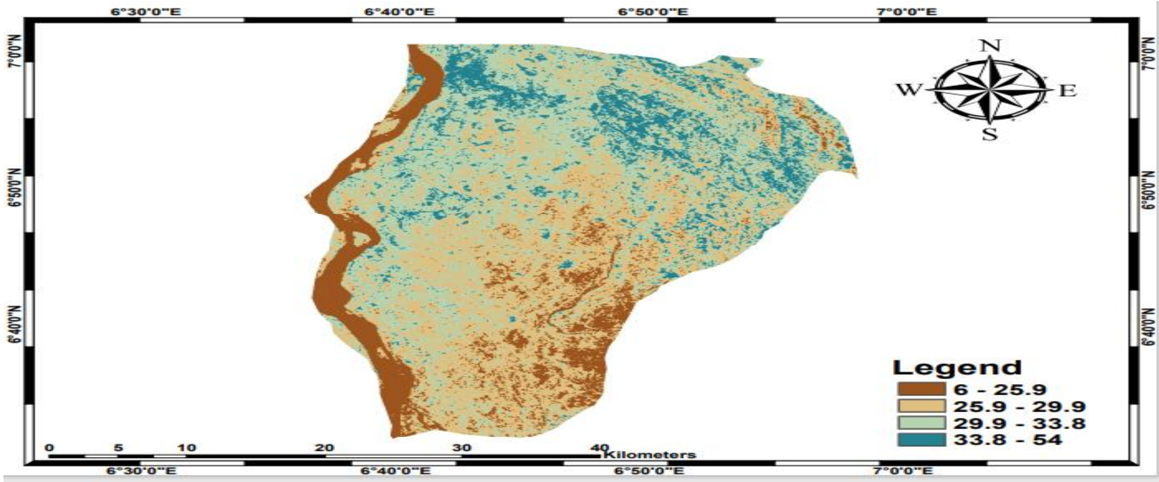


Figure 2: Digital Elevation Model

4.2.2 Slope

The slope map **(Figure 3**) was generated with the SRTMDEM. The study area is mostly dominated by flat topography with slope varying from 0 to 1.57 degrees. The study revealed that most part of the study area lies under a flat or little slope and these are widely distributed throughout the study area. The widespread distributions of low slopeareas have implications on flooding potential in the area. According to El-moustafa (2012), runoff volume is affected by slope and if the slope is very flat, water will not be removed rapidly. Evidence from the study area corroborates this view as most of the areas with slope less than 0.2 degree shows water logging condition and moist area with lots of patches of water bodies.

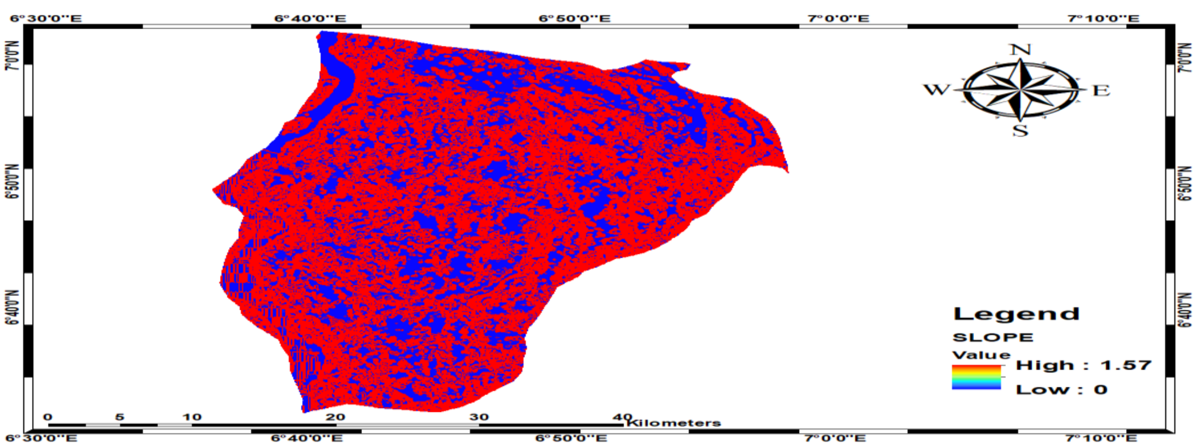


Figure 3: Slope Map of the Study Area

4.2.3 Topographic Potential Index

The Topographic Potential Index (TPI) describes the potential to transfer sediment in a channel's stream. It shows negative values for areas with topographic potential for deposition and positive values for potential erosive areas. The TPI map (**Figure 4**) shows that the TPI value ranges from -16.9 to 13.52. The study area has high positive TPI mean value which indicates that there is a high possibility for erosive actions in the area. The preponderance of areas with high TPI values contributes significantly to erosion process and land degradation risk.

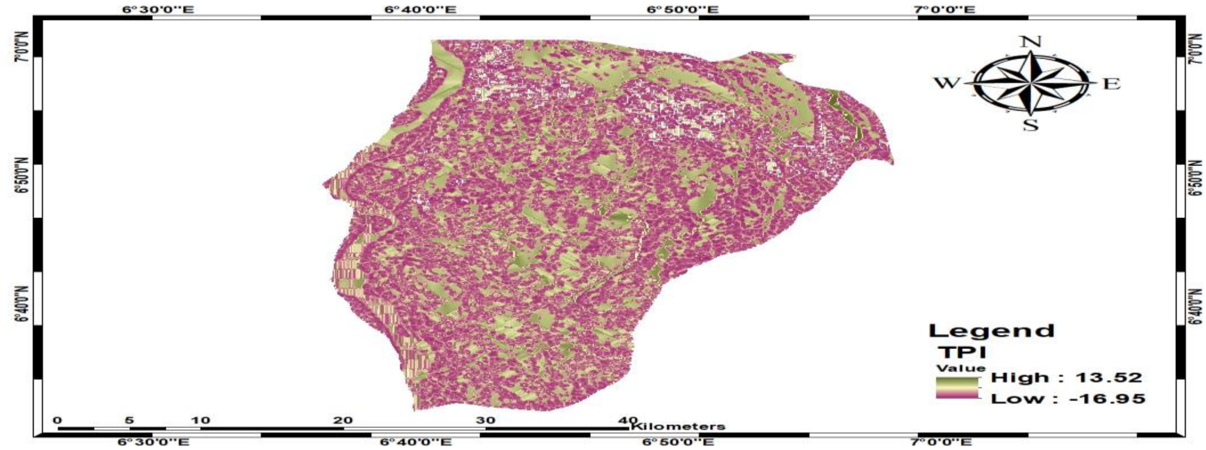


Figure 4: Topographic Potential Index

4.2.4 Terrain Wetness Index

The generated TWI map (Figure 5) clearly indicate that many areas have high TWI values, which is informative for deducing how and why the studyarea is flood prone. Evidently, the lowest and flattest areas will be affected most by the floods because water tends to flow and accumulate in response to gradients in gravitational potential energy. Incidentally, large scale development has taken place on areas with high TWI and this greatly aggravates the flood risk within the area.

Basically, the TPI and the TWI reflect the tendency of water accumulation in the landscape and highlight areas prone to both fast moving and pooling water. In general, these indices show that topographic attributes are major contributing factors to flooding in the area the degree of flood susceptibility was determined by using the weighted overlay method. Flood risk in the study area was characterized into low, moderate, high and very high. Morphometrically, the very high susceptible area is most concentrated in the lower reach of the study area, whereas low and moderate susceptible areas are located in the upper reach of the study area. Low flood risk zone risk was mainly identified in the areas of high-altitude zones.

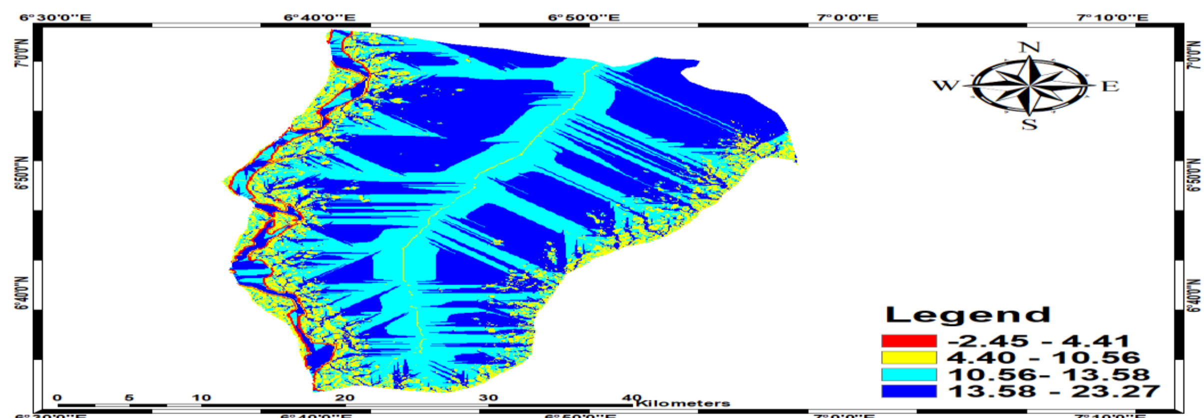


Figure 5: Terrain Wetness Index

4. Conclusion

The study concludes that morphologic and hydrologic properties significantly influence flooding processes in Ibaji Local Government Area, Kogi State. Low elevations, flat slopes, and high terrain wetness indices (TWI) were identified as critical contributors to flood vulnerability in the region. These factors, combined with human-induced land-use changes such as deforestation and agricultural expansion, exacerbate the frequency and severity of floods. The analysis revealed that areas with lower elevation (9m–54m) and gentle slopes (0°–1.57°) are particularly susceptible to waterlogging and overflow during heavy rainfall. These findings underscore the necessity of addressing both natural and anthropogenic factors in flood risk management.

Flooding in Ibaji is further compounded by a lack of efficient drainage systems and the encroachment of development into high-risk zones. The study also highlights that the high TPI values in parts of the area contribute to erosion and land degradation, which, in turn, intensify the flood risks. Effective mitigation strategies must incorporate a comprehensive understanding of these morphologic and hydrologic dynamics to build resilience and minimize future flood-related damages.

5. Recommendations

1. **Adoption of Geospatial Tools for Flood Monitoring and Management:** Government and local authorities should utilize advanced GIS and remote sensing tools to regularly update flood risk maps and monitor changes in vulnerable areas. These tools can provide timely data to guide planning and emergency response efforts.
2. **Sustainable Land Use and Vegetation Restoration:** Reforestation programs and sustainable agricultural practices should be implemented to mitigate the impact of deforestation and soil degradation. These measures will help restore ecological balance, reduce runoff, and enhance the water infiltration capacity of the soil.
3. **Community Awareness and Engagement:** Public awareness campaigns should be conducted to educate residents on the risks associated with encroachment into flood-prone areas and the importance of adopting preventive measures. Community involvement in implementing flood mitigation strategies will foster a sense of ownership and ensure their sustainability.

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