

# Modelling Flood Scenarios in Northeast Nigeria: Simulations, Vulnerabilities and Implications

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## ABSTRACT

*This article presents a comprehensive assessment of flood vulnerability across the individual states of northeastern Nigeria, utilizing advanced methodologies such as Multicriteria Decision Analysis (MCDA), Analytic Hierarchy Process (AHP), and Principal Component Analysis (PCA). The study's primary objectives involve pinpointing high-risk flood areas within each state and investigating the potential of flood simulations to bolster preparedness strategies. Drawing on high-resolution data from sources including the Shuttle Radar Topography Mission (SRTM), Sentinel-2 imagery, and European Digital Archive of Soil Maps, the research leverages PCA to unveil distinct spatial patterns: the Yobe and Borno axis showcase significant variability, while the second principal component highlights notable differences in the Bauchi area. In contrast, the third principal component predominantly captures Adamawa, Gombe, and Taraba states, indicating comparatively lower variability. Notably, flood simulations based on Digital Elevation Models (DEM) faithfully replicate actual flood scenarios, effectively showcasing the viability of simulation techniques for enhancing flood preparedness. The findings spotlight Taraba State's heightened susceptibility due to its lower terrain, rendering it more prone to floods arising from an over-flooded River Benue. Consequently, the simulations underscore the criticality of proactive measures in mitigating flood risks within the region. In summation, this study underscores the effectiveness of integrating MCDA, AHP, PCA, and flood simulations in assessing and mitigating flood vulnerability. The resulting insights establish a knowledge base for informed decision-making, offering valuable support to policymakers and stakeholders in devising resilient flood management strategies for northeastern Nigeria's states.*

## Article History

Received: 6<sup>th</sup> April 2021

Received in revised form: 13 July 2021

Accepted: 26 July 2021

Published Online: December 2021

## Keywords:

Flood, Modelling, Simulation, PCA, MCDA, DEM.

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DOI: 10.11113/ajeess.v3.n2.220

## 1.1 INTRODUCTION

The escalating global climate variability, driven by intensified natural disasters from extreme events, significantly impacts livelihoods and the global economy. These include volcanoes, cyclones/hurricanes, bushfires, avalanches, landslides, floods, earthquakes, and tsunamis. Of these, floods are the most common and impactful natural disaster, causing distress to economies and livelihoods. Floods account for roughly one-third of

economic losses and over half of the deaths tied to global natural disasters (Benz, 2000). The impact and occurrence of these events vary by region and season. In the northern hemisphere, floods peak during the boreal summer months (June to October), while in the southern hemisphere, they occur during the austral summer (January to May).

Tropical regions experience heavier rains, making continuous rainfall exceeding a week likely to trigger

floods. Notably, intense African Easterly Wave activity influences flood-producing rains (Muhammed, 2013). In sub-Saharan Africa, flood occurrences are linked to anomalous meteorological events, especially high monsoonal rain events. The 2007 floods were tied to late rains, causing heavy rainfall on dry soils and intensified surface runoff. Urban expansion exposes more people to floods, compounded by the concentration of populations in flood-prone areas. Governments prioritize flood mapping and control due to increasing perennial floods. Understanding historical and observational hydro-climatological data is vital for addressing climate change impacts (Adnan, 2010). Major causes of flooding in northeast regions include heavy basin rainfall, sedimentation, and blocked urban drainage. Floods are likely yearly in the northeast during peak West African monsoon rains (July to October).

Uncertainties in hydrological studies and flood prediction mainly stem from rainfall variability (Krzysztofowicz, 1999, 2001; Kavetski et al., 2006). Rainfall drives 70-80% of terrestrial hydrological cycle variability (Syed et al., 2004). Given floods' global impact (World Disasters Report, 2003), studying floods in relation to their primary contributor, rainfall, is crucial.

Many parts of the region are subject to periodic flooding. In 2012, a record rainfall caused severe flooding that caused lives and substantial economic losses. This flood lasted for four months between July and October, the first of its kind for 40 years (verbal interview). The probable cause of this flood was attributed by scientist to shifting of rainfall pattern and intensity due to changing climate (Muhammed *et al.*, 2015). For example, previous study by Nkeki *et al.* (2013), showed that the 2012 flood devastated a large part of the northeast, especially along the River Benue trough of Adamawa and Taraba States. They showed that submerged areas in Adamawa that affected 6 LGAs were greater than 1,100km<sup>2</sup>, while Taraba with much lower valleys along the Benue had an area of 4,600 km<sup>2</sup> submerged and affected 5 LGAs massively.

This research is broken down into a number of pragmatic components: first the terrain analysis and modelling were

considered for each State separately considering the sheer size of the areas. Second, the Principal Component Analysis and Multicriteria Decision Analysis using Analytical Hierarchical Process were also considered to determine variabilities and vulnerabilities. A localised scenario simulation and real flood measurements compared in Yola.

## 2.1 Study Area

The north eastern block of Nigeria is one of the six geopolitical zones having an area of 279,203km square. The area is primarily mountainous and forested being in the Savannah. The underlying rock formations are primarily sandstone, shale and siltstone. The percentage distribution of landuse types is forest (80.33%), urban (8.22%), cropland and pasture (15.32%) and lakes, dams and smaller reservoirs combined (21.99%) (Tukur, 2015).

The only one lake is Lake Chad that is shared between four countries (Nigeria, Niger, Cameroon and Chad), dams are Dadin kowa Dam in Gombe State, Kiri Dam in Adamawa State, Kakara Irrigation Dam in Taraba State, Gubi Dam in Bauchi State and many reservoirs that are spread across the region. The major hydrological outlet is the River Benue which is the second largest river in the country.

The northeast (NE) region is depicted in fig.1, and shows the names and locations of the state capitals. The area includes the semi-arid regions of Borno and Yobe States, grassland Savannah of Gombe, Bauchi and Adamawa States as well as mixed grassland-woody vegetation of Taraba State and Montane Vegetation to the southeast of Taraba State (the Mambilla Plateau). The biggest state is Borno with an area exceeding 72,000Km<sup>2</sup> and Gombe being the smallest with an area just above 17, 000Km<sup>2</sup>.

Demographically, Bauchi state has 25% of the total population of the area based on 2006 population census, while Gombe, Taraba and Yobe being the least and accounts for 12% each. Adamawa has moderate value with 17% of the total populace (Tukur, 2015).

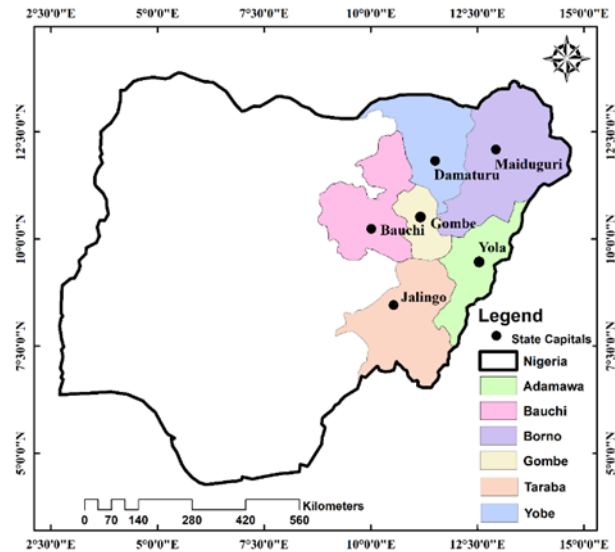


Figure 1: North-eastern States and their capitals. Nearly  $\frac{1}{4}$  of the total landmass of Nigeria is the northeast. It is one of the six geopolitical zones and is made up of 6 states

## 2.2 Major Rivers of the Northeast

The region has a number of rivers whose tributaries stem from different states, and some empties their water into the River Benue which itself originates from the Cameroon Republic. This is especially rivers within Taraba, Adamawa, Bauchi and Gombe States. River Benue passes through Adamawa and Taraba States only. Rivers Gongola (Gombe and Adamawa), Taraba and Donga (in Taraba) empties into River Benue. Other rivers, such Hadejia in Komadugu/Yobe in Yobe State empties their water into the Lake Chad north of Borno State (Tukur, 2015).

## 2.3 Topography of the Northeast

In terms of topography and geology, the northeast is geographically a part of the large Chad Basin area. Other areas fall within the northwest of Nigeria, and the neighbouring countries of Chad, Cameroon and Niger. The northeast area comprises of Borno Plains and Biu Plateau (Borno), Shebshi Hills (Bauchi), Mandara Mountains (Adamawa) and Gotel Mountains (Taraba). The Gotel Mountain encompasses the Mambilla Plateau having the highest peak in Nigeria in a region called *Chabbal Wade*. The elevation information for each state is shown in table 1. Yobe is fairly flat, while Taraba has the highest slope difference due to the present of Mambilla Plateau as the highest peak in Nigeria, and has the lowest valley in the northeast.

Table 1: Elevation of north-eastern states and slope difference

S/N	State	Lowest Point	Highest Point	Slope Difference
1	Adamawa	118	1728	1610
2	Bauchi	186	1716	1530
3	Borno	178	1333	1155
4	Gombe	157	1170	1013
5	Taraba	73	2421	2348
6	Yobe	234	679	445

## 2.4 DATASETS

### 2.4.1 SRTM Digital Elevation Model

The Shuttle Radar Topography Mission (SRTM) was flown aboard the space shuttle *Endeavour* between 11-22 February 2000. The National Aeronautics and Space

Administration (NASA) and the National Geospatial-Intelligence Agency (NGA) participated in an international project to acquire radar data which were used to create the first near-global set of land elevations.

We used the void filled that had additional processing to fill up the voids (small gaps). Since SRTM data are one of

the most widely used elevation data sources, the NGA filled the voids using interpolation algorithms in conjunction with other sources of elevation data. The resolution for SRTM Void Filled data is 1 arc-second (30m) global datasets (<https://ita.cr.usgs.gov/SRTM1Arc>).

#### 2.4.2 TRMM Precipitation

The Tropical Rainfall Measuring Mission (TRMM) is a pioneering satellite mission aimed at enhancing our understanding of global rainfall patterns, particularly in tropical and subtropical regions. Launched in 1997 as a joint project between NASA and the Japan Aerospace Exploration Agency (JAXA), TRMM revolutionized our ability to observe and study precipitation on a global scale. TRMM's core instrument, the Precipitation Radar (PR), along with the Microwave Imager (TMI), provided comprehensive and accurate measurements of rainfall intensity and distribution. The data has spatial resolution of 0.25 x 0.25 degree pixel (Kummerow, 1998).

#### 2.4.3 Sentinel-2 Imageries

Sentinel-2 satellite was launched in 2015 by the European Space Agency (ESA) to provide high resolution multispectral and consist of 13 spectral bands in the Visible and Near Infrared (VNIR) and Shortwave Infrared (SWIR) bandwidths with spatial resolutions ranging from 10 to 60 m. VNIR consists of 4 bands (blue, green, red, and near infrared) with 10m spatial resolution, while SWIR includes 6 bands (4 narrow SWIR bands and 2 wider SWIR bands) with 20m spatial resolution, in addition to 3 bands of 60m spatial resolution for atmospheric correction application (Sadek and Li, 2019). Sentinel-2 L1C products are geometrically corrected with respect to the Universal Transverse Mercator map projection (UTM-WGS 84). Sentinel-2 images are freely available through the USGS Earth Explorer web service.

#### 2.4.4 Climate and Soil Data

All climatic data were collected from Nigerian Meteorology (NIMET) state chapters and as well as World Climate Data records ([worldclimglobal.com](http://worldclimglobal.com)), whereas soil data was extracted from the Nigerian Soil map produced by Soil Survey Division, Federal Department of Agricultural Land Resources (FDALR), Kaduna was downloaded from the European Digital Archive of Soil Maps (EuDASM) (2017).

### 3.1 METHODS

#### 3.1.1 Terrain Simulation

The method involves terrain analysis using satellite digital elevation model data with a 30m spatial resolution. To analyze a specific area of interest (AOI), a mask of the AOI is created and projected onto the data's Universal Transverse Mercator (UTM) coordinate system with WGS 84 datum. The AOI is then clipped from the data. When an AOI spans multiple tiles, they are mosaicked together before clipping.

The digital elevation model (DEM) was employed to simulate flood models at various mean sea levels (msl) to assess its performance. By conducting simulations at different mean sea levels, the study evaluates if the DEM can accurately reproduce flood events for the purpose of flood management. Hillshade visualization in ArcGIS is employed to accentuate the 3D nature of the DEM.

#### 3.1.2 Modelling the Streams

The stream modeling process involves recognizing that the depiction of surface hydrology through digital elevation models (DEMs) simplifies connected flow patterns, which can be influenced by additional conditions. Erosion and accretion, for instance, can impact normal surface hydrology. In this section, we analyze a DEM that accurately represents the mathematical surface of the study area by considering elevation values in the raster. We determine water flow direction from each cell, both in a dry state and when inundated. Cells with significant flow accumulation are identified as rivers and streams, outlining the persistent paths of accumulated water. A network of these waterways is established, hierarchically categorized based on magnitude and volume relative to upstream tributaries. Maps are then generated to illustrate the final collection points of water, showcasing the flow from streams to major rivers solely based on the DEM.

The identification of interconnected rivers and streams is determined by the volume they contribute to the overall flow pattern. This classification is represented by the width and color of these waterways. Five distinct categories, known as stream features, depict the variations in flow patterns. These patterns differ between regions, resulting in diverse collection points for water. Some regions may not contribute to the major rivers at all due to their unique stream features and flow characteristics.

#### 3.2 Water body extraction using Sentinel-2

The water surface areas were extracted using Xu (2006) index which was found to be efficient in distinguishing water from all other surface reflectances. This is

modified normalised difference water index (mNDWI).  
This index is as follows:

$$mNDWI = \frac{Band3 (Green) - Band11 (SWIR1)}{Band3 (Green) + Band11 (SWIR1)}$$

### 3.3 Principal Component Analysis of Rainfall in the Northeast

Principal Components Analysis (PCA), also known as Empirical Orthogonal Function (EOF) analysis among mathematicians, stands as a potent tool within contemporary statistical analysis. This technique facilitates the transformation of data, drawing upon either eigenvalue analysis or the Singular Value Decomposition (SVD) method—a cornerstone of linear algebra. Both PCA and EOF provide analogous outcomes, yet they stem from distinct procedures. Notably, the covariance matrix or the Singular Value Decomposition algorithm fuels the computation of PCA/EOF.

When dealing with extensive matrices, a judicious choice between techniques emerges as pivotal. Specifically, for matrices of substantial scale, covering especially the whole of the northeast region, the Singular Value Decomposition (SVD) route emerges as a prudent selection due to its computational efficiency. This preference is underscored by the computational demands imposed by large satellite datasets, which inherently manifest as voluminous matrices.

### 3.4 Multi-Criteria Decision Analysis

Multi-Criteria Decision Analysis (MCDA) is a systematic approach for making decisions involving multiple conflicting criteria. It involves defining the problem, identifying criteria, assigning weights, and evaluating alternatives (Saaty, 1977; Saaty, 2012). Methods vary from simple weighted sum to complex techniques like AHP and Promethee, aiding decision-makers in clarifying preferences, quantifying trade-offs, and reaching informed choices across diverse fields. MCDA ensures transparent, consistent decisions aligned with objectives (Belton and Stewart, 2002).

## 4.1 RESULTS AND DISCUSSION

### 4.1.1 DEM Simulations for Flood Emundation Areas and Basin Stream Features

This map (figure 2) shows stream network of Adamawa State. The major one is River Benue flowing to the centre of the state, from Cameroon and across the state. Other

major rivers and tributaries across the state are shown. Influences of major rivers are centred around Yola and Numan, while moderate influence could be around Song and to Mubi. Extreme north and south have smaller river catchments.

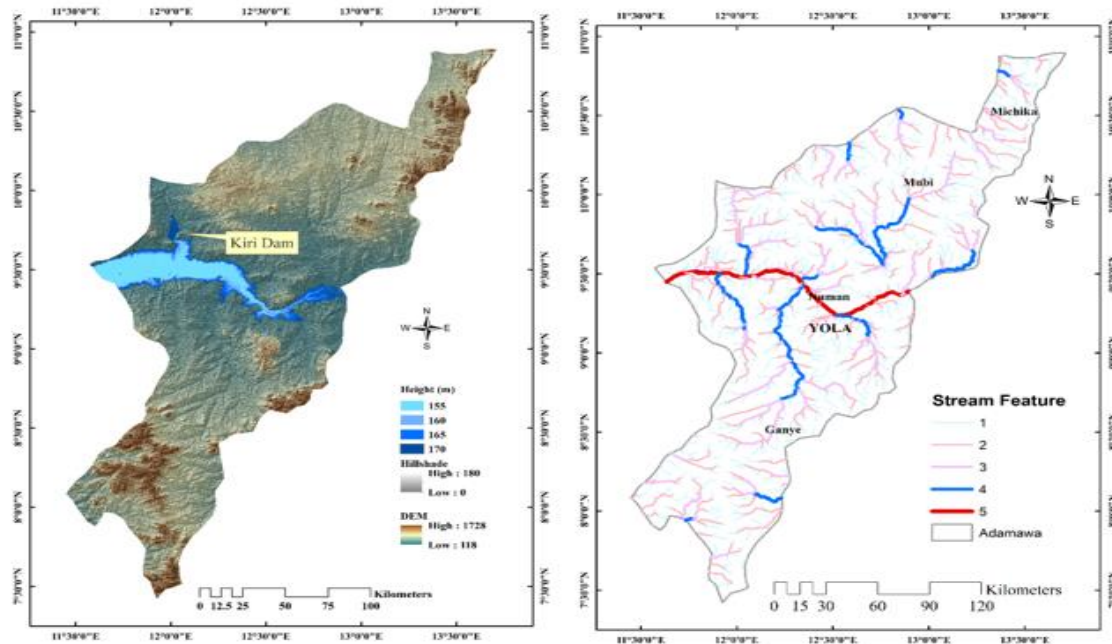
River Benue in Adamawa is nearly 180km from Fufore LGA to the exit at Taraba State border. Explanations here shows the nature of riverine areas based on DEM. This is very important area to focus when expecting floods or for trade purposes. Some minor rivers are perennial, losing all the waters during the dry season, especially River Ngurore located 50km northwest of Yola.

Modelling floods using DEM entails mapping the topography and delineating areas liable to flood based on mean sea level. With hillshade highlighting the topography, mountainous and lower watersheds are shown (figure 2). The major areas liable to severe flooding are located central to the state and along Benue trough.

The Kiri Dam empties its water through River Gongola into River Benue at Numan. This further increases the water volume and level down the tributaries. This, in addition to lower valley water sheds expands the area to be covered by water during flood events. In severe cases, the Benue itself would add pressure to the dam outlet, affecting farm lands and Savannah Sugar Company that is located and fed by the dam. The Kiri dam gets its source from Dadin Kowa Dam in Gombe State, whose origin traces back to Plateau State. The river Benue flows in from Cameroon, and water volume and height depends on both local rainfall/runoff and that of areas surrounding Lagdo Dam in Cameroon. When the Lagdo is getting full, its water is released after informing the

Nigerian government a priority. This model shows water levels at different heights above mean sea level. At 155m, flood could impact just around the edges of the rivers but

at 170, it extends beyond the boundaries and into the catchments of Gyawana before exiting into Karim Lamido LGA of



Taraba State.

Figure 2: Adamawa State showing the Benue Valley as flood-prone areas modelled at various elevations (left), and major stream features of Adamawa Basin (right).

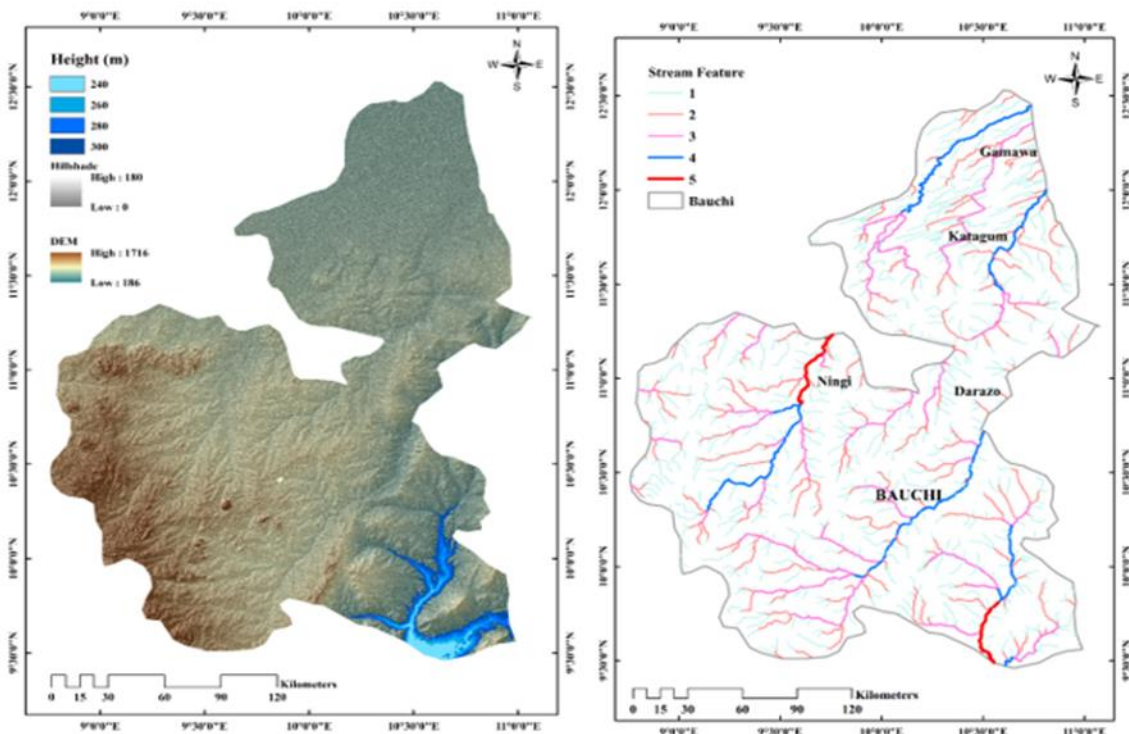




Figure 3: Borno State showing flood-prone areas modelled at various elevations (left), and major stream features of Borno Basin (right).

Although, flash floods can occur across the state, the flood water accumulation is at the south-eastern flank. Bauchi State stream feature shows majority of the river catchments having their waters flowing northeast, for example north and central regions. However, to the southeast, the rivers flow south. The major towns within the vicinity of these rivers are Bauchi, Ningi, Katagan and Gamawa.

Borno state shows nearly flat surface hydrologically to the northeast, and a flood accumulation instance at the south bordering Gombe State (fig. 3). The north-eastern area indicates a viable area for flash flood that can distribute widely and affect many localities. In the south, flood water can empty into Dadinkowa Dam in Gombe.

The stream features show majority of water flowing to the northeast and emptying into River Ngadda south of Kukawa that subsequently empties into Lake Chad. Gombe is a hilly land with hydrological activities existing to the east and south. The southern part collects water

from the hills and drain down to Lamurde of Adamawa State, while the eastern part is an existing Dadinkowa Dam that subsequently flows into Adamawa State to form Kiri Dam. There are minor stream features that connect to finally drain into Dakinkowa Dam. The western streams however, are not connected to the dam.

Taraba State section of River Benue valley is just a about 100m above msl (fig. 4) compared to Benue Valley in Adamawa that is about 155m (fig. 2). This covers a wide area leading to a serious flash flood, especially during the seasonal release of water from the Lagdo Dam of Cameroon.

The simulation shows various areas to be affected at different elevations. At peak of flood event, water can inundate nearly one-third of the state. Most of the streams empty into Benue, at Wukari and Ibbi through Gasol especially. On the Mambilla plateau, River Donga didn't show link to River Benue, but that may be possible when it empties into Benue State.

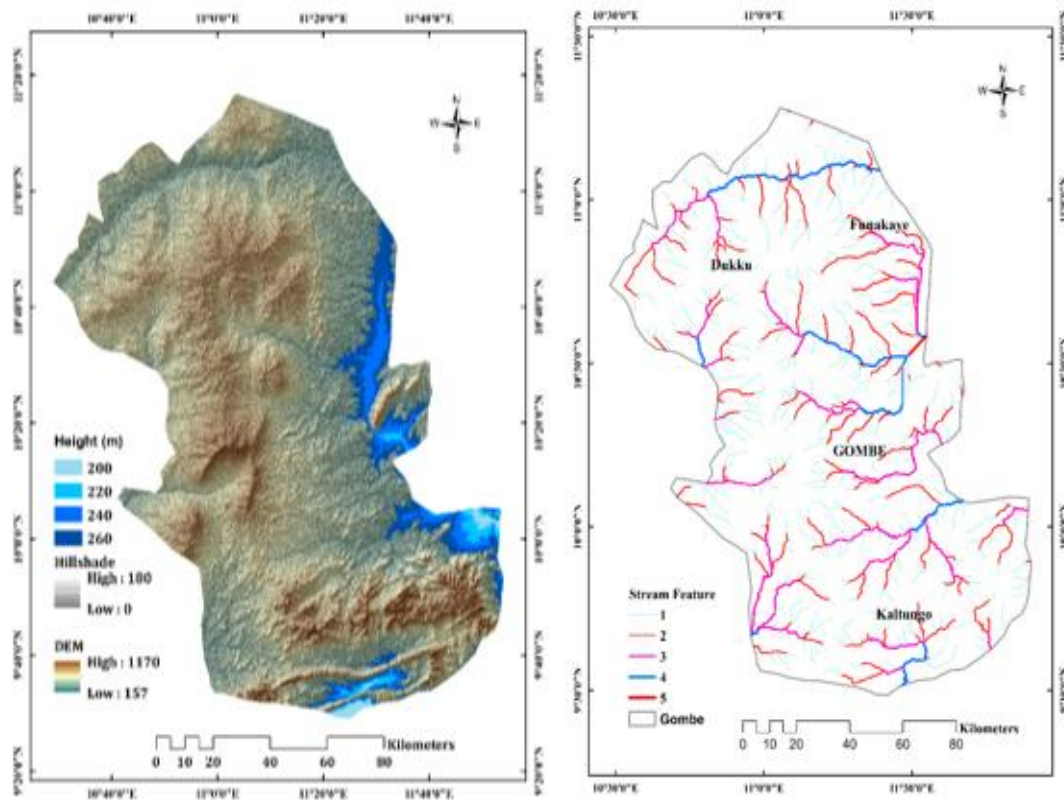


Figure 4: Gombe State showing flood-prone areas modelled at various elevations (left) and major stream features of Gombe Basin (right).

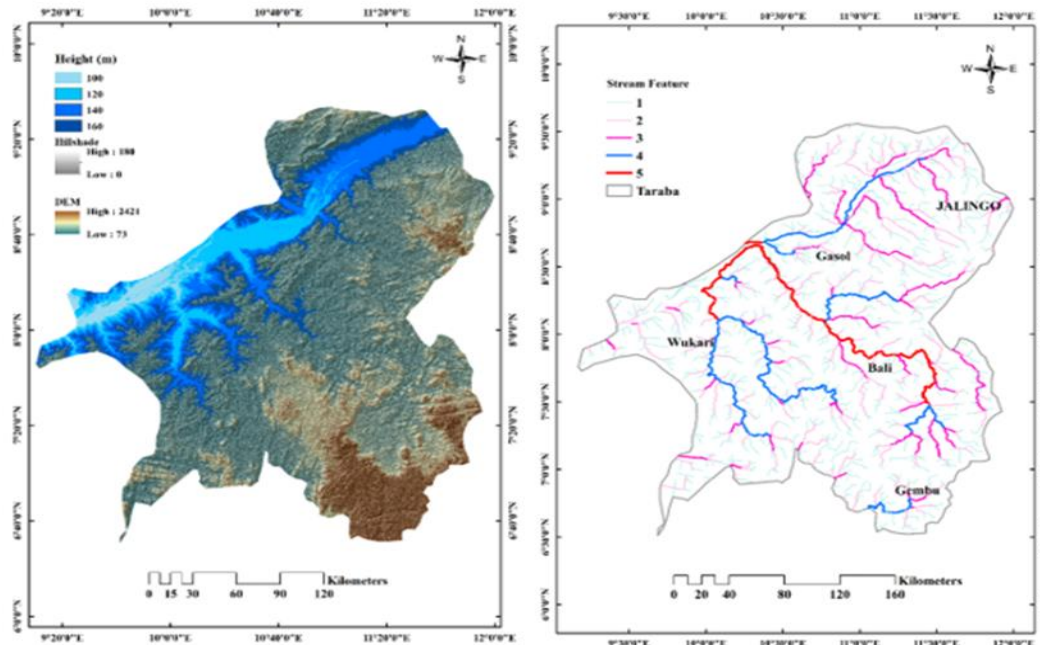


Figure 5: Taraba State showing the Benue Valley as flood-prone areas covering large region (left), and stream features (right).

Yobe is fairly flat to the north and hilly to the south. Simulation shows flood-prone areas to the north-east and south (fig. 6). The northern part is linked to River Komadugu-Yobe that empties into Lake Chad. The southern part empties into Dadinkowa Dam at Gombe State. The stream order shows most of the flow is to the northeast, except that south of Fika town.

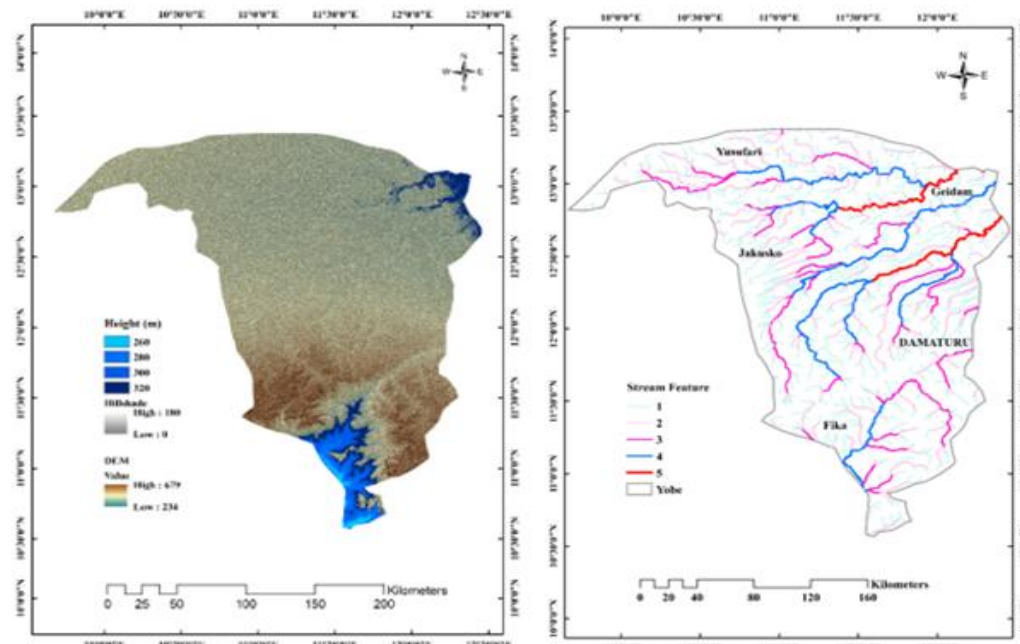


Figure 6: Yobe State showing flood-prone areas modelled at various elevations (left), and major stream features of Yobe Basin (right).

#### 4.2 A case of River Benue in Yola

The changes in the course of water level are due to debris from the weathering rocks and silts upstream

that creates a huge sediment covering the large surface area supposedly covered by water. Sedimentation and withholding of water by the Cameroonian Lagdo Dam



authorities affect navigation by bigger ships that used to convey goods along the River Benue from the sea to Yola.

The river (green) is the product of sentinel water index. The change in water course is attributable to increased sedimentation and the likely impact of water holding by Lagdo Dam authorities. The important lakes (Gerio and Njuwa) appear clearly as well as the vast watershed at the centre of the figure. The normal area covered by River Benue is shown in green and flood in blue (Fig. 7). The normal water surface for May 2019 undulates between high Bagale and Dougirei hills and its course influenced by sediments that accrue over years. The river has never been dredged, and the

sediments expanded into the neighbouring watershed to the centre of the study area.

During the flood event of 3 November 2019, the flood covered almost the whole watershed and swallowed the Lakes Gerio and Njuwa. The surface area normal river flow and lakes for May 2019 was calculated and found to cover 2, 125Ha while flooded water covered 9, 676Ha. That means surface area of inundation is 455.34 % larger than normal water surface area. As the primary baseline of ground topography, the DEM has a significant influence on the calculated river hydraulics and the extent of inundation areas (Nicholas and Walling, 1997; Horritt and Bates, 2001; Kavetski *et al*, 2006) and is important for determining safety locations for planning, especially along the Benue Valley.

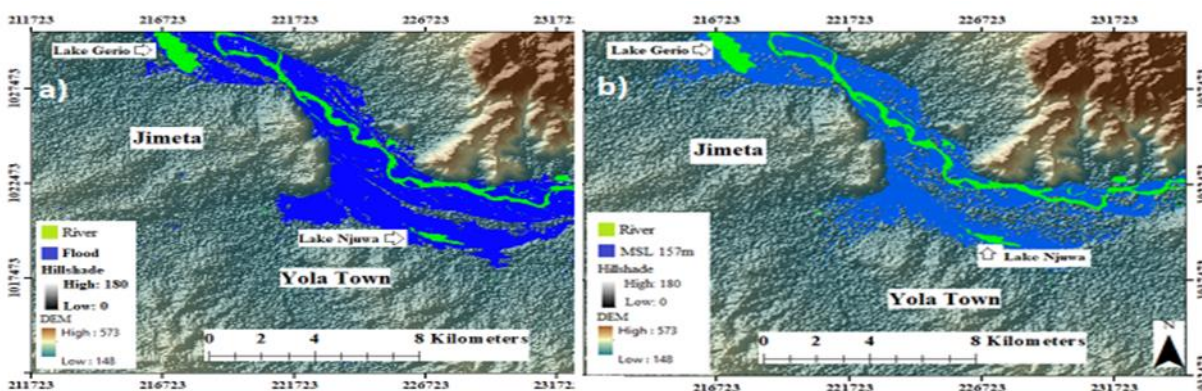


Figure 7: The SRTM DEM shows undulations and valleys with flood water affecting large areas in Yola (Jimeta and Yola Town). Lakes Gerio and Njuwa completely disappeared in the flood. a) The DEM of the study area with an overlay of normal river flow in May 2019 (green) and flood water of 3 November 2019 (blue). b) DEM simulation at 157m above msl, replicating the November flood.

#### 4.3 Comparison Observed and Simulated Floods

The satellite observed flood inundation of November 2019 is compared with simulated results of 157m above mean sea level. Results demonstrates that simulated flood using DEM as compared to normal flood provides a very good correlation. It also shows the variation and structure of surface water arising from the presence and shifting pattern of sediments across time, which is a good determinant of sediment condition during dredging.

This research corroborates with previous studies, showing that DEM with higher resolution produces more accurate flood maps compared to coarser resolution DEM which over-predict the flood extents (Werner, 2001; Brandt, 2005; Cook and Merwade, 2009). DEM represents the general topography of the river bank

(Weepener *et al.*, 2012), floodplain and adjoining hills as an important aspect of hydraulic flood modelling. Hence, high accuracy and high-resolution data estimates flood damage and inundated areas better. While many researchers develop their DEM from low resolution contour maps, this work uses higher resolution DEM of 30m resolution.

#### 4.4 Principal Component Analysis of Rainfall as Precursor to Flood in the Northeast

We associate floods to rainfall, and rainfall to climate and the latter is random. However, these climatic events are random daily weather. They are non-linear in nature and has high dimensionality in terms of time and pattern, intertwined by further random processes of either land, water or air. To best understand these complex events, first we need to reduce the dimensionality and get around

what we call principal component modes. These modes may be able to help us understand and interpret dynamics and physics of the environment that we live in. Here, we use the Principal Component Analysis that has broad applications in atmosphere, land processes and water (see Hannachi *et al*, 2007). Fig. 8 shows the northeast region from which the PCA is undertaken. The northeast region that we are interested in is highlighted in red box. The light boundary to the northeast of the map is the Lake Chad. Peak rain rates are observed to the south at the

Niger Delta around 10-15 degrees longitude south of 8 degrees latitude.

This daily rainfall timeseries (fig. 9) shows peaks in rainfall averaged over the entire northeast region for 2012. Important peaks are observed from early July to end of August. Rain rates less than 2mm were recorded from January to March and mid-November to December.

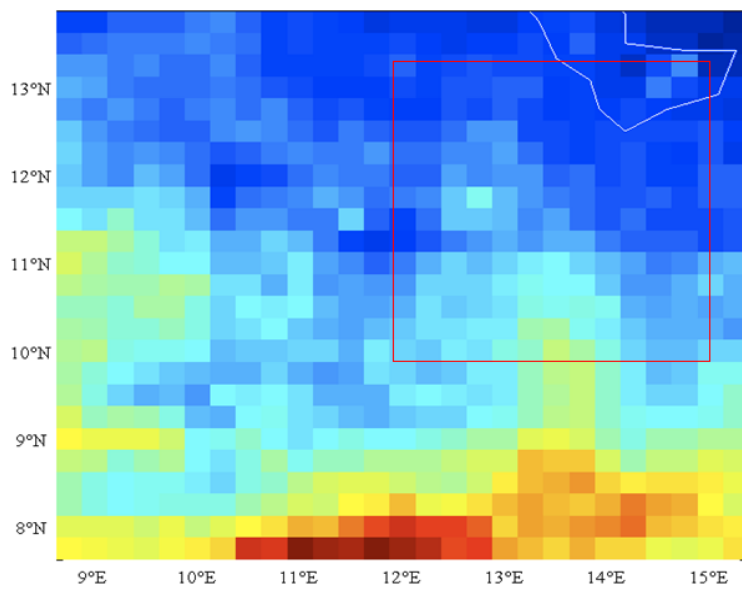


Figure 8: Spatial map of rainfall averaged over the northeast for the year 2012. Data is from TRMM precipitation radar. Each pixel is approximately 25km by 25km.

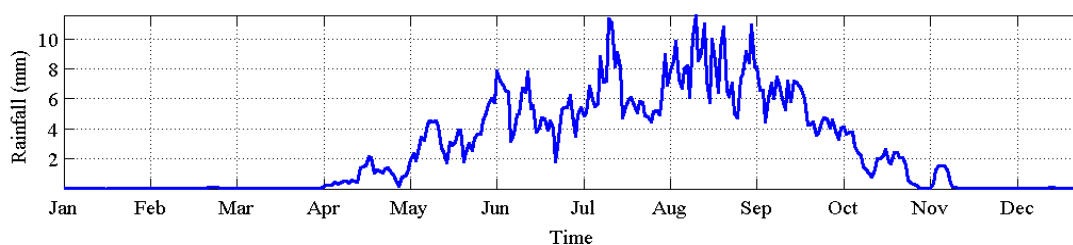


Figure 9: Area averaged daily rainfall time series over the northeast region (highlighted in red box in fig. 8). Data was filtered using finite response filter, windowed to 5 days. This is to remove sharp and spurious signals that may affect interpretation.

The first EOF 1 (33.6%), EOF 2 (7.1%) and EOF3 (5.6 %) variances and all accounting for a total variance of 46.3% variance (fig. 10). Strongest variances are represented by EOF, showing the northernmost part of the study area having substantial changes in rainfall over the period of study. These variability in essence mean changes in precipitation in these areas are large and influenced heavily by air-sea interaction. By coincidence, the northernmost part of the region records low amount

of rainfall per year because this is the region of Nigeria's Sahel Savannah, a small strip of region having systematic changes in local climate akin to desert environment. These areas cover some parts of Borno, Yobe and Bauchi States.

The second EOF shows variances to the second degree mainly to the southwestern part of the study area. These areas are covering mostly Bauchi, Gombe and Taraba

States. These areas are called Guinea Savannah, combining grassland and short trees. Variability of rainfall in these areas are associated with local weather patterns and land surface processes such as agriculture and destruction of forests, thereby giving it an unprecedented change in rainfall pattern.

The third EOF however shows variations in rainfall pattern to the southeast of the region. This area is mostly covered by strong vegetation cover such as Gashaka/Gumti National Park and the mountain vegetation on the Mambilla Plateau. Here, the forest and orographic nature of the region influences rainfall distribution pattern greatly, combining both orographic (relief) that comes in the first quarter of each year and monsoonal rainfall that falls in summer (April-

September). Because of the nature of the terrain and high availability of forest resources, rainfall pattern changes only to a third degree.

In fig. 11, PC1 shows peaks from early July to end of September, while PC2 shows peaks around mid of August. PC3 shows quite random peaks between June and October. An overview of changes in pattern across time of rainfall variability gives us insight into flood events and timing. Smoothing the timeseries to observe natural peaks was first done to examine the rainfall magnitudes across the northeast. Prominent patterns have been observed as well as the time these changes occurred using the SVD-based EOF.

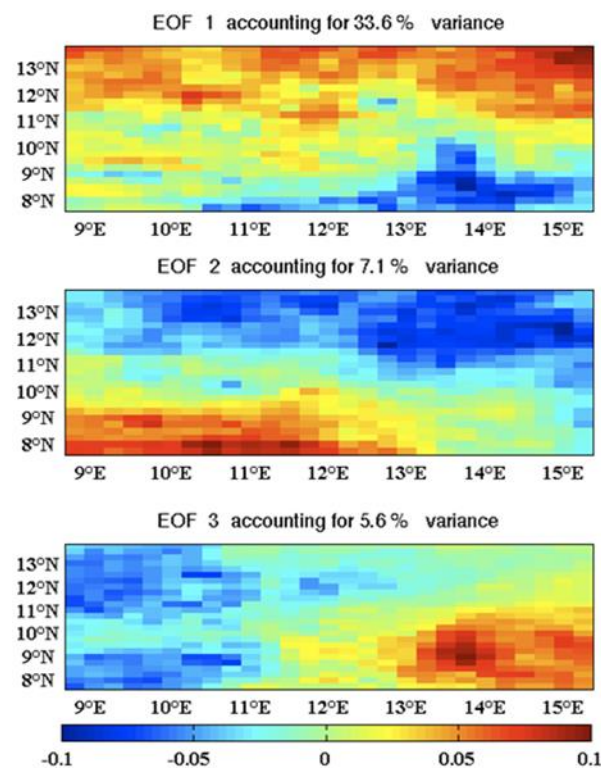


Figure 10: Empirical orthogonal functions of northeast region from the daily rainfall data of 2012.

#### 4.5 Multicriteria Decision Analysis using AHP

The AHP results (tables 2 and 3) clearly revealed that rainfall was selected to the criteria with high impact in determining flooding in an area with 46.2% followed by Slope, Land use/land cover, soil

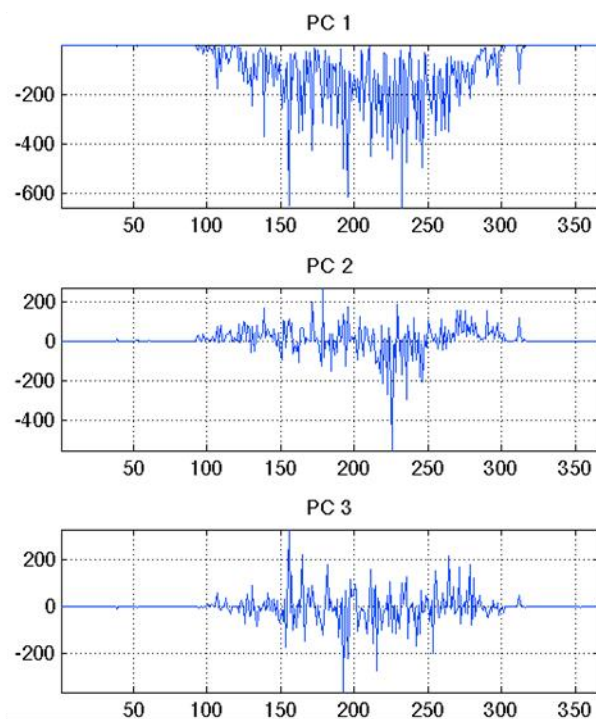


Figure 11: The principal components timeseries of the spatial EOF shown in fig.10. Units are arbitrary. X-axis represent time in days for the year 2012.

and temperature with 32.4%, 10.9%, 7.0% and 3.5% respectively. In addition, the result also revealed that  $CR=0.08$  which is less than 0.01. As such, the level of consistency in PCM is justifiable which implies that there is fair comparison within the selected criteria.

Table 2: Pairwise Comparison Matrix of the selected Criteria

	Rainfall	Slope	Land Use/ Land Cover	Soil	Temperature
Rainfall	1.0000	3.0000	5.0000	5.0000	9.0000
Slope	0.3333	1.0000	5.0000	7.0000	9.0000
Land Use/ Land Cover	0.2000	0.2000	1.0000	3.0000	3.0000
Soil	0.2000	0.1429	0.3333	1.0000	3.0000
Temperature	0.1111	0.1111	0.3333	0.3333	1.0000
Total	1.8444	4.4540	11.6667	16.3333	25.0000

Table 3: Normalization and Weight of the selected Criteria

	Rainfall	Slope	Land Use/ Land Cover	Soil	Temperature	Weight	Weight (%)	Rank
Rainfall	0.542	0.674	0.429	0.306	0.360	0.462	46.208	1 <sup>st</sup>
Slope	0.181	0.225	0.429	0.429	0.360	0.324	32.448	2 <sup>nd</sup>
Land Use/ Land Cover	0.108	0.045	0.086	0.184	0.120	0.109	10.855	3 <sup>rd</sup>
Soil	0.108	0.032	0.029	0.061	0.120	0.070	7.006	4 <sup>th</sup>
Temperature	0.060	0.025	0.029	0.020	0.040	0.035	3.483	5 <sup>th</sup>
	1.000	1.000	1.000	1.000	1.000	1.000	100.000	

$CI=0.09489$ ,  $CR=0.08472$

To succinctly show the results, the criteria maps for each parameter and each state were not shown. Only the final results shown.

Result on the flood vulnerability on the other hand is presented in table 4. The result shows that over 70% of total land area in Taraba and Bauchi are vulnerable to flooding (Table 4). Vulnerable places in Adamawa are Toungo, Ganye, Numan, Demsa, Jimeta and Yola South, in Bauchi are Bogoro, Tafawa-Balewa, Dass, Toro, Alkalari, Bauchi and Ningi (fig. 12). In Borno State, Shani, Kwaya Kusar, Hawul, Biu, Chibok, Askira/Uba, Gwoza,

Kunduga, Kaga and Damboa in Southern Borno are vulnerable to flooding, Gombe State include Gombe, Akko, Yamaltu/Deba, Billiri and Kaltungo in Gombe State (fig. 13). Vulnerable communities in Taraba are Ibi, Wukari, Gasol, Bali, Gashaka, Takum, Ussa, Kurmi and Sardauna, whereas, in Yobe, vulnerable communities are Nangare and Gulani (fig. 14). All these places are vulnerable to flooding best on the fact that they are places with high rainfall amount and are located on lower topography which are the major factors determining flood occurrence as also documented by Nwigwe and Emberga (2014) and Qomariyatus *et al.* (2020).

Table 4: Flood Vulnerability area in all the selected States

States	Highly Vulnerable		Vulnerable		Moderately Vulnerable		Not Vulnerable		Total
	(%)	(km <sup>2</sup> )	(%)	(km <sup>2</sup> )	(%)	(km <sup>2</sup> )	(%)	(km <sup>2</sup> )	
Adamawa	1.5	550.1	50.7	19,178.4	47.5	17,995.5	0.3	128.3	37,852.3
Bauchi	1.6	786.2	73.1	35,452.3	25.2	12,228.4	0.1	47.6	48,514.5
Borno	0.7	491.8	46.0	33,286.1	52.1	37,730.6	1.2	854.5	72,363.0
Gombe	0.0	0.0	35.6	6,224.1	64.0	11,180.1	0.3	57.7	17,462.0
Taraba	0.8	483.0	74.7	44,385.6	22.8	13,525.8	1.7	998.4	59,392.8
Yobe	1.2	558.0	17.9	8,021.7	80.7	36,250.4	0.2	93.5	44,923.6

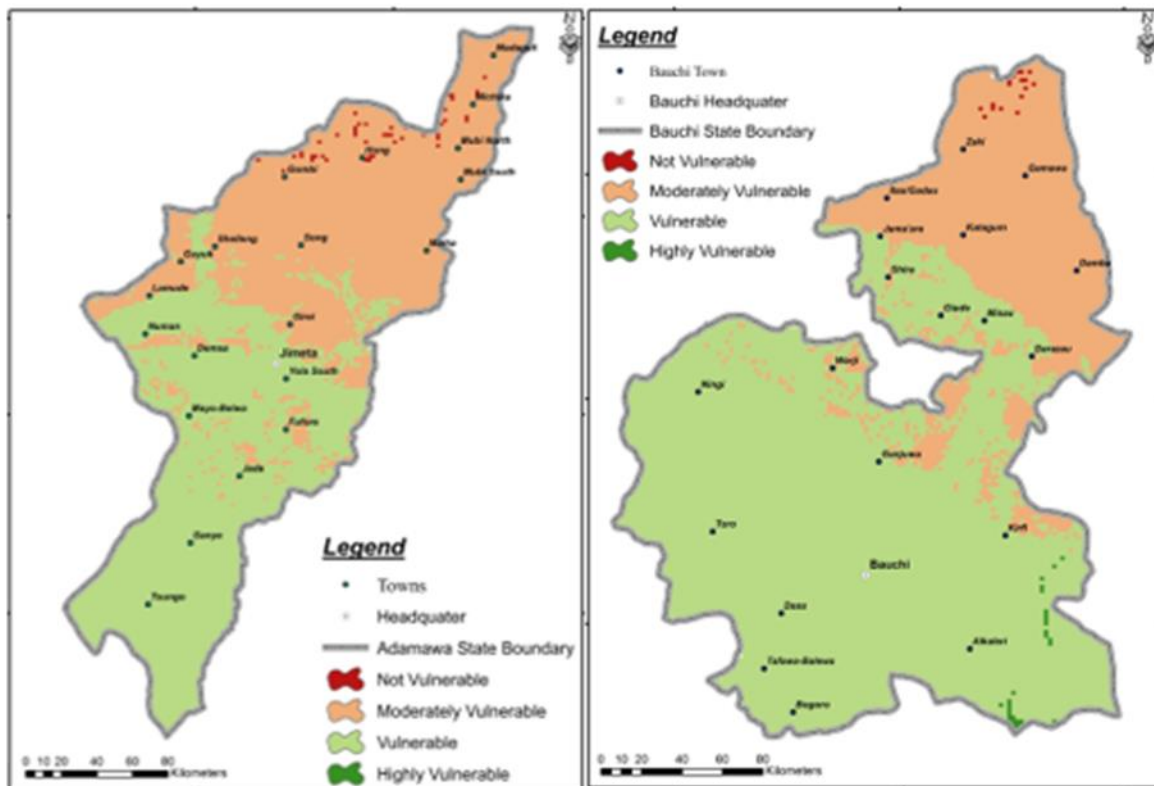


Figure 12: Flood vulnerability map based on MCDA AHP of Adamawa and Bauchi States

#### 4.6 SUMMARY

DEM-based flood mapping provides the best approach to a cost-efficient strategy in delineating flood-prone areas. The idea is based on the ability to map areas of low and high lands using radar-based satellite DEM via geo-mathematical and computing processing techniques. These methods reply solely on morphological characteristics of river basin as a bases of having all

features controlled by hydrology and watersheds. Changes in these areas of hydrologic characterisation may depend on soil, geology and climate. Therefore, modelling these require a complete and inclusive applications of these data. A complete modelled flood analysis in this region is beyond the scope of this research, but necessary for making inundation maps which institutions such as NEMA would require to show specific risks during disaster events



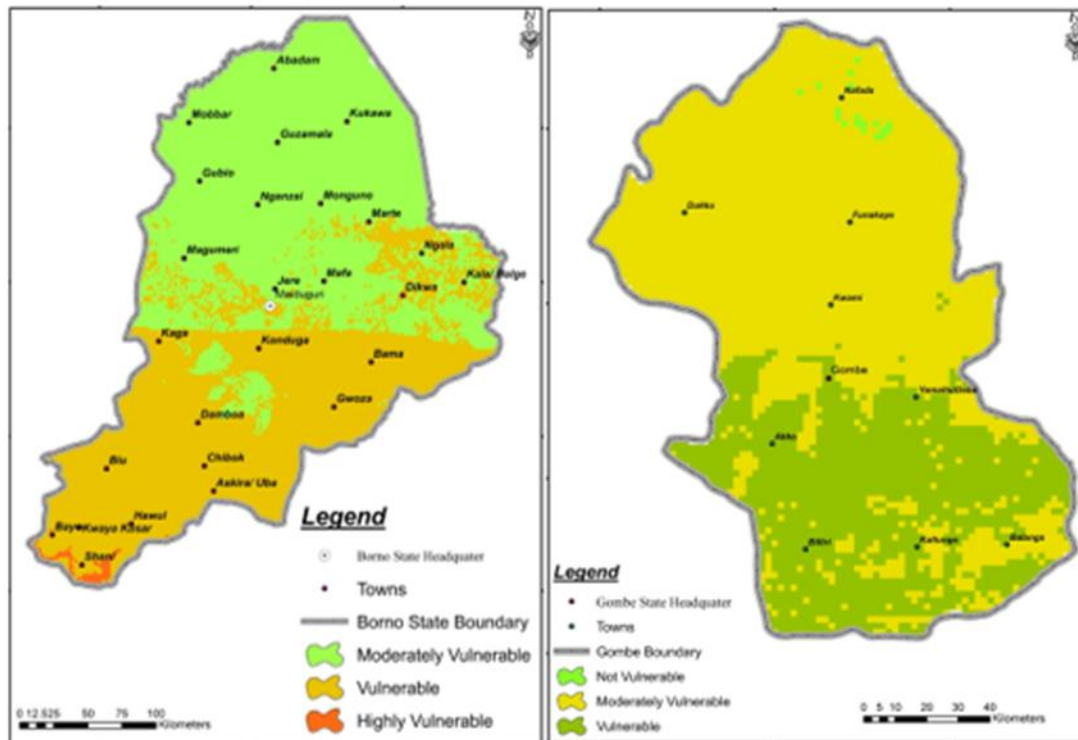


Figure 13: Flood vulnerability map based on MCDA AHP of Borno and Gombe States

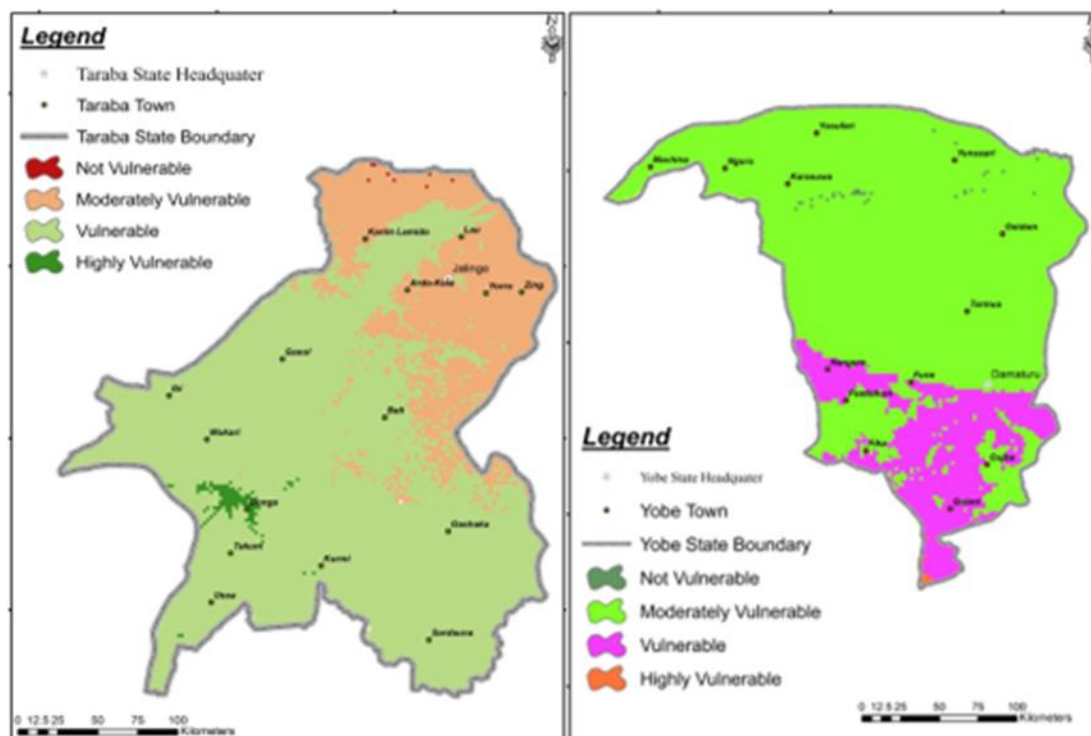


Figure 14: Flood vulnerability map based on MCDA AHP of Taraba and Yobe States

A multicriteria analysis based on analytical hierarchical process was employed to show areas vulnerable to

flooding by characterising land uses, soil, rainfall, temperature and slope. Results show communities that

are vulnerable to flooding putting all these criteria into consideration. Furthermore, municipal simulations employing greater Yola of Adamawa State was used to show changes in River Benue course over the years. Sediments have taken substantial part of the river turning central part of it to banks. Simulations based on DEM and observations were compared and found to give same results.

Based on TRMM timeseries, rainfall within the north-eastern Nigeria starts in April and ends in October, peaking in July and August. Using PCA, serious irregularities in rainfall are observed around Borno/Yobe sides and moderate southward. Little significant changes are observed in Taraba and southern Adamawa.

Wavelets analysis show high water between 1984 and 1994 corresponding to volume of discharge. Continuous wavelet transform show rain variation during raining seasons are within 5-day cycle. Rainfall shows dry spells between 1998 and 2002.

## 5.1 CONCLUSION AND RECOMMENDATIONS

The importance of DEM in flood inundation mapping has been studied, allowing smaller lakes like Gerio and Njuwa to be mapped. While we employ satellite optical instruments to map out flood inundation, we could as well employ DEM to simulate conditions of flood for the purpose of predictability. SRTM DEM simulation gives good result for predicting flood disaster in a safer inland water way devoid of storms. For very small urban areas, a better resolution DEM such as IFSAR and LiDAR with less than 10m should be employed.

DEM-based flood mapping provides the best approach to a cost-efficient strategy in delineating flood-prone areas. The idea is based on the ability to map areas of low and high lands using radar-based satellite DEM via geo-mathematical and computing processing techniques. These methods rely solely on morphological characteristics of river basin as conditions of having all features controlled by hydrology and watersheds. Changes in these areas of hydrologic characterisation may depend on soil, geology and climate.

Therefore, modelling these require a complete and inclusive applications of these data. These data and the DEM can be incorporated into hydrological models such as HEC-RAS and HEC-HMS to model flood in municipal or urban areas. A complete modelled flood analysis in this region is necessary for making inundation maps which

institutions such as National Emergency Management Authority (NEMA) of Nigeria would require to show specific risks during disaster events.

While it is known essentially that sedimentation and siltation are ongoing geomorphic features, it is important to employ the use of ASTER DEM when temporal changes of such are required. For example, seasonal changes in river bank or dam/lake can be studied from the continuous data flow of this data, which is unlike SRTM DEM that was captured once. This of course should have meteorological and soil characteristics embedded within in order to give a full account of gains and losses of sediments which are indicators of flood events.

## Reference

- Adnan, N. A. (2010). Quantifying the impacts of climate and land use changes on the hydrological response of a monsoonal catchment. School of Geography. Faculty of Social and Human Sciences. University of Southampton. Ph.D Thesis. pp273.
- Belton, V., & Stewart, T. (2002). Multiple Criteria Decision Analysis: An Integrated Approach. Kluwer Academic Publishers.
- Benz, G. (2000). Flood disasters: Lessons from the past – worries for the future. Proc. Inst. Civ. Eng. Water Marit. Energy, 142(1), 3–8.
- Cook, A., & Merwade, V. (2009). Effect of topographic data, geometric configuration and modeling approach on flood inundation mapping. Journal of Hydrology, 377(1-2), 131–142.
- Hannachi, A., Jolliffe, I. T., & Stephenson, D. B. (2007). Empirical orthogonal functions and related techniques in atmospheric science: A review. International Journal of Climatology, 27(9), 1119-1152.
- Horritt, M. S., & Bates, P. D. (2001). Effects of spatial resolution on a raster-based model of flood flow. Journal of Hydrology, 253(1-4), 239-249.
- Kavetski, D., Kuczera, G., & Franks, S. W. (2006). Bayesian analysis of input uncertainty in hydrological modeling: 2 Application. Water Resources Research, 42, W03408.
- Kummerow, C., Barnes, W., Kozu, T., Shiue, J., & Simpson, J. (1998). The Tropical Rainfall Measuring Mission (TRMM) sensor package.

- Journal of Atmospheric and Oceanic Technology, 15(3), 809-817.
- Krzyzstofowicz, R. (1999). Bayesian theory of probabilistic forecasting via deterministic hydrological model. *Water Resources Research*, 35(9), 2739–2750.
- Krzyzstofowicz, R. (2001). The case for probabilistic forecasting in hydrology. *Journal of Hydrology*, 249, 2–9.
- Muhammed, I. (2013). The influence of Gulf of Guinea Sea Surface Temperature to West Africa and Sahel Drought of 2005. *Journal of Science, Technology and Education*, 2(1), 56-60.
- Muhammed, I., Ismaila, A. B., & Bibi, U. M. (2015). An assessment of farmer-pastoralist conflict in Nigeria using GIS. *International Journal of Engineering Science Invention*, 4(7), 23-33.
- Nicholas, A. P., & Walling, D. E. (1997). Modelling flood hydraulics and overbank deposition on river floodplains. *Earth Surface Processes and Landforms*, 22(1), 59-77.
- NIMET. (2008). Nigerian Climate Review Bulletin 2007. Nigerian Meteorological Agency. URL <http://www.nimetng.org/>.
- Nkeki, F. N., Henah, P. J., & Ojeh, V. N. (2013). *Journal of Geographic Information System*, 5, 123-135. doi:10.4236/jgis.2013.52013.
- Nwigwe, C., & Emberga, T. T. (2014). An assessment of causes and effects of flood in Nigeria. *Standard Scientific Research and Essays*, 2(7), 307-315.
- Qomariyatus, S., et al. (2020). The analysis of the causes of flood disasters and their impacts in the perspective of environmental law. *IOP Conference Series: Earth and Environmental Science*, 437, 012056.
- Saaty, T. L. (1977). A scaling method for priorities in hierarchical structure. *Journal of Mathematical Psychology*, 15(3), 34-39.
- Saaty, T. L. (2012). *Decision Making for Leaders: The Analytical Hierarchy Process for Decisions in a Complex World* (3rd Revised Edition). RWS Publications.
- Syed, T. H., et al. (2004). Analysis of process controls in land surface hydrological cycle over the continental United States. *Journal of Geophysical Research*, 109(D22105).
- Tukur, A. L. (2015). Tragedy beyond the commons: Livelihoods and environmental challenges in North-East Nigeria. 36th Inaugural Lecture. Modibbo Adama University Yola - Nigeria.
- Weepener, H. L., et al. (2012). The development of a hydrologically improved Digital Elevation Model and derived products for South Africa based on the SRTM DEM. *Water Research Commission (WRC) Report No. 1908/1/11*.
- Werner, M. G. F. (2001). Impact of grid size in GIS-based flood extent mapping using 1-D flow model. *Physics and Chemistry of Earth (B)*, 26, 517-522.
- World Disasters Report. (2003). International Federation of Red Cross and Red Crescent Societies.