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I. Introduction

Floods are among the most devastating natural disasters and cost many lives every year (Dilley et al. 2005). Flooding seriously affects people's lives and property (Wang, 1999). In a time period of 6 years (1989–1994), 80% of federal declared disasters in the US were related to flooding; flood themselves around the world average four billion dollars annually in property damage alone (Wadsworth 1999). The frequency with which they occur is on the increase in many regions of the world (Drogue et al. 2004). It is reported that flood disasters account for about a third of all natural disasters [by number and economic losses]. Nigeria is no exception to countries that experienced flooding in recent time. Many communities have suffered losses due to flood problem. The dramatic river flooding Nigeria is no exception to countries that experienced that experienced flooding in recent time. Many communities have suffered losses due to flood problem

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The dramatic river flooding in Adamawa State that destroyed farmlands and claimed lives and property has affected various parts of the region. Sequel to the topography and sediment type of the study area, possibility of spread exists. Some of the flood prone areas include Yola North and South, Numan Council areas, Loko, Dasin, Fufore areas and Demsa (Figure 2). Galtima and Bashir (2002) recorded a very severe destruction in Fufore council to the extent that as many as 13 villages were submerged and hundreds of hectares of farmland washed away. The dramatic flood disaster was unleashed on the Loko community of Adamawa State floodplain in 1991. Movement was truncated and economic and social activities of the people paralyzed by flooding in Demsa area. Worst experience of this intermittent and infrequent flood occurrence with great impact on the people in recent time was in 2003 and 1999. It was reported on September 23, 2010 of flooding spreading to other parts of the country. This was sequel to the La Nina returns that left Sokoto, Kebbi and Kaduna states residents reeling from the flooding that swept through their farmland killing many and washing away farm produce and properties.

The need and means to protect the environment is of great concern to man. Flood Management is currently a key focus of many national and international research programmes with flooding from rivers, estuaries and the sea posing a serious threat to millions of people around the world during a period of extreme climate variability (FRMRC 2010). Flood occurrence in the Adamawa State floodplain are threats to lives and properties and the frequency is increasing dramatically. Flood management is that art of handling or controlling flood successfully. However, it is important to note that, to effectively manage any disaster, a good knowledge of the root cause(s) and impact of the disaster are necessary. Modelling technology and spatial analysis help flood management initiative.

Oyebande and Adeaga (2002) documented that the Federal Environmental Protection Agency (FEPA) in the Nigeria's agenda 21 document (FEPA 1999) spelt out requirement to tackle flood disaster. The set out objectives for flood combat by FEPA are as follows:

- To provide a master plan for flood control and mitigation in flood prone areas including emergency relief measures for victims;

- To mitigate flooding through the relevant land use laws and edicts;
- To improve institutional capacity for flood prediction and public awareness programmes;
- To minimize the impact of flooding through the provision and maintenance (an effective operation) of appropriate infrastructure.

To come out with abatement measures that will reduce the adverse effects currently been faced, this study emphasized some of the causes and impacts of flooding.

Floods in Adamawa state usually leave over 2,000 people displaced many of them with no access to clean drinking water, leading to cholera outbreaks. According to the Nigeria Emergency Management Agency (NEMA), five districts, namely, Fufore, Demsa, Yola North, Yola South and Numan were flooded in August and early September, 2010 when River Lagdo burst its banks. Demsa and Fufore districts, along with nearby Maiha, were hit with cholera outbreak which left 70 people dead out of over 300 infected (Daily Trust 2010).

In a study conducted by Galtima and Bashir (2002), on the people's perception on the causes of flooding in Yola, Greater Numan and Fufore area of Adamawa floodplain, 58.3% was as a result of release of water from Lagdo dam, 25% due to rainfall intensity and 16.7% accounted for rainfall intensity and siltation. Land use resulting in sediment input into the river leading to rise in water level and reduced channel capacity to contain excess water is another factor that have contributed to the flood problem in the State.

Following the rate and occurrence of devastating flood in Nigeria coupled with predictions of more rainfall, climate change and severe weather conditions in the world; El Nino/La Nina-Southern Oscillation, a quasi-periodic climate pattern that occurs across the tropical Pacific Ocean on average every five years, but over a period which varies from three to seven years; the recent massive release of water from dams; the submerged hundreds of acres of farmland, the strong negative impact of flooding on lives and properties and so on, there is need for an urgent review of the FEPA 1999 combat measures. Some of the issues that ought to be addressed include:

- Assessment of implementation programmes of FEPA combat measures;
- Analysis of the causes of flooding in the environment;
- The need and means to protect the environment;
- The need for strong warning and relocation of people living near river banks;
- The need for rivers to be dredged in the country as most channels are already blocked or too narrow to contain excess water;
- Cooperation between government and dam management, for example, Nigeria and the Republic of Cameroon on the management of Lagdo dam (Galtima and Bashir 2002).

If response is stepped up on the part of the government and the recommendations put forward from research of this nature are followed, then, the flood problem can be successfully managed.

II. Objectives of the Study

The aim of this study is to simulate flooding in Adamawa State in particular using the CAESAR model and Remote Sensing approach and to highlight effective flood management strategies. Flood information were generated using Digital Satellite Imageries, Digital Elevation Model data set, Water level and/or Rainfall and Topographic Maps. These dataset, when incorporated into the simulation process produce a flood model of the study area. The following are the specific objectives of this study;

- To demonstrate how CAESAR model can rapidly simulate channels and floodplain flow pattern.
- To determine and delineate flood in Adamawa State.
- To analyse sediment pattern along Benue River Channel within Adamawa State
- To assess the vulnerability of settlements in the floodplain
- To generate a mathematical model for raster operation in the terrain and to assign vertical scale to Shuttle Radar Topography Mission (SRTM) height information relative to topographic map of the area.
- To suggest urgent sustainable measures for flood management in the State based on findings of this study.

III. Location of the Study

Adamawa State is located in the north-eastern extremity of Nigeria and shares a common border with the Federal Republic of Cameroun. Adamawa covers an area of 3,432,360 hectares. Figure 1 is the map of Nigeria showing the study are in red. The State lies between latitudes 7o 28' and 10o 56' N and longitudes 11o 30' - 13o 45' E in the Upper Benue catchment. The mean annual rainfall for the Savannah zones in the North is between 750- 850mm and it is 1400-¬1600mm for the Guinea zones in the South. The wettest months are July - August while the driest periods are March -May (Figure 5). The mean annual Temperature is 27°C-28°C in the Savannah and 18°C -27°C for the Guinea Zones. Adamawa is divided into two halves by River Benue that flows from Cameroon.

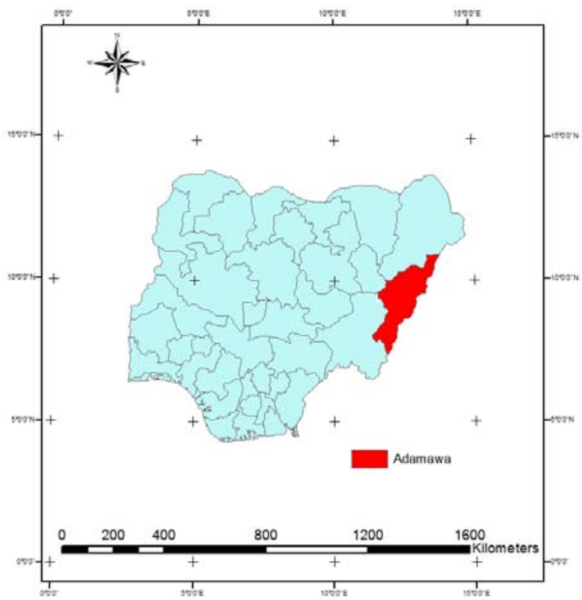

Fig.1 : Map of Nigeria showing Adamawa State in red. (Analogue Map, scanned and modified by authors)

There are three major geological zones corresponding to three structural types which in turn correspond to three associated rock types namely, the Basement complex rocks, the oldest known rock-types and are areas of uplift which consist of igneous and metamorphic rocks other than volcanic; sedimentary rocks, corresponding to areas of sedimentation, that is, the Benue trough lying wholly within the Basement complex rocks; and volcanic rocks which are isolated volcanic areas along the Benue trough and the Cameroun Volcanic line to the east and north-eastern parts of the State. The Quaternary to Recent deposits form the youngest litho-stratigraphical units in the State and are confined to river valleys and floodplains (Ashafa, 2009).

a) The Benue River and its Basic Hydrology

The Nigeria drainage system is divided into eight (8) catchments The two major rivers in the country are the Benue and river Niger. The Benue is an international river entering into Nigeria across the border with Cameroon, and runs for a distance of about 900 km from the border to the confluence with the Niger River at Lokoja, Kogi state (FMWR 1994). The peak flow resulting from local runoff arrives around the middle of September. After the peak, the recession is rapid and continues until around the middle of April when the trough of the hydrograph is attained. The rising limbs start by end of May. The Benue therefore, has one distinct flood peak. The flood hydrograph for Baro and Lokoja are very similar in shape only because the travel time between Baro and Lokoja is short. The peak in Lokoja lags the Baro peak only very slightly (NIWA 2001).

The Benue receives rivers Mayo Ini, Taraba, Donga and Katsina Ala which have their sources, like the Benue in the Cameroon Mountains. Between Lokoja and the Niger Delta, the only significant tributary is Anambra River which has its source from the Ayangba and Ankpa Highlands (NIWA, 2001). The Benue main tributary passes the Garua alluvial plain before joining the river Faro running along the border between Nigeria and Cameroon.

The Faro River transports huge sediment loads containing very coarse sandy materials eroded by heavy rainfall. The sediment loads are transported by floods and accumulate in the Benue near Yola city in Nigeria (FMWR 1994). At the upper reach, the river flows with a relatively steep slope and carries heavy loads of muddy sediments. The Gongola, another main tributary of the Benue originates in Jos plateau and discharges into the Benue near Numan which is located at its right bank. The Gongola also transports a large amount of sediment which accumulates at the river mouth near Numan.

In the lower reach, the Benue flows cover a width of 2 to 3km in the flood season. The major tributaries of Taraba, Donga, and Katsina-Ala originate from high mountains along the border of Cameroon and discharge into the Benue at the left bank. These tributaries have a river length of 300 to 350 km and catchment area of 200, 000 to 220, 000 km2. The tributaries have abundant discharge and clean runoff even in the wet season, compared with the Gongola, because their runoffs come down from high rocky mountains with rainfall of 200mm per annum (FMWR, 1994). Adamawa State is in the Upper Benue catchment (Figure 2).

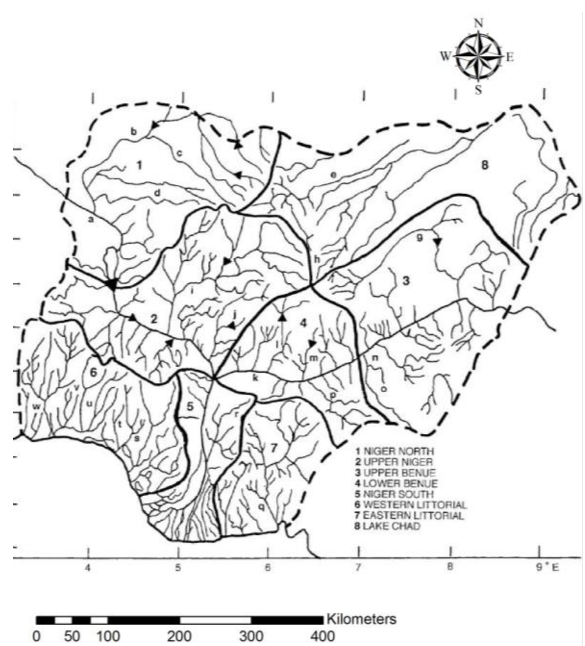

Fig.2 : Nigeria Catchment Map. Adamawa state is within the Upper Benue (3): Source NIWA, 2001.

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IV. Data and Methods

a) Data Acquisition and Procedure

- Collection and sieving of sediment samples into different grain size using USDH48 Sampler and Standard Test Sieve Machine.
- Height Data – 3 arc second SRTM Digital Elevation Model (90m)
- Water level data (to be converted to discharge)
- Topography Harmonization of SRTM and Topographic Map
- DEM preparation with ArcHydro tool kits
- Using CAESAR to simulate flood

CAESAR is a two dimensional flow and sediment transport model. The basic components of the CAESAR model are Digital Elevation Model, flow data and sediment information. Key processes operating in the model is shown in figure 3. It can simulate morphological changes in river catchments or reaches, on a flood by flood basis, over periods up to several thousands of years (Coulthard et al. 2002). CAESAR occupies a unique space in fluvial modelling. It has the capability to simulate timescales that are useful to engineers, researchers of fluvial systems (1-100 years) and to simulate flooding and morphological change of pertinent spatial scales (from 2 km reaches to 400+ km catchments). The cellular framework uses a regular mesh of grid cells to represent the river catchment studied. It is based upon the cellular automaton concept, whereby the repeated iteration of a series of rules on each of these cells determines the behaviour of the whole system. Some factors or rules exist in CAESAR for a hydrological model, hydraulic model (flow routing), fluvial erosion and deposition, and slope, processes.

Each grid cell is assigned initial values for elevation, water discharge, water depth, drainage area and grainsize fractions. For each time-step or iteration, these values are updated in relation to the immediate neighbours according to laws applied to every cell.

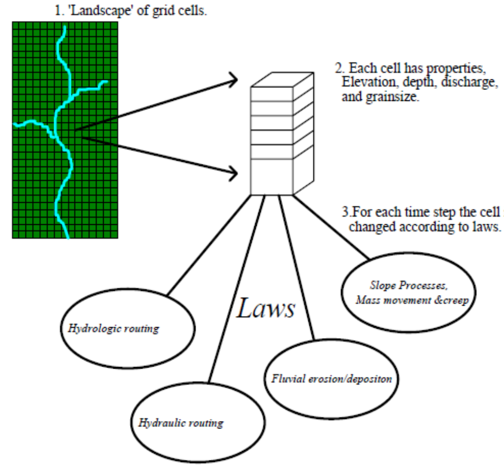

Fig.3 : Key processes operating in the CA Model (Coulthard, 1999).

b) Hydrological Model

For every minute of the model's run, the soil saturation for an individual cell (Jt) is calculated. The saturation for the next time-step T, is then calculated (Jt+1), but for this, an additional parameter is carried over, jt which before each calculation is set to the previous iterations jt+1. Then, if the rainfall rate (r) equals zero, Jt+1 is calculated according to equation 1 (Coulthard, 1999).

$$j_{t+1} = \frac{j_t}{1+\left(\frac{j_t T}{m}\right)} \quad (1)$$

$$J_{t+1} = \frac{m}{T}\log\left(1+\left(\frac{j_t T}{m}\right)\right)$$

If rainfall is not equal to zero, the equation is;

$$j_{t+1} = \frac{r}{\left(\frac{r-j_t}{j_t}\exp\left(\left(\frac{(0-r)T}{m}\right)+1\right)\right)} \quad (2)$$

$$J_{t+1} = \frac{m}{T}\log\left(\frac{m}{\left(\frac{r-j_t}{j_t}\exp\left(\left(\frac{(0-r)T}{m}\right)+1\right)\right)}\right)$$

m is a parameter that controls the rise and fall of the soil moisture deficit (Beven and Kirkby, 1979).

c) Flow Routing

For each grid cell, Coulthard (1999) stated that a runoff threshold is calculated (Equation 3) which is based upon the amount of water that will infiltrate through the soil, a balance of the hydraulic conductivity (K), the slope (S) and the horizontal spacing (Dx).

$$Threshold = KS(Dx)^2 \quad (3)$$

This is then subtracted from the soil sat... produced from equations 1 and 2, and the proportion above is treated as runoff, that below as subsurface flow. This subsurface flow is routed using a multiple flow algorithm as described by Desmet and Govers (1996) (Equation 4).

$$Q_i = Q_o \frac{S_n^x}{\sum S_i^x} \quad (4)$$

Here Q is the fraction of discharge delivered to the neighbouring cell from the total cell discharge (Qo) in m3s-1 , according to the slope S between the cell and its relative neighbours I, numbering from 1-x (x ranging from 3 to 8 depending on the number of neighbours). Qi is discharge routed to cell. With surface flow, the depth is calculated using Manning's equation (equation 5).

$$\text{Q} = \frac{A(R^{0.67} S^{0.5})}{n} \quad (5)$$

Where A is cross sectional area, R is hyd... radius, S is slope and n is Manning's Coefficient. If dealing with a cell 1m wide, this can be re-arranged to give equation 6, with width (w) as 1, leaving depth (d).

$$\text{Q} = d\left[\frac{R^{0.67} S^{0.5}}{n}\right] \quad (6)$$

However, in order to calculate the depth hydraulic radius has to be resolved.

This is a difficult approximation, as what is the hydraulic radius for a grid cell or part of a channel 1m wide? However for a rectangular/trapezoidal channel the hydraulic radius can be simplified as:

$$\text{R} = \frac{\text{A}}{\text{p}} = \frac{\text{wd}}{\text{w+2d}} \quad (7)$$

Excessively low slopes can result in excessive depths being calculated. To account for this, when the slope is less than 0.005, the depth is set to the same value as discharge. Three different methods of calculating the slope were tried, that of the average slope of the neighbours, that of the greatest slope of all the neighbours' and the average of all positive slopes. The method of average of all positive slopes was found to be the most stable, but the model shows some sensitivity to the method of slope calculation. Water is then routed according to equation 8 where the depth of water as well as cell's elevation is considered (Coulthard 1999).

$$\text{Q}_\text{i} = Q\frac{|(e+d)-e|'}{\sum|(\text{e}-\text{d})-\text{e}|'} \quad (8)$$

Here Qi is the discharge routed to cell, Qo the total discharge from the cell, e is the elevation and d depth of water (in meters) for each neighbouring cell i. In both expressions, differences in slope between diagonal neighbours are accounted for by dividing by $\sqrt{2(Dx^2)}$.

The calculation of depth is an important approximation as it allows discharges to be routed over as well as around obstacles.

A multiple flow scanning algorithm technique is employed to route hydrological model output in different directions (figure 4). In each scan, flow is routed to the three down slope neighbours (Murray and Paola 1994), but if the total flow is greater than the subsurface flow, the excess is treated as surface runoff and a flow depth is calculated using Manning's equation.

For all cells with a flow depth, fluvial erosion and deposition is calculated using the Wilcock and Crowe equation (Wilcock and Crowe 2003). This is applied to 11 grain size fractions (from 1 to 256 mm) that are integrated within a series of active layers (Hoey and Ferguson 1994).

Shuttle Radar Topographic Mission (SRTM) Data and topographical map data of Adamawa were converted into DEM in ArcGIS software environment and modified using ArcHydro tool for Terrain Pre-processing and incorporated with water and sediment input to run CAESAR model in reach mode. A sequence of erosion, deposition and landscape evolution was driven. This is then used to simulate individual floods, responding to both local hydraulic responses from runoff events, as well as cumulative inputs arriving from up-catchment that may themselves have been triggered by previous conditions.

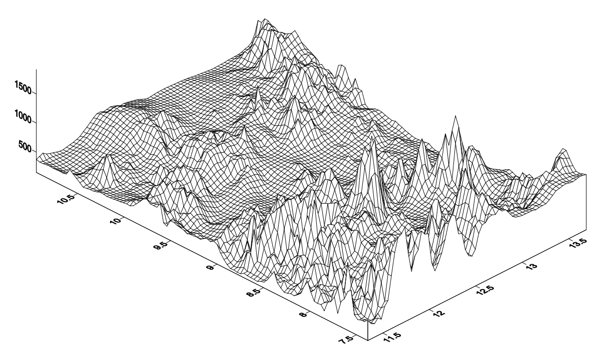

Fig.6 : Perspective View of Wireframe of the surface

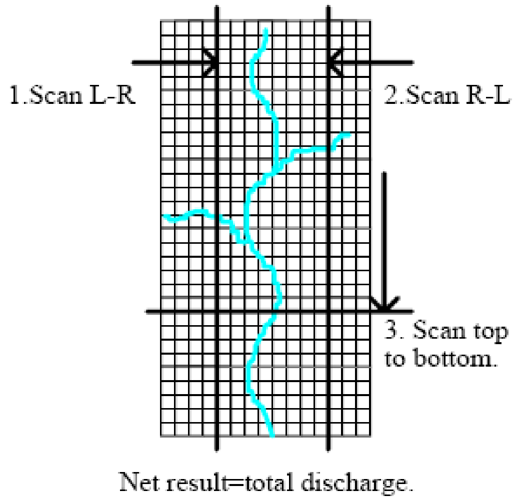

Fig.4 : The scanning multiple flow pattern (from north to south, east to west, west to east and south to north) in Caesar (Coulthard, 1999).

V. Results and Discussion

a) *Topography Harmonization*

Geospatial resemblance ratio between elevations of SRTM-derived DEM and the acquired conventional Topographic Map was found. Elevation information of 39 common nodes from SRTM and Topographic Maps were queried for terrain heights. While coordinate of points coincide, result from histogram reveals that there exist Shift in the queried heights from the two data source. The correction equation graph is given in figure 5. Raster operation mathematical model was generated for the terrain to assign heights to SRTM relative to Topographic Map:

$$H_{topo} = 0.997 H_{srtm} + 0.617 \ (RMS = 0.999) \quad (9)$$

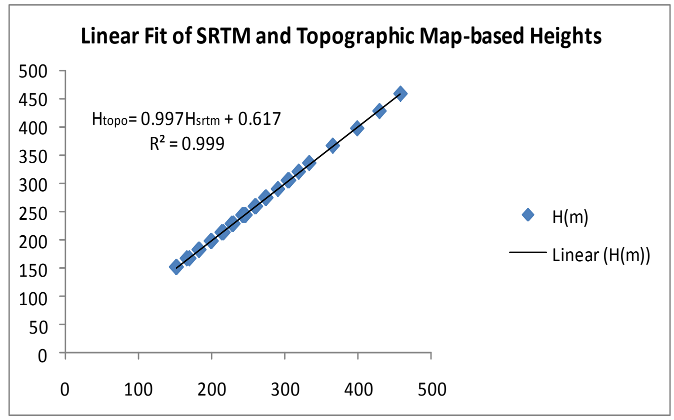

Fig.5 : Correction Equation Graph to assign heights to SRTM relative to Topographic Map

b) *Caesar Flood And Sedimentation Analysis*

i. Flood Analysis

Flow/ discharge were inputted into the model based on Cellular automaton concept, and it was seen to evolve in inundation levels (Figure 7) following the Benue drainage pattern in the study area (Figure 8). Flood was analyzed for low flow, medium flow and high flow by increasing the percentage of water input for the three regimes (Table:1). The flood analysis carried out show that an average of 134 settlements are at risk.

Table 1: Area liable to flooding and settlements at risk

REGIME	DISCHARGE (cu.m/sec)	INUNDATION AREA (Hectares)	SETTLEMENTS AT RISK
Low	120,000.60	43,050	77
Medium	250,000.60	2,337,60	132
High	350,000.60	8,097,06	192

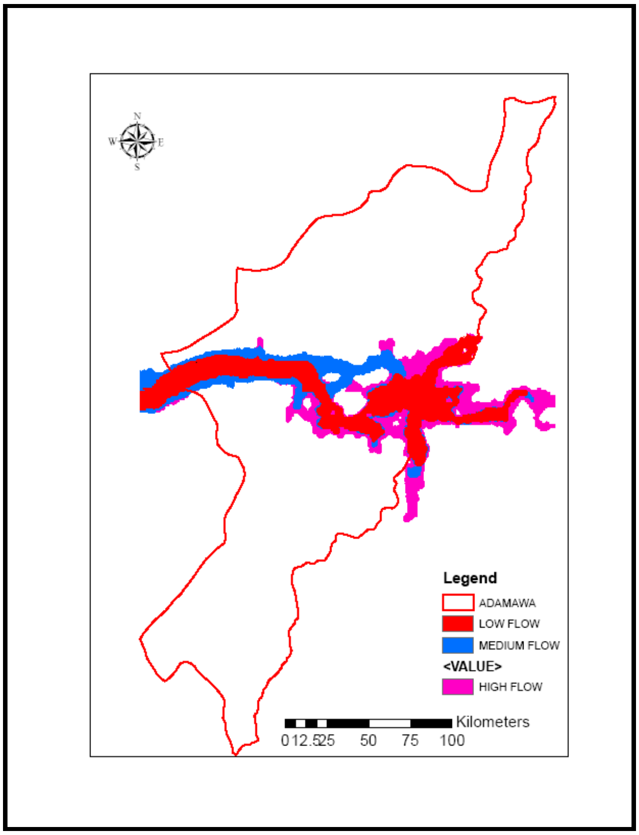

Fig.7 : Superimposition of inundation at Low (red), Medium (blue) and High Flow Regimes

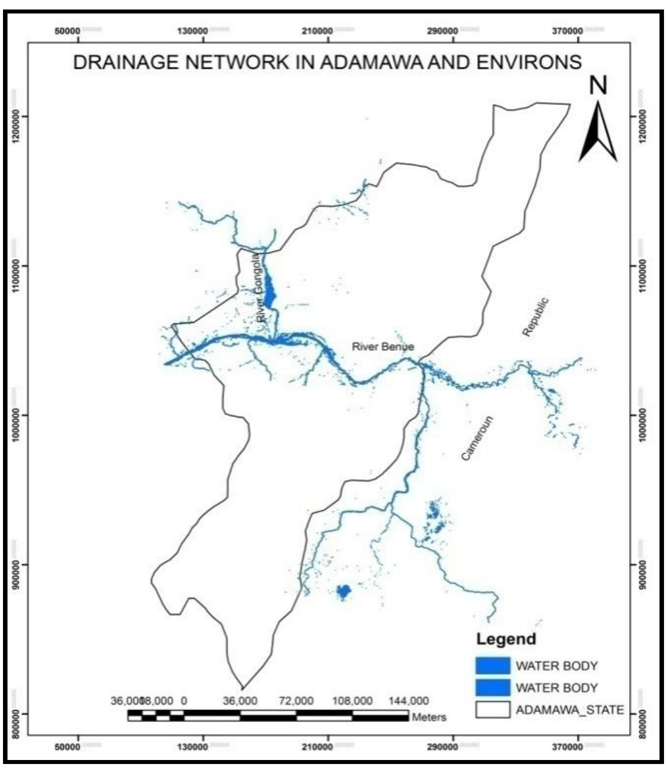

Fig.8 : Benue River Network in Adamawa area (Source: Authors)

ii. *Settlements At Risk*

Following the flood analysis and overlay operation, a large number of settlements in the Adamawa State floodplain were seen to be at risk (Figures 9, 10 and 11). A breakdown of the settlements at risk based on different flow regimes is given in Table 1. Some of the affected areas include Numan, Yola, Jimeta and Ngurore,Wango Dasin, Fufore, Nafori, Jambutu, Luga Damare, Wuro Bokki, Kapo, Imbutu and Ngbalang area, to mention a few.

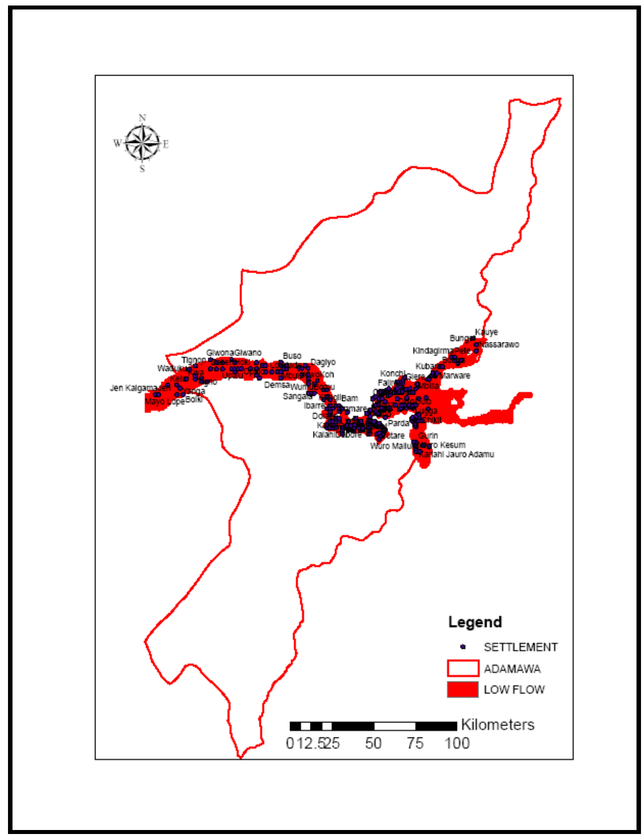

Fig.9 : Settlements on inundated areas at Low Flow Regimes

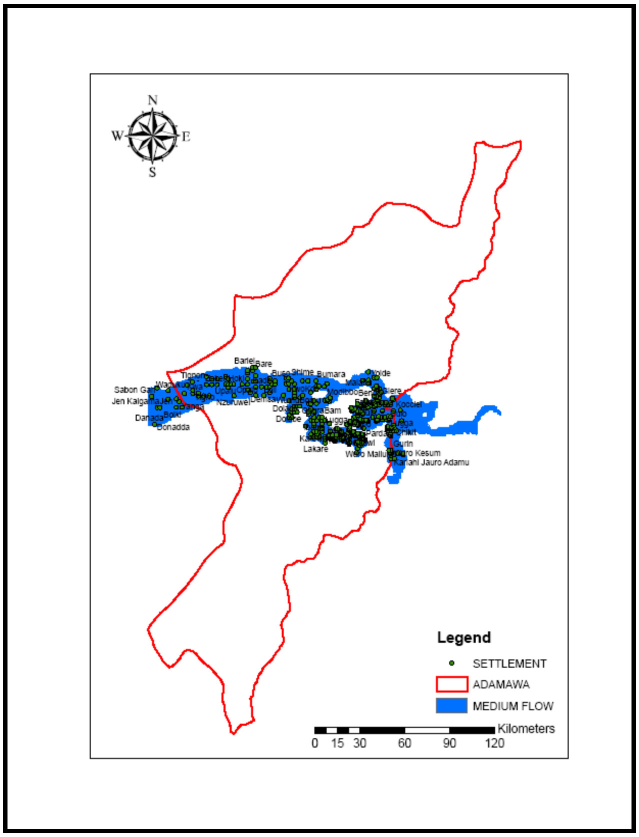

Fig.10 : Settlements on inundated areas at Medium Flow Regimes

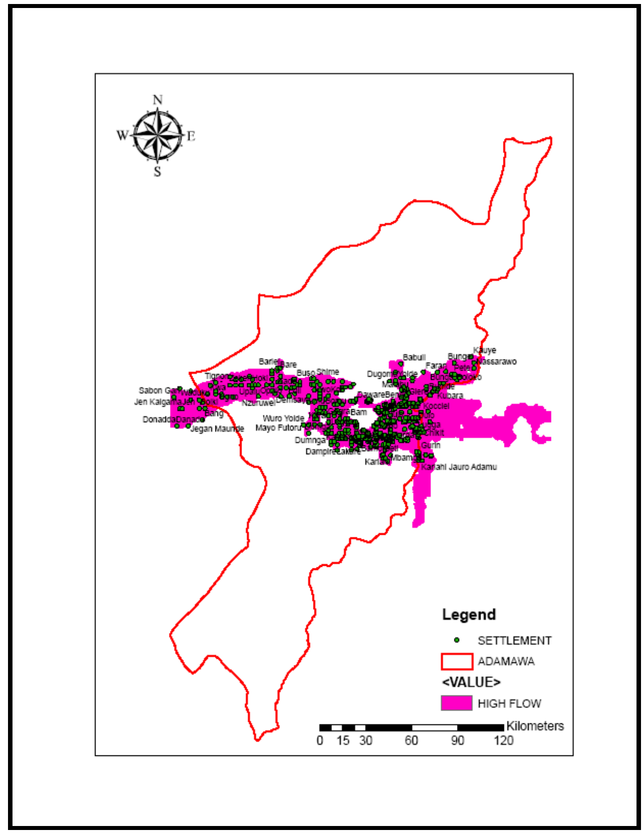

Fig.11 : Settlements on inundated areas at High Flow Regimes

c) Sedimentation Analysis Along The Benue River

Pattern of sedimentation along the Benue channel under different regime was considered. Cross sections A-A', B-B', C-C' and D-D' (Figure 13) and longitudinal profile (E-E') (Figure 14) of River Benue at Adamawa were taken (Figure 12) for normal, low, medium and high flow regimes.

The portion circled in red (Section B-B') (figures 15 and 16) depicts part of the channel with highest number of boulders. During simulation, it was observed that the river starts to overflow its bank at this point. A further investigation reveals that the presence of boulders along the channel hinders smooth flow of water thereby resulting in settlements being inundated. There are no significant differences in the sedimentation pattern along the channel under different flow regimes. This might probably be due to the fact that the river continues further down through Taraba and Benue States before forming the confluence with River Niger at Lokoja.

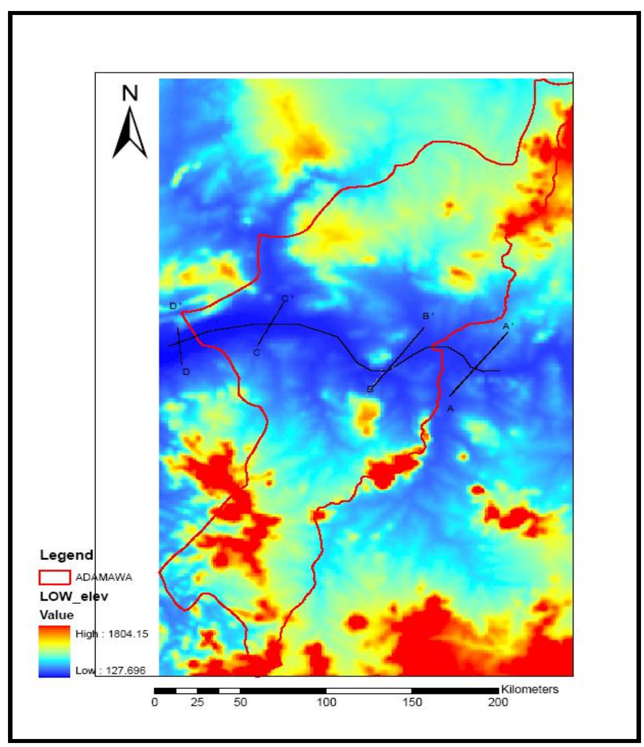

Fig.12 : DEM showing Cross Sections and Longitudinal Section along River Benue at Adamawa

Cross Sections :

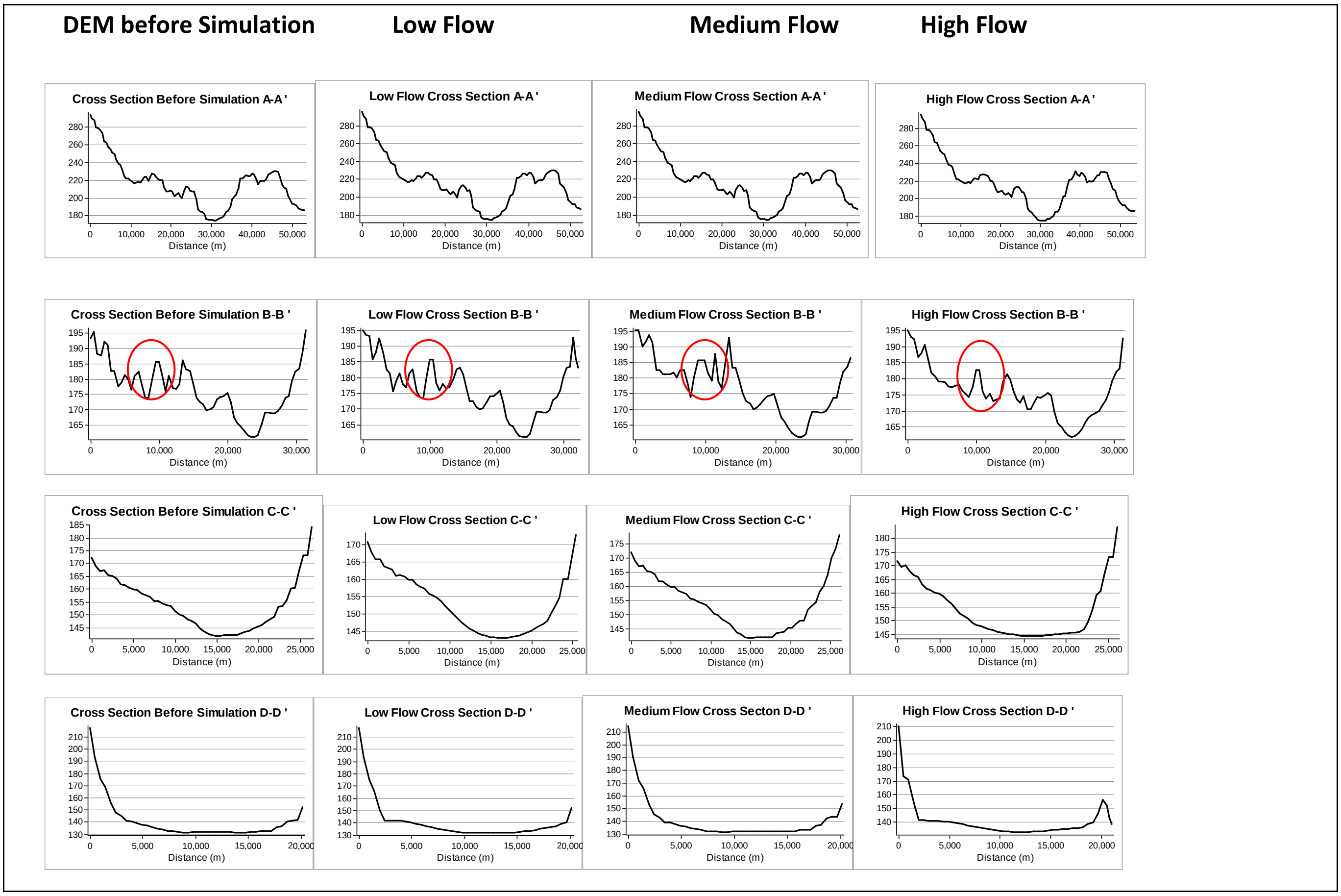

Fig.13 . Cross Sections along the Benue River in Adamawa State at different flow regimes.

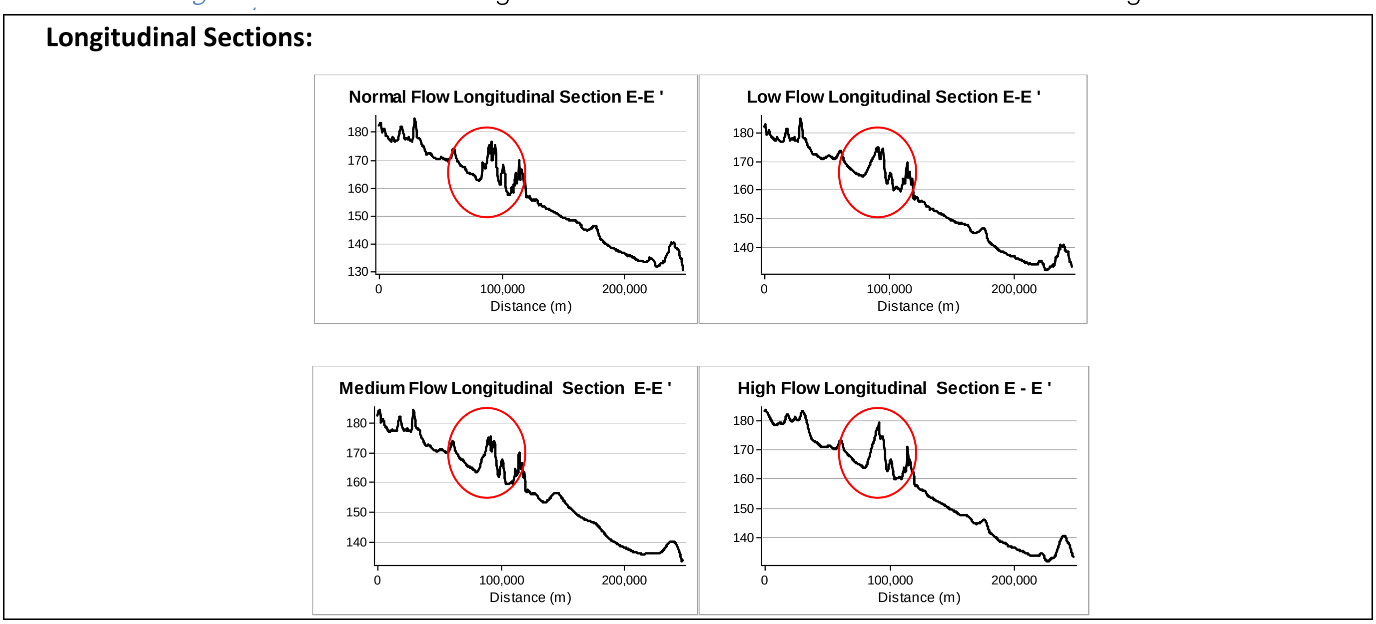

Fig.14 : Longitudinal Sections along the Benue River in Adamawa State for Normal, Low, Medium and High Flows. The circles show section B-B' with highest number of boulders.

VI. Conclusion and Recommendation

a) Conclusion

1. Flood analysis for low, medium and high flow regimes showed that an average of 134 settlements are at risk.
2. Longitudinal and cross section profiles depict the trend in which sediment loads are transported by flood and presence of boulders along the Benue channel.

3. Cellular Automaton Evolutionary Slope and River (CAESAR) model and Geospatial Information System (GIS) have proven in this study to be a useful tool for the determination of inundation level and to assess vulnerability of settlements in the Adamawa State.
4. Sustainable measures such as review of FEPA 1999 flood combat measures, dredging of the Benue, and relocation of people living near river banks were suggested for the management of flooding in Adamawa State.

b) Recommendations

The following recommendations are put forward for effective management and sustainability of the environment.

- The quality data, complex modelling and spatial analysis, and maps from this study would serve for good decision making and effective handling of flood in the Adamawa State floodplain;
- There are no significant differences in the sedimentation pattern along the channel under different flow regimes. This might probably due to the fact that the river continues further down through Taraba and Benue States before forming the confluence with River Niger at Lokoja. A further study over a long period of time is therefore recommended.
- Good policy and planning with results from this effort can reduce the exposure to flooding and offer a genuine control and reliable management.

VII. Acknowledgement

Prof. Tom Coulthard- University of Hull, UK - for assistance and access to his PhD Thesis and Caesar Model.

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