The Flood Hazard Assessment of Kaduna Metropolis, Nigeria

***Sule, Z. O., Sani, S. O. and Anoze, D. S.**
Department of Surveying and Geoinformatics, Federal Polytechnic Idah, Kogi State.
**Corresponding author: onucheyosule@gmail.com*

***Abstract*—The hazard and damage caused by flooding cannot be overemphasized in terms of loss of life, property, displacement of people and disruption of socio-economic activities as well as the loss of valuable agricultural land due to the problems associated with flood plains such as excessive rainfall and dam failures. Several areas along the coast of the Atlantic Ocean and along Major River valleys are affected by floods every year of which, urban flooding is gradually becoming a serious ecological problem in Nigeria. To gain better understanding of the flood problem especially for planning purposes, flood hazard maps are often required. A combination of data records on flood plains such as land use/cover, river/flood stage, and digital elevation models are used to predict future flood stages and likely impacts. Geographical Information System (GIS) and results of analysis of flood stage data using a combination of digital elevation model and land use/land cover data as well as rainfall data were used to map out the areas that are prone to flood hazard and forecast flood in Kaduna Metropolis. Areas under high risk due to flooding were also determined. The study revealed that most of the areas lying close to the River Kaduna's flood plain are under severe threat to flooding and some suggestions are proffered.**

Keywords—Flood probability, Flood hazard management, Mapping, GIS and Rainfall forecasting

I. Introduction

Flooding is in general a temporary condition of partial or complete inundation of normally dry areas from overflow of inland or tidal waters or from unusual and rapid accumulation or runoff. Flooding phenomenon is considered the world's worst global hazard in terms of magnitude, occurrence, geographical spread, loss of life and property, as well as displacement of people and socio-economic activities. In the tropical and subtropical regions, severe flooding hazards of grave consequences resulting from heavy thunder storms, torrential monsoon downpours, hurricanes, cyclones and tidal wave surges in coastal and estuarine environments are yearly occurrence. Flood disasters are said to account for about a third of all natural catastrophes throughout the world (by number and economic losses) and are responsible for more than half of the facilities' damage [1]. Flood damage has been extremely severe in recent decades and it is evident that both the frequency and intensity of floods are increasing. 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 [2].

In Nigeria, most floods occur because of excessive rainfall and dam failures. It has been estimated that more than 700,000 hectares of useful land for agricultural and human settlements are rendered useless due to annual floods. For example, in August 2001, excessive flooding caused severe devastation on land property and human life in Kano and Jigawa States when rivers Challawa and Kano were flooded. It was reported that twenty people died in Kano, and a further 48,500 were displaced. While in Jigawa, 180 deaths were registered, 800 people were injured and 35,500 displaced. The total number of people affected, including those whose farmlands were washed away, exceeded 143,000 [2].

In Kaduna metropolis and environs, flooding is not a regular annual phenomenon but the potential risk is very high in the low-lying settled flood plains. In addition, rapid urban expansion and encroachment of settlements into the areas liable to flood is also continuing rapidly and unabated. More so, recent floods especially of August 23, 2003 caused inundation of huge areas on the flood plain and as a result, cultivable lands and human dwellings were adversely affected and several thousands of people rendered homeless. It was estimated that about 30,000 houses were destroyed in twelve (12) local government districts and at least five thousand (5,000) were left homeless. It was also reported that two (2) people died along the course of River Kaduna from its upper reaches, while more than 1,500 people in Kaduna Metropolis were affected. The areas that were most affected were Malali, Barnawa, Angwan Rimi and other areas of Kaduna Metropolis along River Kaduna. In addition, the people of Kaduna experienced a tremendous increase in floods as a result of heavy down fall of rain that occurred in August 03, 2005 which made the river Kaduna to over flow its bank. Properties worth millions of naira were destroyed, farmlands were washed away, lives were lost and even the Kaduna Bridge was submerged by the flood. In some areas, for example Angwan Rimi, people used canoes to cross from a point to their destination [2].

Flood hazard mapping is a means of providing flood-plain information for planning and management programs. For most practical purposes and certainly in popular usage a meaningful flood definition will incorporate the notions of damage and inundation [3].

This work focuses on mapping out the areas that are prone to flood hazard along the Kaduna River from the application of Geographical Information System (GIS).

II METHODOLOGY

Satellite Imagery (LandSat Enhanced Thematic Mapper (ETM) of 15m resolution) of Kaduna state was acquired and digitized using ArcGIS 9.2 and from which the land use map was produced. The digital terrain model (DTM) and the 3D surface of the area were generated from the Digitial Topographical map. The DTM was used together with the rainfall data for the analysis and compilation of the flood hazard map. Furthermore, the data used in the plotting of Digital Terrain Model (DTM) and the 3D surface were generated from digital topographical map from which the contour map in ArcGIS environment was produced, the TIN surface was first created from the data generated. The 3D surface and the DTM were produced from SURFER 9.0.
The flood hazard zones were identified by interpreting the topographic map, and LandSat imagery. In the process, the watershed of each stream and river was firstly identified from the topographic map and was digitized. After that, flood plains, built up areas were identified and digitized by using the LandSat imagery. The final flood hazard map was prepared by overlaying the digital contour map of the area on the land use map digitized from the LandSat imagery and the overlaid map was transferred to the interpolated kriging surface of the area from which the zoning of the flood hazard areas in Kaduna metropolis was carried out.

Gauge Height and Previous Years of Flooding

The Table 1 shows the records of the gauge height taken along the river Kaduna and also the years in which flooding occurred. The gauge heights were taken in two catchments areas. The areas are: Kaduna south and Bakin Kogi.

Table 1: Gauge Height Records and Previous Flooding.

S/N	Year	Gauge height(M) [Kaduna South]	Gauge height(M) [Bakin Kogi]	Flood Year
1	1995	5.08	4.10	NO
2	1996	5.24	4.16	NO
3	1997	5.41	4.37	NO
4	1998	7.00	4.21	NO
5	1999	7.07	4.90	YES
6	2000	5.55	4.82	YES
7	2001	5.50	3.94	YES
8	2002	5.28	3.64	NO
9	2003	6.10	2.95	YES
10	2004	5.99	2.87	YES
11	2005	9.80	8.50	YES
12	2006	6.20	3.98	NO
13	2007	8.03	5.74	YES
14	2008	7.82	3.89	YES

Source: Data from Kaduna State Water Board and [4]

Flood Forecasting/Prediction

Flood prediction was conducted so as to know the amount of rainfall that will cause flooding in any future year. The data used for the prediction was the annual rainfall data of Kaduna metropolis from 1995 to 2008. The simple linear regression formula was used for the prediction. The formula states that, for two variables X and Y, where Y is dependent on X, the best fit straight line, takes the form [5];

$$Y = mx + c \qquad (i)$$

Where;

$$m = \frac{n\sum(x_i y_i) - \left(\sum x_i\right)\left(\sum y_i\right)}{n\sum x_i^2 - \left(\sum x_i\right)^2} \qquad (ii)$$

$$c = \frac{\left(\sum y_i\right)\left(\sum x_i^2\right) - \left(\sum x_i\right)\left(\sum x_i y_i\right)}{n\sum x_i^2 - \left(\sum x_i\right)^2} \qquad (iii)$$

Y= the Annual rainfall (mm), X= the year, and n= the total number of years.

Table 2: The Annual Rainfall of Kaduna Metropolis

S/N	Year [X]	Annual rainfall(mm)[Y]
1	1995	965.5
2	1996	1294.6
3	1997	1553.1
4	1998	1561.5
5	1999	2332.4
6	2000	1842.2
7	2001	1673.6
8	2002	1934.6
9	2003	1934.4
10	2004	2041.6
11	2005	1822.3
12	2006	1871.7
13	2007	1592.7
14	2008	1668.5
Sum	**28021**	**24088.7**

Source: Data from Kaduna State Water Board.

The computation shows that m= 35.59274725 and c= -69518.2622. The predicted equation now becomes:

$$Y = 35.59274725x - 69518.2622 \qquad (iv)$$

Therefore, with this equation, it is possible to predict the amount of rainfall (Y) for year 2010 to 2017, (Table 3).

Table 3: The Forecasted Rainfall

S/N	Predicted Year	Forecasted Rainfall(Y)[mm]
1	2010	2023.159773
2	2011	2058.75252
3	2012	2094.345267
4	2013	2129.938014
5	2014	2165.530762
6	2015	2201.123509
7	2016	2236.716256
8	2017	2272.309003

Furthermore, the Standard Deviation (δ) of annual rainfall was computed for the previous flooding years, this was done so as to establish a confidence (prediction) interval for the forecasted annual rainfall computed for the year 2010 to 2017 in Table 3. The formula used for the standard deviation was;

$$\delta = \sqrt{\frac{\sum (y-\mu)^2}{(n-1)}} \qquad (v)$$

To get the confidence level, it should be noted that the predicted values are not 100% reliable due to its probabilistic nature. The expected annual rainfalls were calculated at 95% confidence level [6].

. (vi)

Where δ is the standard deviation and n is the number of observations. Therefore the general equation for the confidence (prediction) interval now becomes;

$C.I. =$Y (vii)

Where δ = 240.90(standard deviation).

Rating of the Probability of Flooding in the Flood Hazard Zone

The flood hazard zones were identified by interpreting the topographical map, the land use map, the 3D model, the soil types around the river and in the process the slope and degree of gradient were calculated at different places in relation to the lower plate.
The probability rating of flooding in the flood hazard zone for this study was done by considering some factors based on their significance of causing flooding. These factors are (Table 4):

i. Annual Rainfall, Slope Percentage of the water shed, the degree of gradient of river, etc.
ii. Slope Percentage of the watershed
iii. The degree of gradient of river and stream
iv. The types of soil around the river
v. The drainage density
vi. The land use map [7].

A probability weight was attached to each of the above factors; the weight of each factor was given on the basis of its estimated significance in causing flooding. The weight of each factor is presented in the Table 4.

Table 4: Weight Attached to Factors Causing Flooding

Factors	Weight
Annual rainfall, Slope % of the water shed, the degree of gradient of river	8
Slope percentage of the watershed	6
The degree of gradient of river	5
Drainage density	4
Land use	3
Types of soil around the river	2

Source: [6]

Each of the above factors was divided into number of classes and each class was weighted according to the estimated significance of causing flooding. The maximum weight for each class of every factor was 8, while the minimum was 2. The total weight that was used for considering the rate of probability of flooding for this study was computed by using the formula below:

Total weight of each factor = Factor Weight * Weight of factor class [7].

III RESULTS AND DISCUSSION

Figure 1 is the result of the overlaid digital contour map on the land use map of Kaduna metropolis. Figure 2 depicts the Wire Frame of the area. Figures 3 and 4 depict the flood hazard map and the flood hazard zone of Kaduna metropolis respectively. The graphs in figures 5 and 6 below are the graphs of Annual Rainfall against the Year and Previous Rainfall of Flooding against the year it occurred.

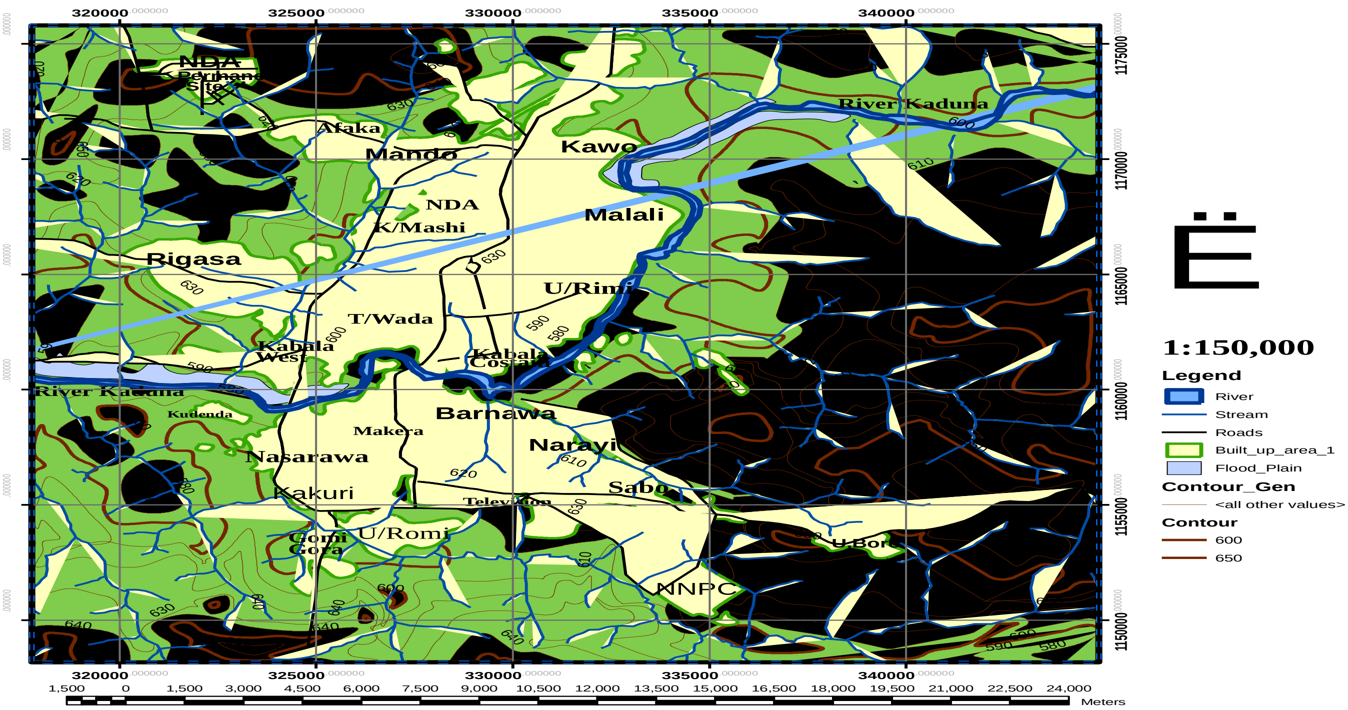

Figure 1: The Overlaid (Landuse and Contour) Map of Kaduna Metropolis

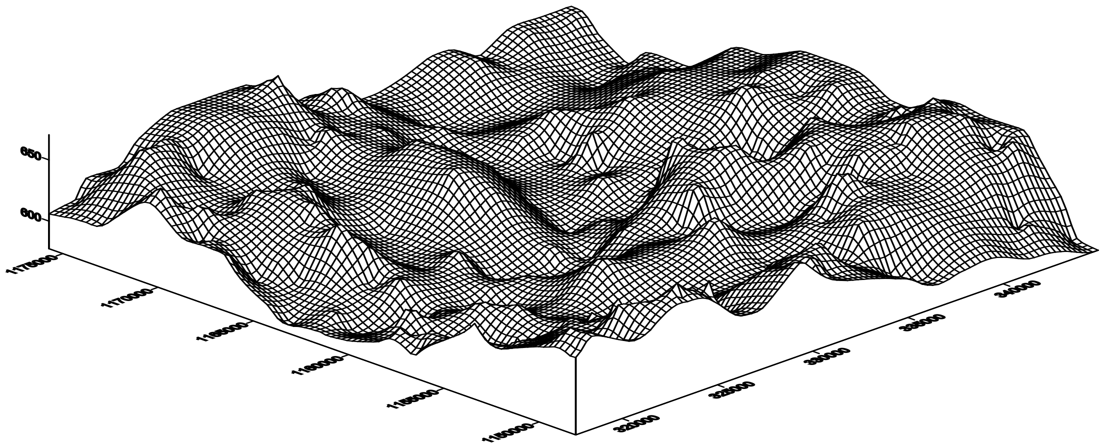

Figure 2: The Digital Elevation Model (Wireframe) of Kaduna Metropolis

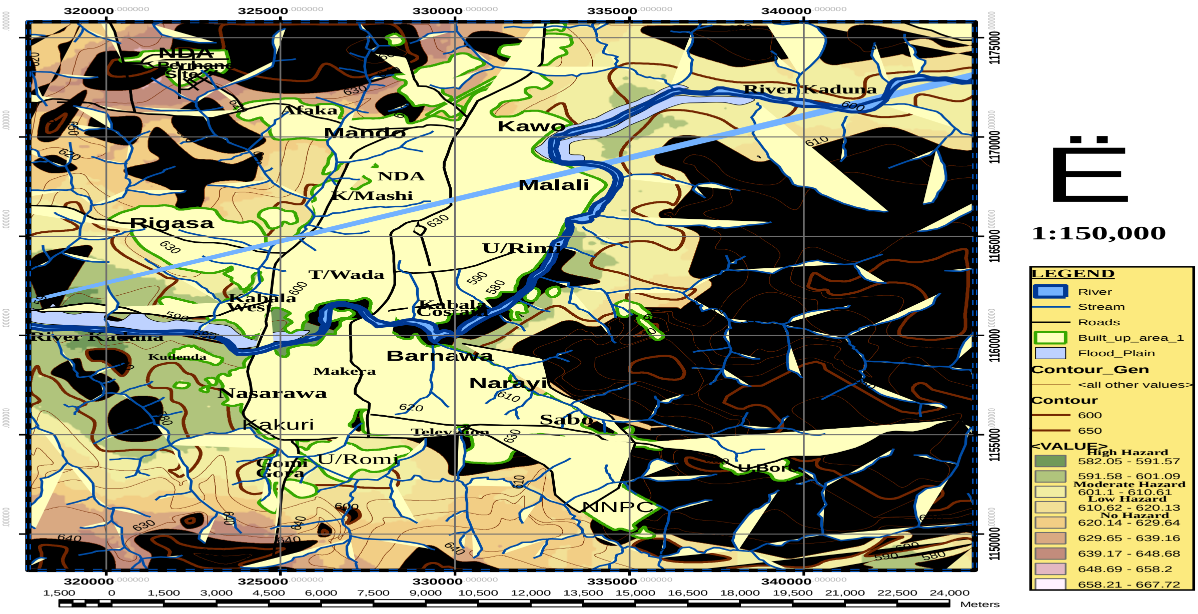

Figure 3: The Hazard Map for Kaduna Metropolis

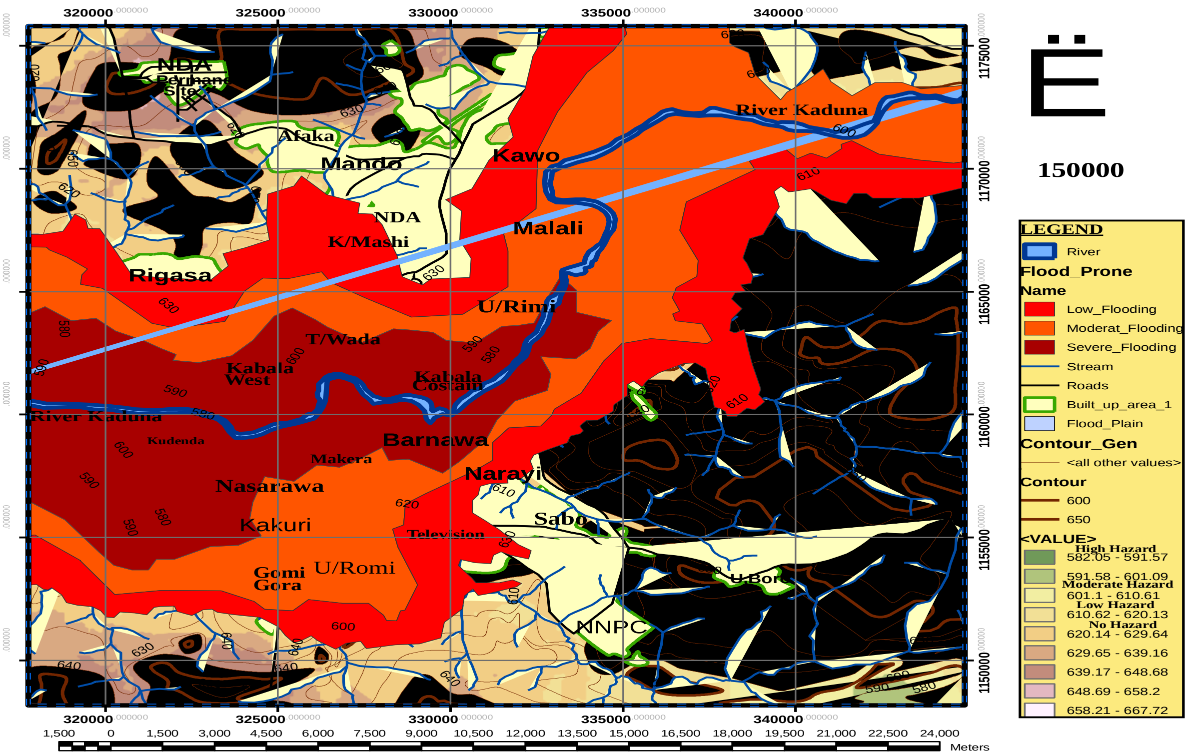

Figure 4: The Flood Hazard Zone of Kaduna Metropolis

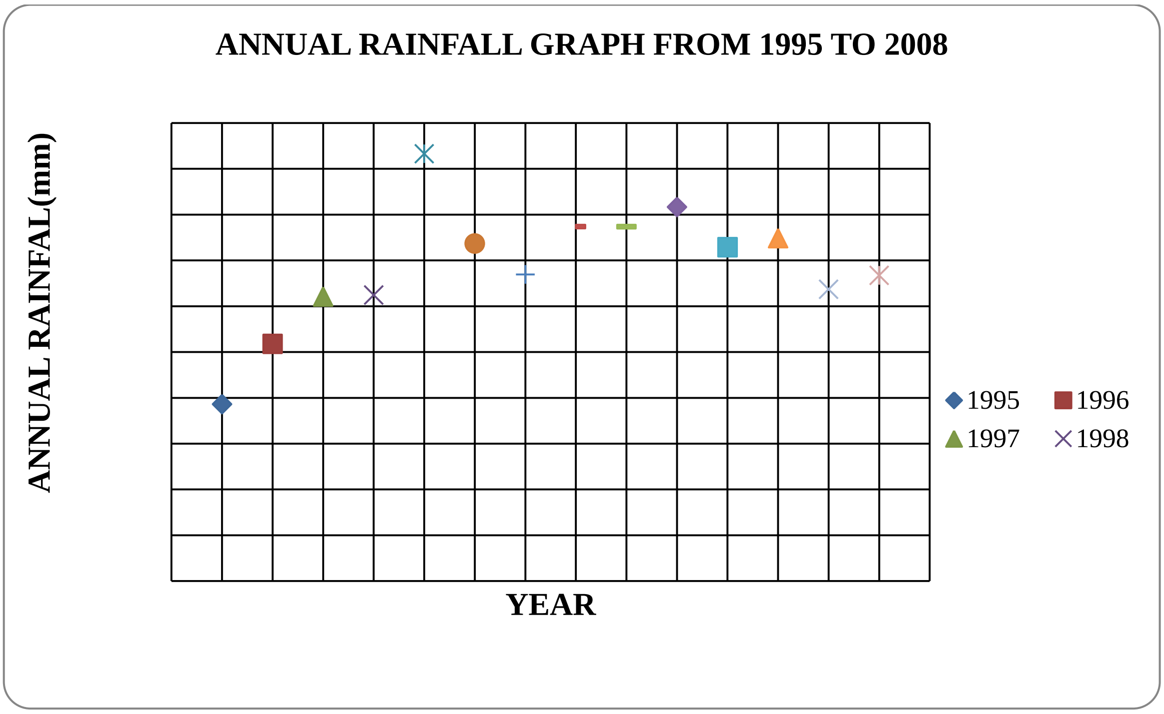

Figure 5: Annual Rainfall

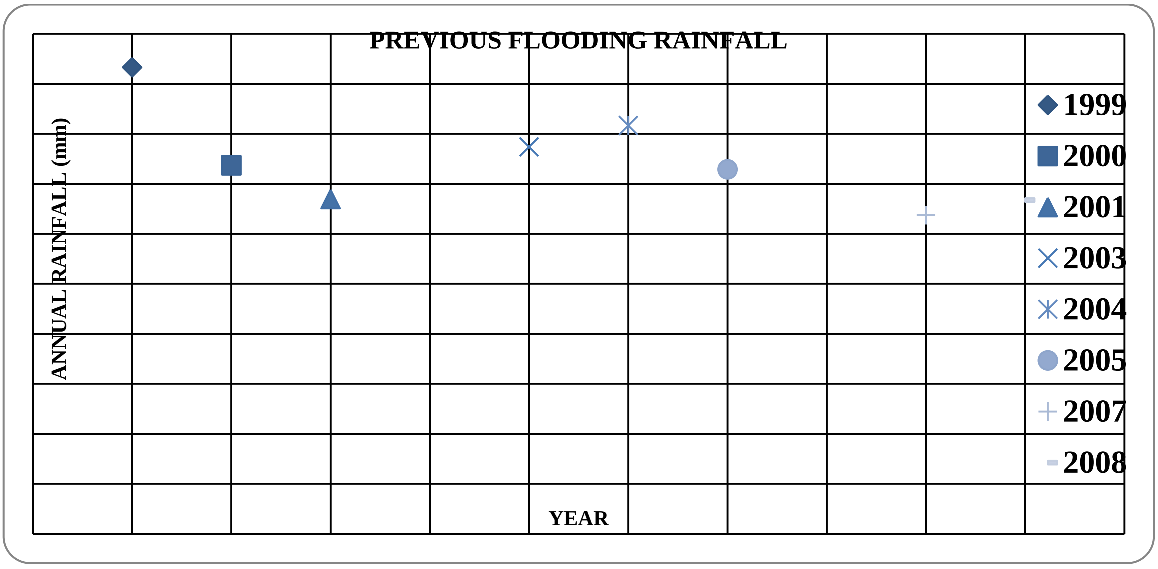

Figure 6: Previous Flooding from Rainfall

IV ANALYSIS

Mapping Analysis

The results revealed that the general relief of the area is an undulating plain land at a height between 579m to 670m. The overlaid map (Figure 1) also revealed that flood plain areas and some areas (Kudenda Village, Kabala West, Kabala Costain, Tunduwada and Barnawa) that are close to the river are under high risk of flooding, example include; farmlands, built up areas, etc. Most of these areas are dense settlements with equally high population densities. The classification in Table 5 shows the areas that are prone to high risk of flooding, moderate risk of flooding and low risk of flooding with elevation ranges of 579-599.222m, 599.222-609.333m and 609.333-619.444m respectively.

Hazard Analysis

The word "hazard" means the probability of occurrence within a specified period of time and within a given area of potentially damaging phenomena [6]. Naturally the areas which have the greatest danger of flooding are the flood plains, fadama farmlands and areas along the river banks. (Figures 3 and 4).

Table 5: The Classification of Flooding in the Area based on the TIN Surface Analysis

S/N	Classification	Elevation Range(M)	Areas
1	High risk of flooding	579.0-599.222	KabalaWest, T/Wada, Kabala Costain, Makera, Barnawa, part of Nasarawa.
2	Moderate risk of flooding	599.222-609.333	Malali, U/Rimi, Kakuri, Kawo, Nasarawa.
3	Low risk of flooding	609.333-619.444	Part of Mando, Afaka, part of Rigasa.

Considering the weight of each factor showed in the Table 4 and its individual corresponding class, the maximum weight of each factor is the result of the multiplication of such factor weight with the weight of its dividing first class. Thus, the maximum weight of each factor, that is Annual rainfall, slope percentage of the watershed, the degree of gradient of river and stream, drainage density, the land use and the soil types around the river, are 64, 48, 40, 32, 24 and 16 respectively. Summing them together gives 224 which is the total maximum weight (Table 6).

For the total minimum weight of each factor, it is the result of the multiplication of the factor weight with the weight of its lowest class. These are 16, 12, 15, 8, 6 and 4 respectively and the summation of the minimum weight gives 61 (Table 6). Considering this, the total weight of the flood hazard zone with the highest probability to be flooded is 224 while the lowest probability is 61.

Table 6: Total Weight of the Flood Probability

Factors	Weight*1st class	Weight*2nd class	Weight*3rd class	Weight*4th class	
Annual Rainfall(mm)	64	48	32	16	
% Slope of the watershed	48	36	24	12	
Degree of gradient of river and stream	40	30	20	15	
Drainage Density	32	24	16	08	
The land use types	24	18	12	06	
The soil types	16	12	06	04	
Total	224	168	110	61	563
% Total	39.79	29.84	19.54	10.83	~~100~~

From Table 6, the percentage total of the summation of the total weight are 39.79%, 29.84%, 19.54% and 10.83% for 224, 168, 110 and 61 respectively.

Considering a statistical range formulated for the total weight data obtained above for the study area, the weight of each class was given as:

- High = 168-224
- Moderate = 111-168
- Low = 61-110

Based on the above weight, the implication is that places having 39.79% of weight class are bound to experience a severe flood hazard which can result to collapsing of many houses, road disruptions, washing away of farmlands and loss of properties. The places that will be affected include: Kabala west, Kabala costain, Barnawa, T/wada, part of Makera and part of Nasarawa. Also places having 29.84% of weight class are bound to experience moderate flooding which can result into the evacuation of some houses and can lead to closing of main traffic bridges. The places that will be affected include: Malali, Kawo, U/Rimi, part of Narayi and Kakuri. Furthermore, places like Television, some parts of Narrayi, K/Marshi, and some places in Kawo will experience Minor Flooding which can cause inconveniences such as closing of minor roads and the submergence of low level bridges.

The Figure 4 shows the zoning of the areas that are prone to severe (high) flooding, moderate flooding and low flooding. The zoning was done by interpreting the hazard map, which is the combination of land use map, digital topographical map and the kriging surface of Kaduna metropolis. From the results, areas having height between the range of 582.05 and 601.09 were classified to be the areas of severe flooding zone, areas having height between the range of 601.10 and 610.61 were classified as the moderate flooding zone and any areas having height between 610.62 and 620.13 were areas of low flooding zone. Each zone was identified on the map/ imagery and digitized and colour was given to each zone created.

The Table 7 below shows the zones and the areas/places that fall in each class of the zones as it can be seen in Figure 4.

Table 7: The Classification of Flood Hazard Zone

S/N	ZONE	RANGE (M)	AREAS
1	Severe Flooding	582.05-601.09	Flood plain, Kabala West, T/Wada, Kabala Costain, Makera, part of Nasarawa.
2	Moderate Flooding	601.10-610.61	Malali, U/Rimi, Kakuri, Kawo, part of Nasarawa.
3	Low Flooding	610.62-620.13	K/Mashi, Narayi, some places in Kawo, some places in Rigasa.

Comparison between the Previous Rainfall and Forecasted Rainfall.

By comparing the annual rainfall of previous years in which flooding occurred, it is likely that flood will occur in year 2010, 2011, etc. See Table 8

Table 8: Previous and Forecasted Rainfall

	PREVIOUS RAINFALL FLOODING		FORECASTED RAINFALL	
S/N	Previous Year (X)	Previous Rainfall (Y)[mm]	Predicted Year (X)	Forecasted Rainfall (Y)[mm]
1	1999	2332.4	2010	2023.2
2	2000	1842.2	2011	2058.8
3	2001	1673.6	2012	2094.3
4	2003	1934.6	2013	2129.9
5	2004	2041.6	2014	2165.5
6	2005	1822.3	2015	2201.1
7	2007	1592.7	2016	2236.7
8	2008	1668.5	2017	2272.3

Furthermore, the graph of Annual Rainfall from 1995 to 2008 (Figure 5) and the graph of Previous Flooding Rainfall (Figure 6) show that the trend are random in behaviour as well as that the floods that occur are not only as a result of the amount of rainfall experienced but some other factors that can influence flooding in any year. These factors may include the gauge height of the river, the drainage density, the land use types, the soil types, infrastructure, etc.

Table 9: The Confidence Interval of Acceptable Future Rainfall and the Forecasted Rainfall

S/N	Range of Acceptable Future Rainfall from Confidence Interval (C.I)mm	Predicted Year	Forecasted Rainfall(mm)
1	2165.47-2499.33	2010	2023.2
2	2165.47-2499.33	2011	2058.8
3	2165.47-2499.33	2012	2094.3
4	2165.47-2499.33	2013	2129.9
5	2165.47-2499.33	2014	2165.5
6	2165.47-2499.33	2015	2201.1
7	2165.47-2499.33	2016	2236.7
8	2165.47-2499.33	2017	2272.3

From table 8, comparing the forecasted rainfall values computed for the predicted years with that of the previous flooding years, it shows that flooding may likely occur in years 2010, 2011, 2012, 2013, 2014, 2015, 2016 and 2017. According to table 8, flooding may not be more severe as previously experienced because the forecasted rainfall for the years 2014, 2015, 2016 and 2017 falls within the confidence interval (C.I). Besides, the flooding that may likely occur in years 2010, 2011, 2012, and 2013 will also not be more severe as previously experienced because their individual forecasted rainfall value falls just short of the lower limit of the confidence interval (C.I).

V CONCLUSIONS

The threat of flooding in Kaduna Metropolis and environs has been highlighted in this study. GIS technologies provide effective means of studying flood hazard. A combination of flood stage data and digital elevation models enabled the estimation of area extent of flood and areas under high risk to flooding. Therefore, to enable proper understanding, management and mitigation, flood information and hazard maps are required. Long-term flood data in addition to discharge and rainfall data are required to generate flood models and scenarios for given flood return periods. Considering the magnitude of the 2003 flood in Kaduna and the fact that floods occur unexpectedly, there is need for an effective hazard mapping and hazard management strategy to abate the problem.

There is the need for a thorough hydrological modelling of the Kaduna River or the whole catchment to its outlet at the Kaduna South Water Works and beyond to enable policy makers make informed decisions on the activities of humans in the floodplains. Flood control structures should be constructed in areas of high vulnerability. There is also the need for consistent flood stage monitoring by the Kaduna State Water Board and National Emergency Management Agency (NEMA). The need for intense computerized GIS database for flood focus cannot be overemphasized such that it will help the planners and decision makers to take positive and prompt step during pre-disaster situation and it will also help them during post disaster activities to assess the damages and losses incurred due to flooding.

REFERENCES

[1] AGBM (2008). Flood Warning System for the Don River. A Publication of Australian Government Bureau of Meteorology. Retrieved from http://www.bom.gov.au/hydro/flood/qld/networks/index.shtml. Accessed on 13-08-2010.

[2] S.P. Aggarwal, and D.N. Jeb, Flood Inundation Modelling of the River Kaduna using Remote Sensing and Geographic Information Systems. Nigerian Journal of Applied Sciences Research. 2008 4(12): 1822-1833.

[3] R. Ward, *Floods a Geographical Perspective.* London: 1978 Macmilian Press Publishing Limited.

[4] A.W. Alayande. and J.A Chukwuemeka The Impacts of Urbanization on Kaduna River Flooding. Journal of American Science 2010. Retrieved from http://www.americanscience.org. Accessed on 14th March, 2010.

[5] P. Dale, Introduction to Mathematical Techniques used in GIS. 2005 CRC Press. USA

[6] J.K. Leonard *Confidence Interval for the Mean*: Business Statistics*, 4th edition.* 2004 The McGraw-Hill Companies International. USA:

[7] P. Pramojanee, C. Tanavud, C. Yongchalermchai and C. Navanugraha. An Application of GIS for Mapping of Flood Hazard and Risk Area in Nakorn Sri, Thammarat Province South of Thailand. Prince of Songla University, 2007 Department of Land Development.