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FLOOD HAZARD ASSESSMENT AND DECISIONS SUPPORT USING GEOGRAPHIC INFORMATION SYSTEM: A CASE STUDY OF UYO CAPITAL CITY, AKWA IBOM STATE, NIGERIA

Uwem J. Ituen[1] --- Imoh Johnson[2] --- Ndifreke Nyah[3]

[1,2,3]*Department of Geography and Natural Resource Management, Faculty of Social Sciences University of Uyo, Uyo, Akwa Ibom State, Nigeria*

Abstract

The study aimed at assessing flood prone areas in Uyo Capital City with a view to suggesting control measures. It used 2008 NigerSat imagery, soil texture, rainfall, and road network data of Uyo. With Multi-criteria evaluation technique, the use of Geographic Information Systems (GIS), Global Positioning System (GPS), Digital Elevation Model (DEM) and single output map algebra were employed to generate flood hazard map of Uyo. The DEM was used to generate contours, terrain elevation, slope, and aspect surfaces, where aspect provided the direction of slope that contributed to flood inundation. Flood mapping was done to determine flood locations based on a 3D terrain assessment while flood hazard assessment formed the basis for flood control in the area. From the result of the study, flood hazard areas in Uyo Capital City were identified and classified into high, moderate, and low hazard zones. Based on this classification however, flood control measures have also been rated as critical, less critical, and non-critical respectively. Out of the 25 flood locations captured during the 2012 flash flood event, twelve locations were found on the critical control zones while thirteen were found on the less critical control zones. Based on the findings from this study, it was however suggested that town planners, construction companies and individuals should work in consultation with Geographers, Hydrologists and other stakeholders in the field who have adequate knowledge of the terrain and the technical ability in flood hazard modeling. Additionally, non-structural flood control measures have also been strongly advocated for implementation in the capital city of Uyo.

Keywords: Geographic information system, Global positioning system, Flood hazard assessment, Flood hazard modeling, Flood mapping, Non-structural flood control, Sustainable development.

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Contribution/Originality

This study contributes in the existing literature that there are flood hazard areas in Uyo Capital City. The classification of the flood hazard areas into high, moderate and low areas is very significant, a major contribution that signifies the originality of this study. This study is one of very few studies that have investigated flooding menace paying particular attention to Uyo Capital City.

1. BACKGROUND TO THE STUDY

1.1. Introduction

The rapid growth of the world's population and urbanization has escalated both the frequency and severity of flood disasters. Flood occurs when an area that is usually dried is covered by a large amount of surface water. This description best portrays a situation whereby surface water or runoff overflows the carrying capacity of a channel. According to (Ward, 1978), flood is defined as a mass of water, which produces runoff on land that is not normally covered by water or a fairly high water flow which overburdens the natural channel provided for the runoff. In the humid tropical environment, floods occur due to intense or prolonged rainfall and sometimes when the area is poorly drained. As the flow of water increases, a point is reached where the channel can no longer drain the volume of water passing through it.

Many major cities of the world have experienced property damages, fatalities, and injuries, economic and social disruptions due to flood disaster. Uyo - the administrative centre of Akwa Ibom State in Nigeria has experienced series of flooding menace particularly during and after intensive or prolonged rainfall in recent times. This has become so endemic that many times, the socio-economic activities are hampered, people lost their lives and properties in the city. This mostly happens at strategic locations in the city during heavy rainfall and thunder storms.

Observations indicate that rainfall is the main source of water in the area. Accordingly, ground water recharge and subsequent discharge to the surface water bodies is significantly dependent on rainfall regimes (Udosen, 2008). Records have it that, the number of rainy days per month is however higher during the wet season; it ranges between 13 and 19 days within the months between May and October (Udosen, 2008). Consequently, there is every indication that flood in the capital city of Uyo can be effectively controlled based on structural and non-structural control measures.

The persistence of flooding incidence in the capital city of Uyo can be attributed to changes in the climatic condition of the area, exceptional rainfall, human activities and excessive infrastructural development. Although there have been series of attempts and interventions by successive governments to combat this menace in the administrative city, it is however evident that only very little have been achieved in this regard. In the midst of all forms of drains construction and erosion control strategies in the city, flooding persists. This problem may not be unconnected with the dynamics of the natural environment in the face of the continued quest for city development. It therefore requires an appreciable knowledge of the modifications and changes on the natural landscape due to the anthropogenic factors if indeed the continued search for a sustainable approach for flood control in the capital city must be achieved.

In the best circumstances however, and for effective flood control, the European Union (EU) had called for greater co-ordination of flood risk management and control in 2004. The co-ordination was in line with flood control strategies proposed by the United States of America (USA) in 1970, the benchmark of which relied on non-structural control measures as opposed to structural measures. According to UNISDR (2009) non-structural flood control measures include those measures not involving physical construction that uses knowledge, practice, or agreement to reduce flood related risks and impacts. Here, emphasis was placed mostly on laws and policy development, public awareness campaign, education, and training. In a similar vein, Kundzewicz (1999) had earlier suggested that non-structural measures were more sustaining than structural measures as it provides proper guidelines for implementing structural measures. The guidelines stem from effective flood hazard assessment and visualization.

In view of the above, and in an effort to properly address flood and related environmental problems, Fox *et al.* (2008) adopted the 3D ArcGIS visualization approach to assess flood and drought problem with Asheville and Buncombe County of North Carolina. The visualization approach became very useful and assisted in the identification of flood location for effective decision making. It is worthy to note also that Lawal (2012) used Geographic Information Systems (GIS) to assess flood susceptible areas of Peril River Basin, Malaysia. Based on Multi-criteria evaluation technique along with Analytical Hierarchy Process (AHP) as reported in Saaty (1980). The result of the assessment showed areas of susceptibility to flooding which also aided effective decision making and control policies to be developed. In the best circumstances, the decisions and control policies indicate that structural measures alone cannot resist the current flood phenomenon prevalent in most parts of the world today; hence, the need for a sustainable approach to flood control is inevitable. Based on this however, this study is aimed at identifying, assessing, and visualizing flood prone areas in the Capital city of Uyo using a GIS analytical approach. Attempt is also made to assess flood hazards, and develop decisions support mechanism for flood control in the capital city.

1.2. Study Area

The study was carried out in Uyo, the capital city of Akwa Ibom State, Nigeria (Please see Figure 1). The city lies between longitudes $7^0 51'$ E and $7^0 59'$ E, and between latitudes $5^0 40'$ N and $5^0 59'$ N. Uyo Capital City covers an approximate area of 188.024 km^2 with an estimated population of 305,961. It was a district headquarters during the colonial era and was later upgraded to a local government headquarters. In 1987, it was further upgraded to the status of a State Capital. With the changes in the status of the area, developments are attracted. Urban expansion and economic growth lead to infrastructural development that extends to nearby local government areas of Itu, Uruan and Ibesikpo Asutan. Land use categories as identified by Ituen and Udoh (2004) shows that residential land use dominate the area while vegetation shrinks.

With the recent upsurge in economic transformation, it is clearly evident that Uyo is highly populated.

Temperature regimes of Uyo correspond with that of the tropical humid climate and ranges between 26.2^{0}C and 35^{0}C with mean annual temperature of 28.4^{0}C (Ukpong, 2009). Uyo is characterized by a gentle undulating terrain. According to Usoro and Akpan (2010) sandstone hills and ravine are attributed to parts of Uruan and Uyo Local Government Areas while other sections of the study area are filled with low lying undulating sandy plains terrain. The area is a Low lying terrain and is susceptible to flooding that result from extreme rainfall. With the growing population, housing and infrastructural development have been intensified some of which are structured and located on the natural water ways thus, inducing flooding.

Uyo is mainly drained by Iba Oku stream network which flows northwards into Ikpa River at the middle segment and empties into the Cross River Estuary. The Iba Oku drainage system drains settlements including Anua, Eniong, Ewet, Afaha Oku, Ikot Ntuen Oku, Ndueotong and Iba Oku, etc. Agricultural and urban land uses are the commonest land use types found in the area. For agriculture, intensive farming without fallowing is commonly practiced in the urban and suburban areas. Urban land use includes built-up areas for various purposes. This however, covers over 75% percent of the Capital City and therefore suggests a clustered or high concentration of human population in the area. Intensive urban development and integrated drainage systems have rendered the surface impervious to infiltration thereby increasing the volume of surface runoff. Besides, the urban drainage system in Uyo is channeled into Iba Oku stream at Afaha Oku. Flooding has been a major problem affecting most parts of the study area. (Please see Figure 1 under illustrations at the end of the manuscript).

2. MATERIALS AND METHOD

In consideration of the technical aspects of this work, a well thought-out approach that could facilitate the realization of the objective of this study required the employment of remote sensing devices including the Global Positioning System (GPS), satellite imagery of Uyo area of Akwa Ibom State accessed from NigerSAT image 2008 and Digital Elevation Model DEM (30 X 30) resolution from United States Geological Surveys. The use of Geographic Information Systems (GIS) software - ArcGIS 9.2 was inevitable for modeling and analysis due to its robust spatial analytical capability.

Soil data was obtained from Cross River Basin Development Authority. While rainfall data was sourced from the University of Uyo weather station. Road map of the study area was obtained from Akwa Ibom State Ministry of Lands and Town Planning. The coordinates of 25 flood locations were obtained with the use of GPS during the 2012 flash flood event in Uyo. These were used as ground-truth data to determine the accuracy of the study.

A survey and analytical methods were employed in this study. Field survey with the use of GPS was adopted to capture the coordinates of flood locations in the study area. The analogue maps were scanned and converted into digital format while ArcGIS geo-referencing tool was applied to rectify the scanned maps. Surface operations were carried out on the DEM to extract and generate the slope, contour, and elevation layers which were used as input layers in the final model. This became possible with use of spatial analyst extension tool. The re-projection was used to convert digital maps to a common projection and datum since the data were from multiple sources.

Flood locations were assessed by mapping of existing flood locations based on the terrain of the study area while flood control zone was created based on flood hazard analysis. Figure 2 clearly depicts the model for the study. (Please see Figure 2 under Illustrations

Following the above schema, 25 existing flood locations were captured using GPS to ascertain the terrain flood menaces do occur. The estimated buffered zones of 150m were projected for flood attenuation and inundation. This was in accordance with the environmental laws which projected standard buffered distance for flood attenuation between 50ft and 500ft, and tarred and undulated nature of the terrain found in the capital city.

The terrain was created as 3D using Surfer 8.0 and overlaid with captured flood locations and road network of the study area. The assessment was done to ascertain parts of the road that have been inundated or found on the low lying terrain or basin in the capital city. The 3D terrain surface involved converting DEM to TIN, generating (x,y,z) points values using ArcMap 9.2 where x and y values represented the coordinates while z represented the elevation or altitude, and performing kriging raster interpolation on grid data using Surfer 8.0 surface operation to produce a 3D terrain perspective view of the capital city.

Flood hazard assessment utilized single output map algebra of spatial analyst extension of Arcmap 9.2 by adopting Multi-criteria Evaluation Techniques on flood hazard causative factors. The causative data layers namely: soil, slope, elevation, land use, aspect, and contours were ranked and re-classified into three layers. Each data layer was assigned a weight based on the significant estimate it had on flooding, summed to 100% or 1 and processed using single output map algebra to produce flood surface. The assessment was ranked and re-classified following FAO (1993) classification scheme as High (1), Moderate (2) and Low (3). (Please see Table 1 under illustrations).

The resultant surface was presented as control surface based on this flood hazard assessment as defined in Table 2. (Pleases see Table 2 under Illustrations) The surface shows critical, less critical, and non critical control zones which were overlaid on road network and captured flood locations for flood control decision to be made.

3. FINDINGS

In view of the terrain analysis, flood locations are found at either low or high lying basins. The basins are observed as flood sources which attenuated to nearby areas. A clear example of this situation is found along Ibrahim Badamasi Babangida (IBB) Way opposite Women Development Centre (WDC) in the capital city. In the high lying terrain, flood locations are attributed to disruption of water-ways by unregulated land development projects and improper drainage network - erosion control linkages. Figure 3 represents a 3D terrain of the study area.

(Please see Figure 3 under illustration). For instance, at the elevation of 72.1m above sea level, floods are peculiar around Udo Eduok Street.

The result from flood hazard assessment presents flood control map of the study area. This is shown in Figure 4 as flood control zone of Uyo Capital City. (Please see Figure 4 under illustrations). Critical zone depicts low built-up activities as a result of high rate of inundation from the low lying basin and runoff associated with the terrain. For instance a section of IBB Way by Women Development Centre is badly damaged because of high flood hazard associated with the terrain. Though various land use such as vegetation, built-up and bare land are found around this area, the terrain does not favor more built-up land uses.

Less critical control zone is characterized by moderate flood hazard. The terrain favors built-up land uses with more residential areas because flood menace is not pronounced in the zone. Less critical zone is also observed with new flood locations as a result of built-up activities blocking the waterways. Such less critical flood hazardous areas are found around bypass and illegal Motor Parks along Abak Road. (Please see Plates 1&2)

In not critical control zone, flood hazard was characterized as lowly hazardous. Though the terrain was either steeper or undulating, flood inundation was reduced. The reduction was due to the presence of more vegetation and bare-land land uses than built-up land use which encourages more infiltration, thereby reducing flooding. One of such areas that experience low flood hazard was Afia Nsit locality.

4. DISCUSSION OF FINDINGS

In flood prone areas, it was noted that the existing flood locations depend on the land use type and the nature of the terrain present in the area. The result shows that flooding in some areas occur due to built-up interference or blockage of natural water ways causing relocation of inundated areas against the natural locations. Similarly, when considering the nature of the terrain, it was equally indicated that inundation can occur on highlands due to blockage of water ways. The findings from hazard assessment presented three control zones namely: critical, less critical, and not critical flood control zones. These zones are characterized by high flood hazard, moderate flood hazard and low flood hazard for critical, less critical, and not critical zones respectively. In each control zone, land uses and the nature of the terrain were the major causes of flood hazard in the study area. Critical flood zone was found as being caused by water overflow from low lying basins and less built-up land use while moderate flood hazard zone was caused by more built-up through sloppy nature of the terrain. Low flood hazard zone on the other hand was mostly caused by more vegetation and bare land uses than built-up land use.

The control zones served as a tool in implementing non-structural flood decision and control measures. The control measures to be implemented on 25 captured flood locations in the capital city were based on flood control tool. Thus, from the captured flood locations, twelve locations were in critical zones while thirteen flood locations were in less critical zones. Zones that were not on critical control state were only experiencing flooding due to attenuation. The measures would ensure sustainability of social, economic, and environmental well-being of the inhabitants in Uyo capital city.

5. CONCLUSION

The study assessed and visualized flood prone areas by creating flood hazard and control zones in the capital city. The assessments guided in implementing of non- structural flood control measures to prevent flood menace in the study area. In the process, several analyses and models were performed on flood causative using Arcmap 9.2 and surfer 8.0 GIS software. Specifically, flood control model assessed existing flood locations and flood hazard in the study area. Flood hazard assessment was based on multi-criteria evaluation techniques on flood causative factors using single output map algebra while existing locations were assess based on terrain analysis. The findings obtained from the assessment shows that flooding were caused by terrain with low lying basins and unregulated built-up activities. The assessment led to the creation of flood control zones that enhance flood control implementation.

Non-structural control measures provided sustainable flood control decisions and support that balance social, economic, and environmental development well-being of the populace using Geographic Information Systems. These measures were introduced to control flood as structural measures alone could not tackle flood problem in Uyo capital city.

6. RECOMMENDATIONS

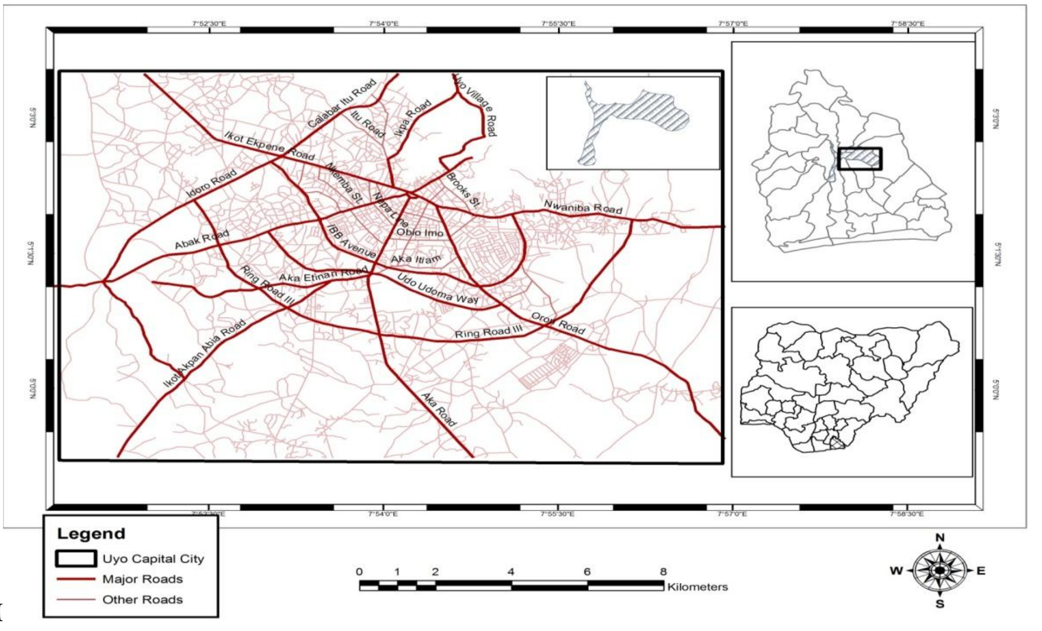
The study recommends non-structural flood control measures to be implemented in the study area. The recommendation stemmed from the fact that over the years, structural measures alone could not deal effectively with flood menace, requiring a combination of both structural and non-structural measures. Among the control measures include capacity building, awareness campaign, and flood mitigation policies. These measures should gear towards town and urban planners, the inhabitants, and flood disasters agencies and flood managers.

Town and urban planners should adhere to flood control advice from related environmental consultants with adequate GIS flood control tools and knowledge along with GIS training on ways of delineating flood prone areas and extent of inundation. This is believed will assist in decision making relative to siting and providing sustainable development projects including provision of effective drainage systems, following flood sources and extent of inundation. In any zone, town planners should properly asses and manage allocation of lands based on the existing water-basins in order to create a drainage path or plan for water passage that will sustain future development. Such plan would prevent and reduce flood menace in the capital city, particularly at the residential areas.

The inhabitant should be enlightened through flood awareness campaign to show different flood hazard zones found in the capital city. The enlightenment should also expose them to the dangers of blocking waterways and drainage systems through illegal buildings and indiscriminate refuse disposal in existing drains. From this knowledge, the inhabitants would know the zones they belong as it serves as an early warning system about any impending flood event. Flood warning signals should be installed on basins with high water overflow.

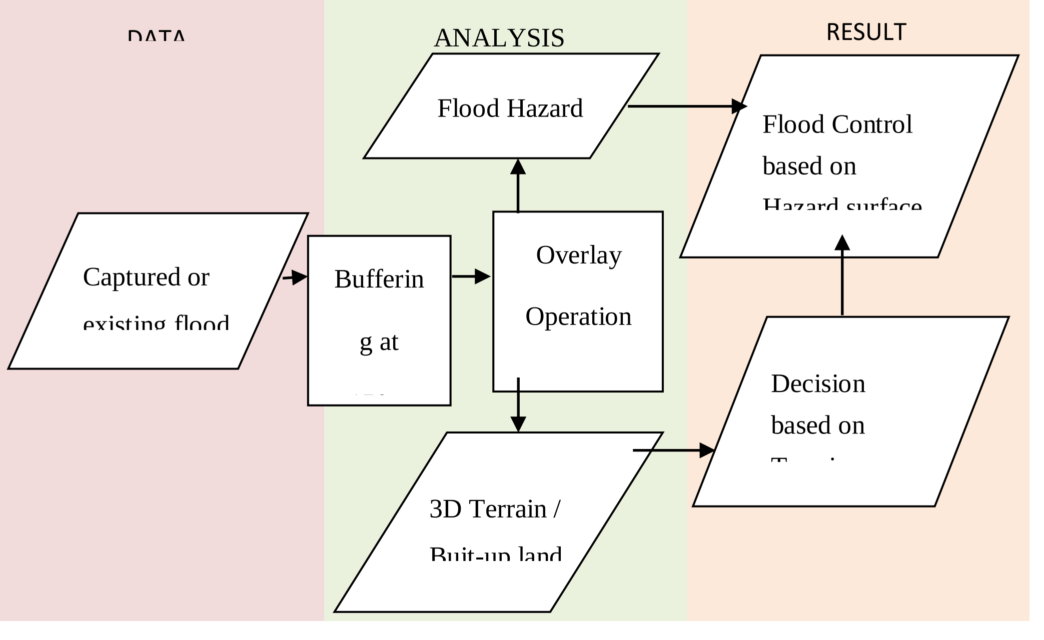
Illustration

Figure-1. Location of Uyo Capital City in Akwa Ibom State, Nigeria



I

Figure-2. Flood Decisions Support and Control model.



Source: Researchers, 2013

Table-1. Ranking and Re-classed data layers

Data layer (Weight)	Values	Hazard Level	Ranking
Land Use and Vegetation (30%)	Built Up	High	1
	Unpaved area (Bare land)	Moderate	2
	Vegetation	Marginal	3
Soil texture layer (20%)	Clayey sand to sand; Clayey sand to sandy clay	High	1
	Sandy clay	Moderate	2
	100 – 500cm sand to clayey sand	Low	3
Contour layer at 10 interval - % (10%)	33.424031	High	1
	66.712015	Moderate	2
	100	Low	3
Slope layer - % (10%)	100 (13.190128)	High	1
	66.666667 (8.793419)	Moderate	2
	33.333333 (4.396709)	Low	3
Aspect layer - % (10%)	100 (359.396912)	High	1
	66.573919 (239.264608)	Moderate	2
	33.147837 (119.132304)	Low	3
Relief / Elevation layer - meters (20%)	32.666667	High	1
	58.333333	Moderate	2
	84	Low	3

Table-2. Classification of flood control zones in the capital city

Flood Control Zones	Reasons
Critical	High flood Hazard zone. The flood might not be much, but it has a severe impact on social, economic, and environmental development in the Capital city.
Less Critical	Moderate flood hazard zone. The flood may be much but it has less impact on social, economic development of the Capital city
Not Critical	Low flood hazard zone. It is a zone of minimum flood impact with no effect on the social, economic, and environmental development in the capital city.

Figure-3. 3D Terrain of Uyo Capital City

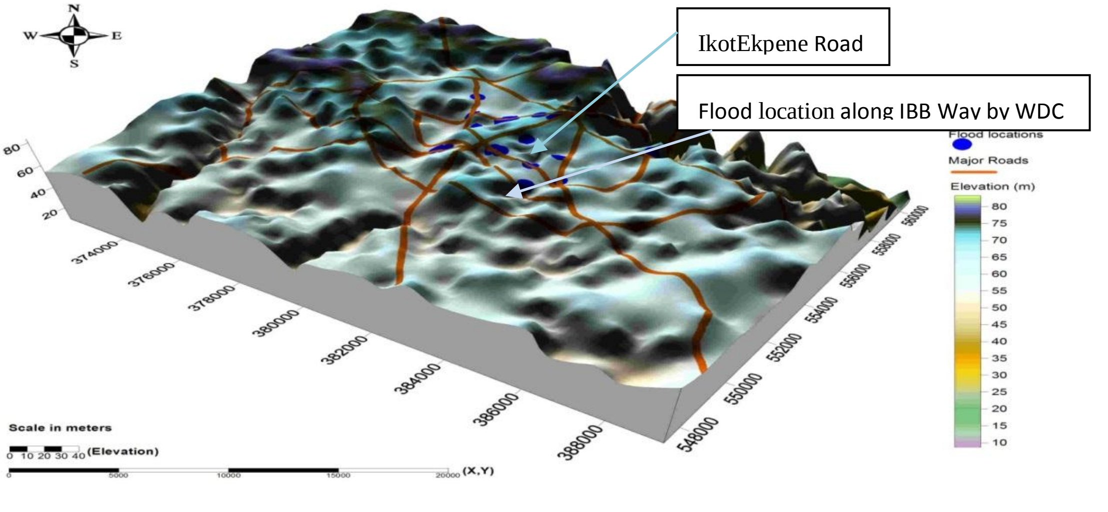


Figure-4. Flood control zone of Uyo Capital City

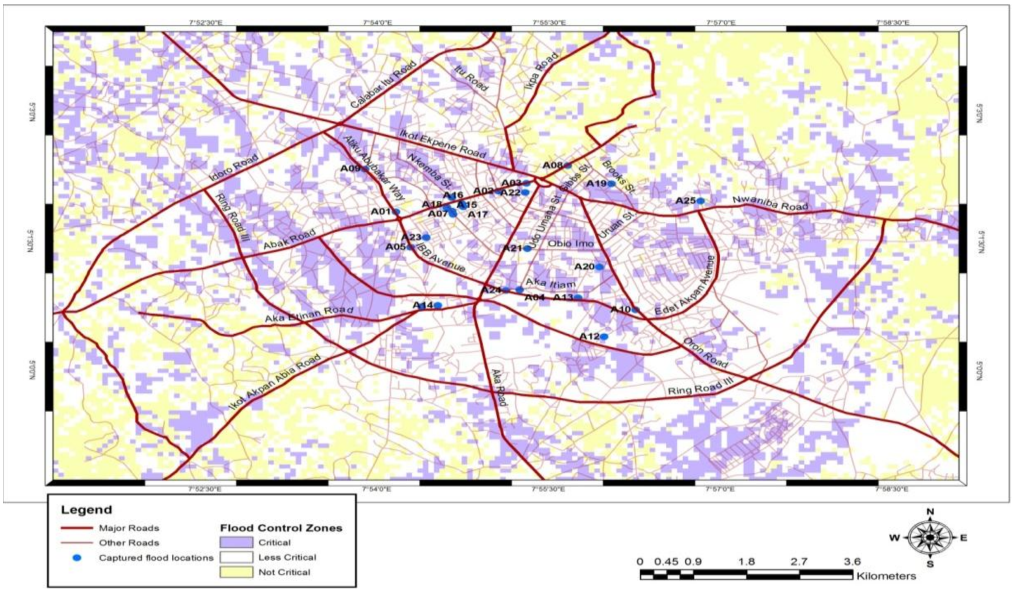


Plate-1. Flood incidence in Uyo Capital City

Plate-2. Flood incidence in Uyo Capital City

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APPENDIX

Table-3. Captured flood location using GPS

```
H  SOFTWARE NAME & VERSION
I  GPSU 4.93,01 REGISTERED to 'ROBERT EKPENYONG'
S DateFormat=mm/d/yyyy
S Units=M,M
S SymbolSet=2

H R DATUM
M E             WGS 84,100, 0.0000000E+00, 0.0000000E+00,0,0,0

H  COORDINATE SYSTEM
U  LAT LON DMS

F,ID-------------------------------------------------,Latitude     ,Longitude     ,Symbol-------------,T,O ,Alt(m)  ,Comment
W,UKANA OFFOT BY UWAH STREET                          ,N05°01'37.05",E007°54'54.32",Waypoint           ,I,E ,    64.6,
W,ATIKU ABUBAKAR BY AFAHA UBE STREET                  ,N05°02'07.82",E007°54'06.39",Waypoint           ,I,E ,    66.0,
W,AKA ETINAN AROUND C-DIVISION                        ,N05°00'26.80",E007°54'37.61",Waypoint           ,I,E ,    59.4,
W,JOHN UDO AKPAN STREET                               ,N05°00'05.17",E007°56'17.99",Waypoint           ,I,E ,    64.8,
W,NSIKAK EDUOK OPP AKWA EFAK STREET                   ,N05°00'33.50",E007°56'03.53",Waypoint           ,I,E ,    69.3,
W,AKA ETINAN BY ATAN ROAD                             ,N05°00'27.81",E007°54'46.48",Waypoint           ,I,E ,    61.6,
W,NKEMBA BY ABAK ROAD                                 ,N05°01'46.88",E007°54'54.11",Waypoint           ,I,E ,    64.1,
W,PORT HARCOURT STREET BY ABAK ROAD                   ,N05°01'42.45",E007°54'59.66",Waypoint           ,I,E ,    67.4,
W,UWAH STREET AND PH STREET JUNCTION                  ,N05°01'40.22",E007°55'00.22",Waypoint           ,I,E ,    67.9,
W,UKANA OFFOT BY PRIMARY SCH FENCE (ST. PATRICK)      ,N05°01'39.65",E007°54'51.35",Waypoint           ,I,E ,    62.4,
W,NSENTIP STREET BY IBESIKPO STREET                   ,N05°01'50.68",E007°55'34.33",Waypoint           ,I,E ,    71.7,
W,ESUENE STREET                                       ,N05°01'17.57",E007°54'39.98",Waypoint           ,I,E ,    61.6,
W,EMCO LANE BY OBIO IMO LANE                          ,N05°00'56.19",E007°56'15.28",Waypoint           ,I,E ,    68.5,
W,AKA ITIAM JUCTION BY UDO UMANA                      ,N05°00'39.41",E007°55'31.52",Waypoint           ,I,E ,    69.2,
W,NSIKAK EDUOK BY IMFI                                ,N05°00'38.97",E007°55'23.97",Waypoint           ,I,E ,    68.6,
W,ORON ROAD AROUND IMC                                ,N05°00'24.83",E007°56'35.24",Waypoint           ,I,E ,    61.5,
W,16 ABAK ROAD AND EVIRON                             ,N05°01'57.45",E007°55'35.04",Waypoint           ,I,E ,    71.2,
W,39 UDO EDUOK STREET                                 ,N05°01'51.71",E007°55'19.55",Waypoint           ,I,E ,    72.1,
W,UKANA OFFOT ROAD BY MKPONG STREET                   ,N05°01'34.71",E007°54'54.75",Waypoint           ,I,E ,    65.0,
W,ETIM OKON USANGA OFF NWANIBA ROAD                   ,N05°01'44.60",E007°57'10.88",Waypoint           ,I,E ,    67.3,
W,BROOK STREET                                        ,N05°01'57.21",E007°56'21.69",Waypoint           ,I,E ,    62.3,
W,ATIKU ABUBAKAR BY FOUR TOWN FENCE                   ,N05°01'36.40",E007°54'23.28",Waypoint           ,I,E ,    66.5,
W,OBIO IMO STREET BY UYO TOWNSHIP STADIUM FENCE       ,N05°01'09.59",E007°55'35.64",Waypoint           ,I,E ,    69.8,
W,IBB OPP WOMEN DEVELOPMENT COMMISSION                ,N05°01'10.42",E007°54'31.43",Waypoint           ,I,E ,    59.5,
W,WELLINGTON BASSEY BY AFIA STREET                    ,N05°02'10.52",E007°55'57.76",Waypoint           ,I,E ,    71.0,
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