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Full Length Research Paper

An application of Geographic Information System in mapping flood risk zones in a north central city in Nigeria

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This study deals with the application of Geographic Information Systems (GIS) in mapping flood risk zones in Makurdi Town. This study draws its relevance from the importance of a GIS database in tackling flood related problems. To create a map of flood risk zones in Makurdi town, the ArcView GIS package was used to digitize a topographic map and other relevant themes of the study area. Through GIS overlay and manipulative functions, a Digital Elevation Model of the study area; and a classification map of flood risk zones in Makurdi town were created. The map of flood risk zones generated shows that Makurdi town is generally susceptible to flooding and very little has been done in steering away development from 'highly susceptible' areas. The study recommends the need for town planners to steer development away from areas of high risk to low risk.

Key words: Flooding, Geographic Information Systems (GIS), mapping, remote sensing, Makurdi, Nigeria.

INTRODUCTION

Today, many countries are trying to reduce property damage and loss of human lives to floods through flood prediction and by creating a database of flood hazard areas. It has been shown by various studies that floods can be more effectively managed when flood predictions are complemented with maps of flood risk zones (Sarma, 1996; Balogun and Okoduwa, 2000; Sanyal and Lu, 2003). The production of a good map of flood risk zones involve using a tool with a broad range of functions capable of manipulating both spatial and attribute data. In this regard, the efficacy of the Geographic Information Systems (GIS) can be relied upon (Ayeni, 1998).

Despite the utilitarian value of GIS capabilities in mapping flood hazards, only few studies have been reported in Nigeria (Fabiyi, 2001). Some studies on the application of GIS in flood risk mapping in Nigeria include Lasaki (2001), Balogun and Utomwen (2003), Ogunsesan (2004), and Weli (2004). The need for more studies of this nature in Nigeria has been stressed in the literature (Ayeni, 1998).

This study explores the capabilities of GIS in mapping flood risk zones in Makurdi. This is because; Makurdi experiences seasonal floods which claim property worth thousands of naira and sometimes human lives. The problem of flood in Makurdi is intensifying due to urbanization in which vegetation cover is being cleared for farm lands and buildings. The River Benue which contributes to flooding in Makurdi reaches a mean flow of 3,150 cubic meters per second (100 km^3 per year) for a 305,000-km^2 watershed. Over the past 20 years, this annual flow has been maintained (at 97 km^3). The average absolute low flow is 240 m^3 per second and the average annual flood flow reaches 12,000 m^3 per second (Andersen et al., 2005). Some of the seriously affected areas include Wurukum

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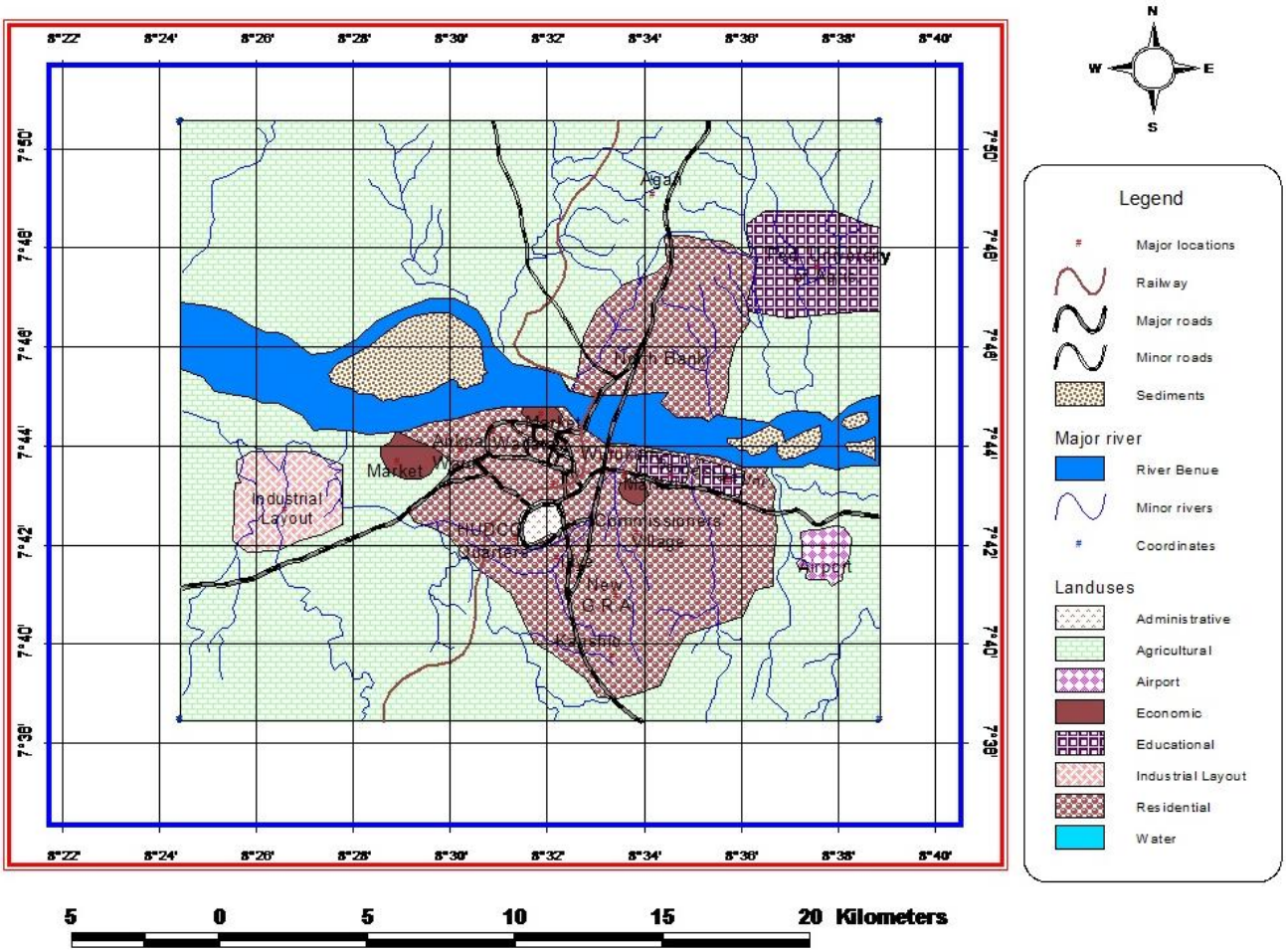

Figure 1. Map of Makurdi showing built up extent.

and Wadata districts. There is very limited information on potential areas that are likely to experience this extreme event available to the Government of Benue state. Hence, the need to find a method of identifying and mapping flood risk zones in Makurdi.

The study not only adds to the existing literature but has produced a map of flood risk zones in Makurdi which will be useful to policy makers in land use zonation in order to steer away development from the risk zones and reduce property damage to floods. It is from these reasons that the study has derived its relevance.

MATERIALS AND METHODS

Study area

Location

Makurdi town is the headquarters of Makurdi Local Government Area and capital of Benue State. The town is located between latitude 7°38'N - 7°50'N, and longitude 8°24'E and 8°38'E. It is situated in the Benue valley in the North Central region of Nigeria. It is traversed by the second largest river in the country, the River Benue (Figure 1).

Relief and drainage

Makurdi town is located in the plains of the River Benue in the Benue Trough. The relief is generally low-lying ranging from below 90 to 150 m on the average. There are interfluves in certain parts of the town where elevation is above the average. The River Benue is the main drainage channel traversing the town. It truncates the town into the North and South Banks. There are also several streams draining Makurdi town on both banks which are tributaries of the River Benue. Most of the streams are perennial and include Kpege, Adaka, Asase, Idye, Urudu and Demekpe amongst others.

Geology and soils

In terms of geology, Makurdi town is basically composed of sedimentary rocks, which sandstones are the dominant rock type. Lowlying areas like Wadata are overlain by shale (Kogbe, 1989). The sandstone is divided into micaceous and feldsphatic sandstones. Some of these are exposed in parts of the town. Soils in the area reflect the geology. There are two major soil types in Makurdi town: 1) hydromorphic soil– this is developed on alluvium sediments found along the River Benue and 2) red ferrasols- this is developed on sedimentary rocks away from the immediate river channel (Nyagba, 1995). It is also significant to mention that human activities have affected the nature of soils in Makurdi town through farming, construction and reclamation.

Climate and vegetation

The climate of Makurdi town is the tropical wet and dry type, Koppen's Aw classification, with double maxima (Ayoade, 1983). The rainy season lasts from April to October, with 5 months of dry season (November to March). Annual rainfall in Makurdi town is consistently high, with an average annual total of approximately 1173 mm (Abah, 2012). Temperature in Makurdi is however, generally high throughout the year, with February and March as the hottest months. Temperature in Makurdi varies from a daily of 40°C and a maximum of 22.5°C (Ologunorisa and Tor, 2006). The vegetation of Makurdi town is the guinea savannah type. This vegetation type has been adversely affected by human activities leading to the clear-cutting of tree cover in many parts of the town. Due to this, artificial vegetation has replaced natural secondary vegetation.

Population and economic activities

Makurdi town is inhabited by many tribes with a population of 297,398 to 157,295 males and 140,103 females (FGN, 2007). These tribes include the Tivs, Idomas, Etilos, Jukuns, Egede, Hausas, Yorubas and Ibos. The Tivs are the dominant tribe. Makurdi town is made up largely of people who engage in civil service duties, commercial activities and agrarian peasantry. Makurdi town is a built up area with the highest concentration of people in high level and Wadata. Dense population also exist in some low-lying parts of the town such as Wurukum.

Types and sources of data

The data used in this study include primary and secondary data. Primary data was obtained through field observation mainly for ground truth evidence of flood occurrences in areas identified as susceptible. Secondary data used in this study include rainfall data collected from the Nigeria Meteorological Agency Makurdi chapter; and maps of various themes of Makurdi town obtained from the Geological Survey Department, Ministry of Lands and Survey, and the Ministry of Works in Makurdi. Most basic of the spatial data-sets used in this study include topographic map of Makurdi town (1:50 000 and 20 m contour interval); drainage map of Makurdi town (1:50 000); soil map of Makurdi town (1:50 000); and land use map of Makurdi town (1:50 000). The study utilized maps with these scales because maps with more preferable scales or satellite imageries of the entire study area were not readily available at the time of the study.

Method of data collection

The data on rainfall was collected for a 30 year period (1979 to 2008). This was the amount of rainfall data readily available for the study. The maps were collected in such a way as to cover the entire study area. Care was taken to avoid leaving any part of Makurdi town uncovered. At the end of the analysis, a map of flood risk zones produced was compared with actual reality to affirm whether areas indicated on the map as flood risk zones are actually accurate. This ground truth was carried out through oral field observation. Areas identified as highly susceptible in Wurukum and Wadata were visited to verify if flooding actually occur and watermarks left on structures after flooding events were observed as proof. Areas where flooding events have been reported by recent media were also noted. Future studies with satellite imageries and ground truth analysis of topographic characteristics will enhance the quality of flood risk maps and help determine actual boundaries of flood extent (Lopez Vicente et al., 2009; Esposito et al., 2011).

Methods of data analyses

The rainfall data was analysed to provide information on the role of rainfall in causing floods in Makurdi town. Annual and monthly rainfall data were analysed to provide evidence that rainfall in Makurdi is high enough to cause flooding. Rainfall data was converted to attribute data and utilised during GIS manipulation and overlay process to assess its interaction with other themes such as relief and drainage for the production of a map of flood susceptible areas. The maps of Makurdi town obtained were converted to digital format to enable the researcher to assemble the necessary data for the study. With assistance from the GIS laboratory at the University of Ibadan Nigeria, the maps were digitized using ArcView 3.2a in addition to other necessary ArcView 3.2a application extension software packages such as Image Analyst and Spatial Analyst. The procedures used in this study are purely GIS manipulations such as overlay analysis.

The overlay process enabled a holistic presentation of different layers of information such as the roads, land uses and areas that will be affected in the event of flood occurrences. The topography of the study area was processed for onward digital capture through the process known as spot-height determination. The map was divided into a regular grid and the highest spots for each gridded cell was recorded against the x and y coordinate values of these particular locations in a table. These data sets were later used in the auto-generation of contour lines of the map within the ArcView 3.2a GIS software environment and the DEM of the study area using Surfer 7.0 GIS software package was created. Spatial Queries were carried out to identify risk zones using proximal search, phenomena search (features within zones) and susceptibility analysis. The map of flood risk zones was prepared using the DEM, rainfall data and drainage characteristic of Makurdi. The soil types and vegetative cover were also considered. The influence of rainfall amounts and the other themes within the relief categories were assessed using GIS overlay manipulations and four susceptibility classes emerged. These classes are as follows:

1. Areas marked as highly susceptible to floods
2. Areas marked as susceptible to floods
3. Areas marked as potentially susceptible to floods
4. Areas marked as not susceptible to floods

The physical phenomena on the map produced compared favourably with the satellite imagery of Makurdi provided by Google (2013) using the available coordinate intersections. However, the margin of error of the GIS software used range from 1 to 10% as a result of the digitization and overlay analyses performed on conventional maps.

RESULTS

Areas susceptible to flooding in Makurdi

The classification of flood risk zones in Makurdi was mainly based on the interaction of relief (Figure 2), rainfall (Figure 3) and drainage. The DEM of Makurdi (Figure 2) revealed that the North Bank area of the town has topography (0 to 207 m) that is prone to erosion. The areas around the old and new bridges lack vegetation and have developed some gullies. According to Omudu and Amuta (2007), "the area is densely populated and there are prominent gully erosion sites and these gullies serve as refuse dumps." The South Bank areas have a topography that is more resistant to erosion. Figure 2 further revealed that Makurdi town is generally more susceptible to rain induced flash floods than river floods.

As presented in Figure 4, there are variations in the degree of susceptibility to flooding in Makurdi town. The

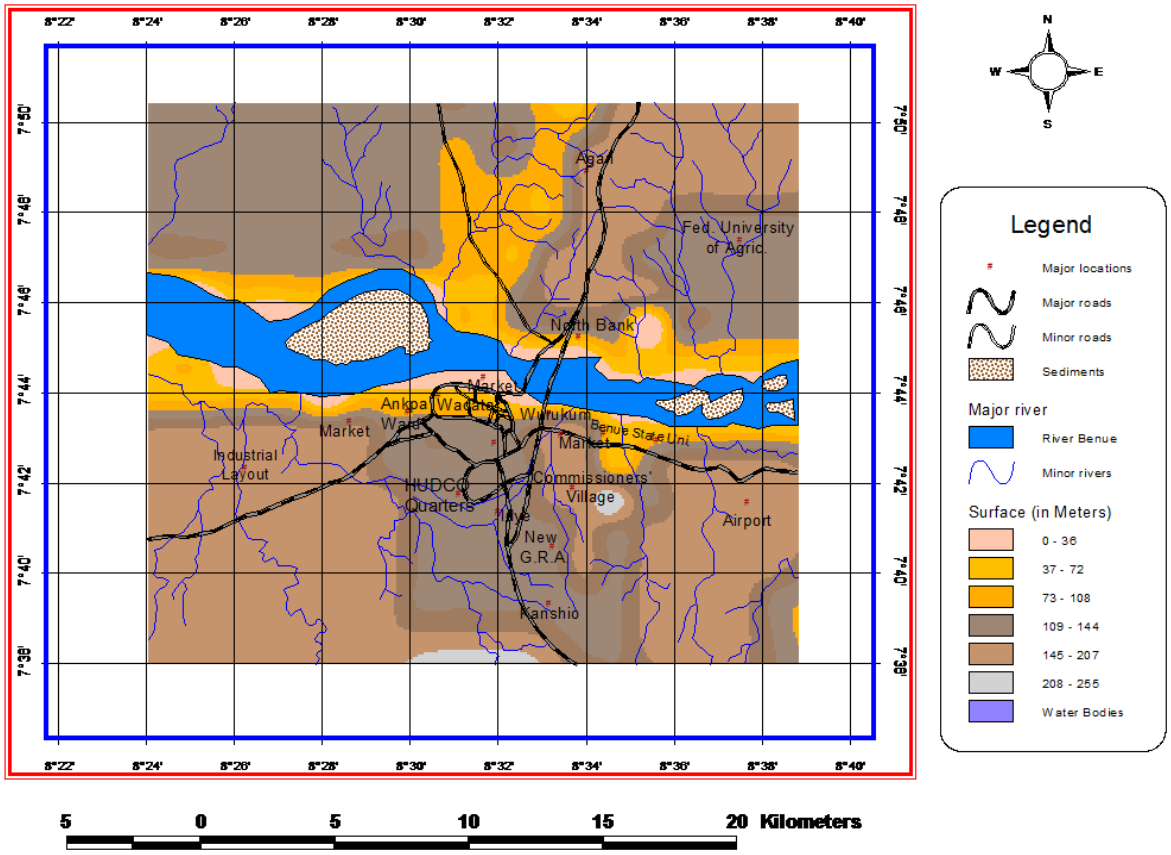

Figure 2. Map of flood risk zones in Makurdi.

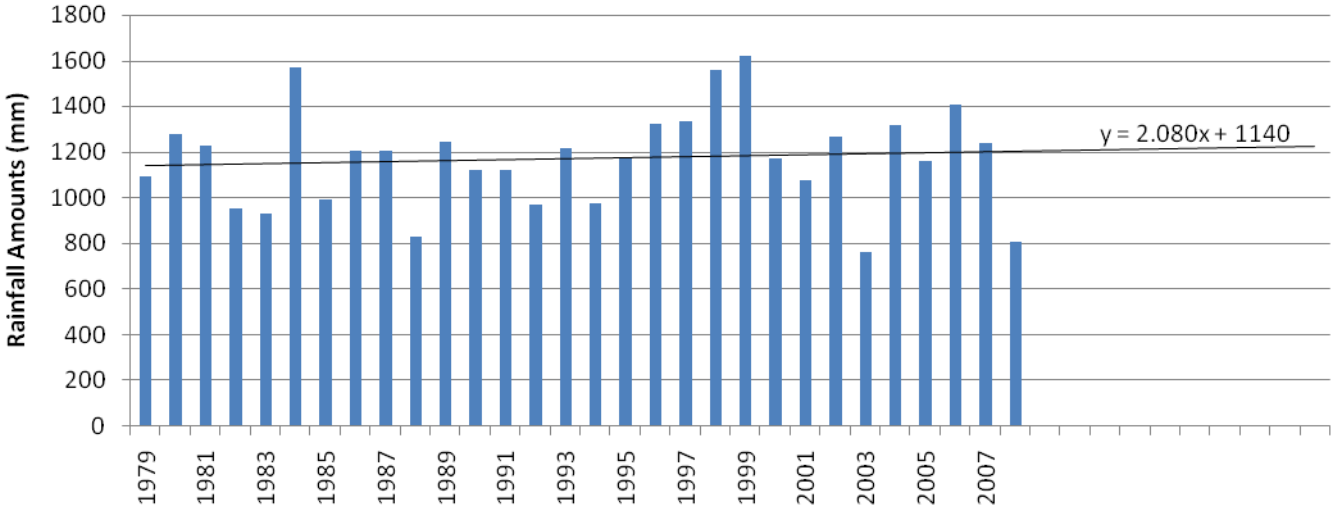

Figure 3. Graph showing annual rainfall totals and linear trend in Makurdi from 1979 to 2008.

areas marked as 'highly susceptible' are mostly the areas closest to the River Benue. Flooding is experienced in most areas in this classification annually. The areas are characterized by very low relief (0 to 72 m) and water-logged soils. These areas include parts of Wadata, Wurukum and settlements close to the riverbank in the North Bank area of Makurdi town. Some important features in this zone include the Wadata market and

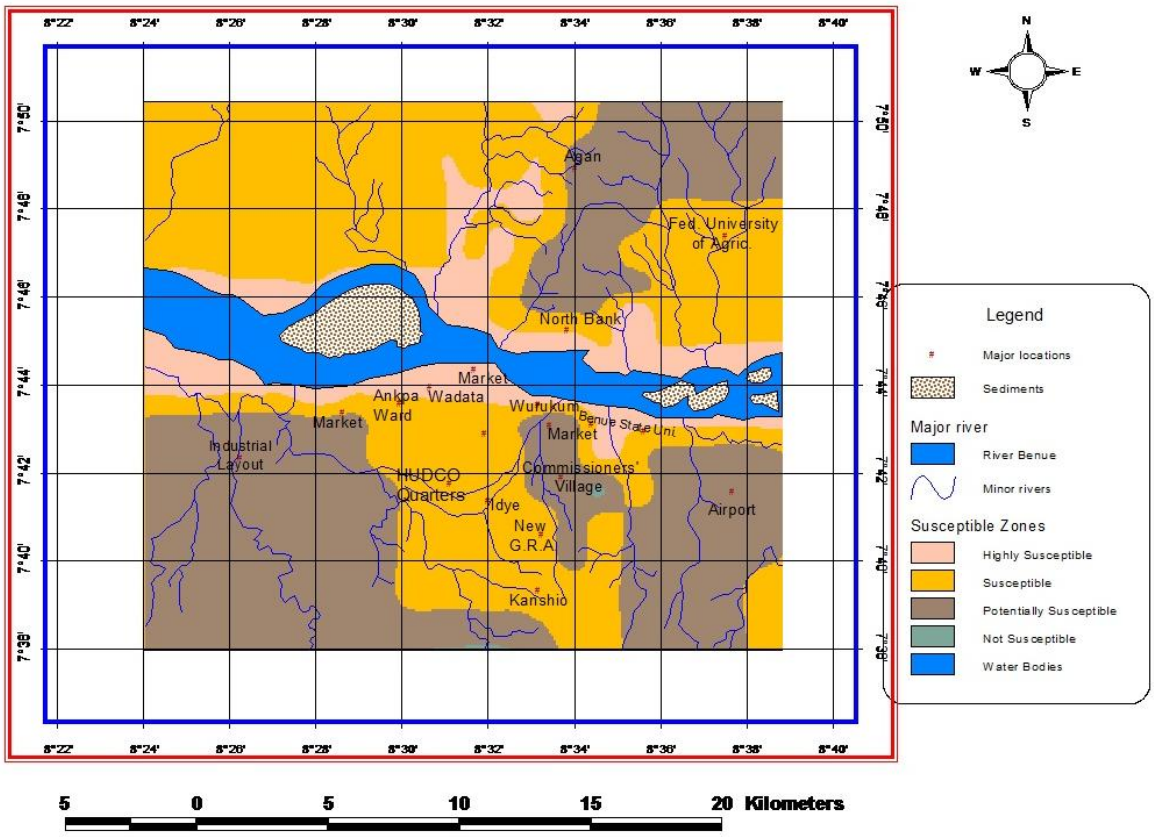

Figure 4. Map of flood risk zones in Makurdi town.

parts of Benue State University. These areas are low-lying and have a high propensity to be flooded in the event of a heavy downpour that may cause the River Benue to overflow its banks. With the kind of soil obtainable in these areas and the level of human intervention, the occurrence of floods is not just limited to the River Benue overflowing its banks but a heavy downpour within a short duration is significant enough to raise flood waters which can cause damage to property and human lives.

The areas marked as 'susceptible' to flooding (73-144 metres) include Ankpa ward, Hudco quarters, Idye, Kanshio and New General Reserved Area (G.R.A.). In North Bank, areas marked as 'susceptible' include mostly farmlands except for some settlements close to the river bank and the University of Agriculture. All these areas are also low in relief and have a tendency to be flooded in the event of a heavy downpour that may cause the River Benue to overflow its banks. Heavy, intense rainfall may generate flood waters which may cause damage in areas of hydromorphic soils with human intervention.

Areas identified as 'potentially susceptible' to flooding (145-207 metres) are parts of the town mostly used for agricultural purposes especially farming and occasionally grazing by cattle herdsmen. Some areas in this zone include Agan, Airport, Industrial layout, Commissioners' Village, parts of Wurukum and Modern Market.

There are also areas marked as 'not susceptible to flooding' (above 208 m). These areas are very few and the most visible area on the map exists in Commissioners' Village. This area has been marked as not susceptible due to the high relief of the area especially since it is bordered by areas of lower relief marked as potentially susceptible.

The map of flood risk zones of Makurdi town has shown that Makurdi town is in fact potentially susceptible to flooding. This statement is drawn from the fact that several areas such as Wurukum, Wadata, Ankpa Ward, Hudco Quarters and parts of North Bank have been attributed to some degree of susceptibility. This was also confirmed through a ground truth exercise and media reports (Hir, 2009; Nwakaudu, 2009; Wantu, 2012). It is therefore necessary to steer away development from areas highly susceptible to floods to areas with lesser susceptibility.

Planning implication of flood risk map of Makurdi town

Makurdi town is steadily undergoing the process of urbanization. The increase in population in Makurdi town comes with an increase in the number of residential houses, infrastructure, roads and other social amenities.

There is a need to properly assign city structures to areas that would be most appropriate. Makurdi town like many other towns in Nigeria is a deviation from a proper master plan. This could be blamed on a number of factors attributable to its origin and inadequate planning by successive governments. In recent years, town planners have made efforts to locate prominent new structures in appropriate areas, for example, the Industrial Layout, Modern Market, Wurukum market, New Central Bank. Despite these efforts, the flood risk map generated reveals that several other structures are not in appropriate places. These include all structures located in the highly susceptible and susceptible zones.

Town planners may need to review the location of major structures in these zones. Where a complete relocation is not possible, future building projects should be directed elsewhere. A major flood event can cause serious damage to human lives and property and should be one of the priorities of town planners in cities located in floodplains.

Flood mitigating strategies in Makurdi town

Flooding is an environmental hazard which has received inadequate attention in Benue State. Major flood control projects are non-existent in Makurdi town. These major control projects include embankments, compartments, river training and flood forecasting (Digby, 2000). However, flood mitigating projects of lesser scales have been constructed in Makurdi town. The most notable control project so far is the construction of large drainage channels to contain stream waters that pass through Makurdi town onwards to the River Benue. Typical examples are the drainages constructed to channel the Urudu and Idye streams which confluence around the Wurukum roundabout close to the River Benue.

In the early 1990s, complaints by traders and residents of Wurukum market and its surrounding areas about continuous damage of property to floods led to the relocation of Wurukum market from its former location at the foot of the New Bridge to its present location. Adjustments in building arrangements have also been made at the Wadata Rice Mill which has been recording loss of property and commercial items due to floods. It is hoped that these adjustments will be sufficient to forestall further damage of property.

Another spirited effort being put up by the present state administration towards containing flood hazards is the construction of new drainage channels along inlands streets in Makurdi town. Where drainages have been absent, new ones are being constructed and where existing ones are damaged or blocked, they are being rehabilitated. Of course, the role of these drainage channels in flood control cannot be underestimated. The amount of runoff dissipated through their combined network effect after rainfall is crucial in curbing the accumulation of flood waters.

Conclusion

This study has demonstrated that GIS mapping capabilities are quite effective in mapping the flood risk zones in Makurdi town. Using the information presented on the generated map, this study concludes that Makurdi town is potentially susceptible to flooding in the event where there is a prolonged or intense downpour which could cause flash floods and raise the volume of the River Benue to tremendous levels making it over spill its banks. Therefore, areas close to the banks of the River Benue should be avoided at all cost to avert damage to property and human lives to flooding since these areas have been found to be highly susceptible. This study also provides useful information to town planners in their relocation, modernization and mitigation strategies. The study recommends the use of satellite imageries in future flood risk mapping studies.

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