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Application of Remote Sensing and Geographic Information System for Assessment of Flood Risk on the Major Downstream Areas of Gombe Metropolis, Nigeria

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Abstract
The world's population is rapidly becoming more urbanized as the world seen a swift urban population increase. Gombe Metropolis is among the urban areas of Nigeria affected by the consequence of frequent seasonal floods leading to a unpropitious effect on the flood communities in many parts of the metropolis. These urbanization dynamics has caused a rapid urban growth through the transformation of many different land uses into the built-up environment. As a result flood risk in the metropolis has been rising in recent years and efforts by the people and government to mitigate the flood risk have not been entirely successful. Thus, this paper attempts to examine the nature of flood risk on the major downstream areas of Gombe metropolis. Fundamentally, this study applied Geographic Information System and Remote Sensing as a tool for integration of spatiotemporal data for modeling and comparison of urban development scenarios and its consequential effect in creating flood risk on the downstream areas of Gombe Metropolis. Therefore, GIS and Remote Sensing have been applied to detect land use/land cover changes, by looking at the trend in Land use/Land Cover Change from 2003 to 2014 in the Gombe Metropolis. In addition, the study identified Land use/Land cover types in different residential areas of the metropolis with more emphasis on the building density in each area. Finally, Gombe Metropolis Flood Risk Zones were detected and developed into Gombe Metropolis Flood Risk Map. The paper was able to reveal a significant growth of built-up environment and the occupation of floodplains in the downstream areas as the main factors for flood risk in Gombe Metropolis. However, the flood risk index established that the residential areas found on the very high to high flood risk zones include Barunde, Government Residential Areas/Gabuka, Pantami, Dawaki, and Tudun Wada. It was further reveal that the residential areas in the moderate flood risk zone are, Jankai, Jekadafari, Herwagana, Bolari/Madaki and MUAK.
Keywords: Geographic Information System, Flood Risk, Gombe Metropolis, Remote Sensing.

1. Introduction

The scale and incidence of occurrence of flood disasters and its effects on lives, properties, and the environment call for a sustainable flood risk measures globally so as to lessen the impact on the persistence of town and cities globally. It is projected that on the average roughly 200 million people in not less than 90 countries are open to the elements of catastrophic eventualities of flood events each year and it will probably increase as a result of climate change effects and the steady rise in the population as well as urban growth in the near future (United Nations/ New Partnership for Africa's Development (UN/NEPAD), 2006).

Davidson (1997) and Wisner *et al*., (2004) described disaster risk in terms of hazard, exposure, vulnerability and capacity measures. Hence, flood risk hazards are produced by two systems, the innate environment (hazard and exposure) on the one hand and the human activities on the other (vulnerability). This paper aimed to focus on the physical exposure aspect of the flood risk and specifically look into land use/cover change with related building density, proximity to floodplains. Many empirical research works have indicated a significant relationship between urbanization and flood risk. The amount of runoff is governed principally by infiltration characteristics and is directly interrelated to the percentage of an area covered by roofs, streets, and other impermeable land surfaces (Derek, 1991). Unplanned urban growth is a key factor in the growth of vulnerability, especially among people living in floodplains and other areas prone to flood risk (Daniel et al., 2012).

Gombe Metropolis has undergone a rapid demographic change that generates a high population pressure on land and the consequent urban developmental processes, especially the growing number of building constructions on a close floodplains areas and thereby exposing the urban poor to flood risk vulnerabilities (Daniel et al., 2012).

This brings urban poor closer to a cruel ring suffering by the frequent seasonal floods on the metropolitan communities. Flood control measures and efforts undertaken by both the public and the government to minimize the effect of flooding have not been adequate successful. Therefore, it is based on this circumstance that this paper applied Geographic Information System and Remote Sensing to assess the nature of flood risk on the major downstream areas of Gombe metropolis, so to discover downstream areas at risk of floods and to recommend the appropriate sustainable flood control measures towards those areas affected.

The use of GIS technique during the last decade is increasingly being applied for identification of natural resources. This can be achieved through the use of multi-temporal remote sensing data which provide valuable information on natural resources like land, water, flood, forests, urban areas and infrastructure facilities such as road network, river etc. Satellite image data provides the potential to obtain flood events land cover information at more frequent intervals and more economical than those obtained by traditional methods (Trotter, 1991). The use of a Geographic Information System (GIS) as a tool to integrate the information and to simulate and compare scenarios of development and options of flood alleviation, their potential for data management and display make Geographic Information Systems a powerful tool in flood studies (Saini and Kaushik, 2012). GIS is becoming an essential tool in flood mapping and analysis because it enables preparation of maps of inundated areas and estimation of damages (Bera, *et al*., 2012). GIS technique has also been utilized as efficient tools in flood risk assessment. Karmakar, *et al*., (2010) proposed a methodology to assess flood risks, involving exposures of land use and soil type to flood water, vulnerability to flood and flood probability of occurrence. Saini and Kaushi (2012) study, has also shown how flood hazard related information can be extracted from remote sensing satellite imageries and synthesized with demographic data to identify land use that is exposed to a different degree of flood risk. Thus, utilization of Remote Sensing and GIS mapping provide improved ways of assessing, analyzing and presenting vulnerability and hazard risk through flood risk mapping which helps urban planners in flood warning, preparedness to mitigate the impact of flood for sustainable urban flood risk management.

2. Study Area

Gombe Metropolis was chosen as the Gombe State Capital City in 1996 and is comparatively located at the center of Gombe state, sharing a boundary with Akko, Yamaltu Deba and Kwadam Local Government Areas. It is absolutely situated at Latitude $10^{0} 8^{1}$ and $11^{0} 23^{1}$ N and Longitude $11^{0} 20^{1}$ and $10^{0} 24^{1}$ E (Gombe State Ministry of Land and Survey, 2003). Almost all the rivers and streams flow from the Akko escarpment in the western region and truncated at the mid-streams parts of the town moving towards the east. Growing rate of erosion and floods has resulted in creation of gully erosions and active gully heads around the central part of the metropolis where seasonal floods are prevalent. Gombe Metropolis is principally a tropical continental dry and wet climate. Wet season normally starts from April to October and the average annual rainfall is within 650-1000mm. However, the relative humidity reaches 94 percent in August and declined to 10 percent in harmattan season (Daniel, et al., 2012).

3. Material and Method

The land use/land cover of the Gombe Metropolis and its periphery was analyzed to explore the changes taken place in different land use types in 2003 and in 2014, and to compare these changes so as to see how it affects the flood frequency in different residential areas in the Metropolis. All residential areas in Gombe Metropolis were delineated as the study area using a topographic map to shape files with ArcMap software.

To determine land use/land cover type changes in a span of a decade (2003 and 2014) in the Gombe Metropolis, GIS and Remote Sensing techniques were applied using Land sat 7 and 8, Enhance Thematic Mapper (ETM) images of 2003 and 2014 respectively, with thirty meters spatial resolution for the analysis. ERDAS Imagine (Image processing software) was used to process the image. A standard false color composite (432 for land sat7 and 543 for land sat 8) combination was applied and the image was further enhanced using histogram equalization to aid interpretation (Natural Resource Canada, 2016).

Since Land Sat 7 and 8 images are panchromatic imageries, the ERDAS Imagine software was used to process the image into a multispectral image through the following process where both images were stacked using false color composite (combination) using file format (Jay and Ryan, 2009).

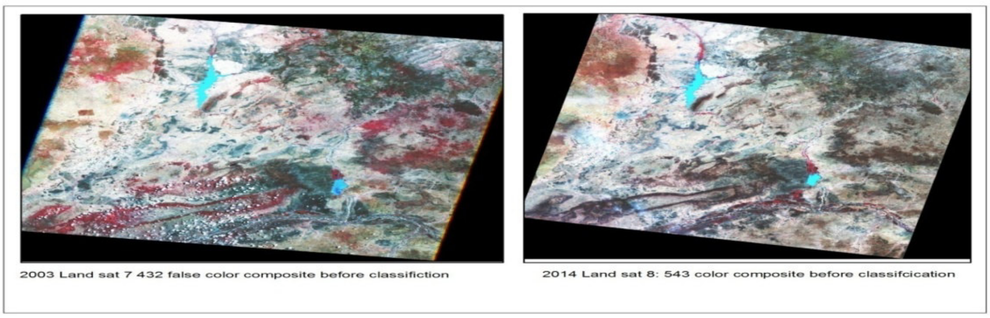


Figure 1: 2003 and 2014 False Color Composite Combinations
Source: Compiled by the Author

Figure 5.1 describes the enhanced Land Sat 7 and 8 of the 2003 and 2014 using the 432 and 543 colors composite respectively before it is interpreted and classified into five land use/land cover types.

Furthermore, pan-sharpening was conducted to the stacked images in order to improve and enhance the images using radiometric enhancement (histogram equalization) (Jay and Ryan, 2009)). Image enhancement can improve the appearance of the imageries and aid in visual interpretations. Since, the Land Sat images are for the entire Gombe State, there was a need to subset the area of interest (study area). Hence the enhanced images were used to subset the study area (Gombe Metropolis) using Area Of Interest (AOI). However, the AOI was generated and

Subsequently, classified into five land use/land cover type classes, of built up areas, agricultural fields, vegetation, bare land and rock surface. Classification is the digital operation to identify and classify pixel in the data into a particular class or theme based on a statistical feature of the pixel brightness values (Natural Resource Canada, 2016). The classified raster images were converted into vector layers and cleaned in ERDAS Imagine before exporting into ArcMAp version 10.3 for further analysis (David, 2002).

The exported vector layers were exported into shape files and categorized according to their various classes using symbology method (David, 2002). The main target is to explore the trend in urban development in terms of built up areas in relation to other land use/land cover types in the metropolis. This is essential to detect how land cover type that is important for controlling runoff water such as vegetation and bare land are affected by urban development. Therefore, the detection method conducted is the multi data classification using multi-temporal images data of the Gombe metropolis of 2003 and 2014.

The map of the residential quarters, the 2014 land use/land cover type and the stream buffers were overlaid and modeled and thereafter, built- up areas within 50 meters buffer was calculated and finally Gombe Metropolis Flood Risk Zones were detected and developed into Gombe Metropolis Flood Risk Map**.** Mapping and measurement of the downstream flood risk areas were achieved by superimposing the 2014 land use/land cover classification map over the respective delineated digitized residential areas of the metropolis layer to determine the percentage of the total land use/land cover classification for each residential area. Furthermore, the percentage of total land area under built-up (building density) for residential areas was calculated in order to observe the extent of sealing rate caused by the built-up density. Finally, the total percentage of built-up areas within a 50-meter buffer in each residential area was established to assess the level of exposure of people to floodplains and areas liable to floods.

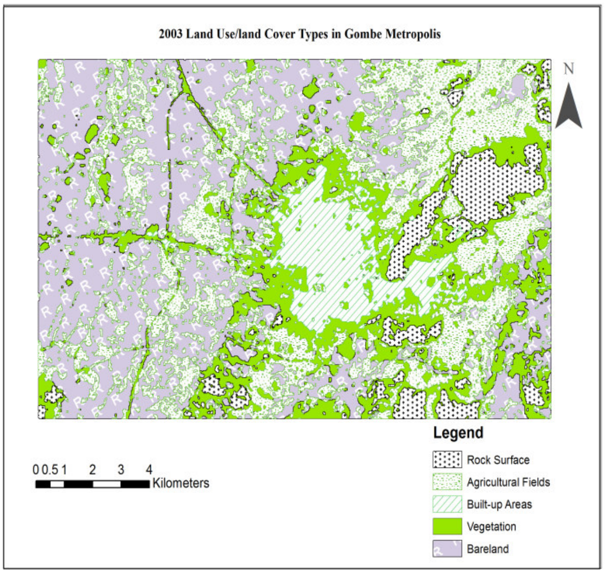
4. Result and Discussion

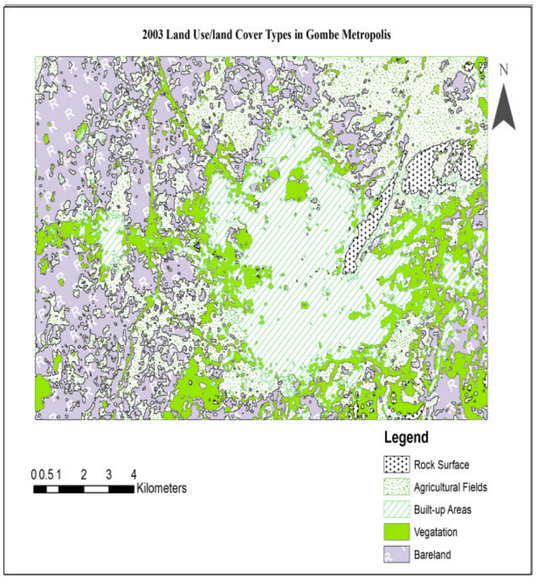
This study applied Geographic Information System and Remote Sensing as a tool for integration of spatiotemporal data for modeling and comparison of urban development scenarios and its consequential impacts on downstream areas of Gombe Metropolis. Therefore, GIS and Remote Sensing have been applied to detect land use/land cover changes, by looking at the trend in Land use/Land Cover Change from 2003 to 2014 in the Gombe Metropolis. Furthermore, the study identified Land use/Land cover types in Different Residential areas of the Metropolis with more emphasis on the building density in each area. The result of the analyses is explained in detail below.

4.1Analysis of Land Use/Land Cover Changes in the Gombe Metropolis

The 2003 and 2014 Land use/Land cover classification conducted can be seen in map 1 and 2 with five classes of agricultural fields, bare land, built up area, rock surface, and vegetation.

The maps show evidence of changes within 2003 and 2014 among different land use/land cover in the metropolis and the end result of these can be seen in creating floods due to the increasing hard surface created by the increasing building density in 2014 which definitely affect infiltration capacity and the subsequent floods in Gombe Metropolis. Calculating the changes based on the extent of the area, attribute tables were utilized in Arc GIS environment to calculate the area geometry by adding additional fields for calculating the area in square kilometers and percentage of the areas covered by each land use/land cover types in the metropolis for 2003 and 2014. Table 1 illustrated the pattern of land use/land cover changes in the Gombe Metropolis between the year 2003 and 2014.





Map 1: Gombe Metropolis 2003 Land use/Land cover Types Map 2: Gombe Metropolis 2014 Land use/land cover Map
Source: Compiled by the Author, 2016

There was a conversion of bare land, rock surfaces and vegetation cover to either agricultural uses or construction of built environment. Because a decrease of 22km^2 of the land area was observed in bare land, while rock surfaces decreased by 8.7km^2 and areas covered by vegetation decreased to by 3.4 km^2. Between 2003 to 2014, areas that were under cultivation increased by 7.7 km^2, because the total vegetation cover in 2003 was 54.6 km^2 and increased to 62.3 km^2 in 2014. Although, the largest increase was detected in the built-up areas with an increase of 26.5km^2 unit of land area of the metropolis (from 14.4 km^2 in 2003 to 40.9 in 2014) as shown in table 1.

Table 1: Land use/Land Cover Change between 2003 and 2014 in Square Kilometer (km^2)

Land use/Land cover Type	2003 Area in km^2	2014 Area in km^2	Area changes in km^2
Agricultural Fields	54.6	62.3	+7.7
Bare land	79.6	57.3	-22.3
Vegetation	36.4	33.0	-3.4
Build up areas	14.4	40.9	+26.5
Rock Surface	13.7	5.0	-8.7
Total Area	198.7	198.7	

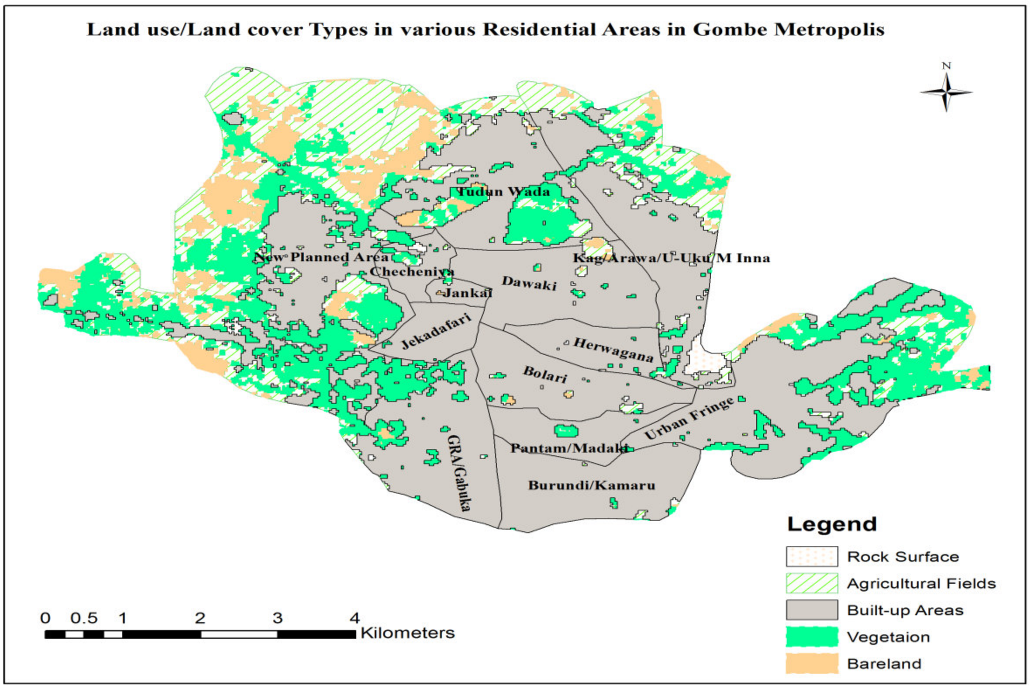
Source: Compiled by the Author, 2016

The inference is that the metropolis is rapidly undergoing a rapid transformation which consequently put the metropolis and the urban fringes under intense utilization of bare land, vegetation cover, and rock surface, resulting in a sealing effect of the earth surface which translates into the increasing flood frequency in the metropolis. This is because the vegetated cover and bare land play a significant role in controlling surface runoffs which are virtually replaced with a hard surface that increase overland flow and reduced infiltration capacity of the soil and consequently create floods. Hence, the total building density increases the sealing surface area of approximately twenty-seven square kilometers of the total land use in the metropolis and its environs from 2003 to 2014. The increasing impermeability of the catchment area has the potential of creating quick and faster rain water flows and consequently flooding occurs. Because the volume of runoff is governed by infiltration characteristics and it is related to slope, soil type, vegetation cover and the percentage of each land use /land cover type in an area. Therefore, in-depth analysis of the built-up areas is necessary to find out the percentage of land area coverage by built-up in each residential area of the Gombe metropolis.

4.1.1 Land use/Land cover types in Residential Areas of the Gombe Metropolis

Determining the percentage of an area covered by each land use/land cover is essential because certain land use /land cover type determine infiltration capacity of a place by either minimizing runoff or increasing quick runoff and the subsequent flooding. For instance, the increasing impervious (non-porous) surface by the built-up environment can affect the increasing flood peak in an urban area. To examine that, the classified 2014 land use/land cover classes of Gombe metropolis was overlaid with Gombe Metropolis residential map and subsequently SQL (Structured Query Language) function and attribute table of the GIS Arc map was applied to calculate the area coverage for each land use/land cover type of Gombe metropolis in 2014.

Map 3 depicts the map of the metropolis showing the residential areas and the various land use/cover classes in each residential area in the metropolis in 2014. The residential areas located at the center of the metropolis as seen on map 3 are almost completely covered with built up constructions and are the potential areas in the metropolis for flood occurrences.



Map 3: Land Use/ Land cover type in different Residential Areas of the Gombe Metropolis
Source: Compiled by the Author, 2016

These areas are mostly the midstream section including Jekadafari (JEK), Checheniya (CHECH), Jankai (JAN), Dawaki (DAW), Bolari/ Madaki (BOL/MAD), Herwagana (HERWA), Tudun Wada (TW), Pantami (PAN), and Mallam Inna/ Unguwa Uku/Arawa/Kagarawal (MUAK) axis.

Table 2: Land use/Land Cover Types in Residential Areas of Gombe Metropolis in Square Meter.

Residential Areas	Agriculture	Bare land	Vegetation	Buildup Area	Rock Surface
JEK	0.000	0.000	9353.64	958537.60	0.00
JAN	8121.29	4500.000	6300.00	286005.95	0.00
DAW	114426.15	28935.50	28716.99	2871343.05	1800.00
BAR	33995.39	1536.38	23677.93	2839428.33	0.00
TW	114959.96	714054.83	1076737.55	2831081.22	0.00
PAN	7931.35	0.00	53038.65	1275593.92	0.00
BOL/MAD	51468.65	18000.00	30661.35	2231358.46	3167.20
NPA	5023444.39	1985763.32	4789206.22	3622155.61	68361.00
MUAK	1554456.84	263556.22	735265.30	3355070.41	204289.41
CHECH	38487.85	0.00	79698.07	652259.06	26100.00
HERWA	14427.14	0.00	27794.11	1273286.17	4032.90
UF	634877.59	222445.40	2273810.59	4569037.94	18000.00
GRA/GAB	54784.02	27000.00	646642.74	3144973.46	11738.22

Source: Compiled by the Author, 2016

On the other hand, places such as the New Planned Area (NPA), Urban Fringe (UF), Barunde (BAR) and Government Residential Areas/ Gabuka (GRA/GAB) at the marginal wards of the metropolis are still having considerable land areas for vegetation cover and bare land. The percentage of building density in each residential area is shown table 2. The summary for area geometry of each land use/land cover type for all residential area in Gombe Metropolis was calculated as shown in table 2. Having seen the land use classes in various residential areas it is important to analyze the built-up area in each residential area to see how various areas may be potential for flood risk

4.1.2 Gombe Metropolis Building Density According to Residential Areas

To determine the infiltration capacity of an area within the metropolis, percent area covers by built-up serve as an indicator for water permeability. The higher is the percentage of areas covers by built-up, the higher is the probability of generating quick volume of runoff that cause flooding in an area. Table 3 depicts the total building density for each residential quarters and its relative percent coverage in the metropolis. The total building density makes up a sealing area of approximately 40.9 square kilometers (40.900, 000 square meters) as explained above. However, highest building densities (sealing rate) are found around the center of the metropolis, ranging from 99 to 81.9 percent area covered by built-up, and these areas include JEK, BAR, HERWA, PAN, JAN, DAW, and GRA/GAB areas. While the least residential areas with percent built-up areas ranging from 59.8 to 23 percent areas include TW, UF, MUAK and NPA. The residential areas with the highest sealing rate (percent built) are the most potential flood vulnerable areas of the metropolis.

Table 3: Total Build-up areas in each Residential Areas

Residential Areas	Building Density in Square Meters	Building Density in Square Kilometer	Areas in Percentage
JEK	958,537.6	1.0	99
JAN	286,006.0	0.3	93
DAW	2,871,343.1	2.9	94
BAR	2,839,428.4	2.8	98
TW	2,831,081.2	2.8	59
PAN	1,275,593.9	1.3	95
BOL/MAD	2,231,358.5	2.2	95
NPA	3,622,155.6	3.6	23
MUAK	3,355,070.4	3.4	55
CHECH	652,259.0	0.7	82
HERWA	1,273,286.2	1.3	96
UF	4,569,037.9	4.6	59
GRA/GAB	3,144,973.5	3.1	81

Source: Compiled by the Author, 2016

An area with high building density is susceptible to flood risk but the risk could be higher if a larger part of the building is exposed to or are located in areas liable to flood risks such as streams, rivers or gullies,

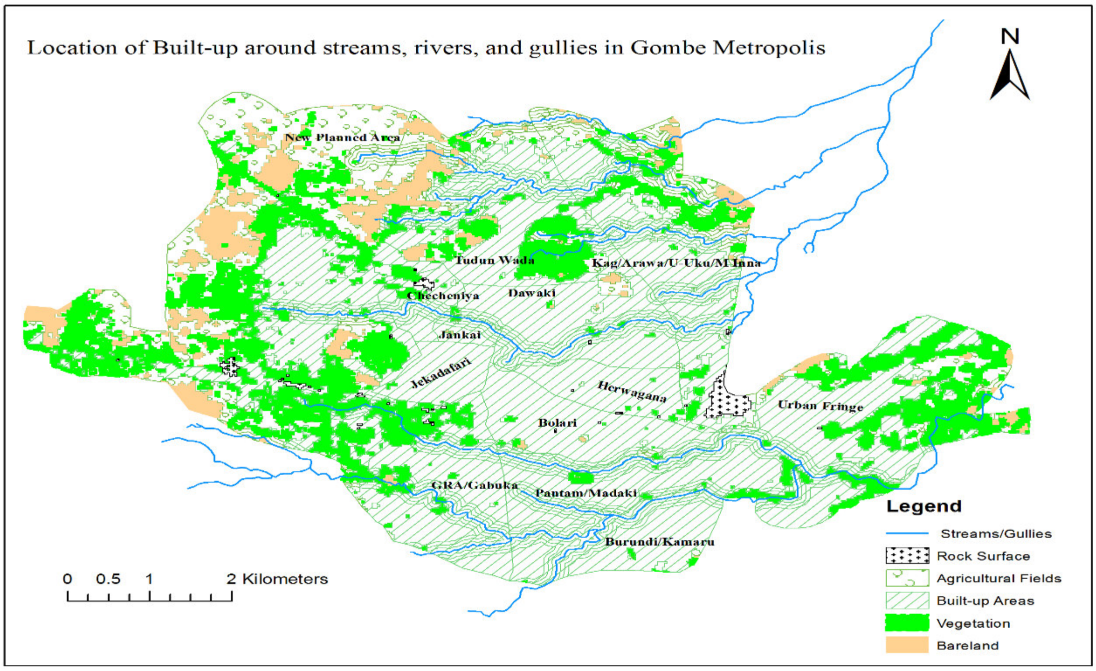
4.2. Analysis of Gombe Metropolis Downstream Areas within Floodplains

Among the key factors causing urban flooding is proximity to waterways, such as streams, rivers, and gullies. Therefore, the study conducted 50, 100 and 150 meters buffers around streams and gullies of Gombe Metropolis in order to determine built-ups areas located on floodplains using proximity tool of the spatial analysis in ArcMap environment. The map of the residential quarters, the 2014 land use/land cover type and the stream buffers were overlaid and thereafter, built- up areas within 50 meters buffer was calculated and the overlaid result can be seen in map 5.4.

Generally, streams and rivers in Gombe Metropolis flow from the South-West and Western part (Akko Escarpment) of the town flowing towards North and North-Eastern part of the metropolis (See Map 4). The up streams start around the New Planned Areas; as such, they are less potential to flood risk. The center of the metropolis is regarded as the midstream section where building density is high, narrow drainage facilities to contain the massive volume of runoff discharging from the upstream, hence is the most potential flood risk areas. On the other hand the downstream is wide streams to accommodate the volume of runoff in the rainy season; hence, a flood occurrence here is also minimal.

4.2.1 Location of Built-up on floodplains in the Metropolis

To find out built-up area located on the areas prone to floods the residential areas, the 2014 land use/land cover type, and the streams/gullies layer were overlaid and modeled. The result of the analysis is shown on map 4.



Map 4: Map of Built-up areas within Floodplains in Gombe Metropolis
Source" Compiled by the Author, 2016

Built-up areas located on floodplains (streams, rivers, and gullies) are vulnerable (exposed) to flood risk in the urban environment. The area extent in terms of built-up areas within floodplains is essential for urban flood risk management. The research calculated the built-up areas in square meters as well as square kilometers in each of the residential quarters of Gombe metropolis by conducting 50 meters buffer zones. According to the building codes and regulations, no building should be erected within 50 meters from a waterway such as a stream.

Table 4 Building Proximity to Floodplains in the Gombe Metropolis

Residential Areas	Built-up Area Within 50Meter Buffer in Square Meter	Buildup Area Within 50 Meter Buffer in Square Kilometer
JEK	0.0	0.000
JAN	51,878.9	0.051
DAW	290,069.1	0.290
BAR	523,437.3	0.523
TW	431,535.4	0.432
PAN	260,440.6	0.260
BOL/MAD	261,157.8	0.026
NPA	130,809.0	0.131
MUAK	490,259.6	0.490
CHECH	99,100.0	0.099
HERWA	0.0	0.000
UF	304,715.9	0.305
GRA/GAB	399,461.3	0.400
Total	3,242,864.9	3.242

Source: Compiled by the Author, 2016

Therefore, by calculating the buffers the researcher was able to know the land extent (encroachment) for each residential quarter that violates the regulations and proper action could easily be taken, such as relocation and resettlement in order to minimize and mitigate future flood damages in Gombe Metropolis. According to table 4, the highest number of buildings located on the floodplains (50-meter buffer zone) can be found in BAR (0.52km^2), MUAK (0.49km^2), TW (0.43km^2), GRA/GAB (0.39km^2), UF (0.30km^2).

The last aspect in risk studies is the production of flood risk map that can give more insight on areas that have a plausible potential to floods. Hence, some variables from the above analysis were used to produce the flood risk index and the flood risk map.

4.3. Gombe Metropolis Flood Risk Mapping

Flood risk mapping is an essential component for land use management in flood risk areas, by providing easily read, rapidly accessible charts and maps that give room for identification of risk areas and prioritize its mitigation effects (Forkuo, 2011). Moreover, the end product of urban flood risk assessment is a risk map prepared to assist in minimizing flood losses by promptly identifying areas of potential flood risk and that make it possible for urban planners to clearly spot the most endangered section of the metropolis. And thereafter, the flood risk assessment can be linked with risk mitigation measures by indicating those areas where preventive mitigation measures can possibly mitigate risk effectively. Hence, flood risk mapping is very significant for a sustainable urban flood risk management.

The variables or indicators used are basically the variables generated from the GIS analysis and elevation values of the residential areas, which include; Percentage of building density in each residential quarter and built-up areas located on the floodplains in each residential area (Proximity to Flood Plains) and elevation. To produce the map, composite index were created from these parameters. The 2014 Land Cover/Land Use of the Gombe Metropolis was used to create the Gombe Metropolis flood residential flood risk zones through the assigning index to each residential quarter. The residential quarters were digitized using ArcMap Software into polygons and subsequently joint with the composite risk index in GIS environment. The process and the result are discussed in detail below.

4.3.1 Flood Risk Index

The index is a statistical measure of change in a representative group of individual data points and its basic function is to allow for comparison of phenomena possible. Therefore, the Flood Risk index gives room for rating, comparison and identification of critical zones or hotspots, so that flood risk variable can be analyzed and compare among flood risk areas.

An additive model was adopted from Forkuo, (2011) in creating a composite index for flood risk because the method of assigning ranks to the variables is essential in constructing risk map (Forkua, 2011). A composite index is a grouping of factors put together in a standardized way to come up with a single index for all the variables. Hence, residential areas in Gombe Metropolis has been assigned ranks for the variables deemed to be the most influential indicators for flood risk in Gombe Metropolis according to the analysis conducted. The ranking is the arrangement of variables in serial order of importance and the variables are, namely, elevation, the percent building density, and proximity to floodplains.

For the purpose of elevation of the study site, the height of three points from each residential quarter in the metropolis was extracted from the relief map generated from the Digital Elevation Model (DEM). Thereafter, average heights of the three points were calculated for each residential area in the metropolis. Table 5 present the summary of the result.

Table 5: Elevation in Various Residential Areas in Gombe Metropolis

Residential Areas	Point 1	Point 2	Point 3	Total Height	Average Height
JEK	490	480	475	1445	482
JAN	460	500	455	1415	472
DAW	455	440	430	1325	442
BAR	450	4435	395	1280	427
TW	490	450	440	1380	460
PAN	450	435	450	1335	445
BOL/MAD	465	465	450	1380	460
NPA	650	600	570	1820	607
MUAK	445	435	404	1285	428
CHECH	490	500	490	1480	493
HERWA	440	440	460	1340	446
UF	400	410	420	1230	410
GRA/GAB	490	470	460	1420	473

Source: Compiled by the Author, 2016

Water flows from high to low elevation surface, the slope affects the amount of surface run-off. Therefore, residential areas located at a lower elevation are more vulnerable to flood risk compared to places at higher elevation areas. Hence, high ranks are assigned to low elevation areas (high risk) and classified into five classes as shown in table 6.

Table.6: Elevation Categories and their Ranks

Elevations Categories in meters	Flood Risk Rank
410.5-449.9	4.5
449.9-489.3	3.5
489.3-528.7	2.5
528.7-568.1	1.5
568.1-607.5	0.5

Source: Compiled by the Author, 2016

The second variable is the percent building density. Land use influence infiltration rate, because vegetative surface favor infiltration while high percentage of building density encourages quick runoff and overland flow of water. Table 7 describes the building density in various residential quarters of Gombe Metropolis.

Table 7 Building Density of Residential Areas in Gombe Metropolis

Residential areas	Building Density in Percentage
JEK	99
JAN	94
DAW	94
BAR	98
TW	59
PAN	95
BOL/MAD	95
NPA	96
MUAK	23
CHECH	82
HERWA	96
UF	59
GRA/GAB	81

Source: Compiled by the Author, 2016

In effect, residential areas with high percentage of building density are more vulnerable to flood risk because of the sealing effect created by the built environment, it decreases water permeability (infiltration rate) and increases runoff. Hence, high score (rank) is given to areas with high percentage of building constructions and the ranking is shown in five class categories in table 8.

Table 8: Percent Building Density Categories and their Ranks

Percent Building Density	Flood Risk Rank
21.5-37.1	0.1
37.1-52.7	1.5
52.7-68.3	2.5
68.3-83.9	3.5
83.9-99.5	4.5

Source: Compiled by the Author, 2016

At last, area extent for each built-up area that is located on floodplains (50 meters buffer from a stream, river or gully) or area liable to flood risk in the metropolis. The totals built up area coverage located on floodplains were also ranked to examine residential areas vulnerable to flood risk due their proximity to areas liable to floods. The distance (proximity to flood plains) was calculated by overlaying the 50-meter stream with a residential map of Gombe metropolis and the result is seen in table 9.

Table 9: Gombe Metropolis Residential Areas within 50 Meters Stream Buffer

Residential Areas	Built-up Area Within 50Meter Buffer in Square Meter
JEK	0.0
JAN	51,878.9
DAW	290,069.1
BAR	523,437.3
TW	431,535.4
PAN	260,440.6
BOL/MAD	26,157.8
NPA	130,809.0
MUAK	490,259.6
CHECH	99,100
HERWA	0.0
UF	304,715.9
GRA/GAB	399,461.3

Source; Compiled by the Author, 2016

Residential Areas or area with the larger built-up area located on the 50-meter stream buffer are having a high flood risk hence those areas are given a high rank and vice versa, in a rating scale of 1-5 (See table 10 below).

Table 10: Categories of Built-up Areas Located on Floodplains and their Ranks

Area Extent in Square Meters	Flood Risk Rank
26,157.5-125,612.8	0.1
125,612.8-225,068.6	1.5
225,068.6 -324,524.4	2.5
324,524.4- 423,980.2	3.5
423,980.2-523,436.0	4.5

Source: Compiled by the Author, 2016

Having given class categories for the variables, the food risk index was designed accordingly as follows.

4.3.2 Flood Risk Index Model

The flood risk factors and the scheme of assigning ranks for those factors are essentially important in arriving at the flood risk composite index for flood risk mapping and thus, the adoption of the additive model, a nonparametric regression model. Subsequently, flood risk index (FRI) for Gombe Metropolis residential areas is creating from the additive model adapted from Forkua (2011) as shown in table 11.

Table 11: Flood Risk Index (FRI) Ranks

FID	Residential Areas	El_R	Bd_R	Pf_R	FRI
1	NPA	0.5	4.5	1.5	6.5
2	GRA/GAB	3.5	4.5	3.5	11.5
3	JEK	3.5	4.5	0.5	8.5
4	JAN	3.5	4.5	0.5	8.5
5	CHECH	2.5	3.5	0.5	6.5
6	TW	3.5	2.5	4.5	10.5
7	MUAK	4.5	0.5	4.5	9.5
8	DAW	4.5	4.5	2.5	11.5
9	HERWA	4.5	4.5	0.5	9.5
10	BOL/MAD	3.5	4.5	0.5	8.5
11	PAN	4.5	4.5	2.5	11.5
12	BAR	4.5	4.5	4.5	13.5
13	UF	4.5	2.5	2.5	9.5

Source: Compiled by the Author, 2016

Note: El_R: elevation Ranked, Bd_R: Building Density Ranked, Pf_R: Proximity to Floodplains Ranked

The FRI= (El_R+ Bd_R+ Pf_R)

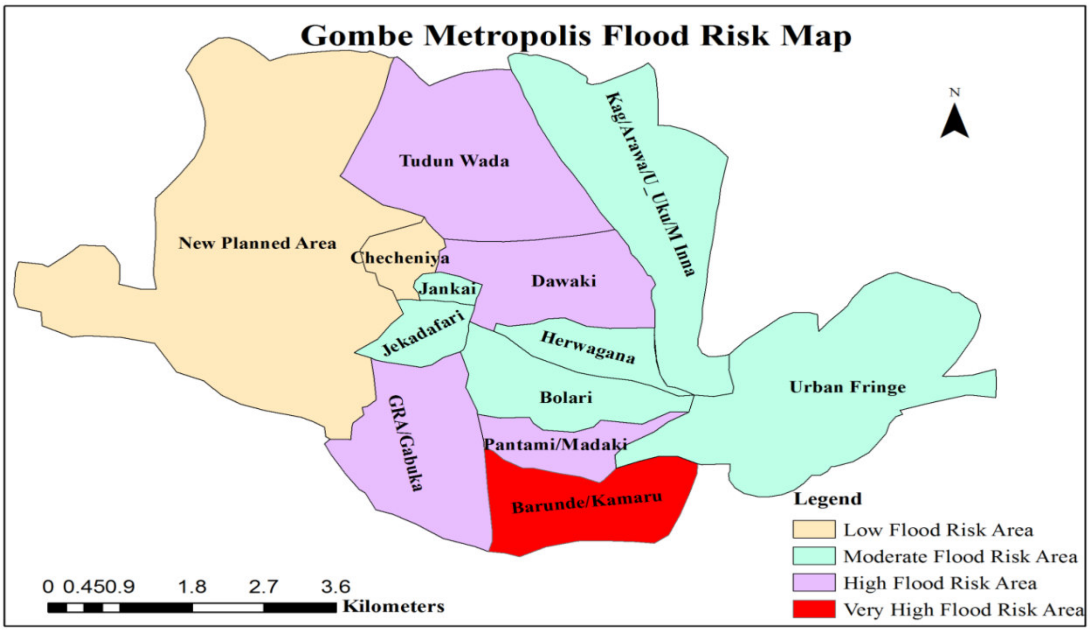
4.3.3 Flood Risk Zones in the Gombe Metropolis

For each indicator, the classification was made for low, moderate, high and very high flood risk zones. Afterward, flood risk index generated was joined with the map of the residential quarters and represented using graduated color map in ArcMap environment, where residential quarters in Gombe Metropolis were categorized into four flood risk zones by natural breaks method. The summary of the zoning can be seen in table 12, and the final map is shown in map 5.

Table 12: Flood Risk Zones in the Gombe Metropolis

Flood Risk Classes	Number of Residential Areas	Flood Risk Zones
6.5-8.3	2	Low Flood Risk
8.3-10.0	6	Moderate Flood Risk
10.0-11.8	4	High Flood Risk
11.8-13.5	1	Very High Flood Risk

Source: Compiled by the Author, 2016



Map 5: Gombe Metropolis Flood Risk Map

Source: Compiled by the Author, 2016

The risk index can be used as a tool to identify priority areas where policy intervention is most needed.

5. Conclusion

The analysis was able to observe and reveal the following findings: The land use/land cover has undergone a significant change in 2014 where built up areas extensively increased the land surface sealing rate from a total land area of 14.4 square kilometers in 2003 to 40.9 square kilometers in 2014. In essence, the total building density increases the sealing surface area of approximately twenty-seven square kilometers of the total land use in the metropolis and its environs within this period. This significant change along has the potential to create quick runoff and floods in the metropolis. However, It was also revealed that the most density residential areas with building densities between 99 to 81 percent are found in JEK, JAN, DAW, BAR, PAN, BOL/MAD, CHECH, HERWA and GRA/GAB. Thus, these residential areas are the potential flood risk area in the metropolis.

It was also revealed that a total building coverage of 3,242,864.9 meters square (3.2 square kilometers) are located within 50 meters stream buffer. However, the most vulnerable and exposed areas with a total building coverage of not less than 300,000 meters are found in BAR, MUAK, UF and GRA/GAB, followed by (less than 300,000 meters coverage) DAW, PAN, and NPA.

The flood risk index established that the area located on the very high flood risk is BAR, while the areas within the high flood risk zones include GRA/GAB, PAN, DAW, and TW. It was further found that the residential areas in the moderate flood risk zone include JAN, JEK, HERWA, BOL/MAD and MUAK.

In view of the above findings, it is recommended that in order to achieve sustainable flood risk mitigation in Gombe Metropolis, the following should be put into considerations. First, there is a need for redevelopment through conversion of built-up areas into open space such as parks and recreation centers in JEK, JAN, DAW, BAR, PAN, BOL/MAD, CHECH, HERWA and GRA/GAB residential areas. Secondly, buildings located within 50 buffer from the gullies and streams should be remove especially in BAR, MUAK, UF, GRA/GAB, DAW, PAN, and NPA residential areas.

Reference

Bera, K., Pal, M., Bandyopadhyay, J., (2012). Application of Remote Sensing and GIS in flood management: a case study of Mongalkote Blocks, Burdwan, West Bengal, India. *International Journal of Scientific and Research Publications*, *2*(11), 1-9.

Daniel, D.I., Juji G.R., Aziukwu, N.A., & Omiola A.H (2012). Analysis of the relationships between urban dynamics and incidences of urban flood disaster in Gombe Metropolis, Nigeria. *Journal of Sustainable Development in Africa 14*(2), 520-550.

David, L.V (2002). *Practical GIS analysis.* London, Taylor and Francis.

Davidson, R. (1997). *An urban earthquake disaster risk index* (Report no. 121). Auckland, New Zealand: The John A. Blume Earthquake Engineering Center.

Derek, B.B., (1991). Urbanization and the national drainage system-impacts, solutions, and prognoses, Northwest. *Environmental Journal*, 7(1).

Forkuo, E.K. (2011). Flood hazard mapping using aster image with GIS. *Journal of Geomantics and Geoscience, 1*(4), 932-950.

Jay, D.G & Ryan, R.J (2009). *Geotechnology and the environment: planning and social economic application*. . Retrieved June 17, 2006 from
http://www.springer.com/series/8088

Karmakar, S., Simonovic, S., Peck, A. & Black, J., (2010). An information system for risk-vulnerability assessment to flood. *Journal of Geographic Information System*, *2*(2), 129-146.

Natural Resources Canada (2016). *Fundamental of remote sensing*. Retrieved June 17, 2016 from www.nrcan.gc.ca/earth-science/geomatics

Saini, S.S. & Kaushik (2012). Risk and vulnerability assessment of flood hazard in part of Ghanggar Basin: A study of Guhla Block Khaithat, Harrana, India. *International Journal of Geomatics and Geoscience, 3*(11), 42-52.

Trotter, C.M. (1991). Remotedly-sensed data as an information systems in natural resources management a review. *Systems International Journal of Geographical Information 5(2),* 225-239.

United Nations/ New Partnership for Africa's Development (UN/NEPAD) (2006). *Global survey of early warning systems: an assessment of capacities, gaps and opportunities towards building a comprehensive global early warning system for all natural hazards.* Retrieved October 12, 2014 from www.unisdr.org.

Wisner, B., Blaikie, P., Cannon T., & Davies I. (2004). *At risk: Natural hazards, people's vulnerability and disasters.* London: Routledge.