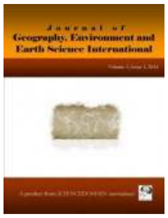

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Alternative Index for Measuring Flood Risk and Its Application in Gombe Metropolis, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author LMD designed the study, wrote the protocol and wrote the first draft of the manuscript. Author SI managed the literature searches, analyses of the study performed the spectroscopy analysis and author SI managed the experimental process and author SI identified the species of plant. Both authors read and approved the final manuscript.

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ABSTRACT

Aim: There is no doubt that the world is now under a serious threat from the environmental hazards due to the fact that the frequency and intensity of hydrological hazards such as floods have been increasing in recent years. Flood risk is a probability of loss which depends on three elements or concepts, namely 1) hazard, 2) vulnerability, and 3) exposure. A clear understanding and distinction between the three elements that create risk- hazard, exposure and vulnerability - gives the necessary information for factoring in most flood-related aspects. This paper focuses on developing a new method for measuring flood risk using the main indicators for geophysical exposure of the risk (percent built-up density, proximity to floodplains and elevation). The new method was afterward applied to study flood risk in Gombe Metropolis using Remote Sensing and GIS so as to achieve the set objectives.

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Methods: The residential areas, streams were digitized, Multi-temporal satellite images were obtained from Land sat 8 Enhance Thematic Mapper (ETM) for 2014 and used for classification of Land cover/use type in the study area. Furthermore, Digital Elevation Model (DEM) was also used to collect elevation data for the entire Gombe Metropolis residential areas. The classified 2014 land use/land cover type of Gombe metropolis was overlaid with the digitized Gombe Metropolis residential areas map. Subsequently, the Structured Query Language (SQL) functions and attribute table of the GIS Arc map was applied to calculate the area coverage for the percent of built up areas and building constructions within 50-meter stream buffer in Gombe metropolis.

Results: The result revealed a remarkable outcome necessary to mitigate flood risk and thereby improving the well-being of the vulnerable flood communities in the metropolis. The finding proves that seven residential areas in Gombe metropolis are within a very high to high flood risk zones. These residential areas include Government Residential Area/Gabuka, Jankai, Checheniya, Pantami, Barunde, Dawaki and Bolari/ Madaki. However, Tudun Wada, MUAK, New Developed Areas, Jekadafari, Herwagana and Urban Fringe residential areas fall within the moderate to low flood risk.

Conclusion: Thus, priorities for flood risk mitigations measures should be focused towards the very high and high flood risk areas in the metropolis.

Keywords: Flood risk; Gombe metropolis; building density; proximity to floodplains.

1. INTRODUCTION

There is no doubt that the world is now under a serious threat and risk from the environment hazards due to the fact that the frequency and intensity of hydrological hazards such as floods have been increasing in recent years, the world over. The risk is one of the components of hazard and is defined as the actual exposure of something of human value to hazard, measured as a product of probability and the related loss [1]. Hence, the risk is a probability of loss which depends on three elements or concepts, namely 1) hazard, 2) vulnerability, and 3) exposure. Thus, flood risk refers to the likelihood of inundation of an area by unexpected rise of water due to dam failure or extreme precipitation with long duration and intensity in which life and properties in the affected area are under risk [2].

Flood risk in an urban area is an overflow of land areas, temporary backwater effect in sewers and local drainage channels caused by the encroachment of floodplain thereby causing obstructions and loss of flood storage [3]. Most of these losses occurred in areas where vulnerable urban settlements were developed close to known hazard areas, such as floodplains. A clear understanding and distinction between the three elements that create risk- hazard, exposure and vulnerability - gives the necessary information for factoring in most flood-related aspects in the overall management of flood risks and at the same time contribute substantially to the development and wellbeing of the people [4]. This research focus on only one aspect of the risk, which is exposure and the variables related to exposure normally include proximity to the source of hazard (i.e. floodplain), elevation and percentage of built up cover (building density).

Urban flood studies show that the projections of climate change trends indicate a future increase in the occurrence of the intense rainfall events; both in terms of their intensity as well as the frequency may have a potential effect of flooding (Intergovernmental Panel on Climate Change [5,6]. However, [7] argued that there is a weak relationship between the hydrological factor and the damaging floods in urban areas. The damaging floods occur from a combined effect of physical and societal processes [3]. This is because in most cases, floods are additionally influenced by human factors and flood hazards in built environments have to be seen as the consequence of natural and man-made factors. Therefore, in order to fully understand urban flood risk, it is important to be familiar with the different kind of components that make risks.

Of all land uses changes that affect the hydrology of an area, urbanization is by far the most forceful impact bringing drastic changes in peak flow characteristics, changes in a total runoff, changes in quality of water and changes in hydrological amenities [8]. Some of the major hydrological effects of urbanization are increasing peak flow, reduced infiltration, and reduced ground water recharge and diminishing base flow [2]. The volume of runoff is governed primarily by infiltration characteristics and is directly related to the percentage of an area covered by roofs, streets and other impervious surfaces at the time of hydrographic rising during storms [9]. The increasing pervious surface has the potential of increasing flood flow peaks during storm period and thereby creating quick runoff flow that led to floods [8].

Furthermore, the encroachment and modification of the urban floodplains of streams and river systems are factors contributing to the increasing damages and risk caused by the floods [10]. It is estimated that over one billion people now live in slum conditions and the majority of population growth around the world is occurring in the periphery and areas liable to flood [11].

Nigeria has not been left out in these global extreme hydrological problems. In recent years, there has been an alarming rise in economic and social losses due to flooding in the country. This systematic rise reached a peak during 2012 floods event, claiming over 400 lives in 27 affected states, displacing about 2 million people, while properties worth billions of naira were destroyed [12]. Many researchers have shown that intensive and unplanned human settlements in flood-prone areas appeared to be playing a major role in increasing flood risk. For instance, [13] identifies the major factor causing flooding in Africa as inadequate drainage system and this fact was supported by many empirical studies.

Idris and Dharmasiri [14] Research works on urban development and the increasing trend of flood risk in Gombe metropolis of Nigeria, shows that improper erosion control, poor drainage system, and poor management of solid waste are among the basic factors causing flooding in Gombe metropolis. In addition, another study in Gombe metropolis by) [15] stated that people habitually built a settlement on drainage channels and indiscriminately dumped refuse on drainage channels as some of the factors that aggravated the flood problem in Gombe metropolis.

Gombe metropolis has experienced a rapid demographic growth which brought a lot of changes in the land use pattern (urban development) and increased the vulnerability of urban areas to flood risk through indiscriminate clearance of former forest formation with dense vegetation for built environment and the occupation of the floodplain areas. Henceforth, the impact of flooding in Gombe is becoming more frequent and seasonal events leading to environmental damage, loss of lives and properties [14,15]. Despite the efforts made by the Government, Individuals, Non-governmental organizations and International donor agencies, the problem of the flood has persisted in Gombe metropolis [15].

The magnitude and frequency of occurrence of flood disasters in urban areas and the impact on lives, properties, and the environment necessitate the need for sustainable flood risk management globally so as to mitigate the impact on the persistence of town and cities all over the world [16]. A crucial concern for world natural hazards is the generation of efforts, strategies, policies and programs of the global governments at various levels to mitigate the events. Since risk is a product of three major concepts, namely, 1) exposure to a hazard, 2) exposure and the 3) vulnerability of element at risk then all approaches must aim at measuring risk and vulnerability through selected comparative indicators in a quantitative way in order to be able to compare different areas or communities.

A sustainable flood risk management requires flood risk assessment to identify forces and factors responsible for a potential flood risk [17]. In urban flood risk studies, urban growth and urbanization process are among the most important factors considered in flood risk assessment, because a lack of proper urban development plan allows people to erect constructions along these areas liable to flood such as flood plains, thereby increasing the risk of flooding in the urban center. Therefore, in this research exposure as a factor for flood risk has been analyzed and specifically percent built up areas, proximity to floodplains and elevation are considered as among the main indicators of exposure to flood risk.

This paper developed a new alternative method to measure flood risk with reference to those indicators highlighted above and further applied it in examining flood risk in Gombe Metropolis, Nigeria.

2. MATERIALS AND METHODS

A risk is a function of hazard (flood), exposure (Geographical context), and vulnerability (socio-economic) [4]. Hence, assessment of the exposure is necessary for this study in order to identify areas within a development plan that are prone to the risk of flooding based on the indicators for physical exposure factor. The factor is physical exposure and the indicators are building density, proximity to floodplains and elevation. To apply the new method to study flood risk in Gombe Metropolis, the following methodology was carried out.

Remote Sensing and GIS are applied appropriately to achieve the set objectives. Multi-temporal satellite images were obtained from Land sat 8 Enhance Thematic Mapper (ETM) of 2014 and used for classification and detection of Land cover/use change in the study area and Digital Elevation Model (DEM) was used to collect data elevation of the entire residential areas. The data obtained comprises of total land use/cover classes, built-up density, contours and elevations, percent built up within 50 meters buffer (proximity to floodplains. The residential areas of the whole Gombe Metropolis were digitized using ArcMap Software (version 10.3) into polygons. Furthermore, the major streams, rivers, and gully in Gombe Metropolis were digitized into line features in ArcMap. And finally, the digitized residential area was clipped with the streamline feature, in order to create 50-meter buffers of built up areas located on each residential areas in Gombe Metropolis as areas close to floodplains or source of risk. Subsequently, the classified 2014 land use/land cover type of Gombe metropolis was overlaid with the digitized Gombe Metropolis residential quarters map and subsequently SQL (Structured Query Language) function and attribute table of the GIS Arc map was applied to calculate the area coverage for built up areas or building density type of Gombe metropolis in 2014.

The study further conducts 50 meters buffers around streams, rivers 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 areas, the 2014 land use/land cover type and the stream buffers were overlaid and modeled and thereafter, built- up areas within each buffer was calculated and a percentage of built up within 50 meters buffer in each of the residential areas was obtained. The elevations were generated from a Digital Elevation Model of the Study Area where three point locations were extracted from each residential area and calculated as average.

2.1 The Alternative Method for Measuring Flood Risk

The research developed an alternative method for measuring flood risk by constructing an index called Flood Risk Index (FRI). Thus the following components were used in constructing the index: Elevation (Ex) of the residential areas, Building Density (B_d) for each residential area, Proximity to Flood Plains (P_f) and Risk Level (R_L).

2.1.1 Assumptions

To use the index the following assumptions can be considered: 1). It is most suitable for the developing countries, 2). Risk elevation is not static; it depends on factors from place to place and 3). Risk elevation also depends on time period.

2.1.2 The formula for the alternative flood index

However, the following formula was invented for calculating the index and symbolize as follows: FRI = $\frac{\mathbf{Ex}}{\mathbf{RL}} \times \frac{\mathbf{Bd}}{\mathbf{Pf}}$. The meanings of the acronyms are as follows:

Whereas FRI stands for the Flood Risk Index showing,

Ex as Elevation of any given point,
R_L as Risk Elevation Level (Based on the lowest point in the study area),
B_d as Building Density and
P_f as Proximity to Flood Plains

2.1.3 Interpretation and measurement of the FRI components

The Ex is the elevation of any given point in an urban area and can be calculated as meter height above sea level. Since elevation influences flood risk by either increasing the probability or decrease it, then the higher the location of a residential area the lower the probabilities of flood risk.

2.1.3.1 R_L: Risk elevation level

The risk R_L is assumed to be the lowest elevation plus the lowest flood level experienced in the study area.

Therefore, to determine high flood risk based on the elevation, the ratio of the highest elevation, the lowest elevation, and the R_L has to be calculated and the value indicates high flood risk because, the higher the elevation, the lower will be the flood risk. Also, the ratio of the lowest elevation and the R_L should be calculated and the value indicates high flood risk.

Let assume that the highest elevation of a place is 607 and the lowest is 420 while lowest flood level is 1 meter. The R_L is equal to the lowest elevation plus the lowest flood level. Hence, R_L =410+1=411. To calculate the ratio the following process should be followed.

Equation 1: $\frac{Ex}{RL} = \frac{607}{411} = 1.5$ }

Value above 1 means Low Flood Risk

Equation 2: $\frac{Ls}{RL} = \frac{410}{411} = 0.99$ }

Value below 1 means High Flood Risk

The second component is Building Density (Bd) and is calculated as a percentage of the built-up area of the study area. High building density increased the probability of flood through the quick generation of runoff due to the effect of the hard surface created by the built-up. Thus, the higher the building density the higher will be the probability of flood occurrences. To calculate Bd., let us assume a hypothetical data for the highest building density as 75 percent and the lowest density is 23 percent.

Then,

$\frac{75}{100} = 0.75$ = High Flood Risk

$\frac{22}{100} = 0.22$ = Low Flood Risk

The last FRI component is Pf which is the total area of built up, located in a close Proximity to the floodplains calculated as the percentage of built up located on a flood plain in a study area. The higher the extent of land occupied by buildings close to streams, is the higher the risk, vice versa. Let us assume a hypothetical data of the highest Pf of 30 and lowest of 12.

$\frac{30}{100} = 0.30$ = High flood risk

$\frac{12}{100} = 0.12$ = Low flood risk

Furthermore, the ratio of the Bd and Pf is computed in order to obtain $^{Bd}/_{Pf}$

For example using the above hypothetical data:

$^{Bd}/_{Pf} = {}^{0.75}/_{0.30} = 2.5$ } High Risk

$^{Bd}/_{Pf} = {}^{0.22}/_{0.12} = 1.8$ } Low Risk

In conclusion, the FRI formula can be applied to calculate the final index value for all the areas in an urban area so as to make a comparison of hot spot areas that can be given high priority for flood mitigations. Various values of indices computed by the index can be classified into categories of high, moderate or low flood risk zones. Finally, the index values generated can be used to draw flood risk map of the study area. The alternative Flood Risk Index developed is applied in Gombe Metropolis flood risk studies using field data generated from Geographical Information System (GIS).

2.1.4 Application of the alternative FRI in gombe metropolis

The data used in this analysis are primarily the field data obtained from the GIS analysis and elevation extracted from the contour map generated from Digital Elevation Model (DEM) of Gombe Metropolis. A flood risk index is an approach aimed at measuring risk through selected comparative indicators in a quantitative way in order to compare different residential area [18]. The variables or the flood risk indicators used for calculating the index are elevations, building density and proximity to flood plains (physical exposure factor).

3. RESULTS AND DISCUSSION OF THE ANALYSIS

3.1 Elevation (Ex)

The elevation was measured as an average point height of three locations in each residential area extracted from the contour map of the Gombe Metropolis and the higher is the location of a residential area the lower is the flood risk. Table 1 shows the three elevation points for each residential area.

The highest elevation is 607 meters above sea level (located at NPA), while the lowest elevation is 410 meter found in UF (See Table 1). Therefore, the residential areas that are located at the highest elevation are regarded as low-risk areas while the residential areas located at the lowest elevations are regarded within high-risk areas. The lowest flood level in 2014 flood disaster in Gombe Metropolis is less than two feet (rounded as 1 m) and the average lowest elevation in Gombe Metropolis is 410 m.

Therefore, 410 m (average lowest elevation) plus the lowest flood level 1m is equal to 411 m as the flood Risk Level (RL).

The alternative flood risk index formula is stated as FRI = $\frac{\mathbf{Ex}}{\mathbf{RL}} \times \frac{\mathbf{Bd}}{\mathbf{Pf}}$.

Thus taking

R_L as Risk Level
Ex as Elevation of any given point

Then:

$\frac{Ex}{RL} = \frac{607}{411} = 1.5$ } Value above 1 Low Flood Risk

$\frac{Ex}{RL} = \frac{410}{411} = 0.99$ } Value below 1 High Flood Risk

3.2 Building Density (Bd)

Building Density is measured as a percentage (%) of each residential quarters covered by buildings. The higher the percentage of building in an area the higher will be the probability of flood. The highest Bd is 99 percent found in JEK, while the lowest Bd is 23 percent found in NPA (See Table 2.).

Then High Building Density is $\frac{99}{100} = 0.99$ = High Flood Risk

The Lowest Building Density is $\frac{23}{100} = 0.23$ = Low Flood Risk

Table 1. 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

Table 2. Gombe metropolis percent building density

Residential area	Building density in square meter	Building density in percentage
JEK	958,537.6	0.99
JAN	286,006.0	0.93
DAW	2,871,343.1	0.94
BAR	2,839,428.3	0.98
TW	2,83,081.2	0.59
PAN	1,275,593.9	0.95
BOL/MAD	2,231,354.5	0.95
NPA	3,622,155.6	0.23
MUAK	3,55.070.4	0.55
CHECH	652,259.1	0.82
HERWA	1,273,286.2	0.96
UF	4,569,037.9	0.59
GRA/GAB	3,144,973.5	0.81

Source: Compiled by the Author, 2016

Table 3. Gombe metropolis area coverage in 50 meter stream buffer

Residential area	Meter square buffer	Percentage
JEK	0.00	0.0
JAN	51,978.9	0.18
DAW	290,069.1	0.10
BAR	523,437.3	0.18
TW	431,535.4	0.15
PAN	260,440.6	0.20
BOL/MAD	261,157.8	0.12
NPA	130,809.0	0.4
MUAK	490,259.6	0.15
CHECH	99,100	0.15
HERWA	0.00	0.0
UF	304,715.8	0.7
GRA/GAB	399,461.3	0.13

Source: Compiled by the Author, 2016

Proximity to Flood Plains: Proximity to flood plains was measured as area coverage of buildings found within 50 meters buffer from a stream, river or gully and the summary of the result is shown in Table 3. The higher is the area coverage within flood plains, the higher will be the flood risk.

Thus;

The highest area coverage closed to flood plains is $\frac{20}{100}$ = 0.20 = High Flood Risk

The lowest area coverage to closed to flood plains is $\frac{4}{100}$ = 0.4 = High Flood Risk

Hence: $^{\mathrm{Bd}}/_{\mathrm{Pf}} = {}^{0.99}/_{0.20} = 4.9$

$^{\mathrm{Bd}}/_{\mathrm{Pf}} = {}^{0.23}/_{0.4} = 0.6$

Now the formula is applied for the final index value

$$\mathrm{FRI} = \frac{\mathrm{Ex}}{\mathrm{RL}} \times \frac{\mathrm{Bd}}{\mathrm{Pf}}$$

The lowest elevation and the highest elevation in Gombe Metropolis were used to get the low risk and the high-risk areas.

The lowest elevation

$$\mathrm{FRI} = \frac{410}{411} \times \frac{0.99}{0.20}$$

$$\mathrm{FRI} = (0.99) \times (4.9) = 4.85 \quad \text{High Risk}$$

The highest elevation

$$\mathrm{FRI} = \frac{\mathrm{Ex}}{\mathrm{RL}} \times \frac{\mathrm{Bd}}{\mathrm{Pf}}$$

$$\mathrm{FRI} = \frac{607}{411} \times \frac{0.23}{0.4}$$

$$\mathrm{FRI} = (1.48) \times (0.6) = 0.85 \quad \text{Low Risk}$$

So any index value above 1 indicates high flood risk area while index values below 1 indicate low flood risk area in Gombe Metropolis. Flood risk is the probability of flood and its related consequences on the element at risk. The risk can be expressed in quantitative terms such as high, medium or low risk. Therefore, the index values generated were categorized into flood risk zones of low, moderate, high and very high flood risk and Table 4 shows the classes and the number of residential areas that fall within each class.

Table 4. Flood risk zones in the Gombe metropolis

Flood risk classes	Number of residential areas	Flood risk zones
0.0-0.9	4	Low Flood Risk
0.9-5.1	3	Moderate Flood Risk
5.1-7.1	4	High Flood Risk
7.1-10.1	2	Very High Flood Risk

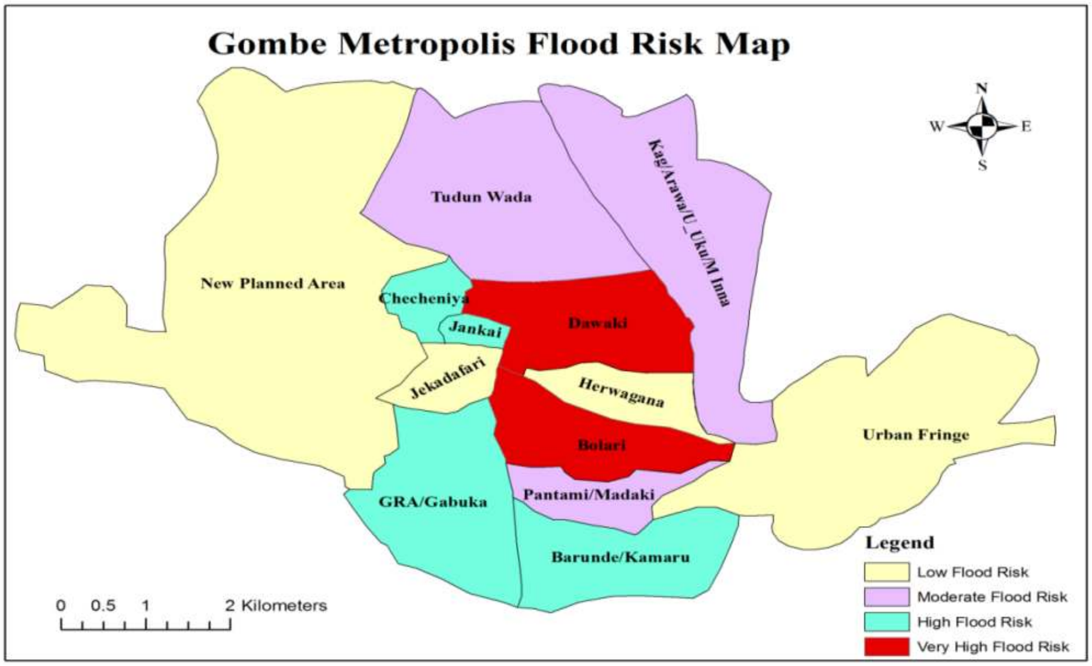
Source: Compiled by the Author, 2016

Table 5 shows the index values for all the residence.

Table 5. Flood Risk Index (FRI) values and categories

FID	Residential areas	FRI	FRI classes
1	NPA	0.9	Low
2	GRA/GAB	7.1	High
3	JEK	0.0	Low
4	JAN	6.3	High
5	CHECH	6.6	High
6	TW	4.4	Moderate
7	MUAK	3.9	Moderate
8	DAW	10.1	Very High
9	HERWA	0.0	Low
10	BOL/MAD	8.9	Very High
11	PAN	5.1	High
12	BAR	5.6	High
13	UF	0.8	Low

Source: Compiled by the Author, 2016



Map 1. Gombe metropolis flood risk map
Source: Compiled by the Author, 2016

Fig. 1. Erosion path in residential area

Fig. 1 shows erosion path in the central path of the metropolis and proximity of buildings to hazardous area. However, Fig. 2 shows a large gully erosion caused by the flood in Gombe metropolis.

Subsequently, flood risk index generated was joined with the map of the residential areas and represented using graduated color map in ArcGIS environment, where residential quarters in Gombe Metropolis were categorized into four flood risk zones by natural breaks method and the result is shown in Map 1.

The flood risk map is a strategy that gives priority to vulnerable areas before less vulnerable areas in flood risk management.

Fig. 2. Gully in the metropolis

4. CONCLUSION

The paper was able to develop a new technique to measure flood risk that can be applicable and useful in the developing countries. One of the basic flood risk factor (geo-physical exposure) was measured using its principal indicators such as percent built up areas, proximity to floodplains and elevation.

The new method was applied to studied flood risk in Gombe Metropolis and the result revealed a remarkable outcome necessary to mitigate flood risk and thereby improving the well-being of the vulnerable flood communities in the metropolis. The result shows that seven residential areas in Gombe metropolis are within a very high to high flood risk zones. These residential areas include, Government Residential Area/Gabuka, Jankai, Checheniya, Pantami, Barunde, Dawaki and Bolari/ Madaki. Thus, priorities for flood risk mitigations should focus towards those areas. However, Tudun Wada, MUAK, New Developed Areas, Jekadafari, Herwagana and Urban Fringe residential area fall within the moderate to low flood risk.

One of the objectives of the natural hazard mitigation is to influence the physical form of cities in order to demarcate hazardous areas and development. Thus, flood control measures in Gombe Metropolis, integrated non-structural methods, like land use planning through removal of buildings constructions within the stream buffers identified in the very high and high flood risk zones of Gombe Metropolis. In addition, there is need for redevelopment of built up in the high building density areas within the very high and high risk zones into open space so as to improve infiltration capacity and to reduce quick runoff flow which in effect will reduce the floods occurrence in the metropolis.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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