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Flood Risk and Vulnerability Analysis of the Lower Usuma River in Gwagwalada Town Abuja, using GIS and HEC-RAS Model

D. O. Balogun[1*], O. O. M. Agunloye[2], A. B. Mohammed[3], U. Ogunbiyi[4], A. A. Okewu[5], E. S. Ikegwuonu[6], B. Nkut[7]
[1]National Biotechnology Development Agency (NABDA), Bioresources Development Centre (BIODEC) Kano, Nigeria.
[2]Federal College of Land Resources Technology, Owerri, Imo State.
[3]Zonal Advanced Space Technology Applications Laboratory, Kano, Nigeria
[4]Federal College of Education, Zaria, Nigeria.
[5,6,7]Department of Geography, Ahmadu Bello University Zaria, Kaduna State, Nigeria.

Abstract **- Globally, flooding is seen as the most common and devastating natural disaster contributing to greater economic and social losses than any other natural disaster. This study evaluated flood risk and vulnerability of Lower Usuma River in Gwagwalada Town for 5, 10, 50, and 100-year return periods deploying Geographic Information System and Hydrologic Engineering Center - River Analysis System modelling technique. The findings revealed that areas of low to moderate vulnerabilities for agricultural lands, economic/commercial, infrastructural, and residential areas have the greatest areal coverage. Areas of high and very high vulnerability for residential buildings are less northwards away from the Lower Usuma River for the various flood return periods. The result also indicates that more residential buildings and commercial establishments are at risk of flood than any other element within the environment. Areas affected by floods from this study include the settlements of Gwagwalada, Ungwan Shanu, Dobi, Dagiri, and Ungwan Dodo, Ungwan Bassa, Old Kutunku, Ungwan, Gwari, Ungwan Aguma, and Abattoir settlements. This study suggests that the government, under its capacity as Federal Capital Development Authority should impose strict restrictions on building projects along natural waterways in Gwagwalada and enforce compliance by individuals, private, and public property developers. Disaster management institutions and academic institutions should enhance their capacity in Geospatial and hydrologic modelling techniques and ensure installations of automated gauge stations and discharge recording equipment along the Lower Usuma River to minimize errors caused by human laxities.**

Keywords: Flood Return Period, Flood Frequency Analysis, Environment, Gumbel Distribution, Modelling.

INTRODUCTION

Floods are regarded as a global environmental tragedy that affects the population in different dimensions. Due to its capacity to destroy lives and assets in its course, it is the most expensive and one of the deadliest natural hazards [1]. Floods can be described as the excess flow of water which exceeds a river channel's carrying capacity, drainage system, dams, and any other water bodies [2]. These excess flow in water bodies occur mostly due to several factors, but heavy rainfall is the leading cause of river flooding in Nigeria. Land use changes due to human activities such as rapid settlement development along river flood plains can influence flood hazards' spatiotemporal pattern [3].

Flood risk is a product of both flood hazard and vulnerability to flooding multiplied by the total value of the assets exposed to the hazard [4]. Flood hazard is referred to the probability that an area with the potential of being flooded will be inundated for a given period. On the other hand, the most significant risk component is flood vulnerability and is the state of being adversely susceptible to a flood event. flood vulnerability assessment is defined as the classification of different flood risk areas in an environment to establish successful flood mitigation strategies [5]. Flood risk and vulnerability maps are essential tools in public enlightenment, disaster response planning, and flood risk management [6]. Geospatial techniques have been deployed successfully in flood hazards, risk, and vulnerability mapping in different places worldwide [7].

In tropical regions, extreme rainstorms, hurricanes, and dam failures have triggered high-magnitude floods that have resulted in severe consequences [8] [9]. However, the apparent explanation for flooding, especially in Nigeria’s municipalities and coastal areas, lies in the extensive distribution of low-lying coastal areas and River floodplains since these areas have quickly become a long-standing human settlement attraction [10]. Global warming has been linked to the sudden rise in the number and severity of recent floods in Jigawa, Kano, Kaduna, Katsina (in Northern Nigeria), Gombe (North-Eastern Nigeria), and most of the Southern States [11]. As a result, Nigerians have become increasingly at risk to a wide range of natural hazards with urbanization and high incidence of poverty pressing residents, despite city planning laws banning them from inhabiting fragile flood plains and unstable hillsides.

Rapid urban growth and torrential rainfall have led to the intensification of flooding within the lower section of the Usuma River in Gwagwalada town Abuja (See Plate 1 and 2) [12]. This is becoming an annual occurrence capable of causing lives, properties, and the ecosystem to be ruined inadvertently. Floods witnessed in Gwagwalada town in 2003, 2006, 2009, and 2011 among others inundated vast lands where lives and properties worth millions of Naira were lost [13]. This frequent river flooding issue is of great concern due to excess rainfall

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followed by high river discharge, so preventive steps must be taken to avoid potential flood disasters cost-effectively through reliable and continuous methodologies that are scientifically relevant [14].

The issue of flooding in Nigeria was explored by several researchers such as [15], [9], [16], [17], [18] and [13] to name a few. They deployed the use of GIS and Remote Sensing techniques to estimate the extent of flood hazard, risk, and vulnerable areas. None of these studies analyzed flood risk and vulnerability of the lower Usuma River with explicit emphasis on Geographic Information Systems (GIS) and Hydrologic Engineering Center - River Analysis System (HEC-RAS) modelling techniques. Therefore, to provide the basic knowledge that will aid disaster management agencies in preparing and maintaining the marginal lands adjacent to the flood plain along the Lower Usuma River, it is imperative to undertake this research. This will help avoid any potential disaster that may occur from any future flood events due to the nature of land use, proximity to the lower Usuma River, climate change and the likely recurrence of flood events in Gwagwalada town. Hence, this study is aimed at carrying out flood risk and vulnerability analysis of the Lower Usuma River in Gwagwalada town, and was achieved by determining flood frequency analysis using Gumbel extreme value distribution, deriving flood risk, and vulnerable zones deploying GIS and HEC-RAS modelling.

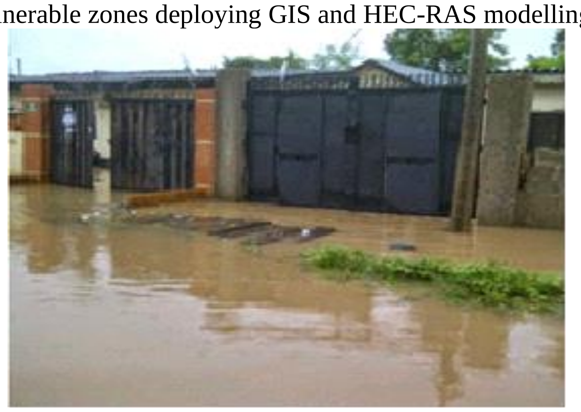

Plate 1: Streets and Buildings Inundated in Gwagwalada Town

Plate 1: Residential Buildings Flooded in Gwagwalada Town

Plate 2. School Building Inundated in Gwagwalada Town

MATERIALS AND METHODS

Study Area

The study area falls within Gwagwalada town, where the Lower Usuma River cuts across. The section of interest within the town lies between Latitude 8° 55' 00" N - 8° 57' 30" N and Longitude 7° 03' 20" E - 7° 06' 40" E (figure 1), the study area is divided into two parts, North-South by the Lower Usuma River. Gwagwalada is one of Abuja's third largest city centers with an area of approximately 1,043km^2.

The town has experienced a rapid rate of urbanization and developmental processes that have encroached outside what was earlier considered the boundary [19]. It is the largest satellite town and third-largest urban agglomerations located within the FCT where farming is the mainstay of the indigenous population. The city experienced an unprecedented influx of traders, civil servants, and the organized private sector, causing the population to burst into and around the capital city due to its nearness to the seat of power [20]. The population of Gwagwalada was put at 4,314 people in 1978. Since then, the population has increased through a high birth rate, low death rate, and migration into the area. Gwagwalada Area Council has a total of 80,841 people, with Gwagwalada town having 23,114 as of 1996. The population growth rate of Abuja for 2006 was (3.2%), with a population of 157,770 as of 2006 in Gwagwalada, which puts the projected population of Gwagwalada for 2018 at 332,001 [19].

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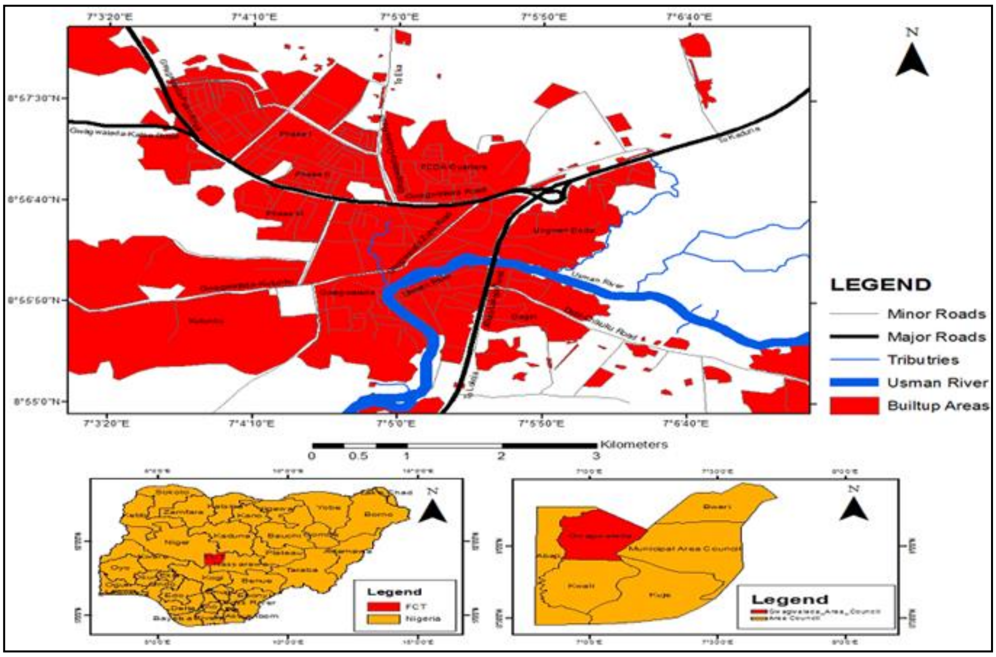

Fig 1: Location of Gwagwalada
Source: Adapted from the Administrative Map of FCT, Nigeria

The study area and its environs has witnessed loss of vegetal cover over time which gave way for urbanization [21]. Several streams drain the entire region westward into the Usuma river. It runs south to join Gurara river, which is the largest River flowing through the territory and whose contents empty into the Niger River [22]. Flash flooding is a characteristic of all streams in this area, particularly during the rainy season. It is evident that flooding is a significant environmental hazard in this area and flood vulnerability is likely to increase with increased construction activities within the Gwagwalada urban area [23].

Types and Sources of Data

Hydrologic data such as river stage heights (1987-2019) were collected from the climatology record and dam safety unit of the lower Usuma Dam Abuja. Latitude/Longitude coordinates from Global Positioning System Data was used to identify and differentiate elements within the environment. Google Earth Imagery was used as the basemap to extract up-to-date individual features such as buildings, roads, bridges, and other structures. The Shuttle Radar Topographical Mission/DEM (SRTM Version 3) was used to extract DEM and create Raster TIN for the study. The HEC-GeoRAS in GIS environment and HEC-RAS hydrological model were deployed combining these data as input to mapping and estimating risk and vulnerable areas (Figure 2).

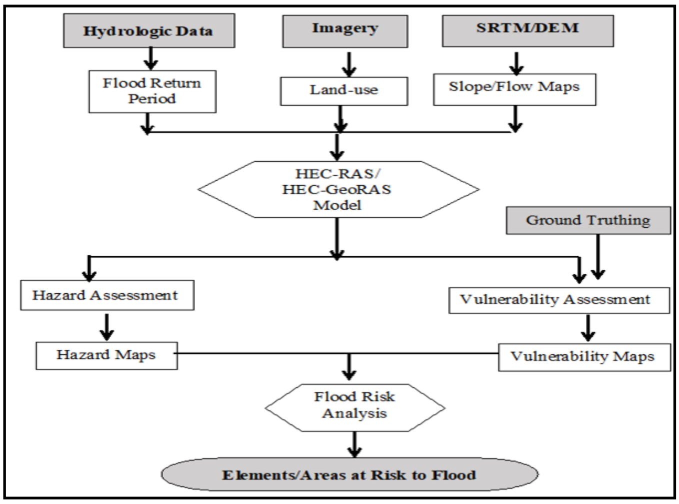

Fig 2: Schematic Diagram of the Methodology

Flood Frequency Analysis (FFA)

The Gumbel extreme value distribution method was deployed in analyzing the annual flood data. It was used to determine flood frequency for 5year, 10year, 50year, and 100year return periods. The annual maximum gauge-level data for 33years (1987-2019) at the Lower Usuma Dam waterworks gauge site (570.00m) were selected and calculated. The result showed a steady rise in flood stage height from 4.50m in a 5year flood to 6.44m in a 100year return period (Table 1). Also, the choice of Gumbel extreme value distribution shows 90% acceptability (co-efficient of regression $R^2 = 0.8977$) which is a good fit for the observed flood data (Figure 3).

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Table 1: Gumbel Extreme Value Distribution

Return Period (Years)	Exceedance Probability	Stage Level (meters)	Rise in Flood Stage (meters)
5	0.2	574.50	4.50
10	0.1	574.97	4.97
50	0.02	576.01	6.01
100	0.01	576.44	6.44

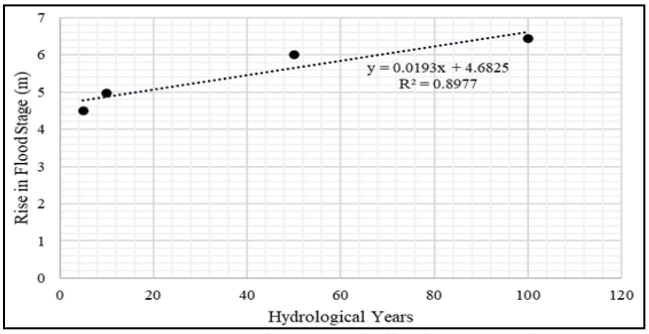

Fig 3: Trend Ratio for Expected Flood Water Levels

Land Use Data Processing

Land use data (figure 4) was created from Google Earth image and added as HEC-GeoRAS input. The RAS Geometry tool and editor tool was used to create the land use database, Manning, and LUManning tables under the RAS Geometry for the HEC-RAS model [24].

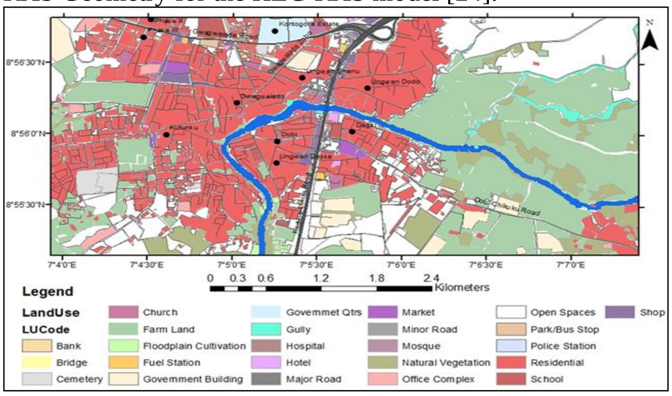

Fig 4: Land Use of the Study Area

Hydraulic Modelling in HEC-RAS and Post-Processing

The basemap for this study was overlaid on the raster TIN layer created from the Digital Elevation Model in ArcGIS. This was used in the development of River centerline, flowpath line, downstream reach lengths, and River cross-sections using HEC-GeoRAS GIS extension. Geometry data containing individual cross-sections in which Manning's values were assigned based on the different land use types in ArcGIS were imported into HEC-RAS model. Discharge and normal depth (producing an overall water surface slope of 0.0003) were put as the boundary conditions for the upstream and downstream boundaries of the study reach, respectively. The HEC-RAS output (RAS SDF file) was converted to a triangulated irregular network (TIN) file in HEC-GeoRAS. The TIN file was converted into Raster. Using Raster calculator tool in ArcGIS, and the underlying DEM terrain layer was subtracted from the water surface raster. The cells with positive values were identified to be flooded, and the values were the inundation depth for the respective flooding scenarios / Plan. Also, all the layers used were projected to Minna UTM Zone 32N Transverse Mercator Projection.

Vulnerability Assessment

Vulnerability analysis was carried out by crossing hazard maps. Each vulnerable class map for the study area for the different return periods was classified into very low vulnerability, low vulnerability, moderate vulnerability, high vulnerability, and very high vulnerability. The derivation of vulnerability class maps includes; Agricultural Activities, Economic/Commercial Activities, Infrastructure, and Residential Buildings. A relative scale which represents the degree of flood hazard (hazard rank) was used in creating the categorized flood Hazard maps. The smaller hazard rank was set for a lower depth or low hazard, while a larger hazard rank was used to indicate a higher hazard as shown in Table 2. Also, ground truthing and field survey techniques simultaneously were employed to correctly identify and differentiate structures on the map with the actual existence on the ground.

Table 2: Hazard Index for Flood Depth

Depth Value of Flooding (m)	Hazard Category	Hazard Rank
Dv1	Very Low	1
Dv2	Low	2
Dv3	Medium	3
Dv4	High	4
Dv5	Very High	5

Dv = Depth Value of Flood Water (m)

Flood Risk Analysis

This analysis was achieved using a 2-dimensional risk analysis table, which considers flood risk as a function of flood hazard and vulnerability [25] (Table 3). Flood risk maps were created from the risk table, and the percentage of areas at risk to flood were calculated and presented as low risk, moderate risk, and high risk. Population at risk to flood is a function of population density of the area and flooded area. Also, population density was calculated by dividing population of the area by the area coverage.

Table 3: Two-Dimensional Table for Risk Analysis

		VULNERABILITY				
		Very Low Vulnerability	Low Vulnerability	Moderate Vulnerability	High Vulnerability	Very High Vulnerability
H	Very Low Hazard	Low Risk	Low Risk	Low Risk	Low Risk	Low Risk
A	Moderately Low Hazard	Low Risk	Low Risk	Low Risk	Moderate Risk	Moderate Risk
Z	Low Hazard	Low Risk	Low Risk	Low Risk	Moderate Risk	Moderate Risk
A	Moderate Hazard	Low Risk	Low Risk	Low Risk	Moderate Risk	Moderate Risk
R	High Hazard	Low Risk	Low Risk	Moderate Risk	High Risk	High Risk
D	Very High Hazard	Low Risk	Moderate Risk	Moderate Risk	High Risk	High Risk

Source: Modified from Westen, (1997)

RESULTS AND DISCUSSION

Flood Vulnerability Analysis

Vulnerable Agricultural Lands

The result from Table 4 shows that the areas with very high vulnerable agricultural land extent are uniform and the lowest with 1.20 km^2 across all return periods. The greatest extents of vulnerable agricultural lands were found within the moderate vulnerable zone with 2.37km^2, 2.36km^2, 2.40km^{2,} and 2.40km^2 for 5, 10, 50, and 100year return periods. From Figure 5, Most of the vulnerable agricultural lands are located outside the built-up areas east of Dagiri settlement, while some are located south of Ungwan Bassa. Also, cultivations were seen along the flood plains outside the built-up areas.

Table 4: Areal Extent of Agricultural Vulnerable Areas

Agricultural Vulnerability	5-YRP Area		10-YRP Area		50-YRP Area		100-YRP Area	
	(km2)	(%)	(km2)	(%)	(km2)	(%)	(km2)	(%)
Very Low	2.19	22.93	2.19	22.96	2.15	20.98	2.15	20.98
Low	2.29	23.98	2.29	24.0	2.28	22.24	2.28	22.24
Moderate	2.37	24.82	2.36	24.74	2.40	23.41	2.40	23.41
High	1.50	15.71	1.50	15.72	2.22	21.66	2.22	21.66
Very High	1.20	12.57	1.20	12.58	1.20	11.71	1.20	11.71
Total	**9.55**	**100**	**9.54**	**100**	**10.25**	**100**	**10.25**	**100**

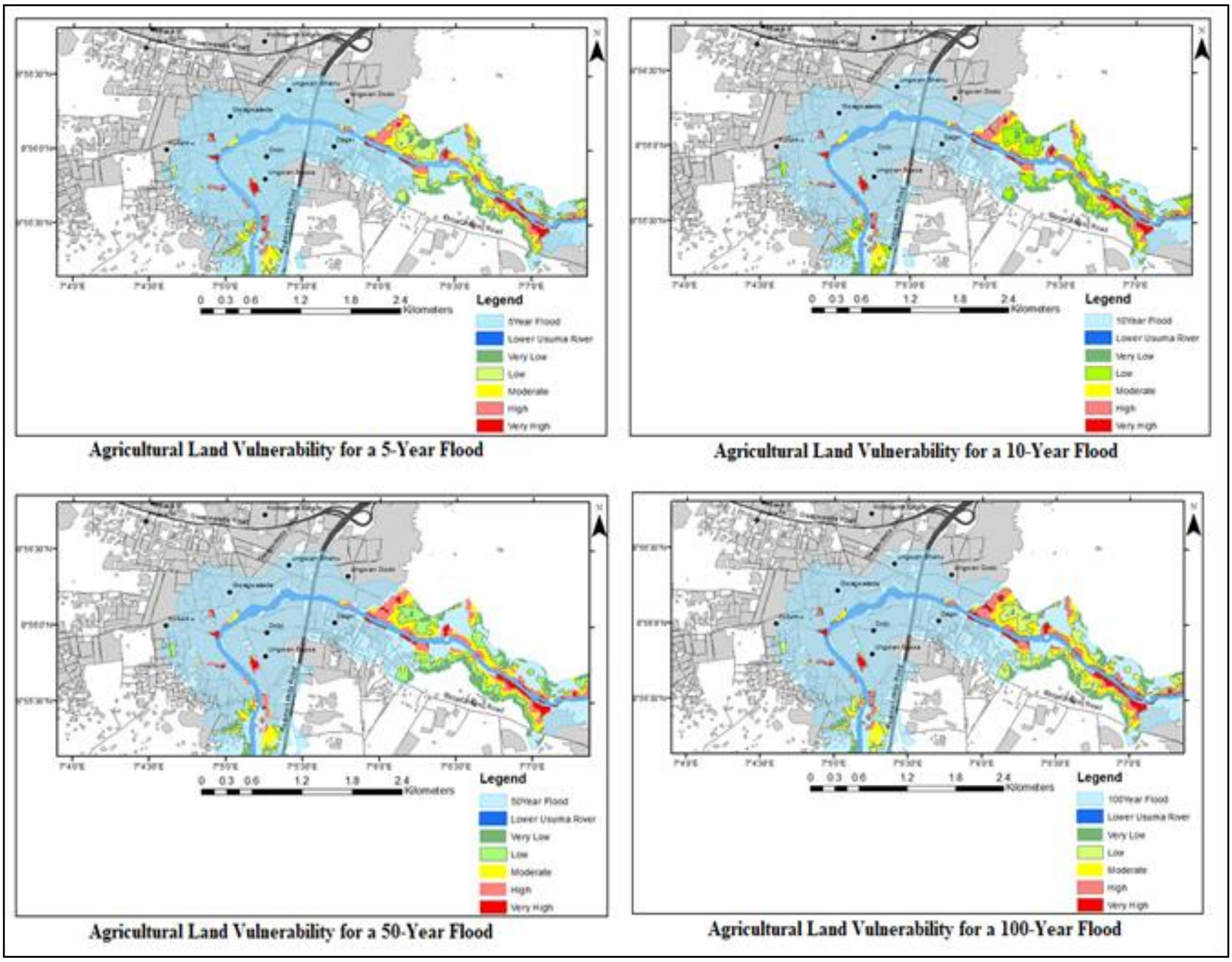

Fig 5: Agricultural Land Vulnerability Maps

Vulnerable Economic and Commercial Activities

The results from vulnerable economic and commercial activities in Table 5 show areas of very high vulnerability extent as the lowest 1.22 km^2 and are uniform across all the return periods. The 5year return period shows moderate vulnerability extent with the highest 2.44km^2 and low vulnerability, with the highest area coverage of 2.41km^2 in the 10year return period. Also, moderate vulnerability extent is most heightened in 50 and 100year return periods with 2.47km^2 and 2.45 km^2. The maps from figure 6 show vulnerable economic activities such as farming outside Ungwan Bassa and Dagiri town, while vulnerable commercial activities (shops and markets) are within Ungwan Shanu, Dobi, Dagiri, and Ungwan Dodo settlements in the study area.

Table 5: Areal Extent of Economic and Commercial Vulnerable Areas

Economic and Commercial Vulnerability	5-YRP Area		10-YRP Area		50-YRP Area		100-YRP Area	
	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Very Low	2.32	23.34	2.32	23.32	2.27	21.33	2.27	21.37
Low	2.40	24.14	2.41	24.22	2.40	22.56	2.40	22.60
Moderate	2.44	24.55	2.44	24.52	2.47	23.21	2.45	23.07
High	1.56	15.69	1.56	15.68	2.28	21.43	2.28	21.47
Very High	1.22	12.27	1.22	12.26	1.22	11.47	1.22	11.49
Total	**9.94**	**100**	**9.95**	**100**	**10.64**	**100**	**10.62**	**100**

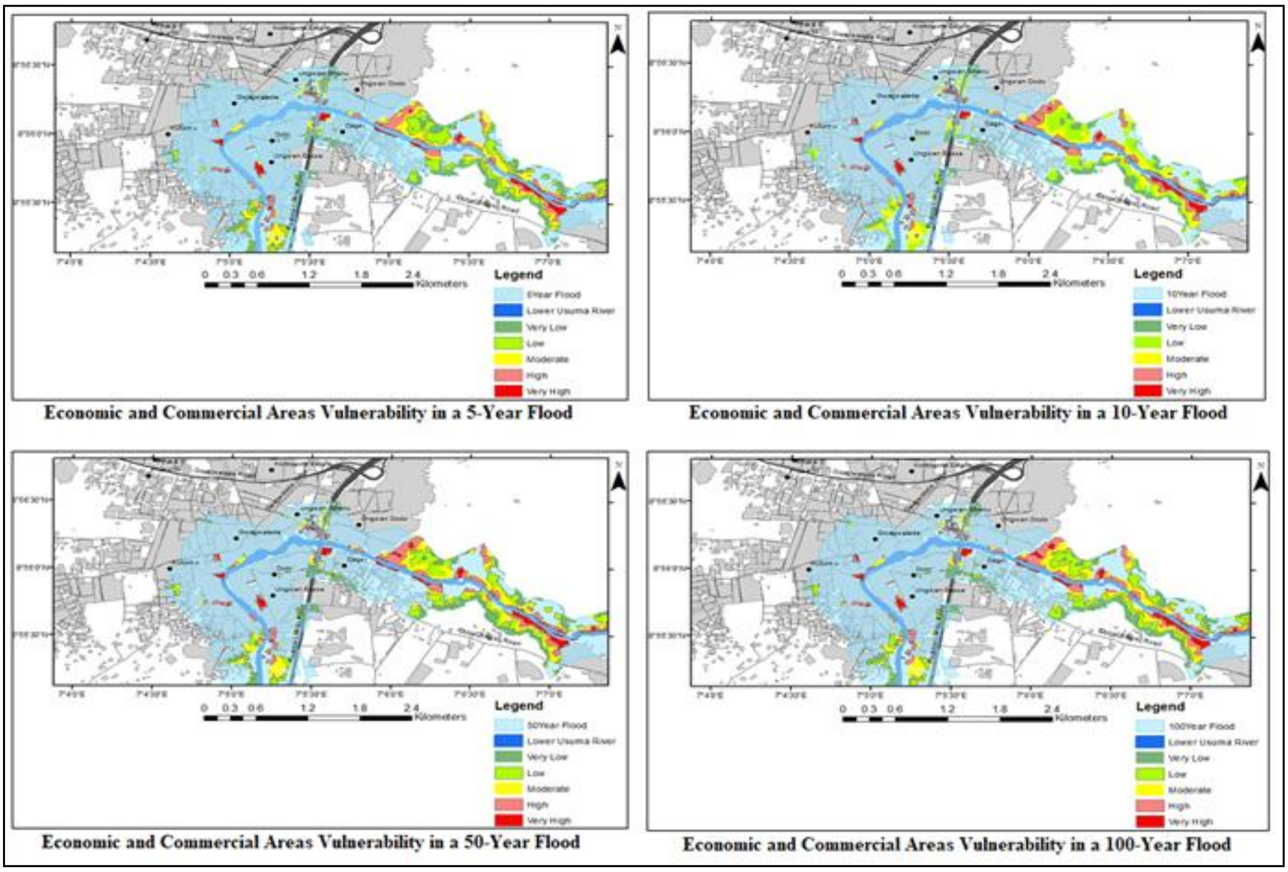

Fig 6: Economic and Commercial Activity Vulnerability Maps

Vulnerable Infrastructures

The result from Table 6 shows infrastructures within areas of very high vulnerabilities as having the least extents which are uniform 0.21 km^2 across all return periods. The largest extents for areas of very low vulnerability were found within 5year and 10year return periods with 0.38km^2 each. Areas of low vulnerability occupies a high of about 0.38km^2 each for 50year and 100year return periods. The maps in Figure 7 shows that vulnerable infrastructures such as major roads, schools, government buildings, churches, and mosques are within Gwagwalada, Ungwan Shanu, Dobi, Dagiri, and Ungwan Dodo, Ungwan Bassa, and Old Kutunku.

Table 6: Areal Extent of Infrastructure Vulnerable Areas

Infrastructure Vulnerability	5-YRP Area		10-YRP Area		50-YRP Area		100-YRP Area	
	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Very Low	0.38	24.84	0.38	24.84	0.36	23.23	0.35	22.88
Low	0.37	24.18	0.37	24.18	0.38	24.52	0.38	24.84
Moderate	0.3	19.61	0.3	19.61	0.3	19.35	0.29	18.95
High	0.27	17.65	0.27	17.65	0.3	19.35	0.3	19.61
Very High	0.21	13.73	0.21	13.73	0.21	13.55	0.21	13.73
Total	**1.53**	**100**	**1.53**	**100**	**1.55**	**100**	**1.53**	**100**

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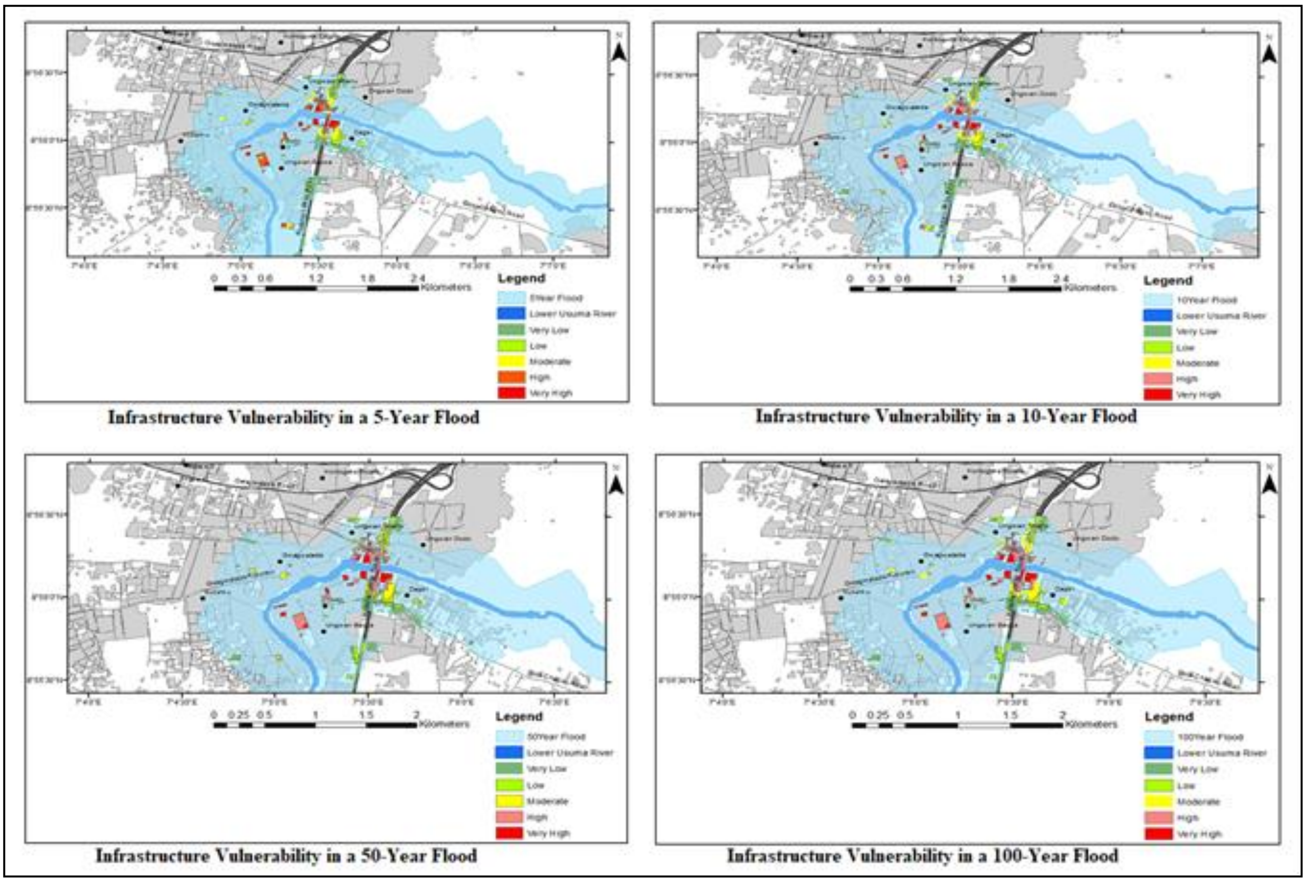

Fig 7: Infrastructural Vulnerability Maps

Vulnerable Residential Buildings

The result from Table 7 shows vulnerable residential buildings within very low vulnerable zones as having the highest land area coverage 3.07km^2, 3.05km^2, 3.04km^{2,} and 2.95km^2 for 5, 10, 50, and 100year return periods, while residential buildings within the very high vulnerable zones occupy the lowest land area with 1.23 km^2, 1.13km^2, 1.33km^2 and 1.33km^2 for 5,10, 50 and 100year return periods respectively. These zones as shown in Figure 8 falls within Dagiri, Ungwan Dodo, Ungwan Shanu, Ungwan Bassa, Ungwan, Gwari, Ungwan Aguma, and Abattoir.

Table 7: Areal Extent of Residential Buildings Vulnerable Areas

Residential Vulnerability	**Buildings**	**5-YRP Area**		**10-YRP Area**		**50-YRP Area**		**100-YRP Area**	
		(km^2)	**(%)**	**(km^2)**	**(%)**	**(km^2)**	**(%)**	**(km^2)**	**(%)**
Very Low		3.07	25.29	3.05	25.25	3.04	24.82	2.95	24.12
Low		2.86	23.56	2.86	23.68	2.85	23.27	2.9	23.71
Moderate		2.82	23.23	2.81	23.26	2.8	22.86	2.8	22.89
High		2.16	17.79	2.23	18.46	2.23	18.2	2.25	18.4
Very High		1.23	10.13	1.13	9.354	1.33	10.86	1.33	10.87
Total		**12.14**	**100**	**12.08**	**100.004**	**12.25**	**100.01**	**12.23**	**99.99**

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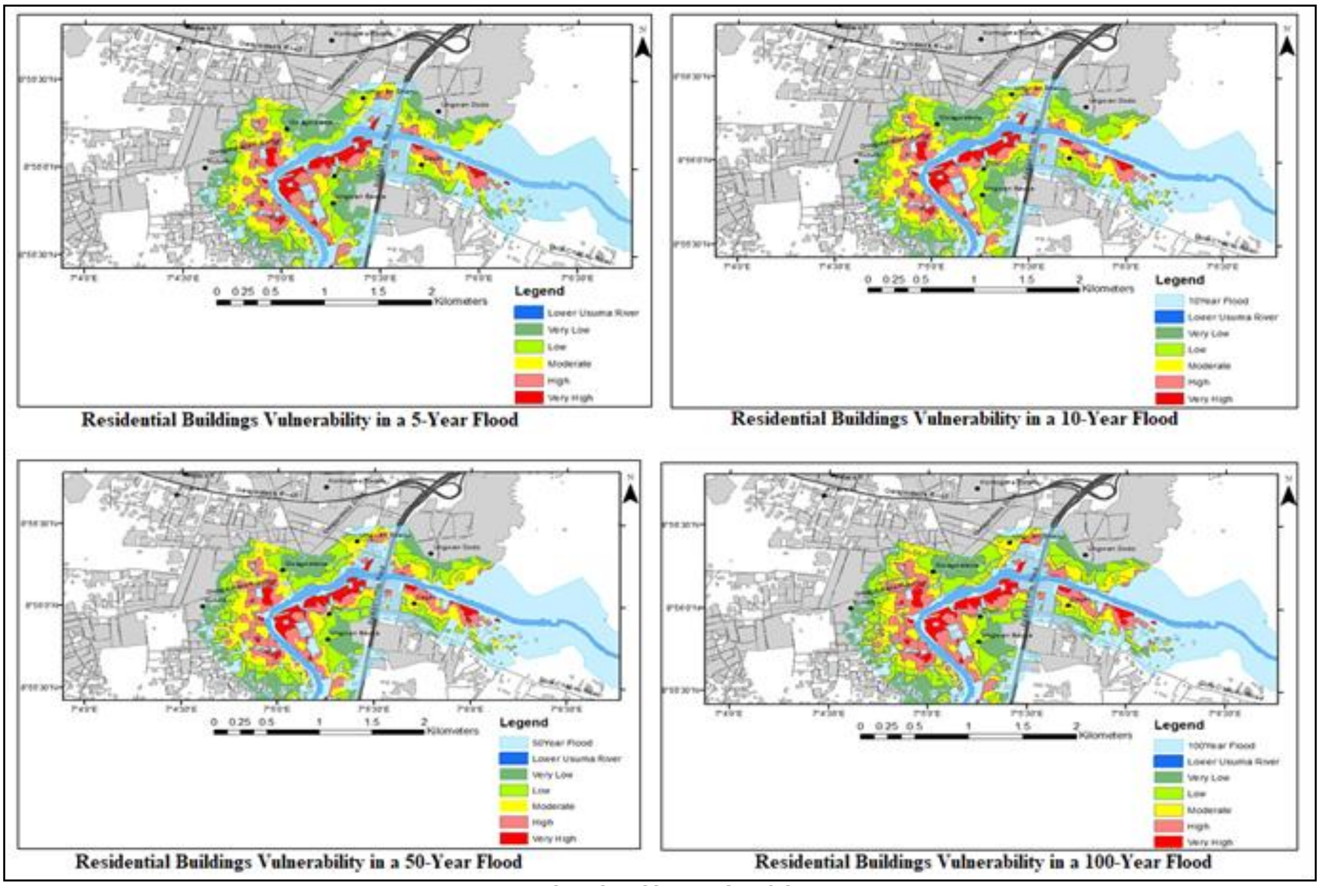

Fig 8: Residential Buildings Vulnerability Maps

Also, the maps from Figure 8 shows that areas of high and very high vulnerability for residential buildings are less northwards away from the Lower Usuma River and more southwards of the River for the various flood return periods. Similar results were reported that floodplains and flooding-free areas are inhabited, and vulnerability to flood decreases northwards from the Usuma River [13].

Flood Risk Analysis

Extent of Areas at Risk to Flood

Table 8 shows an increase in extent from 2.42 km^2 in a 5year and 10year return period to a decrease of 2.32km^2 in 50year and 2.35km^2 in the 100year return period for low risk areas.

Table 8: Areal Extent of Flood Risk in Different Return Periods

RISK LEVEL	5-YRP Area		10-YRP Area		50-YRP Area		100-YRP Area	
	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Low Risk	2.42	22.60	2.42	22.00	2.32	20.33	2.35	20.38
Moderate Risk	5.25	49.02	5.41	49.18	5.75	50.39	5.67	49.18
High Risk	3.04	28.38	3.17	28.82	3.34	29.27	3.51	30.44
Total	**10.71**	**100**	**11**	**100**	**11.41**	**100**	**11.53**	**100**

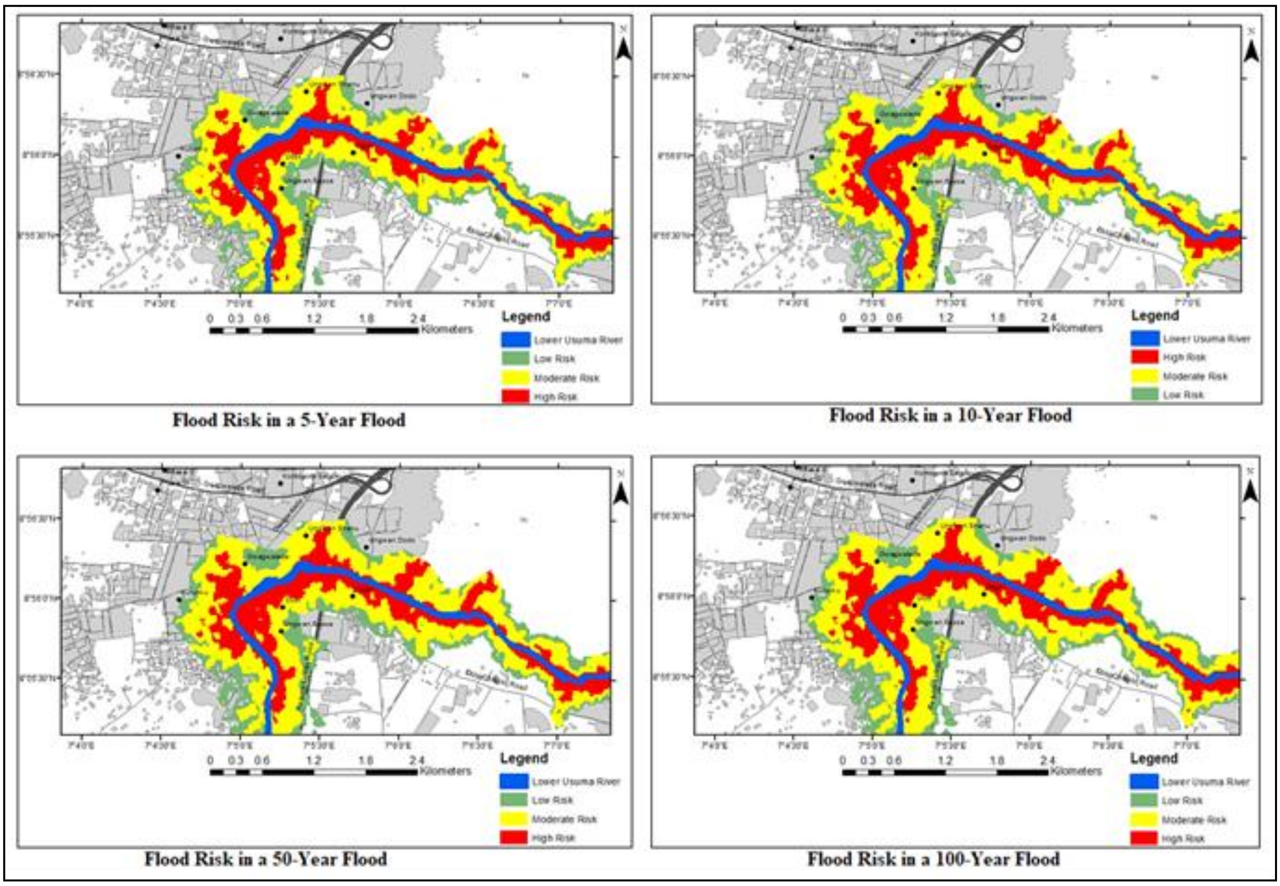

Fig 11: Flood Risk Maps

The area covered by high flood risk varies from 3.04km^2 in the 5-year return period to 3.51km^2 in the 100year return period. While moderate flood risk zone has the greatest extent across the different return periods, which ranges from 5.25km^2 in the 5year return period to high of 5.75km^2 in the 50year return period. The area coverage as shown in figure 11, includes parts of Dobi, Ungwan Bassa, Dagiri, Gwagwalada, Ungwan Shanu, and Old Kutunku settlements.

Population at Risk to Flood

The total projected population of Gwawalada LGA for 2018 (332,001) and land area (1043Km^2) was used to derive the population density (318) persons per square kilometer, which were then used to calculate the population at risk to flood. Table 9 shows a minimum of about 738 (20.34%) persons at low risk to flood in a 50year return period to a maximum of about 770 (22.6%) and 770 (22.01%) persons in a 5year and 10year return period. The moderate risk areas indicated a minimum of about 1670 (49.02%) persons at moderate risk to flood in a 5year return period and a maximum of about 1829 (50.4%) persons in a 50year return period. In contrast, high risk areas showed a minimum of about 967 (28.38%) persons at high risk to flood in a 5year return period to a maximum of about 1116 (30.44%) persons in a 100year return period.

The moderate flood risk zone in the study area has more population concentration in different return periods than other flood risk zones and includes some sections of Dobi, Ungwan Bassa, Dagiri, Gwagwalada, Ungwan Shanu, and Old Kutunku. Also deduced from the result, more people are at risk of flooding in a 100year return period. This result is not in agreement with the study of [26] who stated in their research that more people are at risk of flooding in very high risk zones.

Table 9: Population at Risk to Flood for Different Return Periods

RISK LEVEL	5-YRP		10-YRP		50-YRP		100-YRP	
	No.	**(%)**	**No.**	**(%)**	**No.**	**(%)**	**No.**	**(%)**
Low Risk	770	22.6	770	22.01	738	20.34	747	20.38
Moderate Risk	1670	49.02	1720	49.17	1829	50.4	1803	49.18
High Risk	967	28.38	1008	28.82	1062	29.26	1116	30.44
Total	**3407**	**100**	**3498**	**100**	**3629**	**100**	**3666**	**100**

Elements Within the Environment at Risk to Flood

An inventory of the significant elements at risk to flood in the study area was presented in Table 10. The result shows that about (2,380) residential buildings were within moderate risk areas, and (8) government buildings were within the low risk areas. Majority of the commercial establishments (shops, markets, banks, and hotels) at risk were found within the moderate risk and high risk areas

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(236) and (158). The majority of schools, religious houses and health centers at risk of flood (18), (11), and (6) were found within the moderate risk areas. Infrastructure such as roads (18), bridges (3), power transformers (4), communication masts (3) at risk to flood were found within the moderate risk areas. Also, (1) cemetery was located within moderate and high risk areas which may result in pollution and health hazards. This result indicates that there are more residential buildings and commercial establishments at risk to flood than any other element within the study area. This affirms the study of [13] who reported an increase in buildup expansion around the floodplains of the Usuma River.

Table 10: Major Elements at Risk to Flood

Major Elements	Low Risk	Moderate Risk	High Risk
Residential Buildings	543	2380	952
Commercial Establishments	42	236	158
Roads	10	18	13
Schools	2	11	5
Religious Houses	6	18	10
Government Buildings	8	5	3
Health Centers	1	6	4
Power Transformers	1	4	2
Communication Masts	2	3	1
Bridges	1	3	0
Cemetery	0	1	1
Total	**616**	**2685**	**1149**

CONCLUSION

The result from flood frequency analysis, HEC-RAS modelling, geospatial and statistical manipulations defined the extent of vulnerable and risk areas. This research has revealed that with increasing recurrent intervals, the menace of flood would increase. Areas of low to moderate vulnerabilities for agricultural, economic and commercial, infrastructural, and residential areas have the highest areal coverage. Areas of high and very high vulnerability of residential buildings are fewer northwards away from the Lower Usuma River and higher southwards of the River. The result also indicated that more residential buildings and commercial establishments are at risk to flooding than any other element within the environment. Areas affected by floods from this study include the settlements of Gwagwalada, Ungwan Shanu, Dobi, Dagiri, and Ungwan Dodo, Ungwan Bassa, Old Kutunku, Ungwan, Gwari, Ungwan Aguma, and Abattoir settlements. Given the pattern and likelihood of flooding along the Lower Usuma River, it is therefore recommended that the government under its capacity as Federal Capital Development Authority (FCDA) should impose strict restrictions on building projects along natural waterways and enforce compliance by individuals, private, and public property developers by making sure future floods do not turn into disasters. Since GIS and HEC-RAS hydrologic modelling techniques have become a major tool in disaster mitigation, disaster managers and institutions should advance programs that would enhance their capacity in this regard. Also, to minimize errors caused by human laxities, gauge stations and discharge recording equipment should be installed and automated along the Lower Usuma River.

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