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Flood Inundation Analysis of Lower Usuma River in Gwagwalada Town Abuja, Nigeria.

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Abstract
Flood inundation analysis of Lower Usuma River in Gwagwalada town Abuja was studied. HEC-RAS hydrologic modelling system and GIS were used to determine flood inundation for 5, 10, 50 and 100 year return periods. Flood frequency analysis showed that the water surface elevation gradually rises with increase in return period from 5year to 100year return period and a gradual increase in flooded area from about 24.76% in 5year return period to 26.75% in 100year return period. Also an increase in valleys and channel width of the river, the width of the flooded area increases and water expanded in wider area. The study showed that Gumbel's distribution is suitable for predicting expected flooding. Considering the likely impacts of severe flooding in Gwagwalada town along the Lower Usuma River, there is an urgent need for the State, Local and Administrative Authorities to ensure that appropriate town planning regulations are adhered.

Keywords: Flood Return Period, Flood Inundation, Hydraulic Modelling, Gumbel Distribution.

1.0. Introduction:

Globally, flooding is regarded as the most ubiquitous natural disaster that affects people in different dimensions than any other natural disasters [1]. It is an extreme natural occurring weather event that results in an overflow of large amounts of surface water over land that is not always inundated [2,3]. It occurs in most terrestrial portions of the globe, causing huge annual losses in terms of damage and disruption to economic livelihoods, businesses, infrastructure, services and public health [4]. Long term data on natural disasters suggest that flooding has been by far the most common causes of natural disasters worldwide over the past 100 years [5].

Urbanization aggravates flooding by restricting where flood water can go. In an urban areas, large parts of the ground are covered with roofs, tarred roads and pavements; these obstruct infiltration of rainfall into the soil thereby accelerating runoff. Consequently even quite moderate storms could produce high flows in rivers because there are more hard surfaces and drains [6]. In extreme cases urban floods can result in disasters that setback urban development by years or even decades. Recent statistics clearly indicate that one-third of the overall economic losses from natural disasters are caused by flooding and are on the increase [7].

Global warming has been linked to the sudden rise in the number and severity of recent floods in Jigawa, Kano, and Kaduna, Katsina (in Northern Nigeria), Gombe (North Eastern Nigeria) and most of the Southern States [8]. As a result, Nigerians have become increasingly at risk to a wide range of natural hazards with urbanization and high incidence of poverty pressuring the people, in spite of town planning regulations preventing them from inhabiting vulnerable flood plains and unstable hillsides.

Flood modeling is a relatively new approach which is widely used for flood hazard, and risk assessment. Recent advances through the combination of hydraulic simulation model, HEC-RAS and ArcGIS environment have the potential to further that flexibility to create geometric representations, simple import and export capabilities and displaying the results in spatial format in a more cost-effective manner.

Flood return period is known as a recurrence interval which is an estimate of the interval of time between flood events or river discharge flow of a certain intensity or size [9]. It is a statistical measurement denoting the average recurrence interval over an extended period of time and to dimension structures so that they are capable of withstanding an event of a certain return period (with its associated intensity). The terms "10 year", "50 year", "100 year" and "500 year" floods are used to describe the estimated probability of a flood event happening in any given year [10].

In the past decade in Nigeria, thousands of lives and properties worth millions of Naira have been lost directly or indirectly from flooding every year. In most urban centers of the country most especially in fast growing towns like Gwagwalada in the Federal Capital Territory (FCT), human population increase, increasing paved surfaces, streams and channel obstruction due to bad waste disposal habit and other human activities on flood plains were considered to be the major causes of floods [8]. In addition, rapid urban expansion and encroachment of settlements into the areas liable to flood is also continuing rapidly and unabated. For example, [11] has shown that the built-up area in Gwagwalada town has increased from 0.33km^2 in 1981 to about 11.72 km^2 in 2006 indicating extensive human activities.

Flood resulting from the lower Usuma River in Gwagwalada is becoming an annual event that is capable of causing wanton destruction to lives, properties and the environment. This situation puts the dwellers on environmentally fragile and flood disaster vulnerable locations where properties are easily washed away by the floods [12, 13]. Flood Inundated vast area within Gwagwalada town in year 2003, 2006 and 2009 among others where lives were lost and property worth billions of naira were lost to the ravaging floods [14]. River flooding, coupled with urban development, however, intensifies the rate of flooding in the lower section of the Usuma River, Gwagwalada Abuja, Nigeria. This necessitates the application of flood modeling techniques such as flood frequency analysis, HEC-RAS and Geographic Information System in achieving flood inundation analysis for the study area.

Prior application of GIS technologies in flood studies in Gwagwalada town has predominantly focused on risk and vulnerability mapping. There is therefore a paucity of research in flood frequency and inundation analysis in Gwagwalada town employing (Hydrologic Engineering Centers—River Analysis System) HEC-RAS modelling and Geographic Information System. Such studies are critical for understanding river geometry, urban planning and management of lands adjacent to flood plains.

Hence the aim of this study is to carryout flood inundation analysis of Lower Usuma River in Gwagwalada town Abuja, Nigeria by predicting probable flooding of Lower Usuma River using flood frequency analysis and flood inundation analysis for different return periods using hydraulic modelling and GIS techniques.

2.0. Study Location

Gwagwalada 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 dissected into two parts North-South by the Usuma River. Gwagwalada is a suburb of Federal Capital Territory, Abuja. It is situated along Abuja – Lokoja road, about 55km Southwest of the Abuja city Centre and bordered to the North by Kaduna State, Niger State to the West, Kwali LGA to the South and Abuja municipal area council to the East. The town is one of the largest satellite towns and the third largest urban Centre in the FCT has an area of 1,043 Km^2.

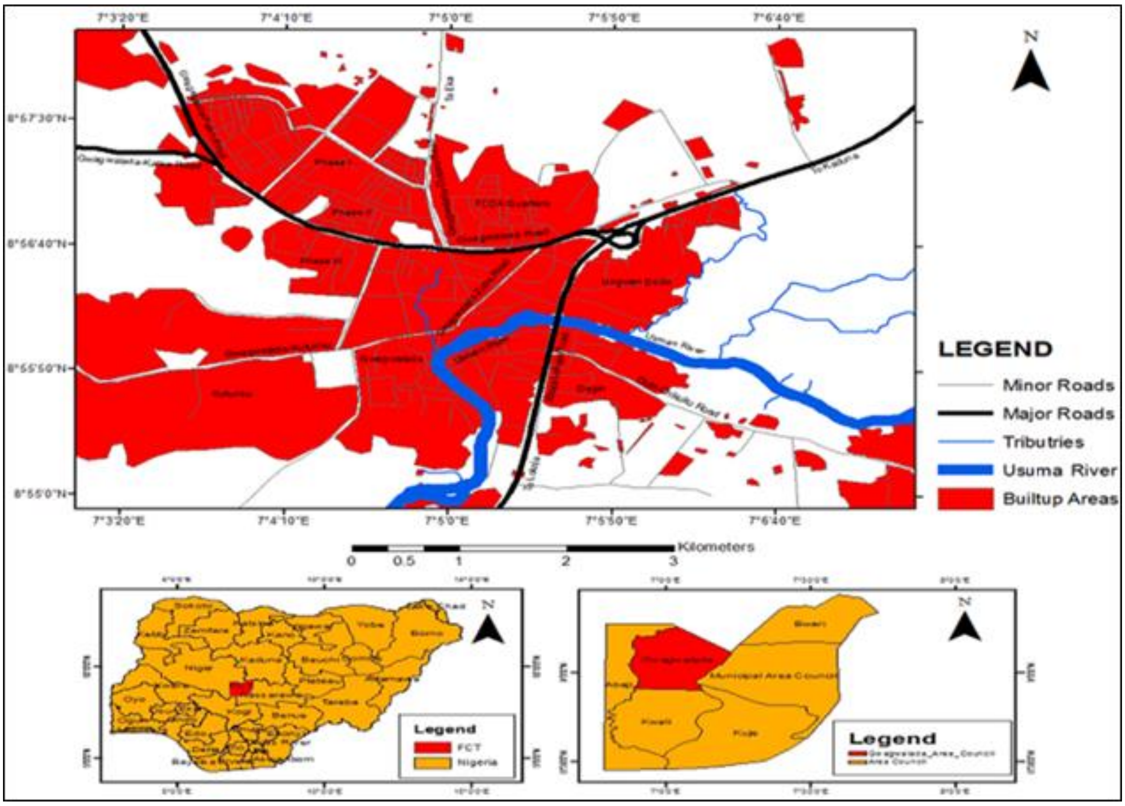


Fig. 1: Location of Gwagwalada
Source: Adapted from the Administrative Map of FCT, Nigeria

Gwagwalada town is one of the oldest and fast growing towns in the FCT and located within Gwagwalada Area Council, one of the area councils among the six area councils in the Federal Capital Territory, Abuja. The town has witnessed mass influx of people thereby increasing the population. Gwagwalada Area Council has a total of 80,841 people, with Gwagwalada town having 23,114 as at 1996 [15]. The population growth rate of Abuja for 2006 was (3.2%), with a population of 157,770 as at 2006 in Gwagwalada which puts the projected population of Gwagwalada for 2015 to be 210,427.

Several streams and rivers drain the area westward to the River Usuma that runs south to join River Gurara, the major river running through the territory and whose contents empty into river Niger [16]. Flash flooding is a characteristic of all streams in this area particularly during the rainy season. It is obvious that flooding is a major environmental hazard in this area and flood vulnerability is likely to increase with increased constructional activities within Gwagwalada urban area [17].

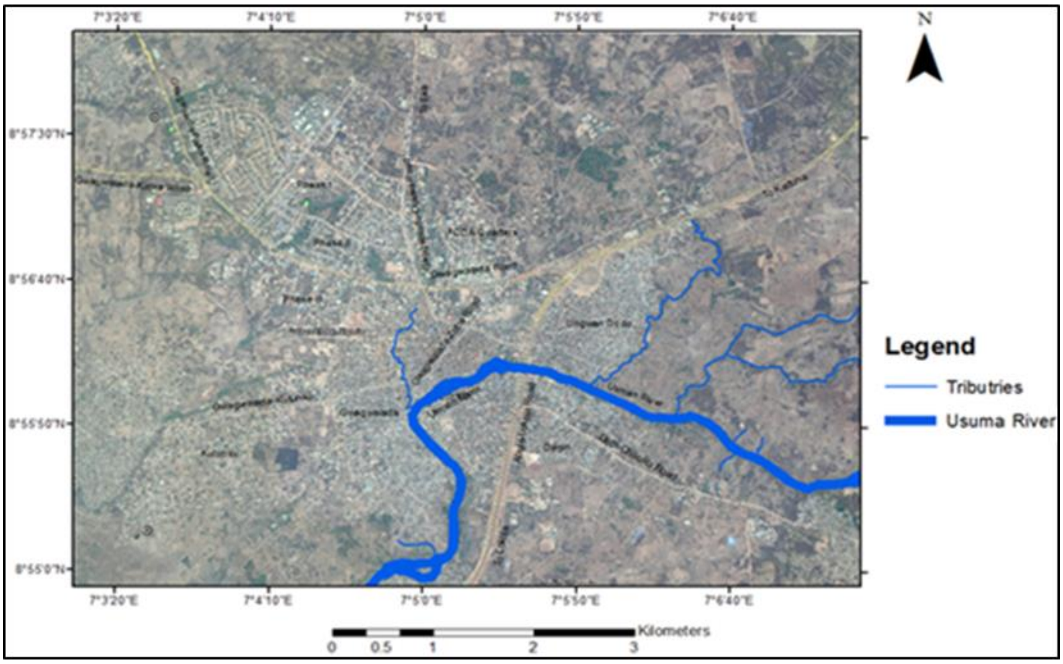


Fig. 2: Lower Usuma River and Its Tributaries
Source: Adapted from Google Earth

3.0. Materials and Methods

3.1. Types and Sources of Data Deployed For the Study

Hydrologic Data was collected from the Climatology Record Dam Safety Unit, Usuma Dam Abuja, Nigeria. This data include river stage heights and discharge data (1987-2018) which was used for calculating the 5, 10, 50 and 100 years flood return period for the study area.

Google Earth Imagery was used for extraction of and up-to-date individual elements such as buildings, roads, bridges and other structures for the study.

Shuttle Radar Topographical Mission/DEM (SRTM Version 3) was acquired from website, www.jpl.nasa.gov/srtm/index.html. It was used for extracting DEM and creating Raster TIN for the study.

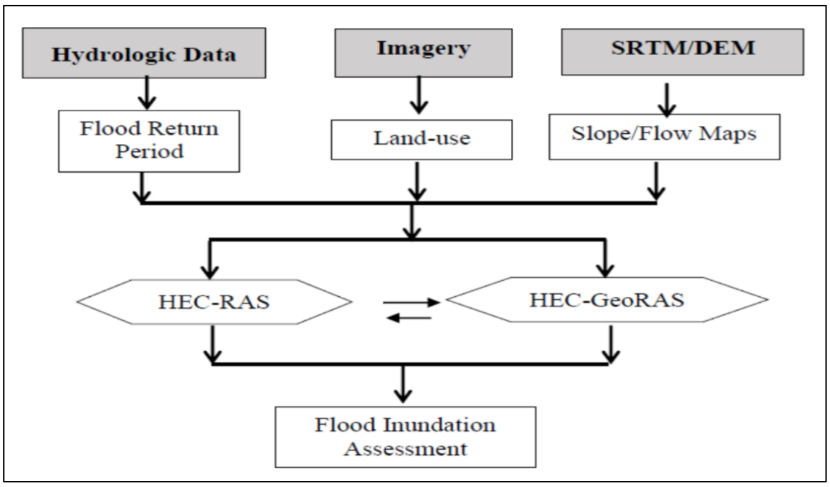


Fig. 3: Schematic Diagram of the Methodology

3.2. Flood Frequency Determination from Hydrologic Data

The Gumbel extreme value distribution method was used in analyzing the annual flood data as shown in Table 1 and 2. In recent years, Gumbel extreme value analysis has been used as a general model of extreme events including flood

flows. To determine the return periods of extreme flood events in the study area, the equation below was used to forecast the flood scenarios for 5, 10, 50 and 100-years return periods. The annual maximum gauge levels data for 32years (1987-2018) at the Usuma Dam Water Works Guage site (570.00m) was selected and calculated. The tables that shows these values are referred to as Gumbel's Extreme value distribution.
Gumbel statistics was used in flood frequency analysis, however, the description of the Gumbel function is stated in the equation (1);

$\mathbf{X_T = X + K * SDV}$ ……………………………… (1)
Where:
X_T = Value of variate with a return period 'T'
X = Mean of the variate
SDV = Standard deviation of the sample
K = Frequency factor expressed as:
$\mathbf{K = (Y_T - Y_n) / S_n}$ …………………….………… (2)
$\mathbf{Y_T = -[\ln.\ln.(T_r/(T_r - 1))]}$ ……….……………….. (3)
Where:
T_r = Return period
Y_{n} = Reduced mean from table
S_n = Reduced standard deviation from table

Table 1: Gumbel Distribution Computation Table Using Discharge Data

Return Period (T)	T/(T-1)	Yt= -[ln.ln.(T/T+1)]	K=(Yt-Yn)/Sn	XT= Ẋ + K * SDV	Expected Flood (m^3/s)
5	1.25	1.5	0.859465738	177.8474913	177.85
10	1.11	2.26	1.538461538	198.8284615	198.83
50	1.02	3.92	3.021531314	244.6553176	244.66
100	1.01	4.61	3.637988028	263.7038301	263.7

Source: Gumbel Statistical Analysis

Table 2: Gumbel Distribution Computation Table Gauge Height Data

Return Period (T)	T/(T-1)	Yt= -[ln.ln.(T/T+1)]	K=(Yt-Yn)/Sn	XT= Ẋ + K * SDV	Rise in Flood Stage (m)	Stage Level (m)
5	1.25	1.5	0.859465738	4.501626016	4.5	574.5
10	1.11	2.26	1.538461538	4.976923077	4.98	574.98
50	1.02	3.92	3.021531314	6.01507192	6.02	576.02
100	1.01	4.61	3.637988028	6.44659162	6.45	576.45

Source: Gumbel Statistical Analysis

3.3. Flood Inundation Analysis
Flood inundation for different return periods were determined using hydraulic modeling and GIS techniques (HEC-RAS/HEC-GeoRAS) [18]. HEC-RAS was used to calculate water-surface profiles and ArcGIS for GIS data processing while HEC-GeoRAS extension for ArcGIS was used to provide the interface between the systems. HEC-GeoRAS automates the extraction of spatial parameters for HEC-RAS input, primarily the three-dimensional stream network and the 3D cross-section definition. Results exported from HEC-RAS was processed in ArcGIS.
The inundation analysis consist of five steps;
i) Preparation of DEM
ii) HEC-GeoRAS pre-processing to generate HEC-RAS import file
iii) Running of HEC-RAS to calculate water surface profiles and modelling water levels using cross sections
iv) Post processing of HEC-RAS results and
v) Extent of flood inundation for 5, 10, 50 and 100-year return periods.

3.4. Land Use Data Processing
Land use data was created from Google Earth image of 2019 and added as HEC-GeoRAS input. The RAS Geometry tool was used in addition with the editor tool to create the land use data within the study area delineated earlier. The land use map was used to develop the Manning and LUManning tables under the RAS Geometry for the HECRAS model.

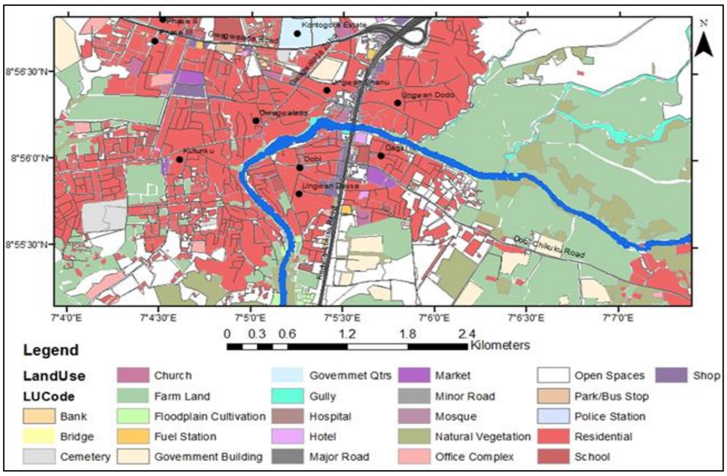


Fig. 4: Land Use of the Study Area
Source: GIS Analysis

3.5. Hydraulic Modeling in HEC-RAS and Post-Processing

The geometry from ArcGIS was 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. Manning's n values were derived from the Gwagwalada town Land-Use database created with HEC-GeoRAS. Manning n-values were assigned to each cross section by using Extract N-Values tool, referring to the class name attribute in land use dataset and LU-Manning Table.

The HEC-RAS output (RAS SDF file) was converted to a TIN file in HEC-GeoRAS. The TIN file forms a bounding polygon created by connecting the endpoints of XS Cut Lines and it is the analysis extent for inundation mapping. The TIN file was converted to Raster and using Raster calculator of ArcGIS, 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.

4.0. Results and Discussions

4.1. Flood Frequency Analysis

4.1.1. Hydrological Variations for the Lower Usuma River

The annual stage height data from 1987-2018 for the lower Usuma River (Figure 5) which showed variations with peaks in 1990 and 2009 with stage level of 4.63m and 4.54m respectively, and lowest in 2004 and 2005 with stage level of 1.95m and 1.02m respectively.

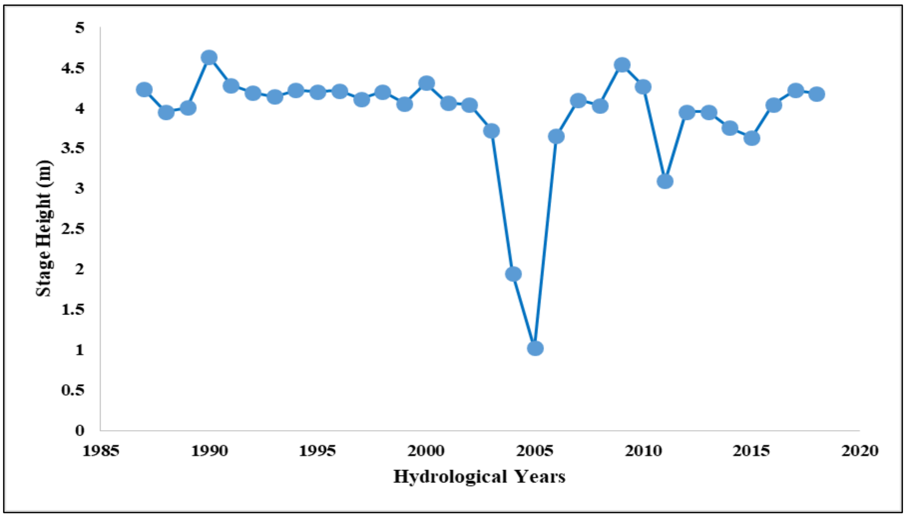


Fig. 5: Variation in Annual Stage Height for the Lower Usuma River
Source: Statistical Analysis

Figure 6 presents the annual discharge data from 1987-2018 for the lower Usuma River which showed variations with peaks in 1990 and 2009 with discharge of 185.65m^3/s and 181.23m^3/s respectively, and lowest in 2004 and 2005 with discharge of 64.08m^3/s and 28.88m^3/s respectively.

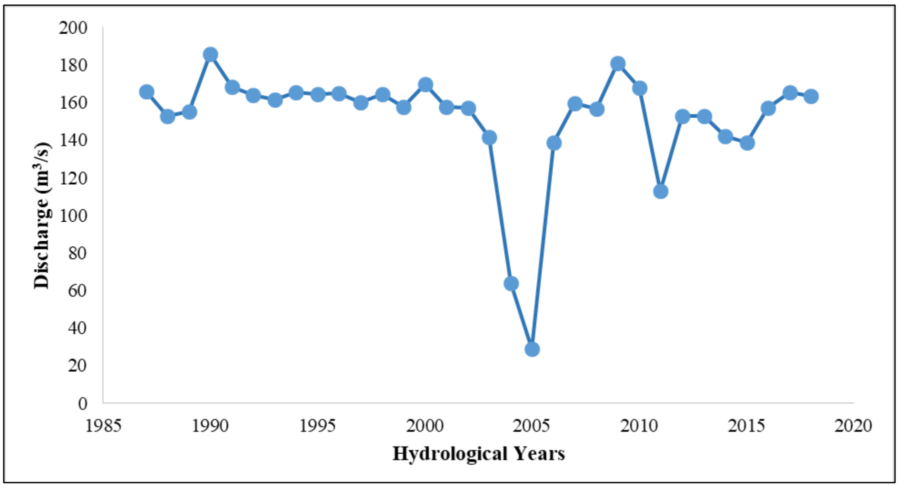


Fig. 6: Variation in Annual Discharge for the Lower Usuma River
Source: Statistical Analysis

4.1.2. Gumbel Distribution Statistical Result

Detailed analyses of gumbel computation are shown in Table 1 and 2. Table 3 shows the expected flood the Lower Usuma River in Gwagwalada Town. The result indicated a gradual rise in flood stage from 5-year flood to 100-year flood return period (4.50m to 6.45m). The 5-year return period represent the lowest stage level of 574.50m indicating a rise of 4.50m above the datum of (570m) and a resultant discharge of 177.85m^3/s, the 10-year return period shows a stage level of 574.98m and a rise of 4.98m above the datum with a discharge of 198.83m^3/s, the 50-year return period shows a stage level of 576.02m with a rise of 6.02m above the datum and discharge of 244.66m^3/s, while the 100-year return period represent the highest stage level of 576.45m with a rise of 6.45m above the datum and a resultant discharge of 263.70m^3/s.

Table 3: Expected Flood the Lower Usuma River in Gwagwalada Town

Return Period (Years)	Gumbel Distribution			
	Exceedence Probability	Discharge (m^3/s)	Stage Level (meters)	Rise in Flood Stage (meters)
5	0.2	177.85	574.50	4.50
10	0.1	198.83	574.98	4.98
50	0.02	244.66	576.02	6.02
100	0.01	263.70	576.45	6.45

Source: Gumbel Statistical Analysis

The results showed a contrasting increase in the response of the water level at different hydrological years based on the return period. This is similar to the findings of [19] where Gumbel results indicated a marginal increase in stage height with increase in return periods.

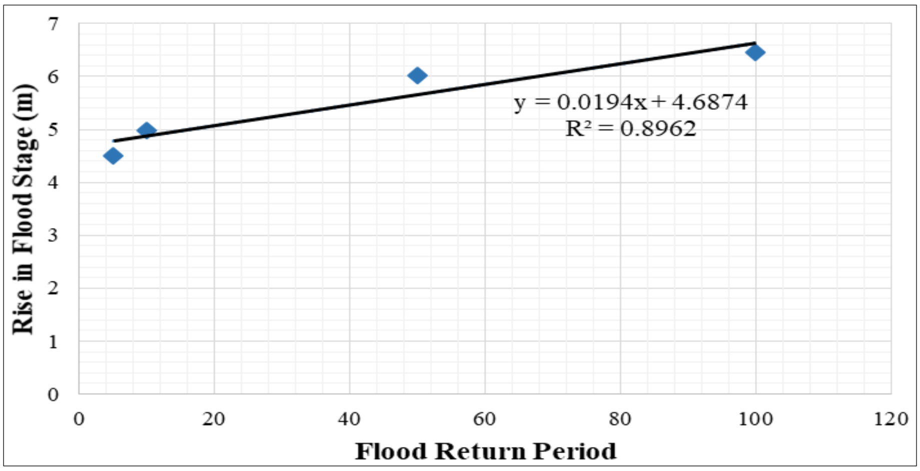


Fig. 7: Relationship between Expected Flood Water Levels and Return Periods
Source: Statistical Analysis

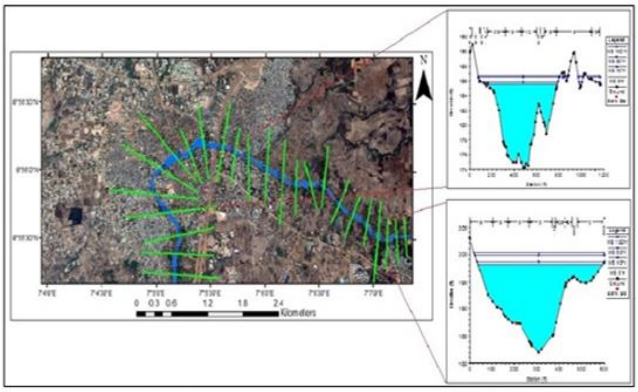
The line graph in figure 7 shows the relationship between expected flood water levels and flood return period. The general characteristics of the water level values for the Lower Usuma River showed linear characteristics with positive co-efficient of regression (R^2 = 0.8962) or approximately 90 % and a polynomial expression (y = 0.0194x + 4.6874). This characteristics clearly shows that Gumbel extreme value distribution is a good fit for the observed flood data with 90% acceptability, this finding is in agreement with the study of [20] who's trend line equation showed a value of 0.954 indicating that Gumbel's distribution is suitable for predicting expected flow in the Osse River.

4.2. Flood Inundation Analysis

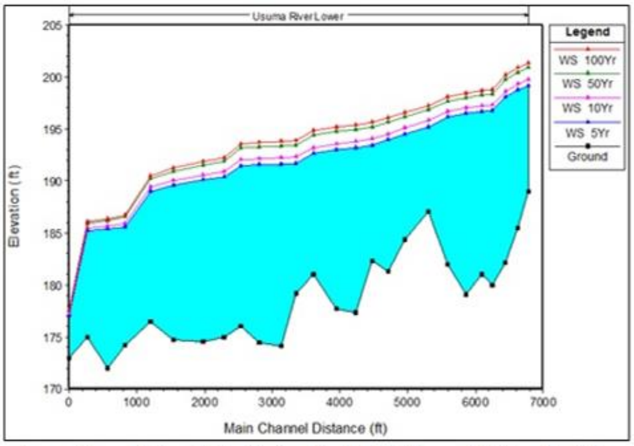
A two-dimensional flood inundation mapping was adopted for this study based on the outcome of the flood frequency analysis and steady flow analysis in HEC-RAS and post processing in HEC-GeoRAS.

4.2.1. HEC-RAS Flood Simulation

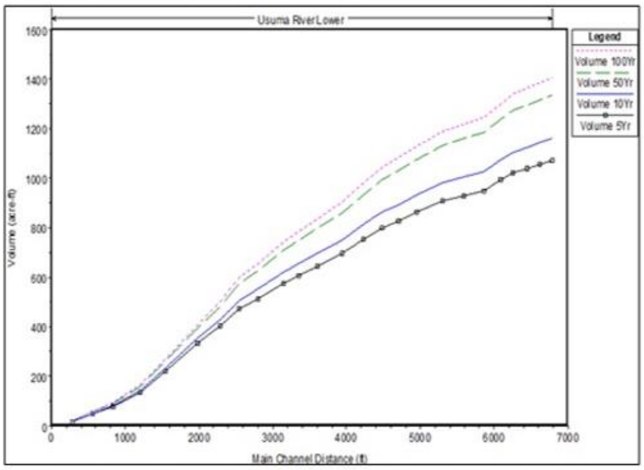
HEC-RAS result consist of Flow Area Profile Plot, Water Volume Profile Plot, Water Surface Profile Plot and water surface elevation plots generated for 5year, 10year, 50year and 100year return period for the entire Lower Usuma River channel in Gwagwalada as shown in figure 8.



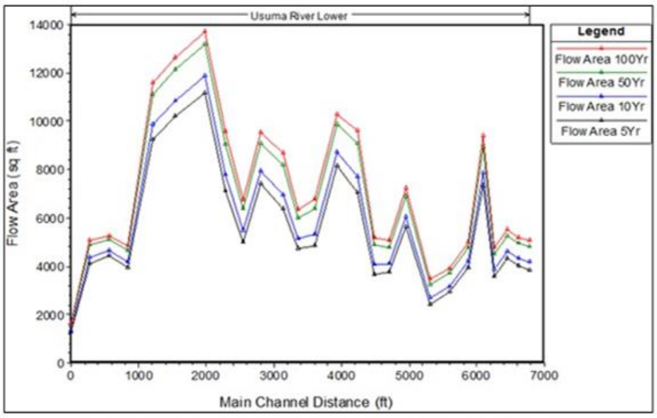
Lower Usuma River Cross-section of Water Profile for each Return Period



Lower Usuma River Water Surface Profile Plot for each Return Period



Lower Usuma River water volume profile plot for each Return Period



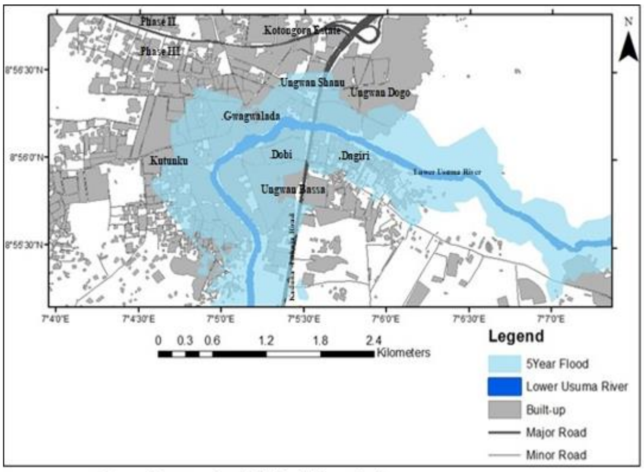
Lower Usuma River Flow Area Profile Plot for each Return Period

Fig. 8: Lower Usuma River Geometry
Source: HEC-RAS Analysis

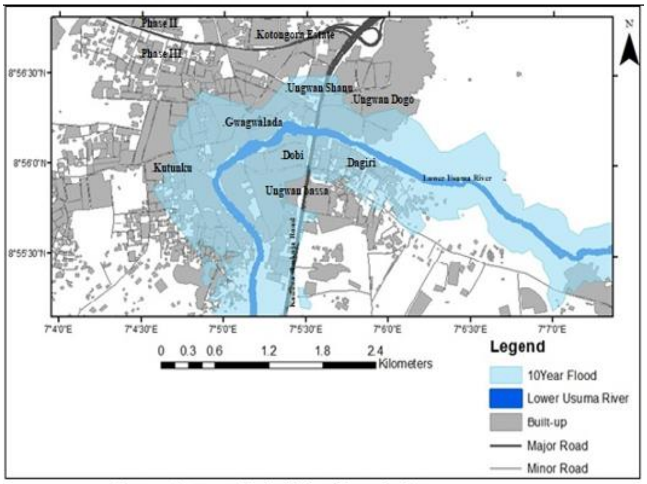
It was observed from the figure above that the water surface elevation gradually rises with increase in return period, from 5year to 100year return period. Anywhere the valley width and the channel increase, the width of the flood area increased and water expanded in wider area. Conversely, anywhere the valleys and channel width are narrow, the width of flood area reduced in the same proportion and also the depth of flood levels increased. This is similar to the findings of [21].

4.3. Flood Inundation Mapping

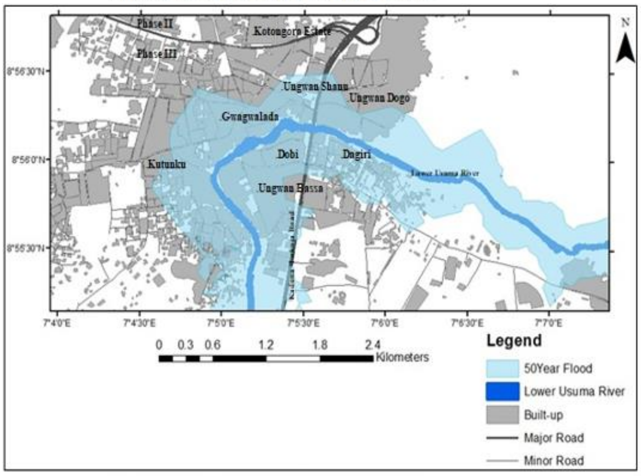
The flood inundation mapping accomplished in the ArcMap using HEC-GeoRAS extension was done for the four model scenarios (5year, 10year, 50year and 100year return period) and presented in Figure 9. The area and proportional analysis of the spatial extent of inundation within the study area were estimated and presented in Table 4 for each of the flood return period.



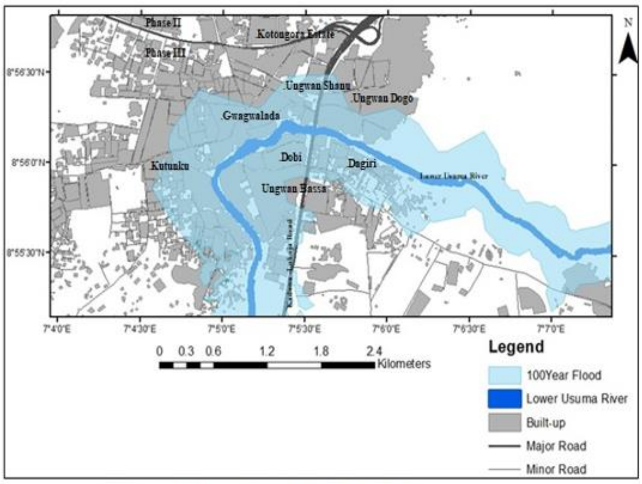
5-year Return Period Flood Inundation



10-year Return Period Flood Inundation



50-year Return Period Flood Inundation



100-year Return Period Flood Inundation

Fig. 9: Flood Inundation Maps
Source: GIS Analysis

Table 4: Inundated Areas for Different Return Periods

Return Period	Water Level (m)	Flooded Area		Non-Flooded Area	
		Area (km^2)	Area (%)	Area (km^2)	Area (%)
5-YRP	4.50	5.47	24.76	16.62	75.24
10-YRP	4.98	5.62	25.44	16.47	74.56
50-YRP	6.02	5.83	26.39	16.26	73.61
100-YRP	6.45	5.91	26.75	16.18	73.25

Source: GIS Analysis

The maps clearly demonstrates that when a 5year flood return period happens, the maximum depth is 4.50m and inundated area covers approximately 5.47 km^2 (23.1%) of Gwagwalada town. This will increase in 10year flood return period with maximum depth of 4.98m to 5.62 km^2 (25.44%). The inundation trend will persist in a 50year flood return period whereby 5.83 km^2 of the study area (26.39%) will be completely flooded with maximum depth of 6.02m. Similarly, the 100year flood return period with maximum depth of 6.45m will cover approximately 5.91 km^2 (26.75%) of the study area. This shows that not much of the land surface are covered by inundation.
Based on the flood inundation results of the study area, the width of inundated corridor for the flood with a return period of 100years was by far the most flooded. This is in agreement with the findings of [22, 23] where the depth of inundation increases with increase in return period. Most of the areas that would experience flooding are the built-up areas around Dagiri, Dobi, Ungwan Bassa, and parts of Ungwan Dodo, Ungwan Shanu, Kutunku, Gwagwalada and Ungwan Shanu settlements.

5.0. Conclusion

The occurrence and impacts of flooding in Gwagwalada town along the Lower Usuma River has been on the increase in recent times and is gradually becoming an annual occurrence and has been highlighted in this study. This study has demonstrated the use of Gumbel's Extreem value distribution statistics in flood frequency analysis, (Hydrologic Engineering Centers—River Analysis System) HEC-RAS hydrologic modelling system and Geographic Information System to determine flood inundation in Gwagwalada Town along the lower Usuma River for 5, 10, 50 and 100 year return periods.
Flood frequency analysis showed that the water surface elevation gradually rises with increase in return period, from 5year to 100year return period. Also, it showed that an increase in valleys and channel width of the river, the width of the flooded area increases and water expanded in wider area. The trend line equation (R^2 = 0.8962) shows that the pattern of the scattered plot is narrow and that Gumbel's distribution is suitable for predicting expected flooding of the river. The inundation analysis also showed a gradual increase in flooded area from about 24.76% in 5year return period to 26.75% in 100year return period. These results are useful in the engineering design of hydraulic structure such as storm water drains, culverts and emergency evacuation of people and properties well in advance.
Considering the likely impacts of severe flooding in Gwagwalada town along the Lower Usuma River, there is an urgent need for the State, Local and Administrative Authorities to ensure that appropriate town planning regulations are adhered to while concerted efforts must be made to stop further development along the Lower Usuma River floodplain to curtail the disaster that might be caused by future flood events.

6.0 Acknowledgments

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