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Analysis of Morphometric Parameters and Prioritization for Flood Vulnerability of River Sub-Basins in Hong LGA Adamawa State, Northeastern Nigeria

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ABSTRACT

Flooding is one of the most destructive natural hazards globally, with its frequency and severity amplified by climate change, land use alterations, and geomorphic characteristics of watersheds. This study assessed flood vulnerability in Hong Local Government Area (LGA), Adamawa State, Nigeria, through morphometric and relief analysis supported by Geographic Information System (GIS) techniques. The objectives were to delineate major basins in the study area, compute morphometric parameters, and prioritize them based on susceptibility to flooding. Six watersheds—Kwaleta, Kilange, Dugwaba, Diltil, Gashala, and Dzakwa—were delineated from Shuttle Radar Topography Mission (SRTM) Digital Elevation Model. Linear, areal, and relief parameters were calculated using standard morphometric formulae, and prioritization was conducted through composite rating (CR) values. Findings reveal significant variation across basins. Drainage density, stream frequency, infiltration number, and ruggedness number showed higher flood susceptibility in Kilange, Gashala and Dugwaba, while Kwaleta, Diltil and Dzakwa exhibited moderate to low vulnerability. These results are significant because the study area is ungauged, and morphometric analysis provides critical baseline data for flood management, land use planning, and runoff harvesting. It is recommended that local authorities integrate these findings into watershed management strategies, strengthen flood early-warning systems, and promote afforestation and soil conservation measures to reduce runoff and enhance resilience.

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INTRODUCTION

Floods are the most frequent natural hazard worldwide (Kousky, 2016). Flood can be defined as an overflowing or eruption of a great body of water over land not usually submerged (Daniel and Udo, 2019). It is an extreme weather event naturally caused by rising global temperature which results in heavy down pour, thermal expansion of the ocean and glacier melt, which in turn result in rise in sea level, thereby causing water to inundate coastal lands. Flooding causes inundation and harm to plants and animals, including man, buildings and infrastructure (Ujene and Oguike, 2020). As such, it is a global natural hazard that has affected lives, led to the loss of properties and extinction of species in the environment. As a matter of concern, flood is a threat that affects the quality of the environment. Given the issues relating to flooding, it is regarded as a factor that is used in defining environmental quality of residential neighborhoods (Smith, 2020; Johnson & Brown, 2018).

Flood hazard is a primary weather-related disaster worldwide. Escalation in flooding events is indeed a dilemma through recent years, as innumerable causalities are caused by them every year (El-Shater *et al.*, 2021). Moreover, climatic change has many consequences as surge in frequency of rainfalls potentially enhance the rate of flooding. Urbanization, associated with intensified hydrological, ecological, environmental and climate changes, gives rise to reduction in groundwater recharge, evapotranspiration (ET) and infiltration, consequently resulting in an increase in quantity of runoff volume during most of the floods (Pirnia *et al.*, 2019).

The incidence of severe rains and their effects on river discharge result in flooding within communities along riverbanks and where there are poor drainage systems and landforms (Amoateng *et al*., 2018). A flood is a temporary condition of partial or complete inundation of two or more acres of normally dry land area or areas with properties (FEMA. 2016). The term is also used to describe the sudden and unexpected rise of water to a specific depth, which can be the result of dam failure or prolonged and intense rainfall putting the lives and property of people and other animals in the area at risk (Akintoye *et al*., 2016, Maddox. 2014). Flooding is still one of the most frequent types of natural disasters reported globally today (Kousky. 2016, Tella *et al.*, 2023). Floods are caused by various natural factors, e.g., meteorological factors, physical characteristics, and land cover (*Pariartha et al.*, 2023) and anthropogenic factors, e.g., community behaviour, land use/land cover (LULC) changes, deforestation (Ramadhan *et al., 2023*), and environmental management (Handayani *et al*., 2020). Various studies have stated that the rise in hydrometeorological disasters is related to the global climate change phenomenon of the world in the last few decades (Thomas and López, 2015; Frimawaty *et al.*, 2023). The flood risk level is increasing due to extreme weather phenomena caused by climate change (Brunner *et al.*, 2018; Puno *et al.*, 2022). Coastal areas will be more vulnerable to climate change disasters (Mycoo *et al.*, 2022), such as flooding, due to water level rises (Gaborit, 2022). Floods can cause widespread devastation, resulting in loss of lives and damages to personal properties as well as critical public infrastructure. It also causes a dramatic change in the geomorphic condition of alluvial channels and semi-alluvial channels (Magilligan *et al.*, 2015). WHO (World Health Organisation) reported that from 1998 to 2017, floods affected more than 2 billion people worldwide (Ghosh *et al.*, 2023). People who live in flood plains or non-resistant buildings, or lack warning systems and awareness of flooding hazards are most vulnerable (Mhd Noor.*et al.*, 2022, Saravanan *et al.*, 2022). For the protection against flood, vulnerability reduction and increasing resiliency are significant approaches (Sanyal. 2005). According to United Nations (United Nation. 2009) vulnerability indicates a degree of damage at flood risk specified amount where UNDP defines it as a condition which is influenced by physical, social, economic and environmental aspects that raises the susceptibility of people to hazard impact (Pelling *et al.*, 2004). There is widespread interest with regards to flood vulnerability studies due to the impacts of flood, particularly on lives and property.

Development of land and water conservation measures necessitates morphometric analysis and prioritisation of sub-watersheds within a basin (Aher, *et al*., 2014). Morphometric analysis has been extensively used for the purpose of prioritisation and assessment of watersheds susceptibility to natural hazards such as floods and erosion (Abuzied, *et al*., 2016); (Alam, *et al.*, 2020); (Strahler 1952), (Miller 1953), and (Schumm 1956) as a guidance. Morphometry is defined as the quantitative analysis of the earth's surface, as well as the shape and dimensions of its landforms (Kaur, *et al.*, 2014); (Vaidya, *et al*., 2013). Morphometric parameters represent relatively simple approaches that can be utilised to investigate a hydrologic basin, and its geological and geomorphic history (Strahler, 1964). Morphometric characteristics of watersheds are a crucial factor that influences flash flood intensity; hence, investigation of the watershed morphometry provides useful insights regarding their hydrological response to rainfall (Borga, *et al*., 2008). Morphometric parameters involve linear aspects, areal aspects, and relief aspects, which can be employed in several investigations such as natural resources assessment and protection, and environmental hazards assessment (Arnous, *et al*., 2011; Charizopoulos *et al*., 2019). They help predicting the response of watershed during periods of heavy rainfall (Kumar, *et al.,* 2000). Worldwide, morphometric analysis was successfully used for flash flood susceptibility mapping (e.g., Adnan, *et al*., 2019); (Alam *et al*., 2020); (Bhatt & Ahmed, 2014); (Das, 2020). Watershed prioritisation refers to ranking sub-watersheds of a watershed according to the order in which they must be considered for the purposes of treatment (Biswas, *et al*., 1999; Puno & Puno, 2019). Morphometric analysis involves computation of basic parameters, linear parameters, relief parameters, and shape parameters of a watershed, and those gain insights about the watersheds characteristics (Melton, 1957; Strahler, 1964). Recently, geospatial techniques (RS and GIS) have been applied efficiently with the goal of watershed management (Chatterjee, *et al*., 2013; Okumura & Araujo, 2014). The availability of free access high quality resolution digital elevation (DEM) has further enhanced the strength of the effective GIS tools that enabled many researchers to study drainage basins and to investigate with high accuracy the parameters of drainage basins. This development led to the possibility of applying and using morphometric analysis based on GIS tools in several topics of research; one of which is watershed prioritisation in terms of susceptibility to erosion and flash floods (Ratnam, Rao, & Amminedu, 2005).

The aim of this study is prioritisation of river sub-basins in Hong Local Government Area based on morphometric analysis and GIS with respect to flood vulnerability. The objectives include delineating major watersheds within Hong Local Government Area and computing the morphometric parameters at the sub-basins level. The study area is characterised by high diversity in topography, morphology, and climatic regime. The high frequency of flash floods in Hong Local Government Area over the last decade has prompted the authors to carry out this study. It is believed that, the findings of the study can provide the required baseline information for flood management in the study area. Geospatial technology is an effective method and for the study area of ungauged catchments such as the ones in Hong Local Government Area

MATERIALS AND METHODS

The Study Area

Hong Hong Local Government Area is geographically located between latitudes 9°50’N and 10°35’N of the equator and between Longitude l2°40’E and l3°15’E of Greenwich Meridian. It shares boundaries with Askira/Uba Local Government Area of Bomo State in the North, Mubi North Local Government Area in the east, Michika Local Government Area in the north- east and Song and Gombi Local Government in the South-West. (Fig. 1) It spans and covers an estimated area of 24,850km2. (Adebayo and Tukur, 1999)

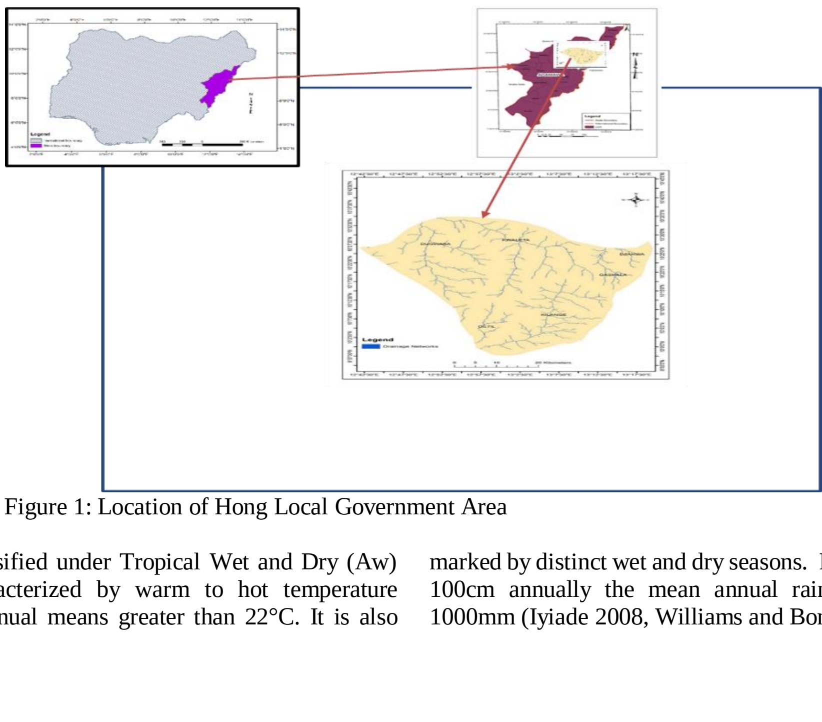

Figure 1: Location of Hong Local Government Area

Hong LGA is classified under Tropical Wet and Dry (Aw) climate type characterized by warm to hot temperature conditions with annual means greater than 22°C. It is also marked by distinct wet and dry seasons. Rainfall is averagely 100cm annually the mean annual rainfall is about 900-1000mm (Iyiade 2008, Williams and Bonni 2009).

The study area consists of different types of basement complex rocks. The distribution of these rocks is associated with land form distribution in the area. Among the basement rock types found in the area are various forms of Igneous and metamorphic rocks which include basement complex, Meta sediments, Gneiss and magnetite.

The glory and beauty of Hong local government area lies in its varied Mountains and other landforms. Nearly one third of the local government area is covered with high lands while two third is low land (Dube *et al.,* 2014). The relief is generally high (>400m above mean sea level [a.m.s.l]) with respect to Nigeria's mean sea level (Adebayo and Dayya, 2004)). The relief and landforms are generally hilly with highlands ranging from about 426 to 1158m above mean sea level (Garkida, Nigeria, Sheet 155).

The dominant drainage pattern of Hong watersheds is dendritic, which is typical for homogeneous impermeable, non-porous rock types, with no structural control, developing on a land surface where the underlying rock is of uniform resistance to erosion (Gizachew & Berhan, 2018). The occurrence of this type of the drainage pattern in the Hong Watersheds as seen in its Basins (Figure 3) influences the occurrence of floods in the study area. The study area is characterized by high relief reaching 1,158 m.

The Watersheds in Hong Local Government Area were delineated using 30m resolution Digital Elevation Model obtained from the United States Geological Surveys (USGS) Earth Explorer website. The delineation procedure was carried out in the ArcMap environment of ArcGIS 10.3 using appropriate tools of the Arc Toolbox. In this procedure, six major basins of Hong Hong Local Government Area were delineated and their drainage networks established (Figure 2).

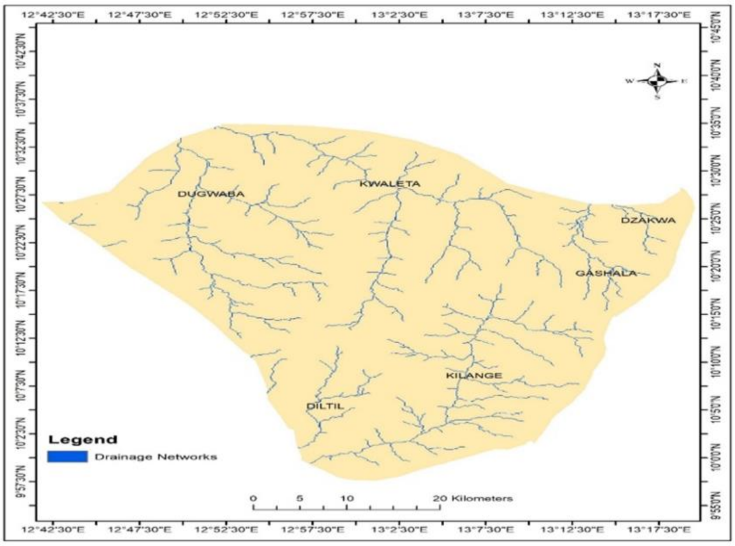

Figure 2: Drainage Network of Hong L.G.A.

Morphometric Analysis

Twenty-four morphometric parameters were determined for the purpose of basin characterization and prioritisation of the Hong Local Government Area watersheds with respect to susceptibility to flooding. Basic parameters such as basin area, basin length, perimeter, number of streams, and lengths of streams for each stream order were measured directly from the DEM using GIS techniques.

Other morphometric parameters including stream frequency, drainage density, elongation ratio, circularity ratio, relief ratio, basin relief, relative relief ratio, basin slope, bifurcation ratio, length of overland flow, and ruggedness number were calculated using the mathematical equations presented in Table 1.

Table 1: Basins Morphometric Parameters and Formulae

Aspect	Parameter	Formulae	Reference
Linear	Basin area (A)	Plan area of the watershed (km2)	Horton (1945)
	Basin perimeter (P)	Perimeter of the watershed (km)	Horton (1945)
	Basin length (Lb)	Length of the basin (km)	Horton (1945)
	Stream order (u)	Hierarchical order	Strahler, (1964)
	Stream Number (N_u)	$N_u = N_1 + N_2 + \ldots + N_n$	Schumn (1956)
	Stream length (L_u)	Length of the stream	Horton, (1945)
	Bifurcation Ratio (R_b)	$R_b = N_u/N_{u+1}$; where, N_u=Total number of stream segment of order'u'; N_{u+1}=Number of segment of next higher order	Schumm, (1956)
	Mean stream length (Lsm)	Lsm = Lu/Nu (km) where, Lu = total stream length of all orders Nu = total no. of stream segments of order "u"	Horton (1945)
	Stream length ratio (R_L)	RL = Lu/Lu − 1, where Lu − 1 = the total stream length of its next lower order	Horton (1945)
Arial	Drainage Density (D_d)	$D_d = \sum L_u/A$; where, ∑Lu=Total length of streams; A=Area of watershed	Horton, (1932)

Aspect	Parameter	Formulae	Reference
	Infiltration number, If	If = Fs/Dd, where Fs is the stream frequency, and Dd represents the drainage density.	Alam (2021)
	Stream Frequency (F_s)	$F_s = \sum N_u/A$; where, $\sum N_u$=Total number of streams; A=Area of watershed	Horton, (1932)
	Drainage Texture ratio (D_t)	$D_t = \sum N_u/P$; where, $\sum N_u$=Total number of streams; P=Perimeter of watershed	Horton, (1945)
	Form Factor (R_f)	$R_f=A/(L_b)^2$; where, A=Area of watershed, Lb=Basin length	Horton, (1932)
	Lemniscate ratio (*K*)	$K=L_b^2/4A$	Chorley *et al*. (1957)
	Circulatory ratio (R_c)	$R_c=4\pi A/P^2$; where, A=Area of watershed, π=3.142, P=Perimeter of watershed	Miller, (1953)
	Elongation ratio (R_e)	$Re=2\sqrt{(A/\pi)}/L_b$; where, A=Area of watershed, π=3.14, L_b=Basin length	Schumm, (1956)
	Length of overland flow (Lof)	$L_{of} = 1/2D_d$; where, D_d=Drainage density	Horton, (1945)
	Compactness Coefficient (C_c)	$Cc=0.2841(P/A^{0.5})$; Where P=Watershed Perimeter, A=Watershed Area	Gravelius (1914)
Relief	Basin relief (H)	Vertical distance between the highest (E_{max}) and lowest (E_{min}) points of watershed.	Schumm, (1956)
	Relief ratio (R_{hl})	$R_{hl}=H/L_b$; Where, H=Basin relief; L_b=Basin length	Schumm, (1956)
	Ruggedness Number (R_n)	Rn=Dd*(H/1000)	Strahler, (1964)
	Shape Factor (B_s)	$Bs=(Lb)^2/A$	Horton, (1945)
	Average Slope	Lb (in meters)/H	Ghany (2015)

The Prioritization Approach

Two processes were involved in the Prioritization Approach. First, ranking of each morphometric parameter across the Basins with respect to its direct or inverse relationship with flooding. Second, prioritization analysis to arrive at a Composite Rating (CR) value.

Ranking of Morphometric Parameters

The Morphometric Ranking Method (Total Rank) was utilised for the purpose of watersheds priotisation (Patel, *et al.,* 2012). Twenty-four morphometric parameters were determined for the purpose of basin characterization and prioritisation of the river sub-catchments in Hong Local Government Area as regards susceptibility to flooding. Basic parameters were measured directly from the DEM using GIS techniques (ArcGIS 10.3 Software), and include basin area, basin length, perimeter, number of streams, and lengths of streams for each stream order.

Morphometric parameters are either directly or inversely related to flooding. Basin morphometric parameters which exhibit direct relationship with flooding were ranked in an order that the highest value of a parameter for a particular basin was rated 1. The next higher value of the parameter for another basin was rated 2, in that order until all the values of the parameter for the six basins were ranked, with the lowest rated 6. A similar ranking procedure was conducted for the parameters that show inverse relationship with watersheds flooding. However, in this case of inverse relationship, the highest value of each parameter for a basin was rated 6 and next higher value of the parameter for another basin rated 5, in that order until all values of the parameter for all the Basins were ranked, with the lowest value of the parameter rated 1.

Prioritization Analysis

Having ranked each parameter across the Basins accordingly, the average rank value for each Basin known as the Composite Rating (CR) Value was computed using the formula suggested by Altaf *et al*., (2014) expressed as;

$$CR = \frac{1}{n}\left(\sum_{i=1}^{n} R_i\right)$$

Where CR is Composite Rating value; Ri is rank of a Sub-Basin parameter; and n is number of parameters used for the analysis.

The Basin with the lowest CR value portrays the highest level of susceptibility and vulnerability to flooding. However, for emphasis and clarity, the degree of vulnerability to flooding was further categorized as shown in Table 2.

Table 2: Categorization of the Degree of Basins' Vulnerability to Flooding

Composite Rating (CR) Value	Degree of vulnerability to Flooding
<3.5	High
3.5-3.9	Moderate
>3.9	Low

RESULTS AND DISCUSSION

Results of Priotisation Analysis and Sub-basins' Degrees of Vulnerability to Flooding

Prioritisation analysis revealed that eleven parameters have a direct relationship with the degree of susceptibility to flooding, which means that the higher the value of the parameter, the higher is the risk degree. These parameters include basin area, drainage density, stream frequency, Lemniscate ratio, circularity ratio, relief ratio, relative relief ratio, basin slope and ruggedness number. On the other hand, five parameters viz; length of overland flow, elongation ratio, shape factor, Infiltration number and Compactness Coefficient have an inverse relationship to degree of susceptibility to flooding. This means that higher values of these parameters connote lower degree to flood risk. Results of the Prioritization Analysis showing the parametric values, rankings and composite ranked values for river sub-basins of Hong Local Government Area are presented in Table 2.

Table 2: Prioritization and Ranking of the Morphometric Parameters for Basins' Degrees of Vulnerability to Flooding

Parameters	Relationship with flooding	Kwaleta	Kilange	Dugwaba	Diltil	Gashala	Dzakwa
Basin area,	Direct	770 (1)	707.9 (2)	672 (3)	164 (5)	176 (4)	61 (6)
Lemniscate ratio	Direct	0.81 (1)	0.63 (6)	0.65 (5)	0.72 (3)	0.75 (2)	0.69 (4)
Drainage Density	Direct	0.7 (4)	0.74 (2)	0.69 (5)	0.72 (3)	0.79 (1)	0.67 (6)
Stream Frequency	Direct	0.94 (5)	0.85 (6)	0.96 (3)	0.95 (4)	1.02 (2)	1.19 (1)
Drainage Texture	Direct	4.37 (3)	4.51 (2)	5.15 (1)	2.32 (4)	2.01 (5)	1.82 (6)
Infiltration number	Inverse	1.36 (4)	1.14 (1)	1.37 (5)	1.30 (3)	1.29 (2)	1.77 (6)
Length of Overland Flow	Inverse	0.72 (4)	0.67 (2)	0.73 (5)	0.69 (3)	0.63 (1)	0.74 (6)
Circularity Ratio	Direct	0.35 (6)	4.98 (1)	0.53 (3)	0.46 (4)	0.45 (5)	4.55 (2)
Elongation Ratio	Inverse	0.63 (1)	0.71 (6)	0.69 (5)	0.66 (3)	0.64 (2)	0.67 (4)
Compactness Coefficient	Inverse	0.12 (3)	0.11 (2)	0.10 (1)	0.23 (5)	0.22 (4)	0.36 (6)
Ruggedness Number	Direct	0.43 (4)	0.40 (5)	0.47 (3)	0.55 (2)	0.61 (1)	0.16 (6)
Relief Ratio	Direct	12.53 (6)	12.8 (5)	16.23 (4)	35.3 (1)	33.7 (2)	18.5 (3)
Shape Factor	Inverse	3.24 (6)	2.52 (1)	2.63 (2)	2,87 (4)	3.03 (5)	2.76 (3)
Av. Slope	Direct	0.08 (1)	0.07 (2)	0.06 (3)	0.03 (5)	0.02 (6)	0.05 (4)
Composite Rating		3.5	3.07	3.42	3.5	3	4.5
Vulnerability Level		Moderate	High	High	Moderate	High	Low

Levels of Vulnerability to Flooding of Sub-basins in Hong Local Government Area

Based on the results, composite ranked values for basins ranged from 3 to 4.5, indicating low through moderate to high vulnerabilities to flooding. The vulnerability of Dzakwa to flooding was found to be low. Kwaleta and Diltil Showed moderate vulnerabilities, while Kilange, Dugwaba, and Gashala exhibited high vulnerabilities to flooding. The vulnerability map of river sub-basins in Hong Local Government Area is presented in Figure 3.

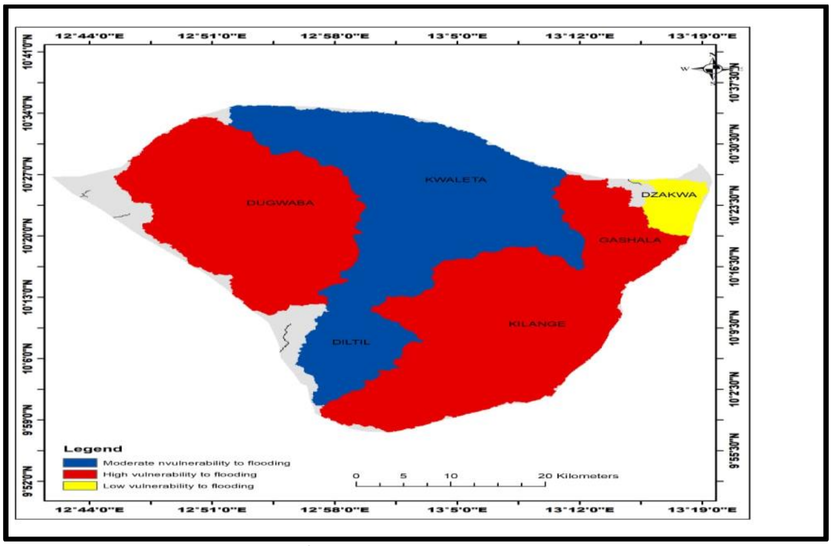

Figure 3: Flood vulnerability of Sub-basins in Hong L.G.A.

CONCLUSION

Hong Local Government Area, Adamawa State, Nigeria, witnessed frequent flood disasters in the last one decade. The recurring flooding in the area necessitates this study, which assessed flood vulnerability through analysis of morphometric and relief parameters using Geographic Information System (GIS) techniques. Geospatial technology is an effective method in the study of ungauged river catchments such as the ones in Hong Local Government Area. The objectives of the study were to delineate major sub-basins in the study area, compute morphometric parameters, and prioritize them based on susceptibility to flooding

Based on the results of the study, composite ranked values for sub-basins ranged from 3 to 4.5, indicating low through moderate to high vulnerabilities to flooding. The vulnerability of the Dzakwa sub-basin to flooding was low. Kwaleta and Diltil sub-basins showed moderate vulnerabilities, while Kilange, Dugwaba, and Gashala exhibited high vulnerabilities to flooding.

It is believed that, the findings of the current study can provide the required baseline information for flood management in the study area. It is expected that further studies should employ multi-criteria analysis to better understand the contributions of other factors such as landcover, soil types and topography to flooding in the study area.

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