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Research Article

Watershed Prioritization to Flood Susceptibility Using Geospatial Techniques in a Southwestern Nigeria Basin

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ABSTRACT

Drainage morphometric is an essential aspect required for effective control of flooding. Ureje Ogbese River Basin (UORB) has experienced flooding repeatedly for years which has led to the destruction of lives and valuable properties. Thus, it is pivotal to examine the morphometry of UORB and access sub-watersheds susceptibility to flooding. In this work, the 30 m-Digital Elevation Model (DEM) from the Shuttle Radar Topographic Mission SRTM was employed to calculate the morphometrics of the drainage basin. To determine the susceptibility to flooding within the study area, the total ranking technique was adopted to prioritize the sub-watersheds. The results from the morphometric analysis reveal that the UORB watershed is characterized by a dendritic drainage pattern with a total of 5985 streams segment and a drainage area coverage of 2642 km^2. The drainage basin has a sixth-order stream that is controlled by the lithology and structure. Prioritization results reveal that 37.5% (sub-watershed III and V) of the study area is at a very high priority to flooding susceptibility while 47.7% of the basin (sub-watersheds II, VI, and VII) is at high priority to flood susceptibility. Hence it is recommended that anthropogenic activities along identified sensitive slopes should be controlled and sensitization in high-risk communities is necessary so that adequate preparations will be made to mitigate future occurrences of floods.

Keywords: Watershed; Flood susceptibility; Drainage morphometrics; Total ranking

INTRODUCTION

Morphometry is the measurement and quantitative analysis of landform configuration, shape, and dimension [1]. The drainage basin is an important component of fluvial geomorphology. This reveals the synergy between various landforms thereby enhancing a better understanding of the spatial features and modification process within the environment. The morphometric parameter of a basin varies by the configuration of the landforms which depends on the climatic and topographical conditions. These parameters can be used to describe and compare basins. In Nigeria, at different times, flooding occurrences have been attributed to heavy rainfall and the release of water from dams [2]. Flood has been a devasting environmental hazard disrupting communal functions and claiming lives and properties. Flood does not discriminate but marginalizes whosoever refuses to prepare for its occurrence [3]. The Morphometric parameter is a fundamental factor that can also influence flooding in a drainage basin most especially the drainage density, stream magnitude, relief ratio, and topology of stream networks. For instance, studies have shown that high drainage density, enhances fast runoff action in basins, and more significantly the degree of abrasion is more likely to increase the intensity of the precipitation [4].

Indeed, quantitative analysis of drainage systems is an essential facet of a watershed [5]. It is important in any hydrological research like groundwater appraisal and management, basin management and environmental evaluation [6]. Over the years, hydrologists are faced different problems, especially those relating to getting data on fluvial land characteristics because some of these basins are poorly gauged or ungauged. The inadequacy of hydrological data on drainage basins affected sustainable water resources planning, design, and management in developing countries including Nigeria [8]. However Remote Sensing (RS) and Geographic Information Systems (GIS) create an avenue through which this challenge may be overcome. Satellite images provide a synoptic view of a large area which makes drainage basin morphometry effortless compared to the conventional methods which can be erroneous [8].

The past decades have witnessed a drastic increase in the use of remotely sensed data in the analysis of drainage basins. Geospatial

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evaluation using satellites like the Shuttle Radar Topographic Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data are being used by researchers to give an accurate, fast and reasonable way of analysing drainage basins [6]. Most of the current literatures on drainage basin morphometry emphasized the applications of the Digital elevation model and GIS [4,7,8,9,10,11]. These studies used processed DEM for generating drainage basin networks and for creating support layers. The DEM is used to infer morphometric parameters such as drainage area, drainage density, drainage order, and relief. Remotely sensed data, and hydrological spatial analysis enhance prompt Identification and differentiation between basins bearing in mind their different peculiarities [12].

Although several authors [13-16] have addressed morphometrics of various watersheds in the country, there is no existing research has evaluated UORB morphometric and its susceptibility to flooding. Therefore, this study examined the drainage morphometric characteristics of the UORB and evaluate the flood susceptibility within the watershed using a prioritization approach.

MATERIALS AND METHODS

The site of focus is River Ureje and River Ogbese as shown in Figure 1. UORB lies between 5˚20'53.161''E–7˚51'39.143''N and 5˚28'59.604''E–7˚0'2.637''N. It springs from the North of Ekiti State, passes through Ondo State and empties into the Osse River in the Western part of Edo State, near a village called Ogbese [17]. The climatic condition of this region is regulated by the hot and dry trade wind from the northeast, while the moist and warm originates from the Southwestern side of the country [14]. The Inter-Tropical Convergence Zone ITCZ is formed from the convergence of both trade winds. It is subjected to yearly variations, over Southwestern Nigeria, hereby forming wet and dry seasons. This in turn results in variation in water volume with its peak periods between August and October while it becomes dry in January and April [14,18]. This explains why most of the small tributaries of the UORB are seasonal. UORB lies within the tropical rainforest ecological zone. It has an average temperature of 25˚C. The UORB is underlain by Precambrian basement complex rock with the local geology being essentially granite-gneiss and migmatite [19]. This includes topsoil and a weathered layer. The soil is well-drained, particularly in the upper course of the study site with a high level of oxidation [17]. The area experiences high annual rainfall and hence there is a constant recharge of both surface and subsurface water. UORB meanders within its steep side channel and flows North-south with a gradient of less than 1%. River Ipaso the major tributary on the east side flow southward direct forming a confluence about 2 miles away from the study site in the south. Other tributaries include the River Elemi and River Awedele in Ado North.

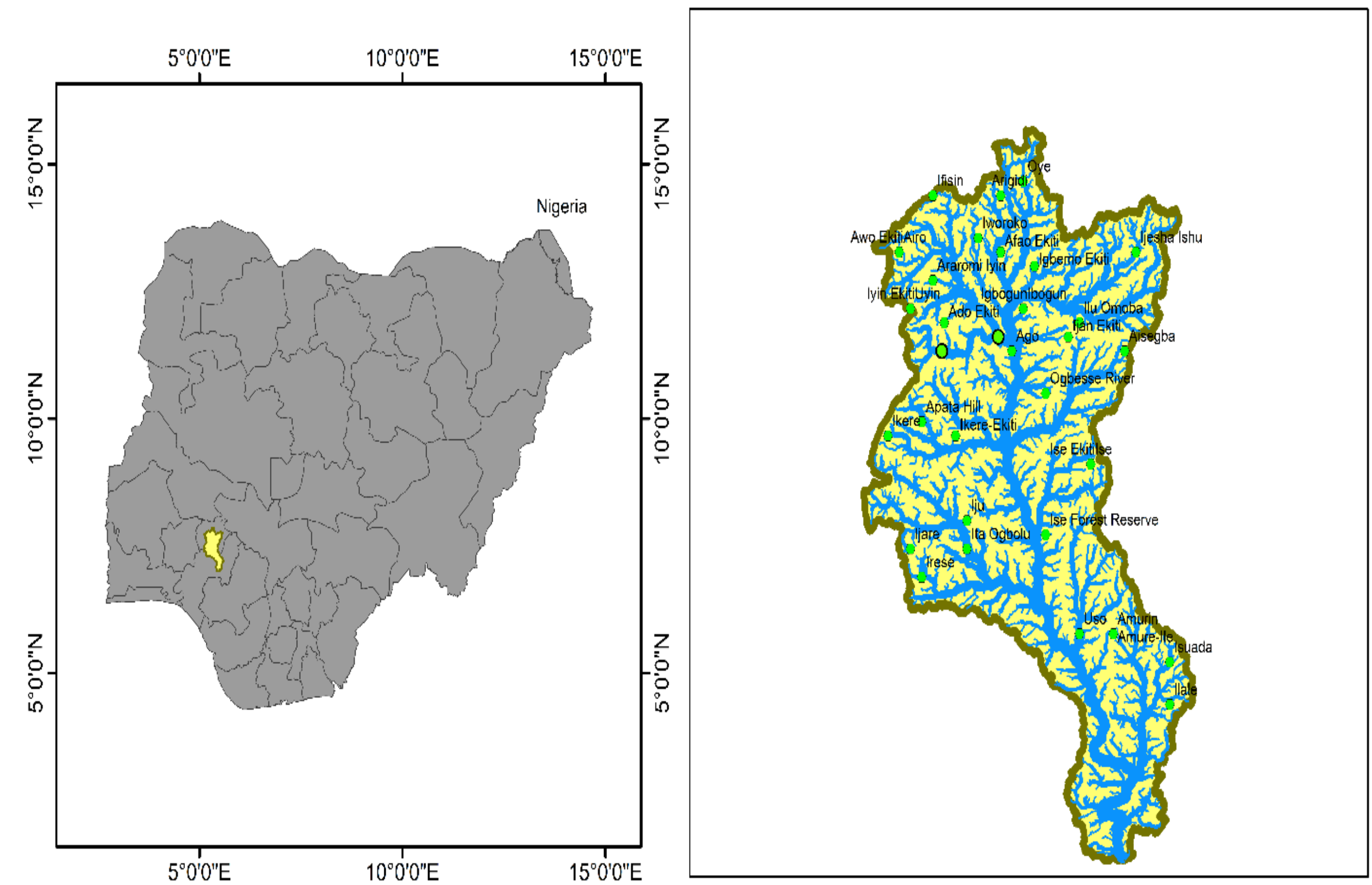

Figure 1: Map showing Ureje Ogbese Drainage Basin. **Note:** ( ) 1, ( )2, ( )3,( )4,( )5,( )6, ( ) UORB

In this study, morphometric analysis and prioritization of the UORB were based on a combination of quantitative and remote sensing and GIS approaches. The geomorphological parameters were ranked to identify the sub-watershed with the highest susceptibility to flooding. The drainage basin was extracted from the Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) data with a spatial resolution of 30 meters. The DEM was georeferenced to Universal transverse Mercator WGS 1984 Northern Hemisphere Zone 31. The UORB was extracted from the SRTM data using the topographic map acquired from the Office of the Surveyor General of Nigeria. To obtain a better understanding of the relief of the study area, we classified the basin elevation into slope percentages. Arc-hydro was also used in the acquisition of rivers and streams within the watersheds. The flow accumulation component was then used to derive the raster format of the stream. All the lines in the flow accumulation were then converted into a vector (polylines) forming streams within the basin of interest. Strahler's stream ordering method was adopted for this paper using the stream ordering tool. Calculations of Area, length, and perimeter were done using appropriate tools. We then exported this attribute table to Microsoft Excel for analysing other parameters. The quantitative and geospatial techniques were implored to analyse the morphometric characteristics of the UORB. Thereafter, we compared and ranked the eight sub-watersheds hierarchically based on the need for maintenance and mitigation from flood susceptibility, whereby high maintenance was classified as a very high priority

In the quantitative technique, the following fundamental morphometric parameters were computed for analysing the characteristics of the basin. These were formulas in Table 1.

Bifurcation Ratio (R_b)

The bifurcation ratio (R_b) refers to the relationship between the number of streams of a certain order and others of the next higher order in a basin [10,20]. The Bifurcation Ratio aids in the interpretation of the shape of the basin and in deciphering the runoff behavior [21]. This parameter is used to establish the level of flood proneness in a drainage basin. The higher the Rb the shorter the time lag for the discharge of a stream to get into an outlet, and the higher will be the peak discharge leading to an increased flood vulnerability of such a basin [21]. The bifurcation ratio also reveals the complexity and degree of dissection of drainage basins [22,23]

Stream Order (u)

The stream order (u) can be described as the hierarchical position of tributaries in a basin. The first attempt to describe the stream order was in 1914 by Gravelius [24]. Horton [25] modified the ordering system to a simpler version by considering the streams which have no tributaries as the first-order streams. Then two first-order streams join and form second-order streams and so forth [20]. The main stem is the primary downstream segment of the highest order [26].

Stream Length (L_u)

The length of the stream was computed based on Strahler's (1964) principles. The stream length of a basin is a crucial hydrological feature of a basin because it reveals the characteristic of surface runoff action with a channel. Streams with longer lengths are generally indicative of flatter surfaces with low gradients [27]. Usually, the complete length of stream segments is highest in the first stream orders and declines as the stream order increases [28].

Stream Frequency (F_s)

The stream frequency (F_S) is the ratio between the overall number of stream segments cumulative of all orders and the basin area [29,30]. This parameter is an interlinking factor in predicting peak flood discharge [4,31]. Stream frequency is related to absorbency, infiltration capacity and topography of the basin. The lower value of Fs indicates a poor drainage network [32] while low permeability and less available surface flow decrease the Fs value in the environments [29,33].

Mean Stream Length (L_{sm})

The mean stream length (L_{sm}) is a dimensional parameter which relates to the size of a component of a drainage network and its contributing watershed [34,35].

Stream Length Ratio (R_L)

The stream length ratio (R_L) describes the ratio of the total length of the stream of a certain order to the next lower order of the stream segment. This parameter has a vital correlation with the surface flow and discharge in a drainage basin [36]. The variation in RL is an indication of major changes in the hydrological characteristics of the underlying rock surface [37]. It also indicates a disparity in the gradient of the slope and topography [14].

Drainage Density (D_d)

The drainage density (D_d) is the ratio of the total length of the stream within a basin to the unit area. The drainage density of a basin indicates the landscape dissection, infiltrate rate of the land and vegetation cover of the basin. Drainage density is expressed as the distance between the streams and reflects the soil profile of a watershed. Watercourse with low D_d may display to coarse drainage texture whereas high drainage density may have to fine drainage texture [5]. According to [38] drainage density that ranges from <5 km/km^2 are characterised by a gentle slope, receives low amount of rainfall and permeable bedrock compared to much larger values of>500 km/km^2 which are mountainous areas where rocks are impermeable, slopes are steep and rainfall totals are high.

Basin Perimeter (p)

The perimeter of a drainage basin can be described as the outer boundary. It is used to determine the actual size of the basin.

Form Factor Ratio (F_f)

The form factor ratio (F_f) is the proportion of the area of a basin to the square of the basin length. This is also called Basin Shape Index. Flood hydrograph always affects the basin form [39,40]. There are different value ranges of form factors. The value of the Ff would always be greater than 0.78 for a perfectly circular basin while elongated basins are characterised by a lower value of form factors [41].

Elongation Ratio (R_e)

The elongation ratio unveils the structure or form of the drainage basin, which is the fraction of the diameter of the circle of the same area as the basin to the maximum basin length [20,39]. The elongation ratio of a watershed ranges between 0-1.0. When the Re value of a basin lies between 0 to 0.6, this indicates basin rotundity and also a low degree of assimilation within such a watershed. For values between 0.6–1.0, it is assumed that such a basin has a pear shape with high integration. Basins with values around 1.0 are characterized by low relief while values between 0.6 and 0.8 are usually associated with a steep slope and high relief [40].

Circularity Ratio (R_c)

The circularity ratio is a dimensionless property, which describes the ratio of the basin area to the area of the circle having the same parameter as the basin [42]. There is a correlation between Rc and the existence of structural disturbance [20]. Rc reflects the evolution stages of a basin with the low values indicating the youthful phase and the high value signifying the mature phase of a basin [29].

Ruggedness Number (R_n)

The ruggedness number (R_n) is described as the product of maximum basin relief (H) and drainage density (D_d) considering that both indices are in the same unit. R_n is an indication of the structural complexity of the terrain present in the drainage basin [39,43]. High ruggedness numbers are found in steep slope basins in which both the drainage density and basin relief values are large [6]. Patton and Baker (1976) acknowledged that basins with high R_n and fine drainage texture might be expected to have high flood potential.

Relief Ratio (R_h)

The relief ratio, (Rh) is the ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line [39,43]. The Rh is an indicator of the intensity of the runoff process operating on a slope of the basin. According to [44] the relief ratio increase with a decline in drainage area and size of watersheds of a given drainage basin.

Basin Relief (B_h)

The basin relief is the difference in the elevation of the highest and lowest points in a watershed [39].

Drainage intensity (D_i)

It is the ratio between the stream frequency and drainage density [5]. Rivers with low drainage intensity, drainage texture and drainage density are susceptible to soil erosion [37].

Length of overland flow (L_g)

This is an important perimeter that affects both physiographic and hydrologic development [25]. It describes the length of flow on the ground from the basin perimeter to the nearby channel. The shorter the Lg the faster the surface runoff.

Infiltration number (I_f)

This reveals the infiltration physiognomies of a drainage area. There is an inverse relationship between infiltration number and infiltration capacity. Thus when the infiltration number is higher, the lower the infiltration and the higher the runoff [47].

This study computed the seventeen parameters explained above for the UORB basin. Table 1 shows how these fundamental morphometric parameters were calculated based on the formulae suggested by [5,25,39,42]. The entire paper was prepared using both geospatial and quantitative analysis. The results of these analyses are expressed in the form of text, tables and maps.

Table 1: Morphometric Analysis of the Uorb.

Classification		Morphometric Parameter	Derivative	References
Linear	1	Basin Area (A)	Area Of the Watershed (Km)	
	2	Stream Order (U)	Hierarchical Rank	[24]
	3	Stream Length (L_u)	Lu = L1 + L2 + ⋯ + Ln (Km)	[5]
	4	Basin Perimeter (P)	Perimeter Of the River Basin (Km)	[25]
	5	Mean Stream Length (L_{sm})	Lsm=Lu/Nu Where Nu is the total number. of stream segments of order "U"	[25]
	6	Total Number of Streams (N_u)	Total number of streams of all orders	[24]
	7	Stream Length Ratio (R_L)	R_L = Lu/Lu−1	
			Where Lu−1 is the total stream length of its next lower order	
Basin aerial				
	8	Form Factor (F_f)	Ff = A/Lb2	[25]
	9	Circulatory Ratio (R_c)	$R_c = 12.57 \times (A/P2)$	[42]
	10	Elongation Ratio (R_e)	$R_e = 2\sqrt{(A/\pi)}/L_b$	[39]
	11	Basin Length (L_b)	Length Of The Basin (Km)	[36]

Drainage texture analysis				
	12	Drainage Intensity (D_i)	$D_i = F_s/D_d$	
	13	Infiltration Number (I_f)	$If = F_s \times D_d$	[46]
	14	Stream Frequency (F_s)	$F_s = Nu/A$	[46]
	15	Drainage Density	(D_d) Dd=L/A	[36]
			Where: L=Total Length Of Stream, A= Area Of Basin	
	16	Length Of Overland Flow (L_g), Km	Lg = 1/2Dd (Km)	[25]
Relief parameter				
	17	Relief Ratio (Rh)	$Rh = B_h/L_b$ Where: B_h=Basin Relief, L_b=Basin Length	[39]
	18	Ruggedness Number (Rn) (km)	Rn=$B_h \times D_d$ Where: B_h= Basin Relief, D_d=Drainage Density	[39]
	19	Basin Relief In Km (B_h)	B_h = H–h Where: H =Maxmium Elevation h= Minimum Elevation	[35]

RESULTS

Linear parameters

From the analysis has shown in Table 2, it was observed that the study area has 8 sub-watersheds covering areas like Iworoko, Ado Ekiti, Ise, Irese, Isuada, Ilu Moba, and Igbemo Ekiti. Following the analysis of the digital elevation model, the study reveals that UORB is a dendritic drainage pattern with 6th order. It was noticed that the stream frequency decreased as the stream order increased, however there was a deviation in the 6th order, this divergence may be due to the structural setting. The high stream order could be an indication of poor permeability and infiltration capacity within the sub-basins. It was also observed that the total number of streams (Nu) is 5,985. The total stream length of the UORB is 2,800 km, stream. Arguably, the higher the stream order the longer the length of the stream. For this study, the highest stream length was 1,396 km in the 1st order while it was 697 km and 371 km, in the 2nd and 3rd order. These stream lengths are otherwise indicated by their chronological development from the source to the mouth of the streams. A longer stream is advantageous over a shorter stream because longer streams have wider areas to collect water and are flatter and low gradient surfaces. The length of the basin is approximately 96.10 km, the highest bifurcation ratio (2.40) is found in the 1st and 2nd order. The mean bifurcation ratio is relatively low (1.47) which is an indication that the basin is less vulnerable to flooding.

Table 2: Shows results from UORB morphometrics.

S/N	Morphometric Parameter	Values
1	Basin Relief (Bh)	577
2	Relief Ratio (Rh)	6
3	Ruggedness Number (Rn)	0.611
4	Circulatory Ratio (Rc)	0.19
5	Relative Perimeter (Pr)	6.34
6	Infiltration Number (If)	2.4
7	Drainage Intensity (Di)	2.14
8	Area Of Basin Km^2	2642
9	Perimeter Of Basin Km	417
10	Length Of Basin Km Lb	96.1
11	Form Factor Ratio (Rf)	0.29

12	Elongation Ratio (Re)	0.32						
13	Stream Frequency (Fs)	2.27						
14	Drainage Density (Dd)	1.06						
15	Length Of Overland Flow (Lg)	0.53						
16	Form Factor (Rf)	0.29						
17	Maximum Elevation (H)	747						
18	Minimum Elevation (h)	170						
19	Stream Order	6	i	ii	iii	iv	v	vi
20	Total Number Of Stream (Nu)	5985	3038	1268	793	434	190	262
21	Stream Length (Lu), Km	2800	1396	697	371	434	190	262
22	Bifurcation Ratio (Rb)		i/ii	ii/iii	iii/iv	iv/v	v/vi	
			2.4	1.6	1.83	2.28	0.73	
23	Stream Length Ratio (Rl)		ii/i	iii/ii	iv/iii	v/iv	vi/v	
			0.5	0.53	0.4	0.56	1.28	
24	Mean Bifurcation Ratio (Rbm)	1.47						

Relief parameters

These indicators describe the topographical characteristics of the basin which is required during preliminary assessment. The estimated basin relief of the study area is 577 while it ranges between 747 m and 170 m within the various sub-watersheds. The basin relief reveals the flood pattern and the level of deposition and transportation of sediment within the basin. UORB has a rugged number of 0.611 implying that the area is less prone to soil erosion and flooding. The slope varies between 00 and 70.20 with a mean of 4.14 and a standard deviation of 4.69. The northwest of the basin has experienced repeated flooding in past years due to its steep slope while the gentle slope is in the southeast and northeast of the basin.

Drainage texture parameter

UORB has a low drainage density of 1.09 km/km^2. This indicates that the basin has a coarse drainage texture, larger and is dominated by a gentle slope and permeable surfaces [46]. The drainage intensity varies between 1.01 and 1.19 and an average of 2.14. The low drainage intensity suggests that stream frequency and drainage density had a minimal impact on the extent of surface erosion in the basin. The lower values of drainage density and drainage intensity indicate the various sub-basins are less susceptible to erosion and have a less likelihood of being flooded.

Basin aerial parameters

The UORB basin has a low form factor of 0.29 which indicate the basin is elongated and receive less precipitation and less runoff duration actions on the entire drainage basin. The circulatory ratio is dimensionless and this variable that reveals the youth stage of the tributaries in the life cycle of a basin, of the UORB, is 0.19 indicating the basin has an elongated shape, high permeability of topsoil, and geologic materials are homogenous. The elongation ratio is a significant parameter, and it reveals the hydrological characteristics of the basin and its shape. The elongation ratio value for the study area is 0.32. The value reveals the basin's very elongated and mild integration in the basin.

DISCUSSION

Flood prioritisation of the watershed

From the watershed analysis, we discovered a significant characteristic that was relevant to understanding the behaviour of the UORB. To this end, the eight sub-watershed (as shown in Figure 2) were compared and ranked to ensure that adequate concentration is given to the at-risk sub-watershed area by stakeholders during planning and maintenance. The prioritization was done using the total ranking method which was computed from the result of fourteen drainage morphometrics parameters and was normalized and classified from very high to very low (Table 3). The sub-watershed was arranged hierarchically based on flood susceptibility and runoff. Certain parameters were ranked higher because they had a greater influence on flooding and runoff compared to others. These parameters include drainage density, circularity ratio, ruggedness number, basin slope, stream frequency, and relief ratio. Thus watersheds that had the highest value were ranked higher. Whereas parameters such as length of overland, elongation ratio, and shape factor that had an inverse relationship with flooding were ranked inversely, where the sub-basin with the lower value gets the highest ranking. We discovered that sub-watershed (III and V) were the top-ranked constituting about 37.5% of the total area as the very high priority class signifying very high susceptibility to flooding while sub-watershed (VII, VI, II) account for 47.5% of the study area found to be high priority class to susceptible flood Figure 3. The low-priority category is sub-watershed (I) covering 2.7% of the study area [47].

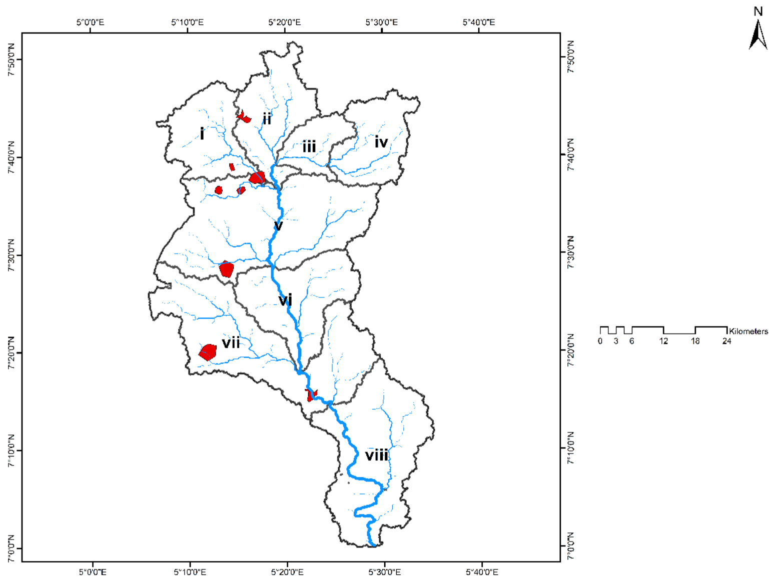

Figure 2: Ureje Ogbese Drainage Basin showing the sub-watershed and previous flood location. **Note:** ( )1, ( )2, ( )3, (—) 4, (—)5, (—)6 (■), Areas with previous flood incidences, ( ) Areas with no previous flood incidences, (▭)Sub-watershed

Table 3: Shows the UORB sub-watershed prioritization.

Watershed	B_h	R_h	R_n	R_c	If	A	R_f	R_e	F_s	D_d	L_g	H_I	S_w	R_v	Total Ranking	Normalization	Priority Ranking	Priority
I	3	2	3	2	2	2	2	3	2	3	3	2	4	2	35	0	2	Low
II	4	2	5	2	2	3	4	4	1	4	4	3	4	2	44	1	4	High
III	2	1	2	4	5	1	3	5	4	5	5	3	5	1	46	1	7	Very High
IV	2	3	2	3	3	2	3	4	3	4	4	2	3	4	42	1	3	Moderate
V	5	4	4	3	4	5	5	1	5	1	1	4	2	3	47	1	8	Very High
VI	3	3	3	4	4	3	2	3	3	3	3	5	3	3	45	1	6	High
VII	4	4	4	1	3	4	4	2	4	2	2	4	2	4	44	1	4	High
VIII	1	5	1	5	1	4	1	2	2	2	2	1	1	5	33	0	1	Very Low

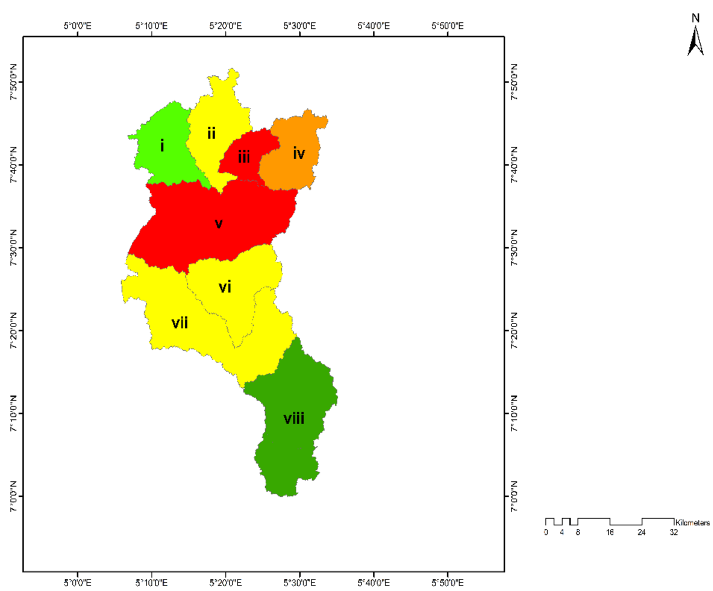

Figure 3: Flood prioritization map of Ureje Ogbese river basins. **Note:** (■) Very high priority, (■) High priority, (■),Moderate priority, (■)Very low priority, (■)Low priority

The result from the assessment of the UORB morphometric and prioritization from the present study can be used by relevant authorities in catchment development and planning. Also, the outcome can be used to select sub-basin that are highly susceptible to flood to devise protection, prevention, and mitigation measure to enhance risk reduction strategies. To mitigate the effect of flooding in the study area, especially in the sub-watershed V, the existing mini dam on river Ureje should be expanded to further increase the water retention threshold [48,49].

CONCLUSION

In as much as this paper has focused on the morphometric parameter of the UORB basin and unveiled the degree of sub-watershed susceptibility to flooding. Geospatial techniques and analysis are beneficial to get a more valid and accurate measurement of morphometric parameters of watersheds. It has revealed a robust methodology for extracting drainage networks and the derivation of the channel morphometric parameter with DEM. This gives an in-depth knowledge of the hydrological behaviour of the catchment and its influences on flooding in the study area. The catchment has a moderate to high relief, flat ground slope, and a dendritic elongated shape that influences the occurrences of floods downstream most especially high-priority sub-watershed V when precipitation is at its peak. The changing hydrological pattern of the basin, augmentation and controlling of flood and its associated problems in the lower catchment area heighten the hydro-geomorphic nature of the basin. This may however increase the risk of flooding in future in the area.

RECOMMENDATION

Anthropogenic interference with watersheds especially in the construction of roads along sensitive slopes, expansion of settlement zone, agriculture activities on forests and upslope areas, overgrazing etc. These activities within this area should be controlled to reduce the susceptibility to flooding in the future times. Hence to curtail the extent of damages and losses caused by flooding downstream and protect settlements, effective mitigation strategies should be adopted at the upper course of the UORB. To accomplish this, the government and non-governmental organisations should consistently carry out flood preparedness in form of sensitization and mitigation activities this will help to create awareness of flood risk associated with the basin.

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