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Flood influence using GIS and remote sensing based morphometric parameters: A case study in Niger delta region

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ABSTRACT

This study delineates morphometric parameters for determining flood influence on river catchments in the Niger Delta Region using geospatial techniques. Data from the United States Geological Survey; Shuttle radar topographic mission was processed using ArcGIS 10.6 software. The results of the hydrological data analysis, compound factors, and weighted overlay approach demonstrate that early peak flows from the River Niger cause flooding along the riverbanks, as evidenced by the stream frequency findings. The Ikoli River's catchments consistently provide the River Niger with its peak discharge for a considerable time. The Orashi, Bomadi, Forcados, Nun, and Ikoli River basins all have a low relief ratio and hence little impact on floods. However, catchments with a higher relief ratio contribute more water in a shorter amount of time and produce floods in lower locations. Because of its high runoff parameters and short concentration time, the Orashi River catchment is the most flood-prone, followed by the Niger and Forcardos River catchments, which indicate "high," and the Ikoli, Nun, and Bomadi River catchments, which indicate "medium." It is therefore advised that the Orashi, Niger, and Forcados river catchments be prioritized in order to reduce the impact of floods in the Niger Delta research region.

Contribution/ Originality: Flood impacts caused by river catchments can be detected using geospatial mapping tools. Remote sensing data combined with GIS technology can be used to investigate the effects of floods on river catchments in the Niger Delta region.

1. INTRODUCTION

The hydrological and morphometric parameters in determining flood influence on river catchments are vital because flood is a major problem globally, which has caused economic hardship. Furthermore, many countries in the world including Nigeria, Ghana, Thailand, the US, China, Germany, India, etc. are suffering from flooding due to climate change, resulting in the loss of lives and properties. The flood that hit Thailand 2011 [1] was the costliest natural disaster in terms of economic impact between 1900 and 2013, as data from the Center for Research on the Epidemiology of Disasters shows. The flood cost an estimated 40 billion dollars. Since the morphometric characteristics of a stream or river basin play such a crucial role in simulating the numerous hydrological processes occurring in such a basin, an understanding of these characteristics is essential. Traditional morphometric analysis include measurements such stream width and length, bifurcation ratio, stream density per unit drainage area, elevation change, drainage basin perimeter, and area. A watershed, often called a drainage basin, is an open-air system that is essential for studying certain facets of the hydrological cycle Obi, et al. [2]. Rastogi and Sharma [3] define a drainage basin or watershed as "a system in which precipitation inputs undergo the processes of infiltration, percolation, through flow, and overland flow (surface run-off), resulting in output in the form of evapotranspiration, which is the direct loss of water from the ground, water, surface, and vegetation". Flooding, gully erosion, and other environmental consequences have been recognized and tracked with the use of remote sensing and Geographic Information system (GIS) technology [4]. Morphometric studies in geomorphology were originally initiated by Horton [5]. The prevailing climate, geology, geomorphology, structure, and so on are all expressed in the drainage basin and its channel network, making morphometric study of these features crucial to understanding the drainage basin's geo-hydrological vital function. The correlation between drainage characteristics and the aforementioned has been shown by several researchers [6, 7]. Examining drainage basins is essential for any kind of hydrological assessment, including but not limited to groundwater potential assessment, groundwater planning, pedological study, and ecological analysis [8]. Size, shape, slope of drainage area, drainage density, size, and length of the tributaries are all physiographic properties of drainage basins that are linked to several key hydrologic phenomena. Insight into how drainage morphometric networks affect landforms and their attributes is greatly aided by a detailed morphometric analysis of a basin. Analyzing morphometric factors quantitatively has shown to be of great use in natural resource management, soil and water conservation, and the appraisal of river basins. Measures of landforms, real soil characteristics, and disintegration qualities may all be better grasped by incorporating the drainage morphometric framework into one's thinking. Several river basins and sub-basins throughout the world have had their characteristics assessed using more traditional methods. Reddy, et al. [9]; Horton [6]. According to Desmond, et al. [10], the Orashi river basin is morphometrically elevated and vulnerable to erosion and flooding as a result of sand accumulation caused by a lack of proper dredging of the Niger Delta's rivers. To better understand the geo-hydrological factors that lead to floods in the Niger Delta rivers basin, this study applies morphometric analysis based on GIS and remote sensing technology. The findings of this paper are expected to give background data to improve the proper management of watersheds in the region.

1.1. Study Area

The location chosen for this research is located in Bayelsa State, Nigeria, which is part of the middle Niger Delta sedimentary basin in southern Nigeria (Figure 1). Positioned between 4°57′30″N and 4°54′30″N, and 6°15′30″E and 6°21′30″E, respectively, the region is shown here. It is part of the Yenagoa Metropolis, and there is a solid road system that connects the many neighborhoods there. The elevation of the research region varies between 14 and 38 meters, and it often floods during the wet season [11].

2. MATERIAL AND METHODS

Using primary data like GPS coordinates for sample locations and secondary data like the Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) retrieved from United Stated Geological survey. This research integrates remote sensing and geographic information system technologies. The data sources were integrated into a common projection using the ArcGIS 10.6 geographic information system program using the Universal Transverse Mercator (UTM) 32N coordinate system. When seen as a whole, the picture produced by the Digital Elevation Model reveals the geographical distribution and fluctuation of elevation values across the region.

The method used in this research work is based on Geographical Information Systems database with the aid of hydrology tools, compound factor, and weighted overlay analysis.

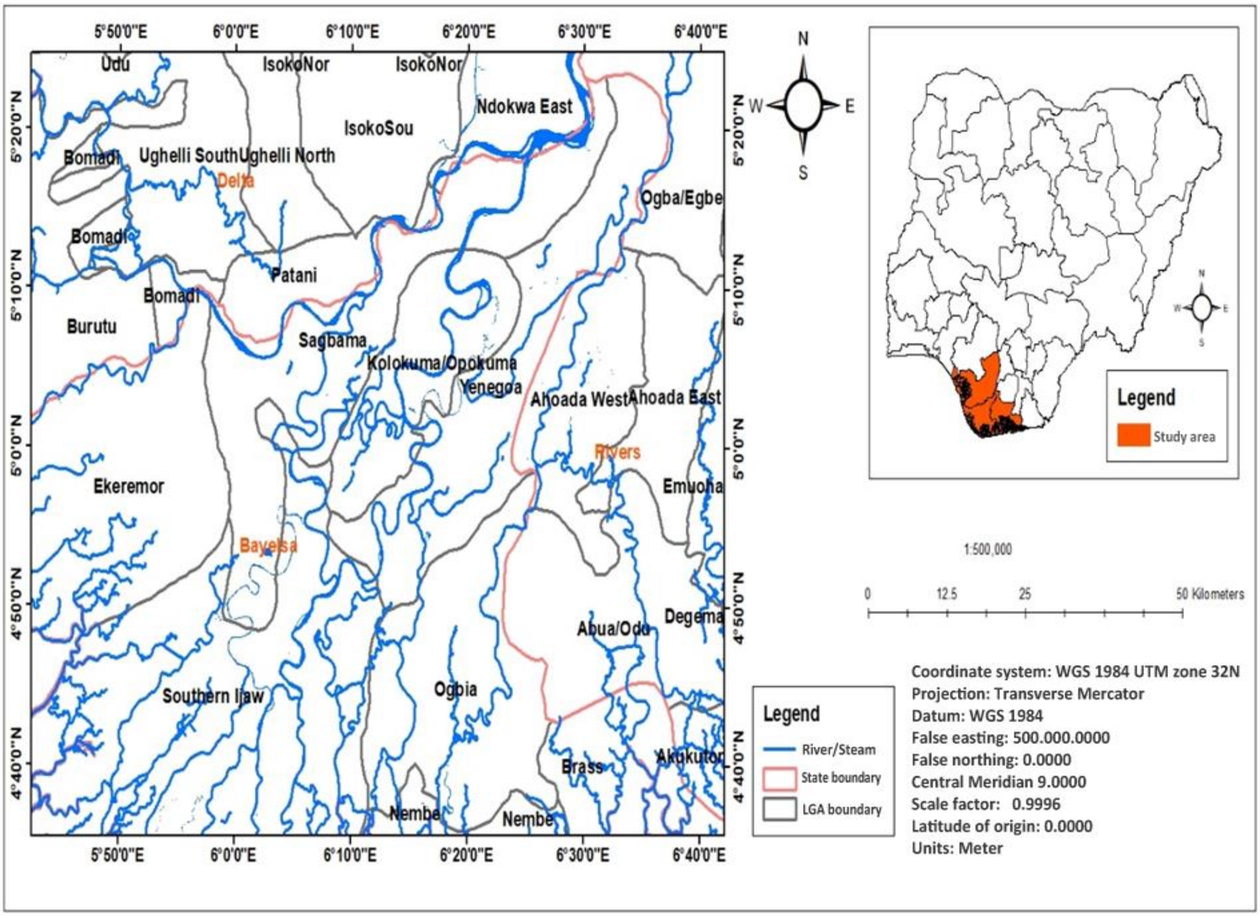

Figure 1. Map of the study area.

The data was analyzed using ArcGIS 10.6 software Environmental Systems Research Institute (ESRI, Inc) and Arc Hydro tools. The application was also used to construct the Digital Elevation Model from Shuttle Radar Topographic Mission (SRTM) data obtained from an open data source. Following that, the elevation data was used to define and delineate the characteristics of the drainage basins.

Strahler's stream ordering [12] was used to determine the drainage basin's morphometric properties as well as the region's stream order characteristics. Because the sequence of streams within river basins is an important aspect in establishing a basin's overall hydrology, this study used Horton's method of scientifically quantifying the drainage basins rather than depending solely on qualitative descriptions. This study determined the following basin morphometric parameters: basin length, basin area, stream order, and stream length, mean bifurcation ratio, relief ratio, drainage density, stream frequency, drainage texture, and form factor.

3. RESULTS AND DISCUSSION

3.1. Flood Influence using Morphometric Parameter

Morphometry, described by Clarke [13] as "the measurement and mathematical study of the earth's surface configuration, including the shape and magnitude of its landforms," makes the use of Morphometric parameters in flood effect assessment critical. Taking into account the basin's linear, areal, and relief measurements aids in determining the degree of flood impact.

3.2. Stream Order (Nu)

Most drainage basin analyses begin with the identification of stream order. One way to rank rivers is by their relative importance as tributaries, hence the ranking of streams is a useful metric. Leopold, et al. [14]. To evaluate the hydrodynamic nature of a drainage basin, a hierarchical ordering of streams is required. Strahler [15] states that the first stream order consists of the tiniest tributaries, such as those that drain from a fingertip. A second stream order is created when two first stream orders collide; a third stream order is created when two second stream orders collide, and so on. From Table 2, it is indicated that the Bomadi River and Forcados River catchments have three stream orders as shown in Figure 2 and 3, while the Orashi River, Niger River, Ikoli River, and Nun River catchments have up to four stream order tributaries, according to Figure 7, 5, 4, and 6, with 1st, 2nd, 3rd, and 4th streams depicted in Table 2.

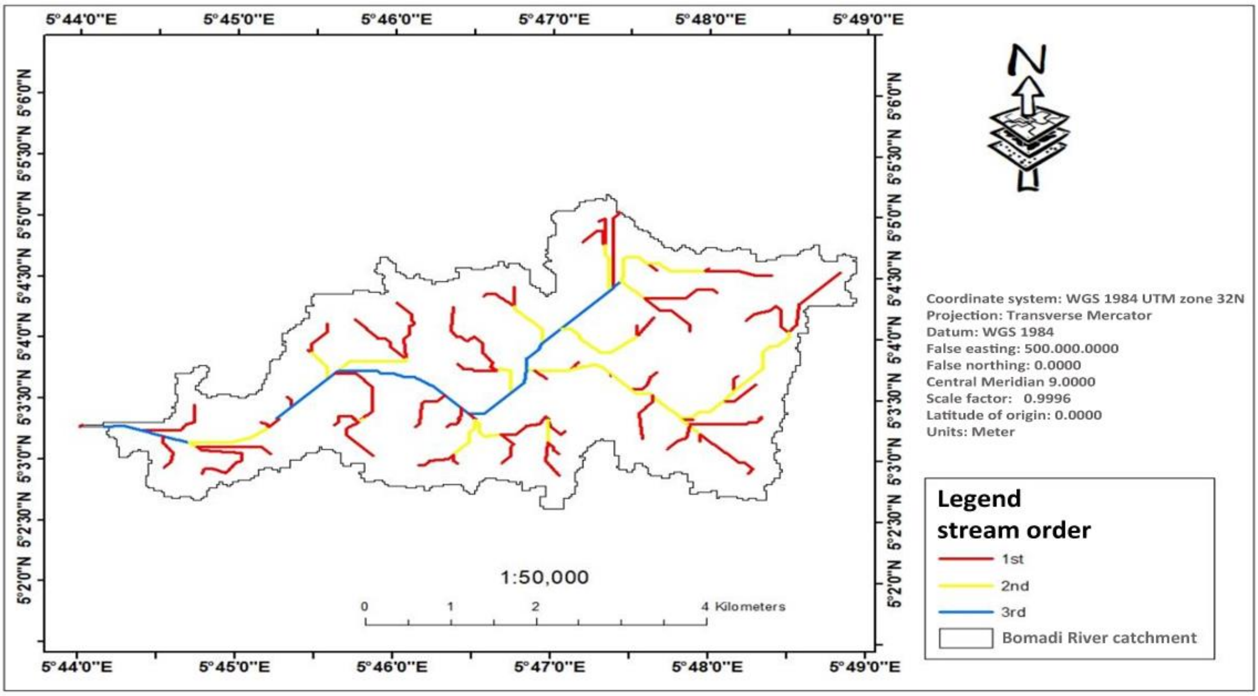

Figure 2. Stream order in Bomadi River catchment.

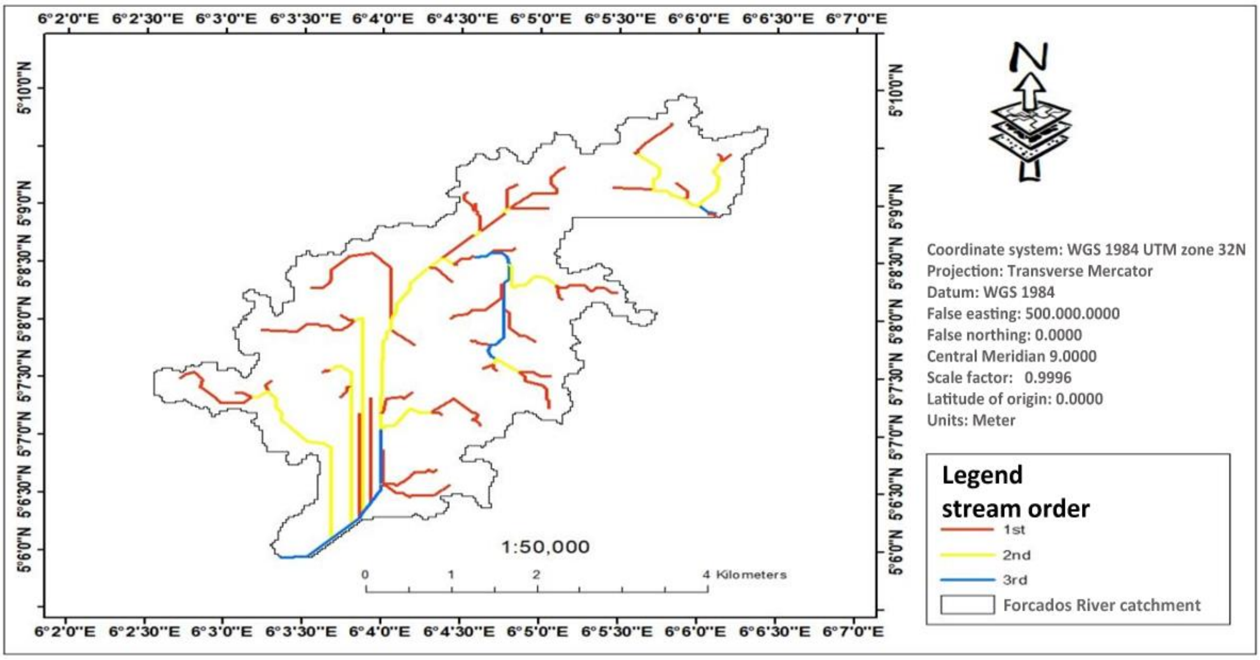

Figure 3. Stream order in Forcados River catchment.

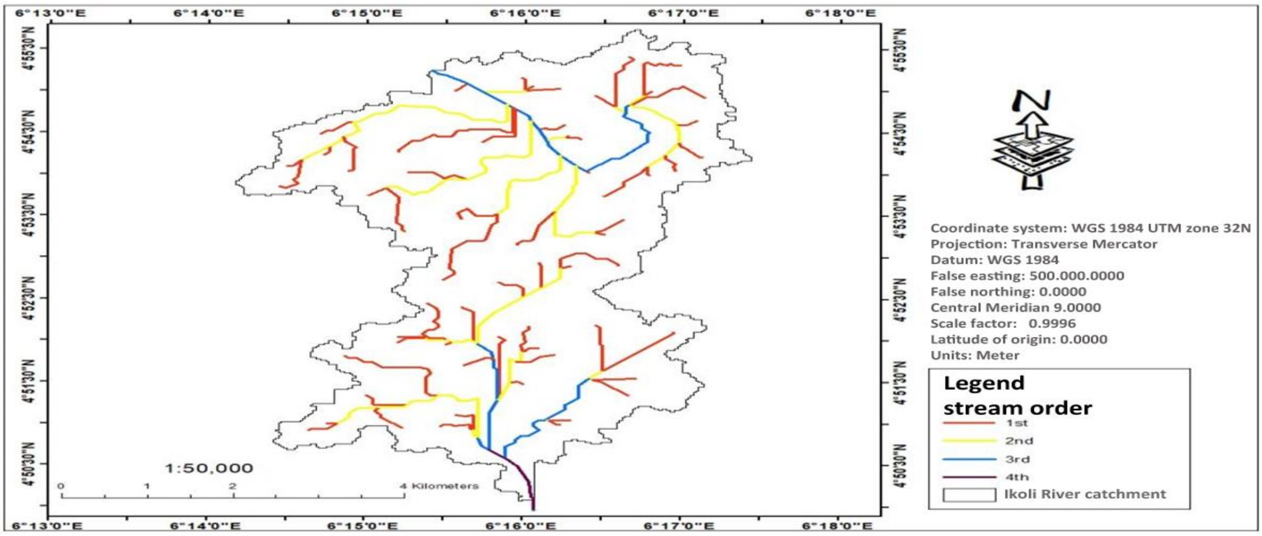

Figure 4. Stream order in Ikoli River catchment.

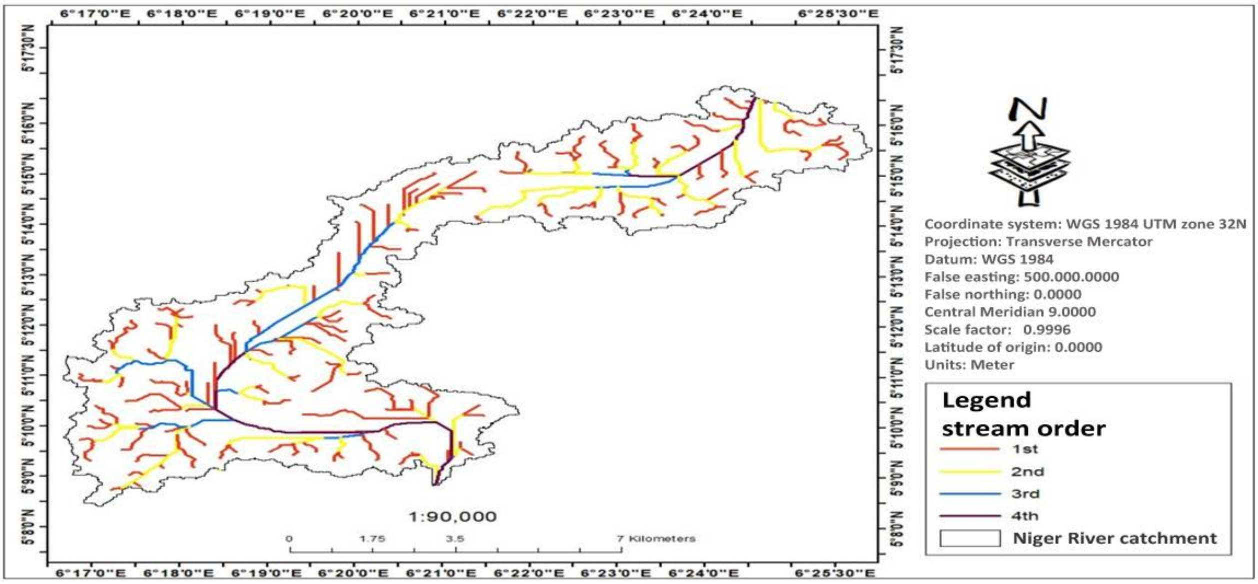

Figure 5. Stream order in Niger River catchment.

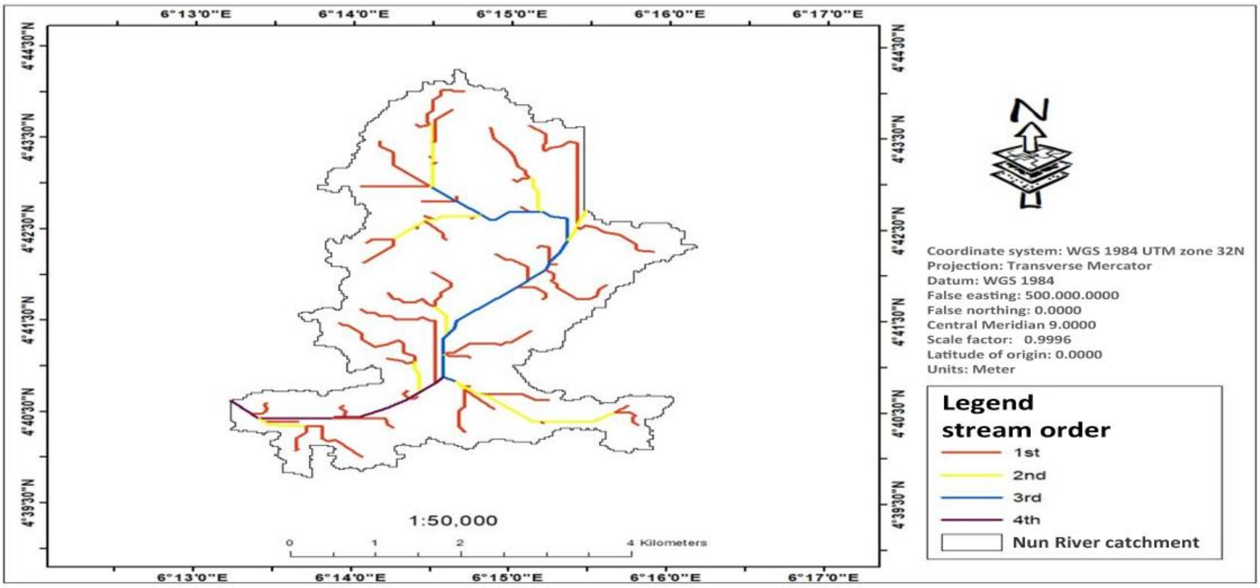

Figure 6. Stream order in Nun River catchment.

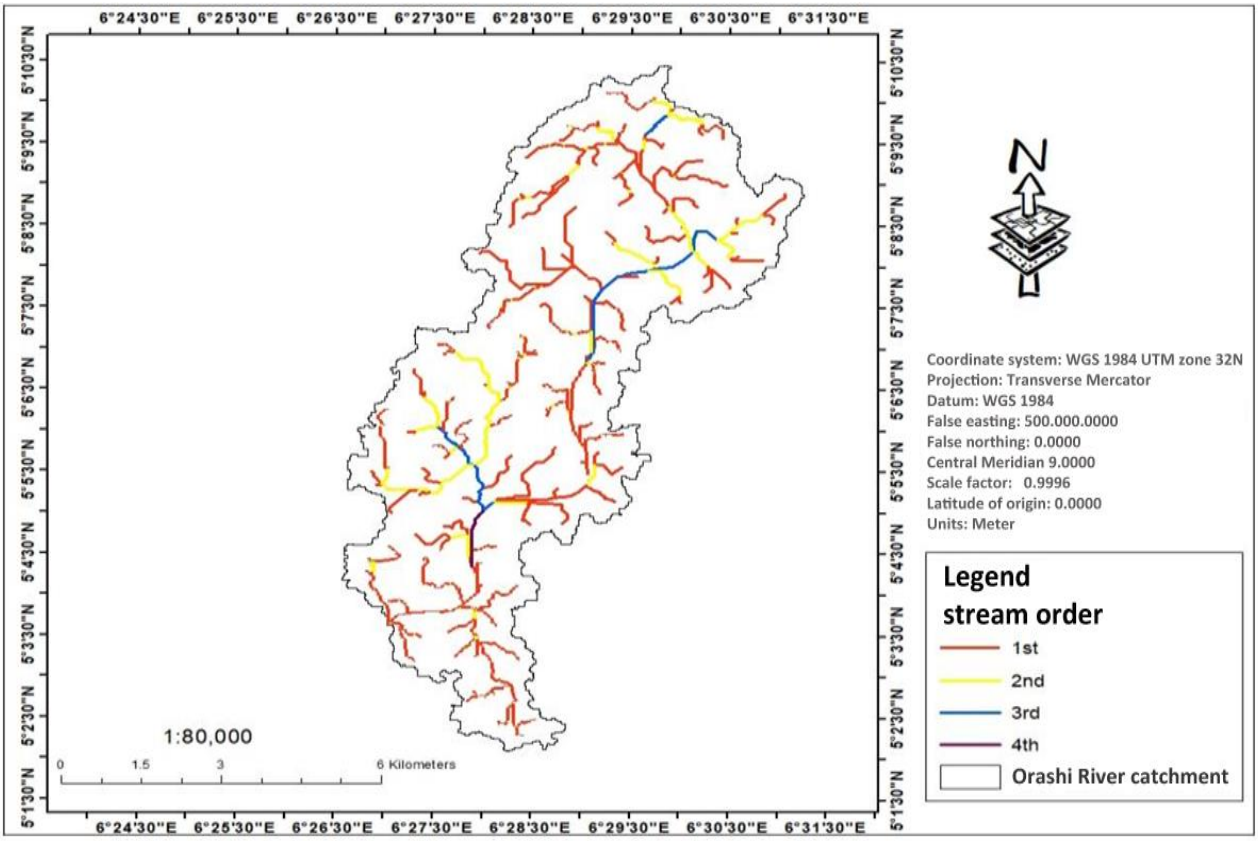

Figure 7. Stream order in Orashi River catchment.

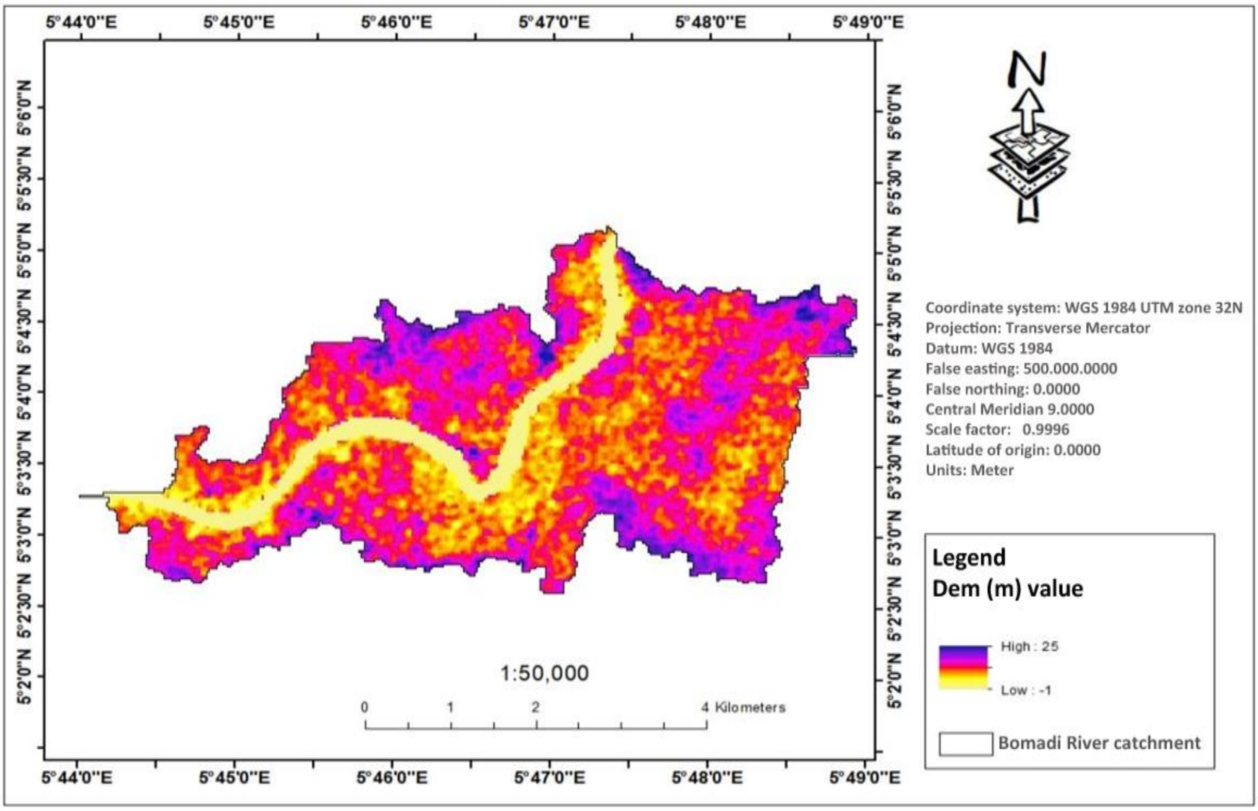

Figure 8. Digital elevation model in Bomadi River catchment.

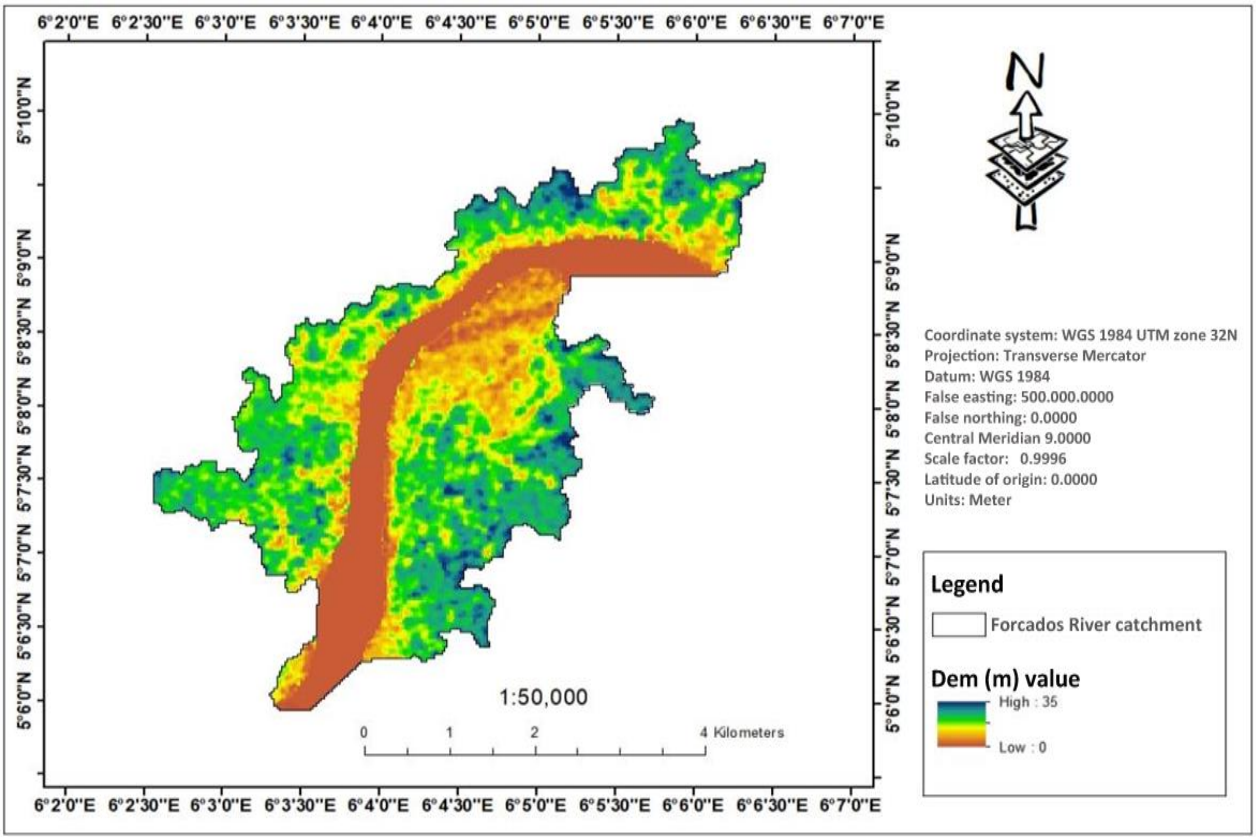

Figure 9. Digital elevation model in Forcados River catchment.

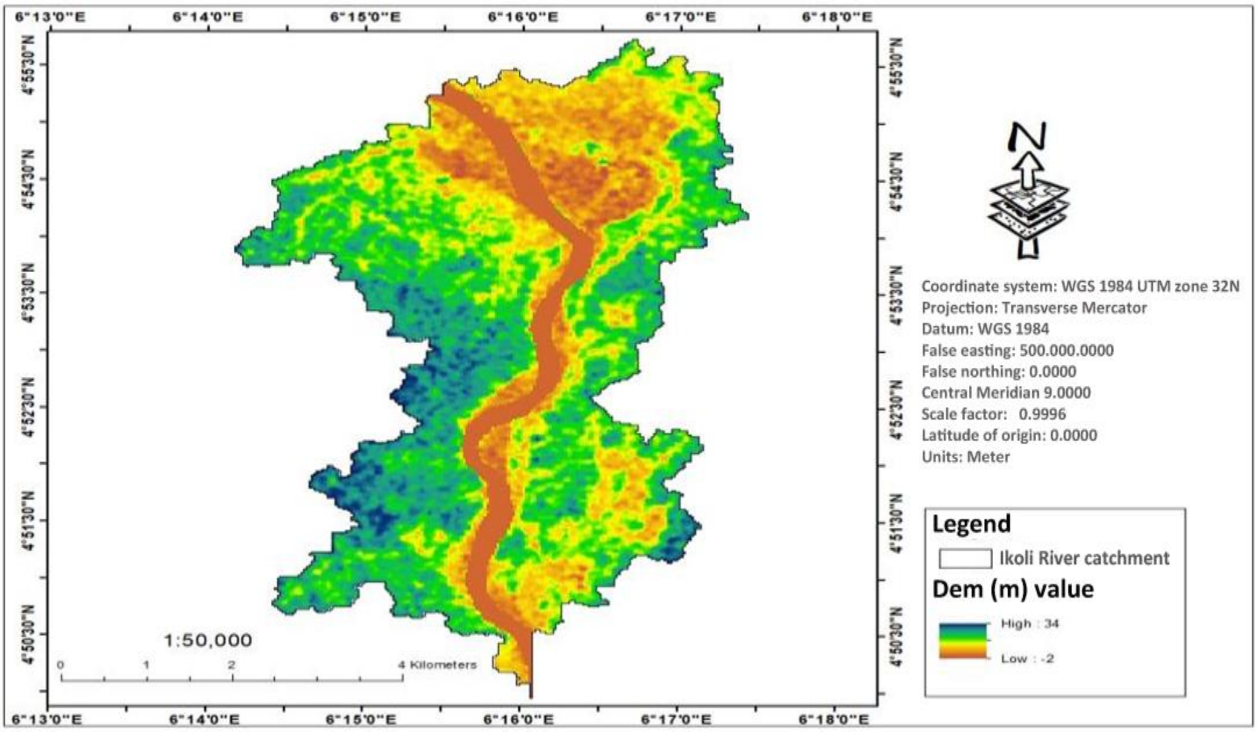

Figure 10. Digital elevation model in Ikoli River catchment.

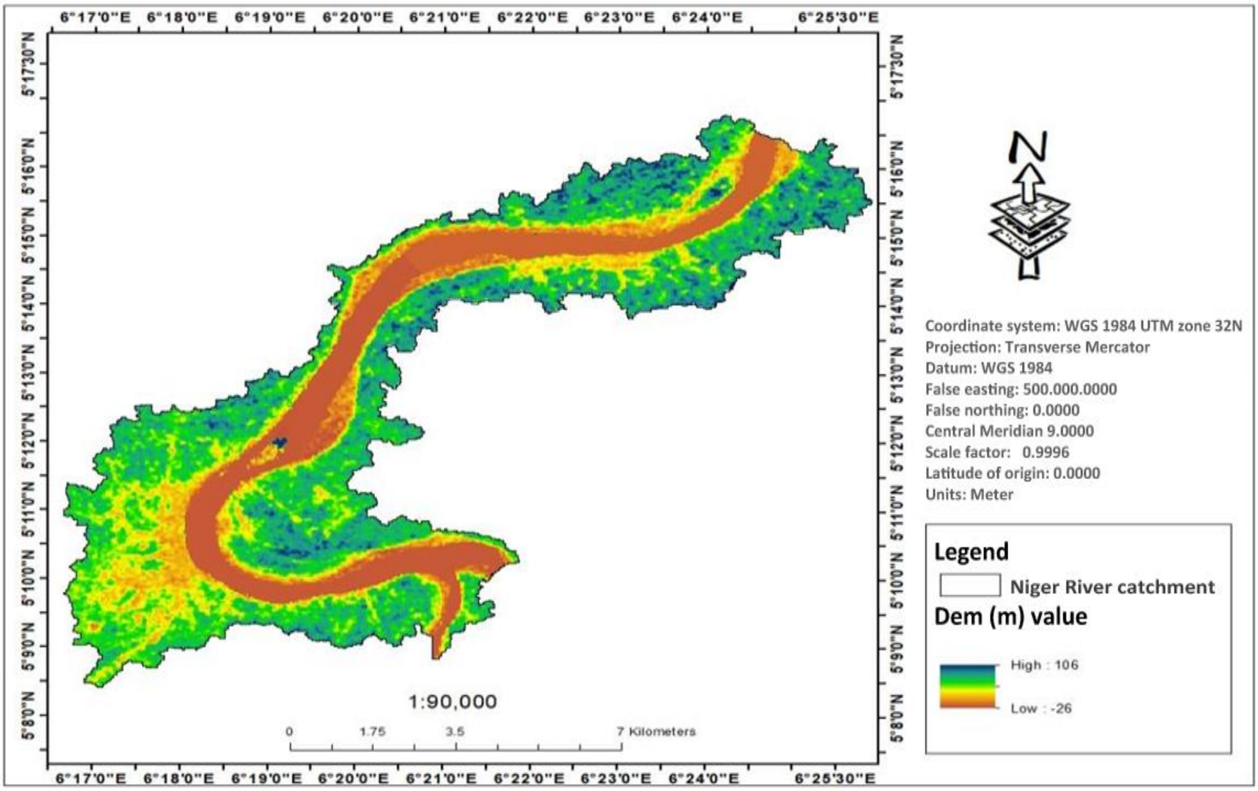

Figure 11. Digital elevation model in Niger River catchment.

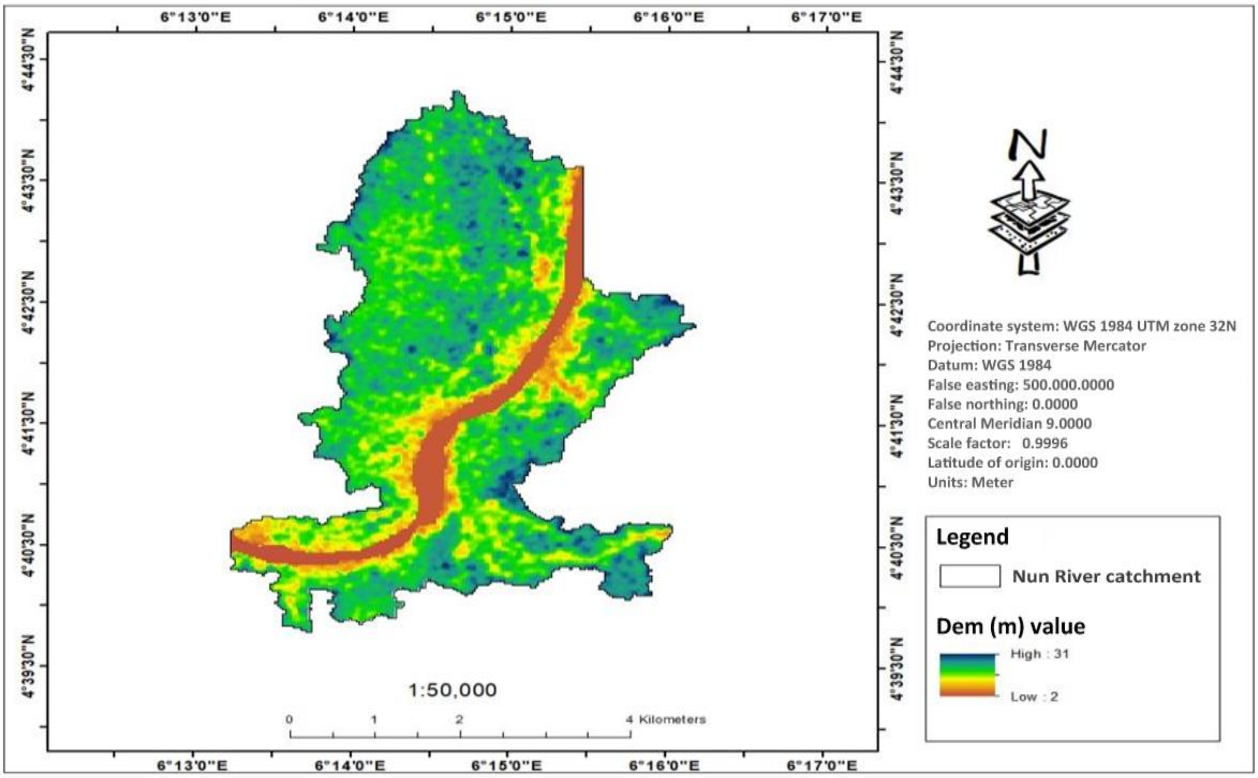

Figure 12. Digital elevation model in Nun River catchment.

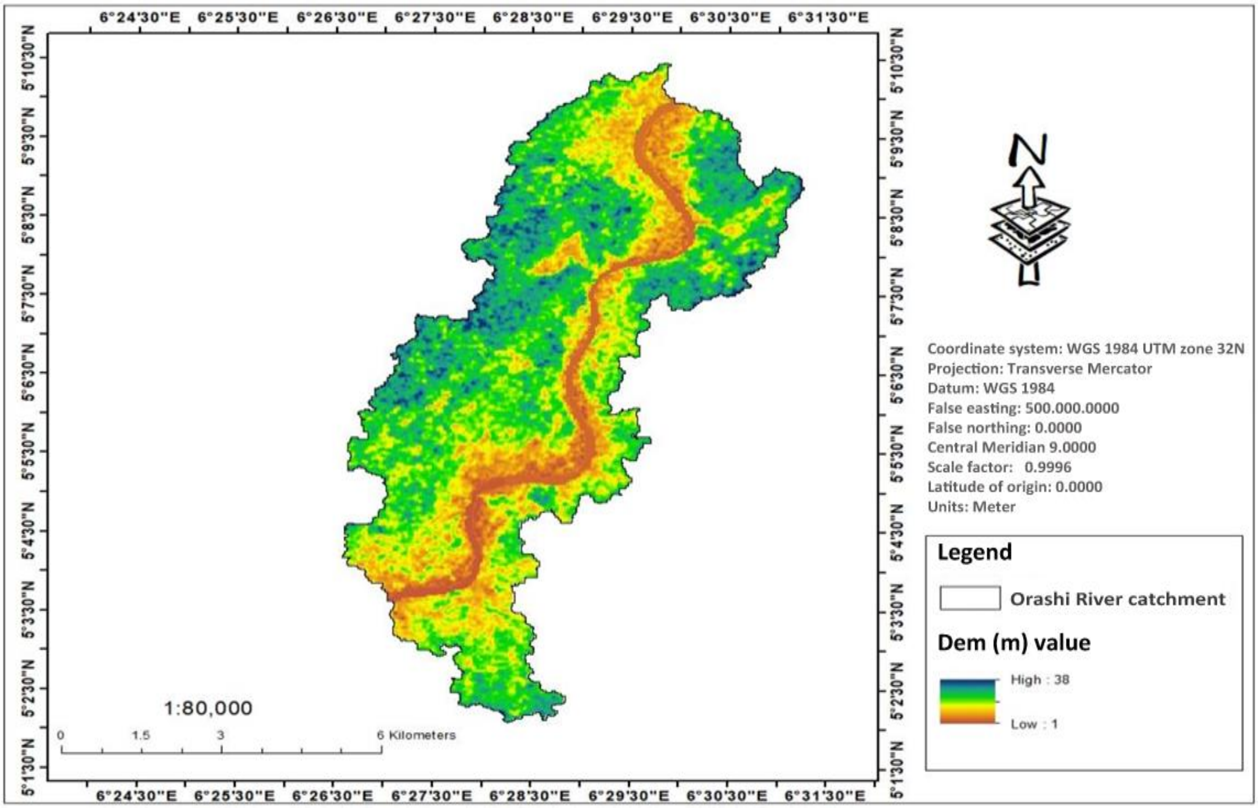

Figure 13. Digital elevation model in Orashi River catchment.

Table 1. Basic parameter in study area.

Catchments	P(km)	A (km^2)	LB (km)	Elev in (m) (Min)	Elev (m)(max)
Bomadi river	42.10	22710.58	8.80	-1	25
Orashi river	72.08	37146.26	14.98	1	38
Forcados river	44.88	20285.29	8.76	0	35
Niger river	112.52	84326.14	21.47	-26	106
Ikoli river	54.71	33987.51	10.45	-2	34
Nun river	45.07	224.65	8.92	2	31

Note: Perimeter (P), Area (A) Basin length (LB), Elevation (Elev).

Table 2. Stream order in study area.

Catchments	I order	II order	III order	IV order	Total
Bomadi river	56	28	18		102
Orashi river	751	177	50	2	980
Forcados river	49	23	14		86
Niger river	153	78	39	24	294
Ikoli river	61	37	20	2	120
Nun river	47	24	14	8	93

3.3. Stream Length (Lu)

The overall length of each order is the sum of its shortest and longest stream segments. The average length of a stream can be calculated by adding all streams in a particular order and dividing by the total number of streams in that order. Because it provides insight into the properties of the surface runoff, the length of streams is a crucial hydrological property of the basin. Regions with steeper topography and more refined sedimentary structures often have streams with shorter meandering distances. Low slopes and flatter surfaces are typical with longer streams. Most of the time, the overall length of stream segments is greatest in the first stream order and decreases in subsequent stream orders. When plotted against their respective order, the logarithms of the total number of stream segments follow a straight line [6]. If this pattern breaks down, it might be due to regional uplift over the drainage basin.

Table 3. Stream length in kilometre.

Catchments	I	II	III	IV	Total (km)
Bomadi river	28.24	13.34	6.69		48.27
Orashi river	81.51	19.01	75.09	1.31	179.92
Forcados river	25.25	16.75	51.20		93.2
Niger river	93.05	46.38	18.55	14.44	172.42
Ikoli river	37.74	21.25	9.96	1.52	70.47
Nun river	29.62	8.27	5.89	2.96	46.74

3.4. Rb (Bifurcation Ratio)

Regarding floods, the Rb is crucial in regulating the highest points of the runoff hydrograph [16, 17]. Flat topography has a Rb of 2, whereas severely dissected terrain yields a Rb of 3-4 [6]. Catchment Rb levels vary from one order to the next in the research region (Table 4). Differences in Rb levels represent geomorphically distinct areas and topographically distinct phases of development [18]. Catchment geology and lithology determine basin-wide Rb value fluctuation [15]. Table 4 shows that the catchment areas' Mean Bifurcation Ratio (Rbm) values range from 1.77 to 9.93, which may be interpreted as both low and high values for the catchment areas' mean Rbs. A higher Rbs number suggests a more developed landscape, one with integrated drainage that reaches its maximum flow rate during floods [19]. For example, Table 4 shows that the greatest Rb values may be found in the catchments of the Orashi and Ikoli rivers, leading to the highest discharge levels during the rainy season.

Table 4. Bifurcation ratio in study area.

Catchments	I/II	II/III	III/IV	Total
Bomadi river	2	1.55		1.77
Orashi river	4.24	3.54	2.5	9.93
Forcados river	2.13	1.64		1.88
Niger river	1.96	2	1.62	1.86
Ikoli river	1.65	1.85	10	9.5
Nun river	1.95	1.71	1.75	1.80

3.5. Drainage Density (Dd)

Drainage density, or the proximity of channels, is an important factor in determining how quickly water may move [20]. To a large extent, the Dd determines the amount of water that flows off of a terrain, which in turn affects the height of floods [21, 22]. High Dd values indicate a high potential for flooding due to the presence of impermeable subsurface material, scant vegetation, and/or mountainous relief [22]. Between 2.04 and 4.60 km/km2, we see a wide range of Dd values across the research region (Table 5). As a result of rapid runoff from the high relief and impermeable underlying material, the lower portions of the Forcados River and Orashi River catchments often experience flooding. The catchment areas of the Bomadi, Niger, Ikoli, and Nun rivers have low drainage density values because of the relatively flat terrain, which in turn causes very little water to flow during the flood season.

3.6. Stream Frequency (Fs)

Peak discharge may be predicted in part by considering stream frequency [19, 23]. Streams are more likely to form in areas with little vegetation, high relief, and inadequate infiltration capacity [9, 24]. Stream frequency measurements for six catchments in the research region range from 1.70 to 17.15 km/km2. The catchment areas of the Orashi River, Bomadi River, Forcados River, Nun River, Niger River, and Ikoli River are, from highest to lowest, the most Fs-rich. Less permeable soil in the catchments of the Orashi, Bomadi, Forcados, and Nun rivers results in more water flow during periods of intense rainfall. Due to the high topography and flat-topped hillocks in the Niger River catchments, which results in a greater volume of water being discharged in a shorter amount of time, the stream frequency value is high. Due to poor relief and increased agricultural activity, the Ikoli River basin has low stream frequency values during wet seasons. Finally, the frequency data demonstrate that the riverbanks of the Niger flood when the river's peak flow occurs early. Ikoli River catchments take longer to deliver peak discharge to the River Niger because of low water flow.

3.7. Texture Ratio (T)

Climate, precipitation, vegetation, rock and soil type, infiltration capacity, relief, and developmental stage are only a few of the environmental factors that might influence texture ratio [25]. The texture of soft, vegetatively unprotected rocks is delicate, whereas the texture of large, resistant rocks is coarse Sreedevi, et al. [26]. Smith [25] categorizes the T depending on particle size into four categories: coarse (4 per km), intermediate (4-10 per km), fine (10-15 per km), and ultra-fine (>15 per km). In the study area, drainage texture ranged from 1.92 to 13.6, with a mean of 11 (Table 5). For example, the Bomadi River, Forcados River, Nun River, Niger River, and Ikoli River all have texture ratio values between 1.92 and 2.61 per km, indicating coarse, while the Orashi River catchment has the highest value at 13.6 per km, indicating fine causes peak discharge during the period of rainfall.

3.8. Relief Ratio (Rh)

Catchment steepness may be quantified using a metric called the relief ratio. Figures 8-13 show the digital elevation, which is an excellent measure of the strength of water flows from a catchment slope. Increases in peak discharge and flow velocities are possible because of the reduced lag time implied by the large relief ratio. Flood peaks rise as relief, hill slopes, and stream gradients are steeper and the time of concentration of runoff reduces [27]. The relief ratio ranges from 1.3 to 4.94 throughout the studied region (Table 5). The topography with steep slopes and the catchments with the greatest relief ratio have a larger peak flow with greater velocities [28]. Orashi River, Bomadi River, Forcados River, Nun River, and Ikoli River basins all have a low relief ratio, suggesting almost level topography, and their impact on floods is negligible. This is because the catchments contribute more water in a shorter time and create floods in the lower areas. Flooding is a problem for them since they live in greater relief ratio locations.

3.9. Ruggedness Number (Rn)

Taking into account topographic features including elevation change and water runoff, the Ruggedness number (Rn) quantifies the structural complexity of a region. Basins with a high Ruggedness number and fine drainage texture may be more prone to flooding, as suggested by Patton and Baker [23]. Because of its steep relief, fine drainage texture, and potential for significant surface flow, the Niger River has the highest ruggedness score in the study region (Table 5). With a moderate roughness number, the catchments of the Bomadi River, Orashi River, Ikoli River, and Nun River may be predicted to have partly flat top surfaces or ridges and valley topography, a relatively high degree of dissection, and a runoff that is somewhere in the middle. With a lower roughness score, the Forcados watershed has simpler topography and hence less precipitation.

3.10. Form Factor (Ff)

The form factor, which is a representation of the contour of a basin, may be used to estimate the intensity of the flow within a catchment and is directly correlated with the maximum flow rate [6, 29]. The catchment areas' form factors are on the order of 0.18 to 0.31. This low form factor value indicates less side flow over shorter time periods and more main flow over longer time periods [9]. High form factor values in the Ikoli River catchment indicate high flow for a longer period of time, while low form factor values in the Bomadi River, Orashi River, Forcados River, Niger River, and Nun River catchments indicate low main flow for a shorter period of time, leading to high peak lows in a shorter period.

3.11. Time of Concentration (Tc)

The concentration time is the distance that water must travel before leaving the basin. The longest duration of concentration indicates the longest distance water must travel before reaching the catchment's exit [30]. The study area indicates the lowest time concentration value is observed in the catchments of the Niger River, followed by the Forcados, Nun, and Bomadi River catchments, and the Orashi River, followed by the Ikoli River catchment in Table 5. The catchment having the highest time of concentration value represents the longer duration of flow discharges. As a result, the Niger River will have more runoff, followed by the Forcados, Nun, and Bomadi River catchments.

3.12. Infiltration Number (If)

You may get a sense of the infiltration qualities of a catchment by looking at the infiltration number, which is calculated by multiplying the drainage density by the stream frequency. As a rule, it decreases with increasing basin infiltration capacity [31]. When the infiltration rate is high, runoff rates are also high. The greatest infiltration numbers in the research region were found in the Forcados and Orashi River catchments, indicating that inadequate infiltration capacity is the primary source of increased rainfall intensity and runoff during the study period Table 5.

Table 5. Derived morphometric parameters.

Catchments	Dd	FS	T	Ff	Rbm	Rn	Tc	If	Rh
Bomadi river	2.13	4.49	2.42	0.29	1.77	6.2	55.88	9.56	2.95
Orashi river	3.15	17.15	13.60	0.25	9. 3	7.78	110.31	54.02	2.44
Forcados river	4.6	4.24	1.92	0.26	1.88	1.35	49.49	19.50	3.99
Niger river	2.04	3.48	2.61	0.18	1.86	269.28	36.07	7.10	4.94
Ikoli river	2.06	1.70	2.19	0.31	4.5	6.80	65.21	3.50	3.30
Nun river	2.09	4.14	2.06	0.28	1.80	6.79	54.68	8.65	3.25

Table 6. Ranking of weightage base on flood run off influence.

Weightage	Flood run off influence
1	Very low run off
2	Low run off
3	Medium run off
4	High run off
5	Very high run off
6	Extremely high run off

Table 7. Ordering of catchments influences in study area.

Catchments	Dd	FS	T	Ff	Rbm	Rn	Tc	If	Rh	CF	Priority
Bomadi river	4	5	4	4	1	2	3	4	2	3.2	Medium
Orashi river	5	6	6	2	6	5	1	6	1	4.2	Very High
Forcados river	6	4	1	3	4	1	5	5	5	3.8	High
Niger river	1	2	5	1	3	6	6	2	6	3.6	High
Ikoli river	2	1	3	6	5	4	2	1	4	3.1	Medium
Nun river	3	3	2	5	2	3	4	3	3	3.1	Medium

Note: Drainage density (Dd), Stream frequency (FS), Texture ratio (T), Form factor (Ff), Mean Bifurcation ratio (Rbm), Relief ratio (Rh), Ruggedness number (Rn), Time of concentration (Tc), Infiltration number (If).

3.13. Compound Factor and Weighted Overlay Method

In order to evaluate the factors that contribute to flooding in each catchment in the basin, morphometric parameters were considered. In general, the greater the value of a characteristic, such as the mean Bifurcation ratio, Drainage density, Stream frequency, Texture ratio, Form factor, Ruggedness number, Relief ratio, or Infiltration number, the higher the flood runoff. As a result, Tables 6 and 7 indicate that the parameter with the highest value was assigned a weight of 6, the parameter with the second highest value was assigned a weight of 5, and so on down to the parameter with the lowest value, which was assigned a weight of 1. Runoff increases as the Time of concentration parameter is decreased. The lowest value of Time of focus received weightage 6, the next lowest received weightage 5, and so on up to the maximum value, which received weightage 1. The influence of flood mapping in the study area (Figure 14). The maps based on weightage and class are provided as

CF1= (Mean Bifurcation ratio)].

CF2 = [class (Drainage density)].

CF3 = [class (Stream frequency)].

CF4 = [class (Texture ratio)].

CF5 = [class (Relief ratio)].

CF6= [class (Ruggedness number)].

CF7 = [class (Form factor)].

CF8 = [class (Time of concentration)].

CF9 = [class (Infiltration number)].

CF= (CF1+CF2+CF3+CF4+CF5+CF6+CF7+CF8+CF9)/9.

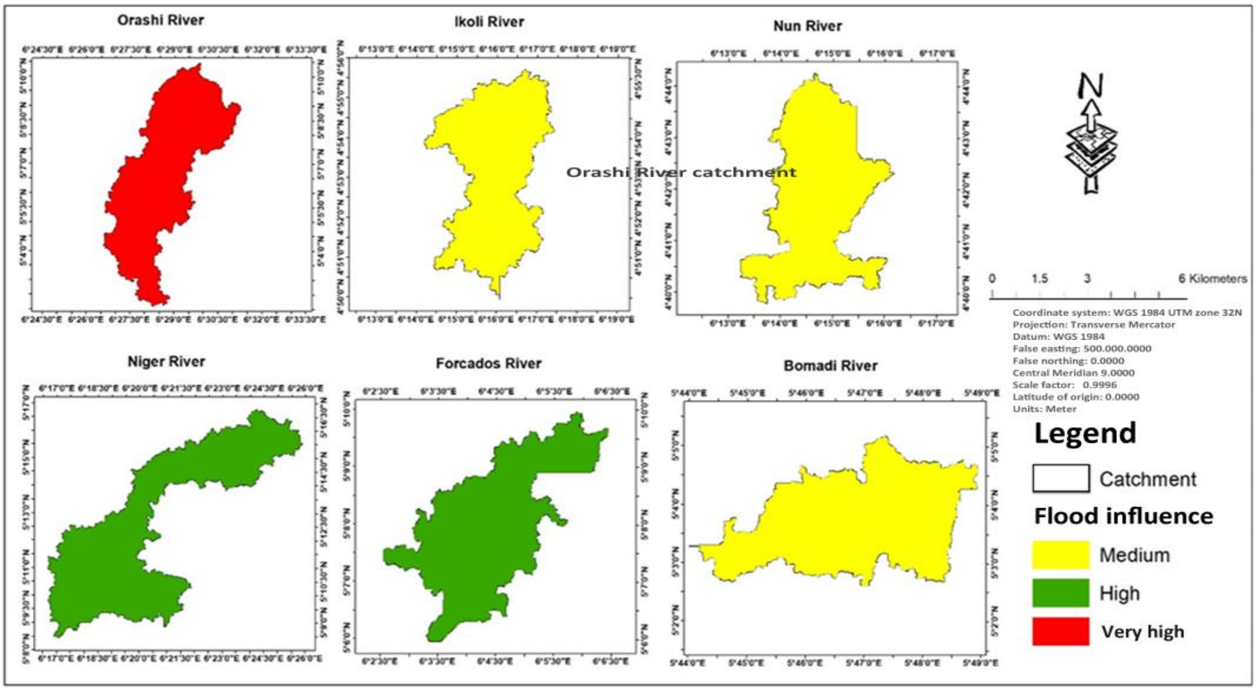

Figure 14. Final map of catchments that influence flooding in the area.

The compound factor for the six catchments in Table 7 and Figure 14, indicating red, has the greatest flood influence in the Orashi River catchment and is classified as very high in terms of priority as a result of on during rainy season because of high runoff parameters such as mean Bifurcation ratio, Drainage density, Stream frequency, Texture ratio, Form factor, Ruggedness number, Relief ratio, and Infiltration number and less on time of concentration, followed by Niger and Forcardos River catchments indicating red and is classified high . The Ikoli River, Nun River, and Bomadi River catchments are indicated in yellow in Table 7 and Figure 14, with medium parameters such as Mean Bifurcation ratio, Drainage density, Stream frequency, Texture ratio, Form factor, Ruggedness number, Relief ratio, and Infiltration number and moderate time of concentration causing medium influence towards flooding in the environment.

4. CONCLUSION

Flooding and erosion are two examples of environmental dangers that may be predicted in part by looking at the size, shape, and geology of the river basin. Indicators of this kind are fundamental for foreseeing natural disasters like floods. They reveal the frequency and severity of floods and the pace at which rain falls along a major river. Consequently, hydrological and morphometric data are being used with GIS and remote sensing technologies in the Niger Delta Region to assess the effects of flooding on river catchments. The results of the hydrological and morphometric parameters for determining flood influence on river catchments show that the stream order in the study area ranges from 3^{rd} to 4^{th} order, with elevation values ranging from-26 to 106 m. The final output of the compound factor shows that the various river catchments have three types of flood influence: very high in the Orashi river catchment, high in the Niger and Forcados river catchments, and medium in the Ikoli and Nun River catchments. As a result, the catchments of the Orashi, Niger, and Forcados rivers should be prioritized over those of the Ikoli and Nun rivers.

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Authors' Contributions: Both authors contributed equally to the conception and design of the study.

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