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Morphometric Analysis of Sub- watersheds in Oguta and Environs, Southeastern Nigeria Using GIS and Remote Sensing Data

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Abstract Morphometric analysis of the sub- watersheds in Oguta area, Southeastern Nigeria using GIS processed Remote Sensing data was carried out with the objectives of evaluating their morphometric characteristics and other landuse/landcover dynamics. The present study involved the measurement of the linear, aerial and relief aspects of the dimensions of the sub-watersheds. Analysis of the landuse classification revealed that Njaba drainage basin is made up of 37.32% farmland and grassland, 27.51% forest, 20.06% bare land, and 5.28% water, while the Orashi drainage basin comprises of 30.23% farmland, 10.35% urban settlement, 20.14% forest land, 15.13% bare land and 24.14% water body. It was also revealed from the study that Njaba drainage basin has a basin length of 21.48km^2 while that of Orashi drainage basin was estimated to be 29.59km^2. Similarly, whereas the former has an area of 21.48 km^2 the latter has an estimated area of about 29.59km^2. Further morphometric analysis revealed that the bifurcation ratio of Njaba and Orashi drainage basins were estimated at 1.80 and 3.92 respectively, while their drainage densities were put at about 0.54 and 0.51 respectively. Finally, the basin relief ratios of the basins were estimated at 0.0038 and 0.00367 respectively while their form factor was given as 0.31 and 0.189 respectively. The form factor values estimated from this study revealed that the Njaba drainage basin is circular while Orashi drainage basin revealed an elongated dimension. These morphometric characteristics are key indices that are invaluable in assessing the geo-hydrological behavior of the drainage basins and their vulnerability to flooding.

Keywords: *drainage basin, Oguta, basin morphometry, watershed, flood management, GIS*

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1. Introduction

Watershed is an area of land drained by rivers and its tributaries. Its boundary is marked by ridges of high land beyond which any precipitation will drain into adjacent basins. This boundary is called a drainage divide. Drainage basin or watershed can also be described as an open system and is considered a fundamental element in the analysis of a part of the hydrological cycle. It is a system where inputs from precipitation (rain and snow) undergo the process of infiltration, percolation, through flow and overland flow (surface run-off) thereby proceeding as output in the form of evapo- transpiration (the loss of water directly from the ground, water, surface and vegetation) [1]. Drainage basins be assessed and characterized by measuring their dimensions with respect to their linear, aerial, and relief aspect. This research is an attempt to understand the drainage basins by evaluating their morphometric parameters which includes their basin shape, length, area, stream order, number of stream segments, bifurcation ratio, drainage density, and frequency. It is an attempt to combine the geomorphologic and hydrological attributes of the drainage basins.

Integration of remote sensing and geographic information system (GIS) technologies have been utilized productively worldwide to detect and monitor changes in the landscape and the consequential environmental impacts like flooding, gully erosion, etc. Previous studies have used remote sensory and GIS data to examine land use changes in recent times with the objective of identifying patterns of urban development that could be associated with specific environmental factors [2]. There are numerous examples of traditional and expert based image classification systems for detection, monitoring and mapping the land use and land cover characteristics worldwide using remote sensing data. Remote Sensing and GIS techniques have also proven to be efficient tools in the delineation, characterization and morphometric analysis of drainage basins worldwide. Drainage basin analysis is also very important in any hydrological investigation like assessment of groundwater potential and management. Various environmental hazards associated with hydrologic phenomena are most often correlatable with the physiographic characteristics of drainage basins such as size, shape, slope of drainage area, drainage density, and of course length of the tributaries [3]. Remote sensing data can be used in conjunction with conventional data for delineation of ridgelines, characterization, priority evaluation, problem identification, assessment of potentials and management needs, identification of erosion prone areas, evolving water conservation strategies, selection of sites for check dams and reservoirs, Etc. [4].

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms [5]. Morphometric studies in the field of hydrology were first initiated by Horton [6]. The morphometric analysis of the drainage basin and channel network play a vital role for understanding the geo-hydrological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology, structural, etc. antecedents of the catchment. The relationship between various drainage parameters and the aforesaid factors are well- recognized by many workers [7,8,9,10]. The drainage basin analysis is important in any hydrological investigation like assessment of groundwater potential, groundwater management, pedology and environmental assessment. Hydrologists and Geomorphologists have recognized that certain relations are most important between runoff characteristics, and geographic and geomorphic characteristics of drainage basin systems. Various important hydrologic phenomena can be correlated with the physiographic characteristics of drainage basins such as size, shape, slope of drainage area, drainage density, size and length of the contributories. Geology, relief and climate are the primary determinants of running water ecosystems functioning at the basin scale. Detailed morphometric analysis of a basin is a great help in understanding the influence of drainage morphometric network on landforms and their characteristics. The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management. The influence of drainage morphometric system is very significant in understanding the landform processes, soil physical properties and erosion characteristics. Drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods [7,11,12]. Geographical Information System (GIS) techniques are now a day used for assessing various terrain and morphometric parameters of the drainage basins and watersheds, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information. The goal of the present study is to analyze the linear and areal morphometric characteristics of drainage basin in south-eastern part of Nigeria using Geographical Information System (GIS), as so far no exhaustive work on the morphometric investigation of the region has been carried out. This study gives an insight into the different geo-hydrological characteristics of the drainage basin which in turn help in the management of the water and other natural resources of the area.

2. Location, Physiography, Hydrology and Geology of the Study Area

The study area of interest in this research is Oguta Local Government Area with a consideration of sub-watershed within Oguta Lake/Upper reaches of the Otamiri, and Upper reaches of Otamiri/ Njaba areas. It has an estimated area of 484.58 km^2 and a population of 142,340 persons. It lies within a perimeter of 36.62692km and is located within latitudes $5^0 40^1$29.918N-$5^0 41^1$09.200N and longitudes $6^0 49^1$32.06E to $6^0 50^1$02.05E. The study area belongs to the coastal sedimentary lowlands of the southern Nigeria hydrological province as shown in Figure 1. The climate is divided into two main seasons: wet and dry season. Most of the area has a mean annual rainfall of about 2152mm [13]. This occurs during the wet season, April to October, and associated with moisture laden maritime southwest trade winds from the Atlantic Ocean. The temperature in the study area ranges between 23° to 26°C.The terrain of the study area is characterized by two types of land forms; gently undulating ridges and nearly flat topography. The ridges trend in the north-south direction and have an average elevation of about 122 m [14]. The southern part of the study area consists of gently undulating ridges of coastal plain sands of the Benin Formation mainly around Ogbaku, Awomama ,Mgbidi, Izombe and Nkwesi areas. Other areas around Orsu-Obodo towards Oguta town and its immediate environs, have alluvium deltaic plain deposits (Recent deposits) located mainly along the banks of Orashi and Njaba Rivers.

The geology and geomorphology of the Niger delta have been described in details by various authors [15,16,17]. The formation of the present day Niger delta started during Early Paleocene and it resulted mainly from the buildup of fine grained sediments eroded and transported by the River Niger and its tributaries. The subsurface geology of the Niger delta consists of three litho-stratigraphic units(Akata, Agbada and Benin Formations) which are in turn overlain by various types of Quaternary deposits [18]. The Quaternary deposits(normally 40–150m thick) generally consist of rapidly alternating sequences of sand and silt/clay with the latter becoming increasingly more prominent seawards. The surface distribution of the various geomorphic units of the Niger delta is shown in Table 1 and Figure 1 below.

Table 1. Geologic and geomorphic units of the Niger delta basin (Etu–Efeotor and Akpokodje, 1990).

Geologic/ geomorphic units	Lithology	Age
Alluvium(general)	Gravel, sand, silt	Quaternary
Freshwater backswamp, meander	Sand, clay, some silt, gravel	Quaternary
Mangrove and salt water/ backswamps	Medium – fine sands, clay and some silt	Quaternary
Active/ abandoned beach ridges	Sand, clay , and some silt	Quaternary
Sombreiro –warri deltaic plain	Sand, clay, and some silt	Quaternary
Benin Formation	Coarse to medium sand with subordinate silt and clay lenses	Miocene
Agbada Formation	Mixture of sand, clay and silt.	Eocene
Akata Formation	clay	Paleocene

The study area falls within the coastal plain sands and the alluvial deposits of the Quaternary sediments of the Niger Delta.The Niger Delta is made up of three generalized lithostratigraphic units (from oldest to youngest) namely Akata, Agbada and the topmost Benin Formations. The Akata Formation is the basal unit of the Niger Delta lithostratigraphy consisting of massive monotonous and generally dark grey marine shales. The formation is generally very rich in fauna and flora remains [19]. Sandstone lenses (rings) occur near the top of the formation, particularly at the contact with the overlying Agbada Formation. Akata Formation is the major source rock for the Hydrocarbons of the Niger delta [20]. Its thickness is uncertain but may reach 7000m in the central part of the delta with age ranging from *Paloecene* to *Holocene* [21]. The Agbada Formation that overlies the Akata (basal) Formation is a paralic sequence represented by an alternation of sandstones and shales in various proportions [22].

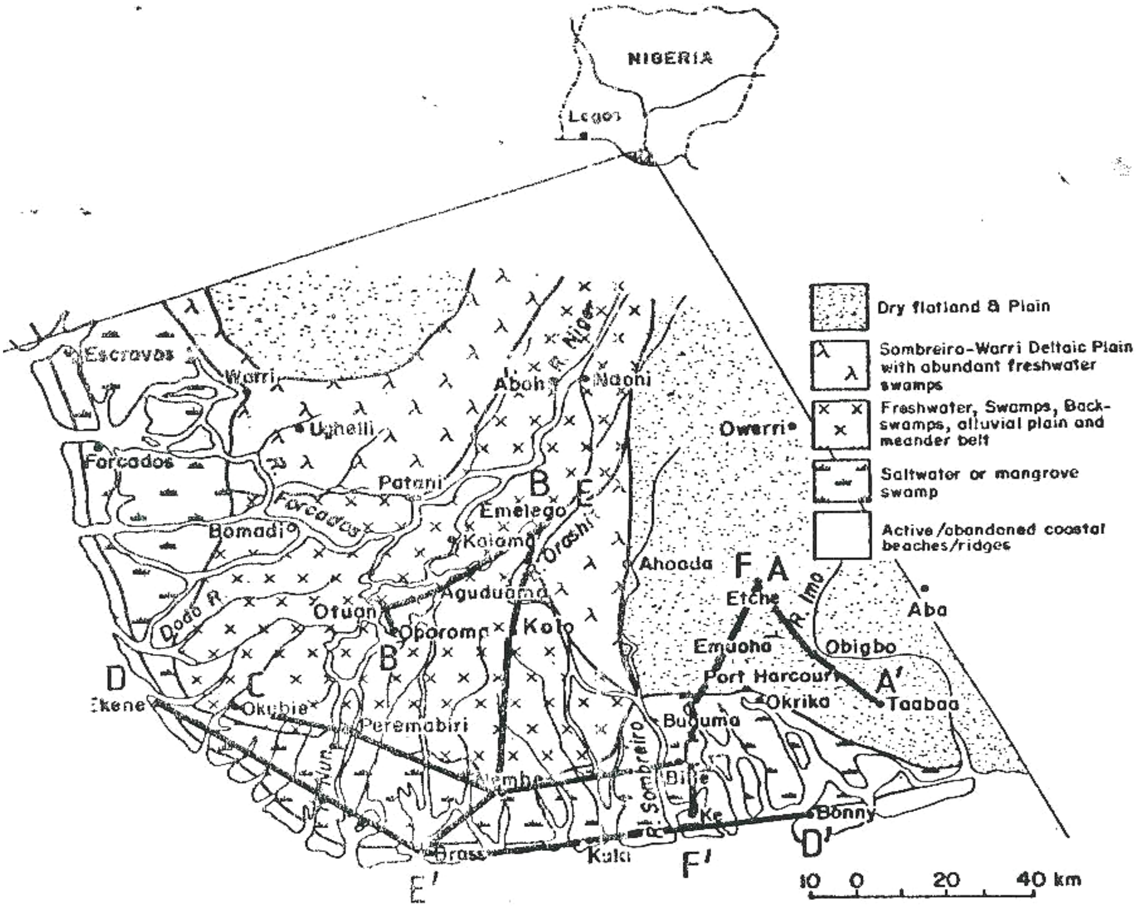

Figure 1. The major geomorphological units of the Niger delta basin (after (Etu–Efeotor and Akpokodje, 1990)

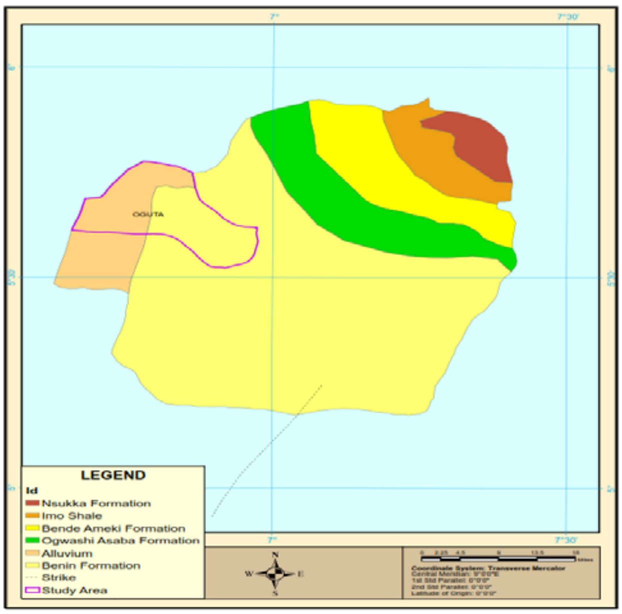

Figure 2. Geological map of Imo State showing the study area

Oguta lies within the Benin Formation and consists of continental sands with lenses of clay/shale and some isolated units of gravel, conglomerate and sandstones [23]. The formation is Pliocene to Miocene in age and overlies the Agbada Formation which consists of sands and shale units [24]. studied the surface geology of Oguta Lake area using road cuts and low hills and observed that it consists of ferruginized sands which are occasionally massively bedded and pebbly. The regional geology of the Tertiary Niger Delta Basin of Nigeria in which the study area is located has been studied extensively. A dominant feature within Oguta study area is the prevalence of alluvium deposits and the Benin Formation.

Four rivers (Njaba, Awbana, Utu and Orashi) are associated with the Oguta Lake with most of them draining into it [25]. Figure 3 is the drainage map of Imo State showing the study area. The Njaba and Awbana Rivers discharge into the lake all the year round while perennial Utu Stream flows into the Oguta Lake during the rainy season. The Orashi River flows past the lake in its southwestern portion. The total annual inflow from the rivers and stream was estimated to be about 25,801.60m^3. The annual return and overland flow into the lake was also estimated to be about 69.000 and 138,000m^3 respectively while the annual recharge of the lake from precipitation is about 693, 000m^3. The annual groundwater inflow into the lake was also estimated at about 2,750,400m. The total annual water inflow therefore greatly outweighs the total annual outflow [26]. These statistics show that Oguta Lake is adequately recharged all the year round.

Figure 3. Drainage map of Imo state showing the study area

3. Materials and Method

An integration of remote sensing and geographic information system technology was adopted in this study. Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) of the United States Geological Survey Agency was processed to derive several morphometric outputs, while Landsat 7 was processed to derive some key informations such as landuse / landcover map using unsupervised classification schemes. All these datasets were brought into the same coordinate system of the Universal Transverse Mercator (UTM) projection 32N in the ArcGIS 10.2 geographic information system software. The Digital Elevation Model image shows the distribution and spatial variation of elevation values at every geographic point/location within the area. This enables the processing and delineation of drainage basin parameters which are deduced from the elevation values. Drainage basin morphometric parameters and stream order characteristics of the area were extracted from the digitized data using the Strahler's method of stream ordering [11]. Stream order determines the hierarchical position of a stream within a drainage basin.

4. Result Interpretation and Discussion

The study area has two major drainage basins as shown in Figure 4 which includes the Njaba and Orashi drainage basins. Communities within Orashi drainage basins include Owosha, Akata, Izombe, Umuofor, and Umuede, while those within Njaba drainage basin include Oguta, Nkwesi, Umuechi, and Egbu communities. Horton's contribution of quantitatively assessing the drainage basins was adopted for this research rather than the qualitative descriptions. This is most often carried out by defining the morphometric parameters of a basin such as basin length, basin area, stream order, stream length, mean stream length, bifurcation ratio, mean bifurcation ratio, relief ratio, drainage density, stream frequency, drainage texture, form factor, etc. These parameters have previously been developed and used in previous studies of geomorphology and surface- water hydrology, such as flood characteristics, sediment yield, and evolution of basin morphology [27,28].

4.1. Basin Length

This is estimated as the straight line distance between the mouth of the basin and the drainage divide nearest to the source of the main stream. This was used to infer the drainage shape, which is of obvious importance in influencing peak flow although it is a feature which is difficult to express numerically [29]. It is noted that the shape of a drainage basin may conceivably affect stream discharge characteristics. It was therefore revealed from this study that Njaba drainage basin has a length of 21.48 sq. km while that of Orashi drainage basin was estimated to be 29.59 sq. km (Table 1).

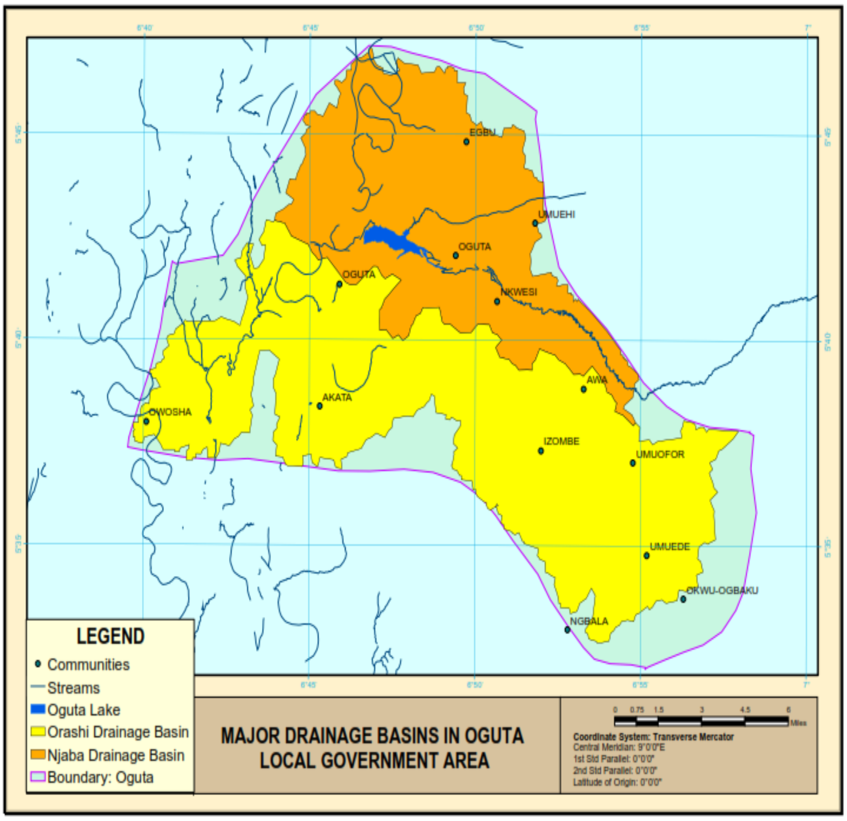

Figure 4. Major drainage basins (sub-watersheds) of the Oguta area

4.2. Basin Relief

Basin relief is the difference in elevation between the highest and lowest points within a particular basin. It controls the stream gradient and therefore influences flood patterns and the amount of sediment that can be transported. Previous studies have revealed that sediment load increases exponentially with basin relief [30]. The basin relief ratio of Njaba and Orashi drainage basins revealed estimated values 0.0038 and 0.00367 as shown in Table 2.

The basin relief ratio index is the ratio of basin relief to basin length. This ratio helps to make adequate comparison of the different sizes of the basins since it standardizes the change in elevation over distance. The relief ratios of the Njaba drainage basin and that of Orashi drainage basin was estimated to be in the range of 0.0038 and 0.00367 respectively.

[31], in their study of morphometric analysis of Ogunpa and Ogbere drainage basins re-emphasized the importance of the relief ratio of drainage basins and established that relief ratio is an indicator of rates of erosion operating along the slope of a basin.

4.3. Basin Relief Ratio

Table 2. Drainage Basins and the Relief Characteristics

S/N	Drainage Basins	Total Relief (Km)	Basin Length (Km)	Relief Ratio
1	Njaba Drainage Basins	0.082	21.48	0.0038
2	Orashi Drainage Basin	0.109	29.59	0.00367

4.4. Drainage Shape

The basin shape is largely controlled by geological structures and is an important geometrical form of the stream network . Basin circularity (Rc) ratio as the ratio of the basin area (Au) having the same perimeter as the basin [32]. The form factor values vary from 0 (in highly elongated shape) to 1(in perfect circular shape). Thus the higher the value of form factor, the more circular the shape of the basin and vise versa [33]. An index of drainage shape is computed as a unit-less dimension of drainage area divided by the square of the basin length [34]. If two basins have the same area, the more elongate one will tend to have smaller flood peaks, but long lasting flood flows [35]. Njaba drainage basin has the higher form factor of 0.31 (tending towards a circle) while the Orashi drainage basin has a lower form factor of 0.189(Table 3.0). Njaba is therefore more circular than Orashi, while Orashi is seem to be more elongated than Njaba as indicated in Figure 5.

Table 3. Drainage Basins Geometry and Shape Characteristics

S/N	Drainage Basins	Basin Area(Km^2)	Basin Length(Km)	Form Factor
1	Njaba Drainage Basins	145.633	21.4783	0.316
2	Orashi Drainage Basin	230.87	29.5937	0.264

4.5. The Bifurcation Ratio

Bifurcation ratio is the relationship between the number of streams of one order and those of the next highest order. It is normally obtained by dividing the number of streams in one order by the number in the next highest order. The human significance of the bifurcation ratio is that as the ratio is reduced, so also is the risk of flooding for the concerned part, rather than the entire basin [36]. The bifurcation ration of Njaba and Orashi drainage basins were therefore estimated 1.80 and 3.92 respectively as indicated in Table 4 below.

Table 4. Distribution of drainage basins and the number of stream order

S/N	Drainage Basins	1st Order	2nd Order	3rd Order	4th Order	Bifurcation Ratio
1	Njaba Drainage Basins	404	183	131	0	1.80
2	Orashi Drainage Basin	513	293	237	27	3.92

4.6. Drainage Density

Drainage density has been very useful in hydrological studies. The pattern and arrangement of natural stream channels determines the efficiency of the drainage system [37]. Other factors being constant, the time required for water to flow a given distance is directly proportional to the length. Drainage density can be defined as the total stream channel per unit area. The drainage densities of the Njaba and Orashi basins are estimated at 0.54 and 0.51 respectively (Table 5).

Table 5. Distribution of Drainage Basins and their Stream Network Characteristics

S/N	DRAINAGE BASINS	Basin Area: A(Km^2)	Total Stream Length (Km)L	Drainage Density Dd=L/A (Km^2/Km)
1	Njaba Drainage Basins	145.63	78.20	0.54
2	Orashi Drainage Basin	230.87	117.47	0.51

4.7. Land Use Characteristics of the Study Area

Human land-use activities may affect all aspects of drainage basin and channel characteristics that control the rate of water movement and thus flood conditions [38]. Landuse classes adopted in this study include forest, farmland, barren land (deforested land), water body, etc. After a quantitative assessment of the landuse maps shown in Figure 5a and Figure 5b, we discovered that Njaba drainage basin is made up of 37.32% farmland and grassland, 27.51% forest, 20.06% bare land, and 5.28% water. Similarly, Orashi drainage basin comprises of 30.23% farmland, 10.35% urban settlement, 20.14% forest land, 15.13% bare land and 24.14% water body. Forest vegetation growing within the basin attenuates incoming sunlight, thus influencing ground surface to contribute organic materials of different sizes to the channel [39]. This process adds nutrients, habitat, and roughness elements that may alter flow hydraulics and sediment movements providing low velocity, shallow-water nursery habitat for young fishes which increases out of bank roughness, causing attenuated flood peaks [40].

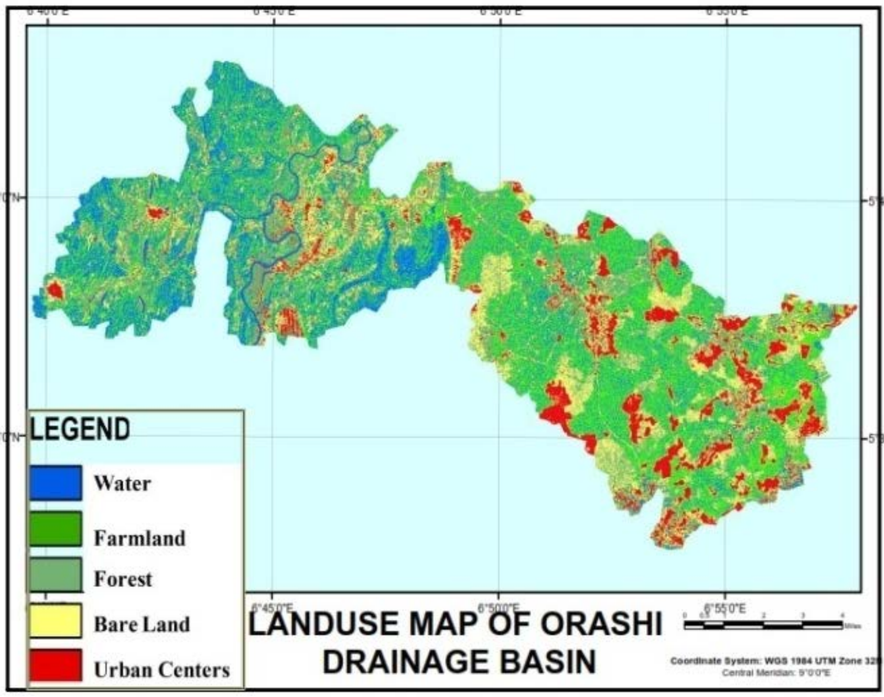

Figure 5.a. Land Use Map of Orashi Drainage Basin

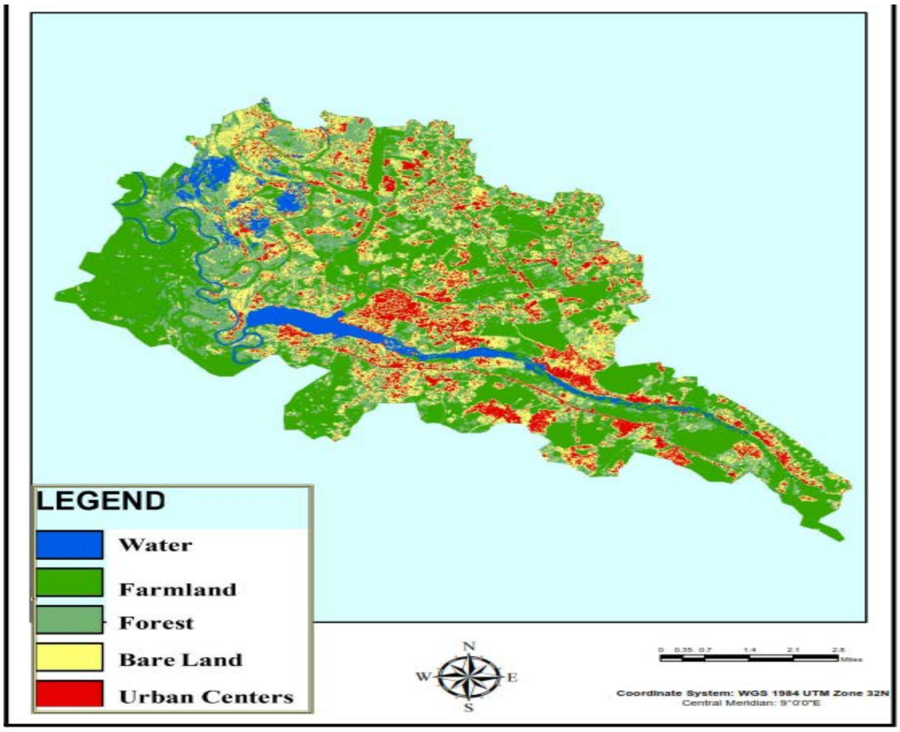

Figure 5.b. Land Use Map of Njaba Drainage Basin

5. Summary, Conclusion and Recommendation

Characteristics of drainage basins include: size, shape, vegetation cover, geology are important indices for predicting environmental hazards especially erosion and flood. They reveal how fast rainfall reaches a main river, their frequency and the severity of flooding. This study shows how the configuration of drainage basins contributes significantly to environmental hazards occurrence in an area. Elongated basins of Orashi presents narrow outlets which reduces runoff velocity and induces long lasting flood peaks while Njaba's broaden and near circular shape enhances high runoff movement thus enhances a quality drainage system. A higher bifurcation ratio and relief of Orashi possess a great threat and induces erosion flood occurrence which deepens to achieve stability of drainage basin.

Based on the assessment of Land Use and Land Cover, it is observed that these predicted environmental hazards are linked to human activities. Urban settlement is higher in Orashi than Njaba, where hazards are predicted to be lower. This predicted low hazard within Njaba could be attributed to a high resistance arising from erosion and flood hazards. This large span coverage of forest also indicate a high forest resource such as timbers can boost construction industries. A higher coverage of grassland and farmland within Njaba basin can as well present opportunities for agricultural development.

The mitigation of potential environmental hazards within these basins goes beyond advocacy. Environmental laws should be implemented to deter defaulters, while engineering designs of settlement, roads and associated projects should be adopted to enhance environmental sustainability of public infrastructure. A proper land zoning system should not just be adopted, but meticulously followed in land allocation and citing of industries, schools and other to reduce risk of vulnerable population.

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