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SPATIO-TEMPORAL ASSESSMENT OF HYDROLOGICAL CHANGES WITHIN THE ENVIRONS OF AGULU LAKE

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Abstract:

This study investigates the dynamics of hydrological changes in Agulu Lake of Anambra state of Nigeria within a period of 2014 to 2023, with the aim of accessing it spatial and temporal dynamics. The objectives include assessing the spatial and temporal changes of the hydrological dynamics in the period of study, and to produce the map of Agulu Lake and its immediate environs to show the hydrological changes within the period, so as to make some recommendations for its sustainable use and exploitation. Landsat satellite imagery was utilized to analyze and map the changes in the lake's environment. The methodology applied involved acquisition of primary data from the site and the secondary data through extraction, classification and processing of satellite imageries using ArcGIS software. The results of the Landuse/Landcover (LULC) classification and analysis revealed that Agulu lake is drastically shrinking from its initial size, and there is a notable reduction in the available water space within Agulu lake and its environs between 2014 from 0.347 km^2 (1.82% of the entire study area) to 0.278 km^2 (1.46% of the study area) in 2023. On the contrary, Vegetation and Built-up areas are increasing at alarming rate within the lakes environment. To mitigate these challenges, it is recommended that development pressures within the Agulu lake's environment be properly controlled, while conservative and sustainable land use practices be implemented within the lake's immediate environment.

Key Words— ***Assessment, Spatio-Temporal, Hydrology, Agulu Lake, Remote Sensing.***

1.0 INTRODUCTION

1.1 Background to the Study

Water being an integral part of the earth and human existence is found in different forms and storages on, beneath or above the earth surface in the solid, liquid or in gaseous state. It could be an Ocean, Sea, River, Stream, Lake, Pond, Hail, Dew, Ice etc. Lake forms one of the surface storages where large volume of water is contained. The field of science that focuses on the study of lakes is referred to as Limnology (Balasubramanian, (2015); Welch, (1952)). Lake could be defined base on the geological, hydrological and ecological views. The definition is geological when it looks at the geological processes that led to its formation, such as tectonic activities, glaciation and many others. Hydrographic definition focuses on the sources and outlet of water within the lake, while ecological definition does with the ecological factors and ecosystem. Abhijit *et al* (2014), defines a lake as an enclosed body of water (usually fresh water) totally surrounded by land and with no direct access to the sea. In support of this, Nelson (Jr) and Gregor (2002), define lakes as inland bodies of water that lack any direct exchange with an ocean. From their definitions, a lake can be seen as any larger body of water that has no connection with the sea or Ocean. Such a large body of water is surrounded by land. Balasubramanian (2015), has however

thrown more light into the definition of lake by defining a lake as a large body of natural water collected in a depression, which differs from a pond due to its larger size, presence of biotic life and many other ecological factors. He further stated that though a reservoir is similar to a lake, it comprises less habitat and is mostly man-made. He concluded by saying that a body of water is considered a lake on earth when it is inland, and not part of the ocean. Environmental Fact Sheet (2019), in describing and differentiating between lakes and ponds, says that there is no distinction between them, although lakes are generally larger and/or deeper than ponds, that names for lakes and ponds generally originated from the early settlers living near them. Thus, both lakes and ponds could be seen as open bodies of water surrounded by land.

Several types of lake are in existence. These are classified based on some factors such as the nature of their inflow-outflow of water, mixing of water, origin and the trophic levels within it, to include; Lakes formed due to landslides, Salt lakes, Oxbow lakes, Crater lakes, Sinkhole lakes, Lakes formed due to erosion, Kettle lake, Artificial lake, and Fjord lake (Balasubramanian 2015). Other forms of lakes that could be mentioned fall within one of the classes listed above.

Lakes play key roles in the livelihood of human and in ecosystem balance, and sustainability. Brönmark and Hansson (2002), has opined that although the amount of water in lakes constitute only a minute fraction of the total freshwater resource on earth, lakes and ponds are important freshwater habitats throughout many regions of the world. According to Balasubramanian (2015), the presence of a lake, in any region, greatly influences the lives of the people living adjacent to it as they are good sources of water supply for drinking in some places. He also pointed out that lakes are helpful in controlling weather and local climate, and for creating irrigation facilities and recreation. Abhijit *et al* (2014), has listed the usefulness of lakes to include; drinking and municipal water supply, industrial and cooling water supply, power generation, navigation, commercial and recreational fisheries, body contact recreation, boating, and other aesthetic recreational uses. They also pointed out that in addition to the above, lake water is used for agricultural irrigation, canalisation and for waste disposal. Lakes provide habitats for many water birds, animals and other forms of biodiversity (Sendera and Garbowskib, 2019).

Being part of the ecosystem, lakes play key role in weather and temperature regulations. They are also tourist attractive features and a source of income to many nations and communities. Nelson (Jr) and Gregor (2002), has pointed out the importance of lake in ecosystems to be vital because many organisms depend on freshwater for survival, and humans frequently depend on lakes for a great many 'goods and services' such as drinking water, waste removal, fisheries, agricultural irrigation, industrial activity, and recreation. Thus, lakes could be seen as major components of ecosystem.

The study of lakes and their features could be done through different means, ranging from ground based surveys to remote sensing methods. According to Udoudo *et al* (2024), mapping and presentation of water resources and its environment could be done through the ground-based hydrographic survey, but the use of remote sensing and GIS technique provides a quicker means of studying their hydrological settings and connectivity. Remote sensing based information capturing provides a bird-eye view of the larger area of study that could take more time if it were to be based on a ground based data acquisition. Remote sensing is defined as the acquisition of an information about an object through remote means, involving the use of instruments called sensors, without getting into a direct physical contact with the object in which its information is demanded (Adjei-Darka, 2017; Lillesand *et al* 2008; Qihao, 2013; Udoudo *et al* 2023; Udoudo *et al* 2024).

The application of remote sensing in studying water resources has an advantages over ground or surface based data collection method in different ways. It is a reliable source of information especially when the direct contact with the object of study is very difficult or the object is very large to be covered with ground based methods (Udoudo *et al* 2024). A more holistic hydrographic information can easily be obtained by the use of satellite remote sensing technique than the ground method or technique when studying the water bodies (Ekpa and Ojinnaka 2015; Lillesand *et al* 2008).

The knowledge of the Landuse and Landcover (LULC) of any hydrological or limnological unit is important to have an insight whether the region has water bodies or not. This can easily be done through LULC classification. According to Udoudo *et al* 2023, Landuse refers to the different uses to which man put land into including agricultural, waste disposal, industrial, residential, recreational, institutional etc, while Landcover depicts the natural features covering the terrain surface, including such features as water bodies, swamps, desert or sand dunes, bare land and forest or vegetation covers. Image classification for LULC can be supervised or unsupervised. The level one classification scheme according to Anderson *et al* (1976), categorizes LULC into five classes namely; Agriculture, Vegetation, Built-Area, Bare-Earth and Water Body.

This study investigates the spatial/dynamical changes over time (temporal) in Agulu Lake of Anambra state of Nigeria and it immediate environment within the study period which ranges from 2014 to 2023, with the aim of accessing the trend of its spatial and temporal dynamics. The objectives include assessing the spatial and temporal changes of the identifiable dynamics within the area in the period of study, and to produce the map of Agulu Lake and its immediate environs within the study period to show the changes, and make some recommendations to the Agulu lake management authority for an insightful managerial and sustainable approach to the lake's stability and sustainable exploitation.

1.2 Statement of Problem

Agulu lake is facing a lot of threats and challenges ranging from natural, hydrological, ecological, anthropogenic, environmental, managerial challenges and so on. There is much pollution of the lake as aresult of indiscriminate waste disposal. Waste from the increasing urbanization around the lake's environment has posts serious threat to the freshness of the lake. While the size of the lake is gradually reducing, there is a yearly increase in area of built-up of residential structures within the Agulu lake environment. This cannot go without some negative environmental consequences including the waste pollution as noticed in the lake. The size of the Agulu lake is noticed to shrink yearly while that of vegetation within its coastal region is increasing as a result of coastal agriculture activities. This exposes the lake coastline to coastal erosion. The resultant effect of this is that much soil (sand) and nutrients are washed into the lake, making the edge to become shallower. As this happens yearly, siltation and eutrophication becomes the order of the day and consequently, much vegetation grow at the shallow part of the lake to shrink its size, and there is no much management effort to curtail this. Many lakes all over the world face many of similar challenges ranging. Such challenges according to Brönmark and Hansson (2002), include human impact on biodiversity, eutrophication, acidification, contamination with heavy metals, and invasion by exotic species. Eutrophication is a very serious environmental issue in lake stability and sustainability. Here, much nutrients that trigger the growth of weeds are washed into the lake from agricultural activities within the coastal line of the lakes. This can shrink the shorelines or lead to the dead of shallow lakes.

For most shallow lakes (including Agulu lake) to survive due to anthropogenic and environmental factors which lead to deadness of lakes, there must be proper management and sustainable use of their resources. Sendera and Garbowskib (2019), who carried out a study on the restoration of Lake Piskory, highlights the direct human and government management effort as a key factor to restore dead lake and to conserve them after restoration. Such efforts include protection and conservation of the shoreline and its ecosystem. Increase in fresh water effluents discharged from development activities within the watershed of lake environment have resulted in reducing normal salinity level in the lakes, while high level of nutrients input into the lake from domestic, agricultural and industrial wastewaters have caused excessive growth of unwanted aquatic plants and, consequently, slow water circulation, destruction of spawning and nursery grounds, and deterioration in fish productivity (Abayazid and Al-Shinnawy 2012).

1.3 Aim and Objectives of the Study

The aim of this study focuses on the assessment of the dynamics of the spatio-temporal changes within the environs of Agulu Lake of Anambra state of Nigeria within a period of 2014 to 2023. The objectives include assessing the spatial and temporal changes of the hydrological dynamics in the period of study, producing maps of Agulu Lake and its immediate environs to show the hydrological changes within the period, and making some recommendations for its sustainable use and exploitation.

2.0 THE STUDY AREA

Agulu lake is located near the boundary between Anaocha and Awka-south LGA. Agulu lake is known by local people and the surrounding communities to be in Anaocha LGA, but by following the Nigerian national, state and local government boundary maps, it is located in Awka-South LGA (Figure. 2.2). The study area, which is Agulu Lake is in Anambra state, found in Igbo land and within the South Eastern part of Nigeria (Figure 2.1). The official and indigenous language of the area is Igbo language. The geological settings of the area show that the soil is made up of laterite, shales, sand stones with abundance of clay and fine sand. This gives it the reddish to brownish coloured soil that is mildly cemented. As a result of this, the lake holds its water all year round.

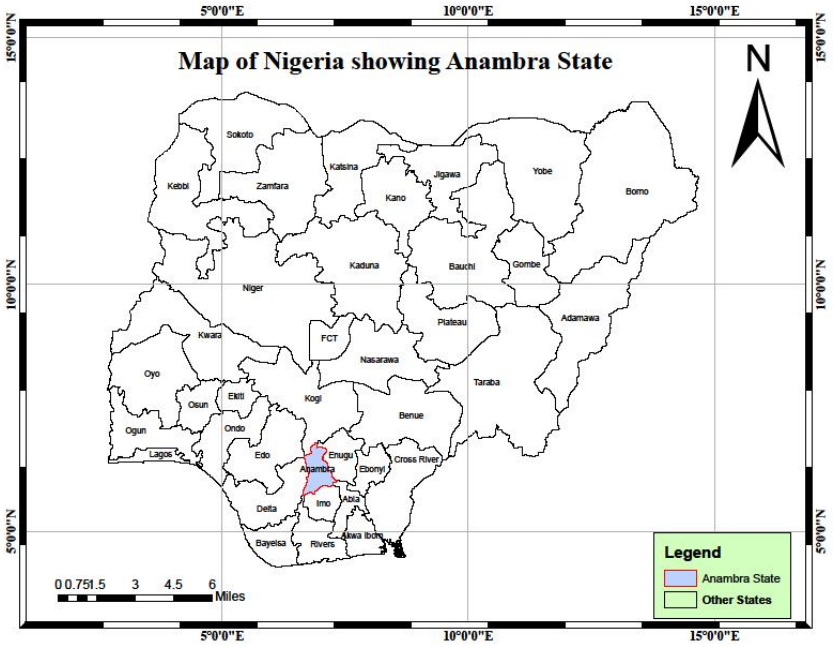


Figure 2.1: Map of Nigeria showing Anambra State

The hydrology of the area also shows a high connectivity of stream channels to the lake. This helps to channel much runoff into the lake after precipitation in addition to it natural storage.

Agulu lake is located in the tropical zone of Nigeria signifying that it has two major seasons yearly; the rainy and the dry seasons with about five months of dry season (November to March), and seven months of rainy season (April to October).

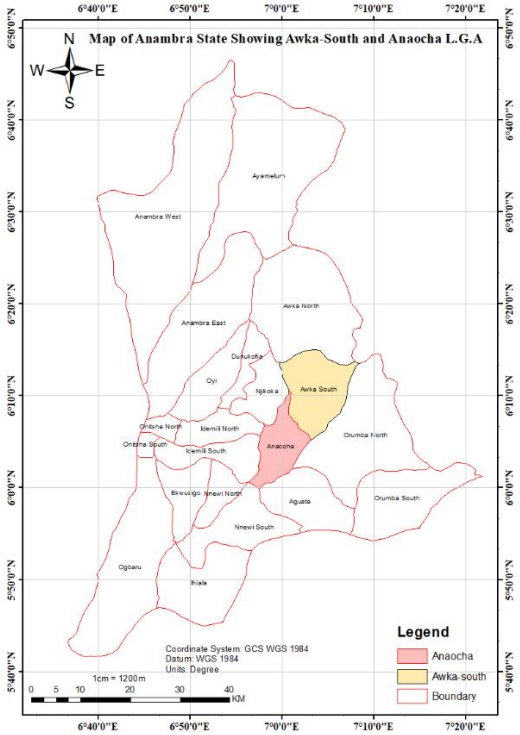


Figure 2.2 (a)

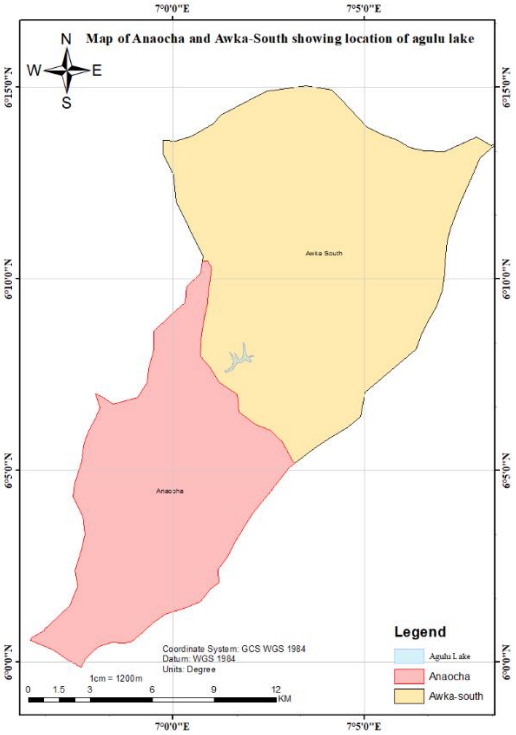


Figure 2.2 (b)

(a) Map of Anambra state showing Anaocha and Awka South LGAs, (b) Map of Anaocha and Awka South LGAs showing the spatial location of Agulu lake

The area is located at the Ecotom of the transition between the tropical rainforest and the wooden savanna grassland and is thus dominated mostly by the grassland and low forest vegetation that have scanty emergence of some taller trees (Udoudo *et al* 2024). The soil texture is mostly muddy and wet during rainy seasons, and this make it good in water holding and retention.



Figure 2.3 (a)

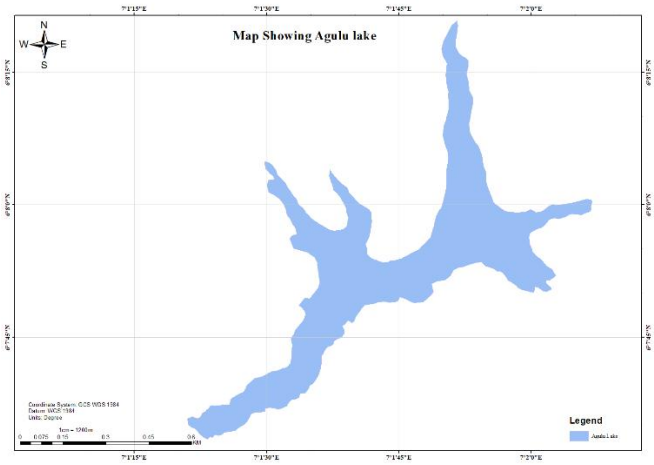


Figure 2.3 (b)

(a): Google Earth image of Agulu Lake, (b): Digitized Map of Agulu Lake



Figure 2.4 (a)



Figure 2.4 (b)

Figures 2.4 (a) and (b): Ground-Based Sectional Photographs Agulu Lake

The most notable feature that makes Agulu to be popular is the "Agulu Lake" (Fig.2.3 (a) and (b) and Fig. 2.4 (a) and (b)). The lake serves as a natural landmark, tourist center and also as a source of local livelihood. Agulu lake is known to be the home of crocodiles as their traditional belief system prohibits killing of crocodiles, rather they are worshipped. Thus Agulu serves as one of the major tourist attraction sites in the state.

3.0 MATERIALS AND METHOD

The methodology applied in this study involved the acquisition and processing of remote sensing satellite imageries, through GIS techniques to study the dynamics and temporal changes within the Agulu lake and it immediate environ. Primary data were also collected through site visit. The software applied in the study for data processing and analysis was ArcGIS. Microsoft office tools (MS-Excel and MS-Word) were also used for making of charts and for editing and arrangement of text. Remote sensing data source for this study was the Landsat 8 OLI satellite image of the study area downloaded from www.earthexplorer.usgs.gov and was imported into the ArcGIS environment, and with the help of clipping tool, the desired area or area of interest was clipped out.

3.1 Satellite Image Acquisition and Processing

3.1.1 Steps of Downloading Landsat Images

Downloading of satellite imageries was done at intervals of three years to suit the purpose of the study. Thus, the images downloaded covered; 2014, 2017, 2020, and 2023. This is because the dynamics and changes studied were at three years' interval covering from 2014 to 2023.

7) .

1) Click on the download button
2) Click on product options
3) You can either download the whole file which gives you more data
4) But for the purpose of this research, we only need the bands (1-7) which is what was downloaded
5) Choose the file destination (where to see the file after download)
6) Then wait for the download to be completed (Figure. 3.1 (a) and (b))

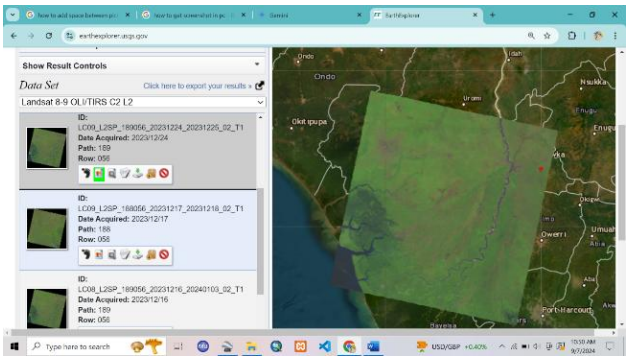


Figure 3.1 (a)

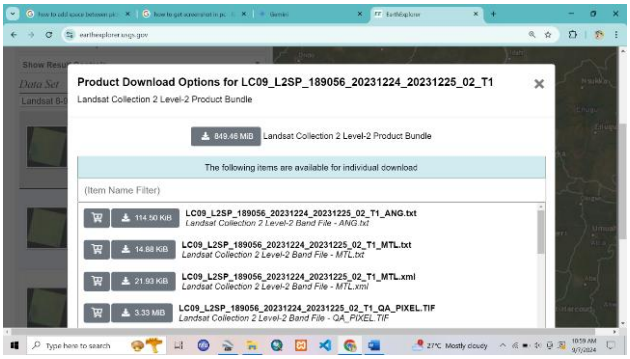


Figure 3.1 (b)

Figures 3.1 (a) and (b): Downloading Landsat Images

3.1.2 Importing Landsat Data into GIS

1) Use the "Add Data" or "Import" function in your GIS software to load the Landsat image file (Figure. 3.2).
2) Select from band 1 to band 7
3) Then click on the add button.
4) The software should recognize the multi-spectral nature of the image and allow you to add each band as a separate layer.

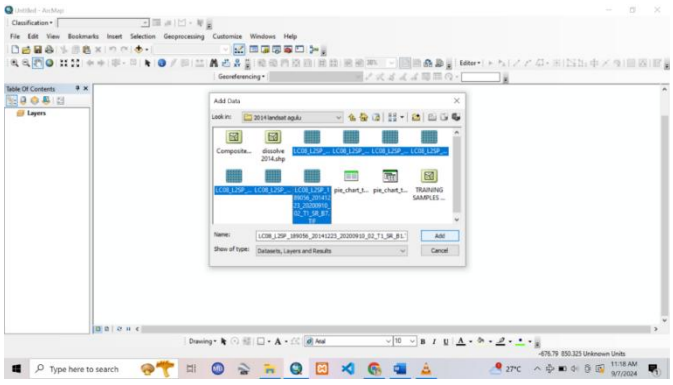


Figure 3.2: Importing Landsat Data into ArcGIS

3.1.2 Image Classification Process

The Landsat image was classified with ArcGIS to get the LULC feature classes Fig. 3.3 (a) and (b). Classifying the satellite imageries helped to group the available LULC features into different categories for easy identification and analysis. Image classification here was done by supervised classification. The level one LULC classification scheme designed by Anderson *et al* (1976) that groups LULC into five classes; Agriculture, Vegetation, Built-Area, Bare-Earth and Water Body was adopted for this study.

Supervised image classification was done following the steps shown here;

1) Select training sites for each LULC class and extract spectral signatures.
2) Use algorithms like interactive supervised classification to classify pixels
3) Select the training sample table this helps keep track of all the classification done on the map.
4) Using the polygon tool in the classification tab to select pixels that look similar to each other, Example, Waterbodies – blue, Vegetation – green, Bare land – yellow, and Built up area – red.
5) After choosing multiple samples for one classification using the training samples table you can merge training samples and name them one common name and give them one common color, e.g. waterbodies are usually associated with blue color.
6) When you are done with classification you click on interactive supervised classification from the classification tab on the menu bar (Fig. 3.3).

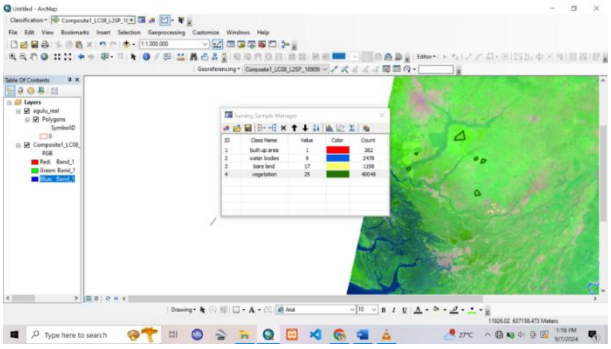


Figure 3.3 (a)

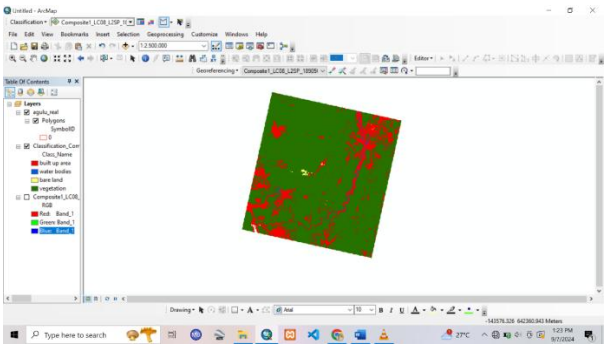


Figure 3.3 (b)

Figures 3.3 (a) and (b): Part of Image Classification Process

4.0 RESULTS AND DISCUSSION

The results in this study are shown in forms of discussions, maps, tables, and charts, to enable complex temporal and dynamic processes to be visualized. To achieve a reliable and efficient dynamical alterations, the area coverage of the different LULC classes are presented for each of the years studied.

4.1 Classified Images of Agulu Lake and its Environ from 2014-2023

4.1.1 Land Use/Land Cover (LULC) Distribution in the Study Area in 2014

The map in Figure 4.1 shows the LULC distribution in study area for 2014. As seen in the diagram, the dominant land cover type was vegetation, indicated by green colour, and covering approximately 52.26% of the entire area. This shows that there was much vegetative

cover, including farmland around the lake region as at 2014. Shore line vegetation is very helpful in preserving the lake's coastline especially for shallow lakes. Next in size was the Built-up areas, shown in red colour, which accounts for 30.41%, indicating some level of urbanization. These high residential setups within the lake region will certainly have an environmental impact on the lake. The third largest LULC class was Bare Land, comprising 15.52% of the total LULC class of the area, suggesting that there were some exposed soil or rocks within the area.

Water bodies occupy the smallest area of 1.82%, indicating limited water resources within the study region. Thus the major available water body here is mainly the lake. This information provides insights into the spatial patterns and characteristics of the study area (Figure 4.1).

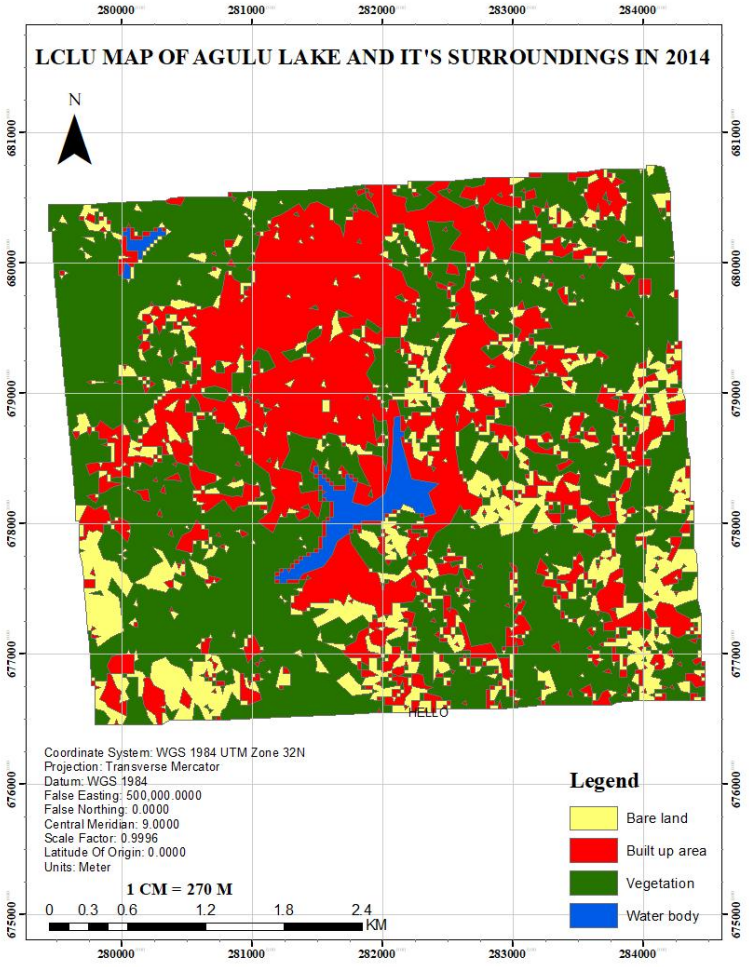
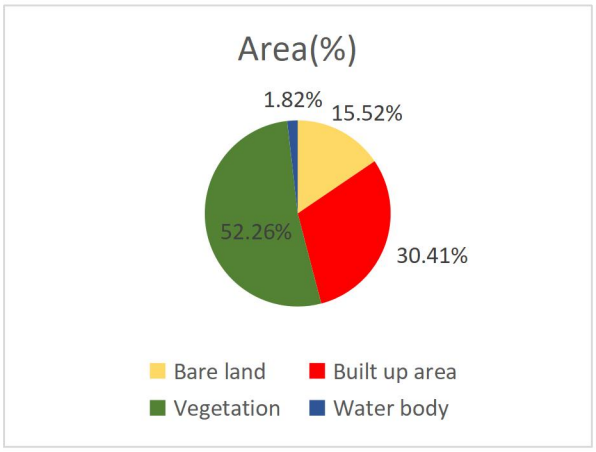


Figure 4.1: LULC Map for Agulu Lake and its Environ in 2014

The summary of the LULC classes in Agulu lake and its environ as at 2014 are presented in the pie chart and the bar chart in Figure 4.2 (a) and (b).



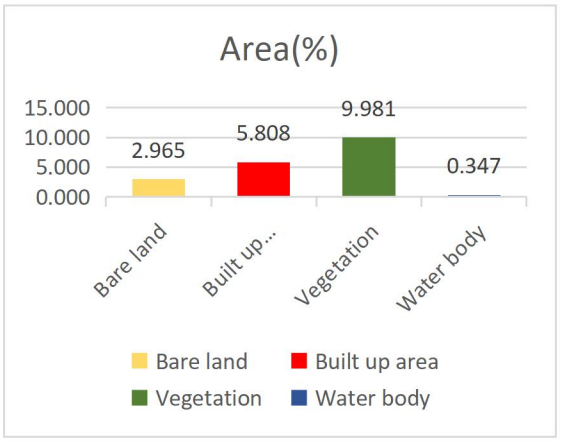
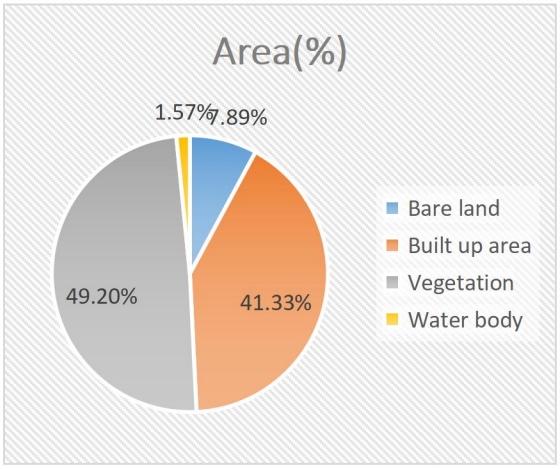


Figure 4.2 (a) Figure 4.2 (b)

Figures 4.2 (a): Pie Chart of LULC Map 2014 (b): Bar Chart of LULC Map 2014

4.1.2 Land Use/Land Cover (LULC) Distribution in the Study Area in 2017

The land use/land cover distribution in a study area as at 2017 shows a little distiction from that of 2014. The LULC classes in the Agulu lake and its environ at 2017 are presented in the pie chart and the bar chart in Figure 4.3 (a) and (b).



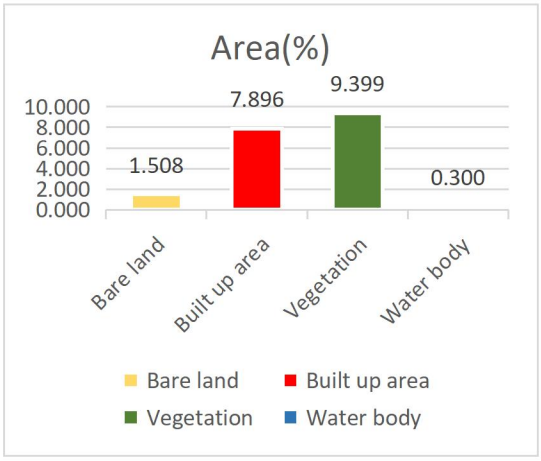


Figure 4.3 (a) Figure 4.3 (b)

Figures 4.3 (a): Pie Chart of LULC Map 2017 (b): Bar Chart of LULC Map 2017

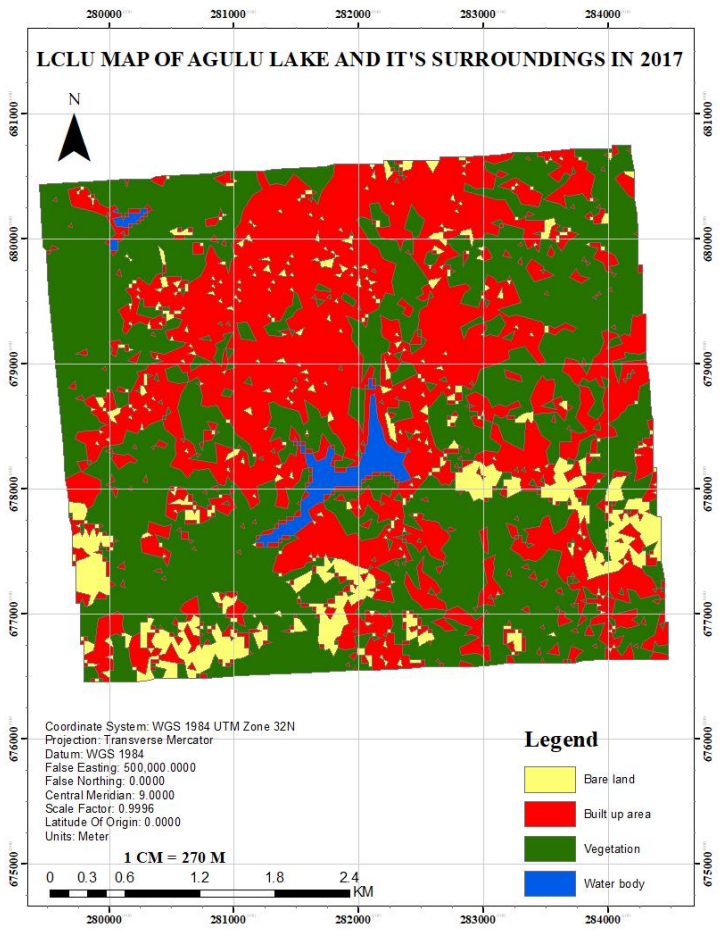


Figure 4.4: LULC Map for Agulu Lake and its Environ in 2017

Bare land comprises 7.89% of the area, suggesting exposed soil or rock are now reducing in area. This may be due to high pressure of increasing residence and builtup area. Water bodies occupy the smallest area of 1.57%, indicating reduction in the lake space within the study area between 2014 and 2017 (Fig.4.4). This information provides insights into the spatial and temporal patterns and characteristic dynamics of the study area.

4.1.3 Land Use/Land Cover (LULC) Distribution in the Study Area in 2020

The map in Fig. 4.5 shows the LULC distribution in a study area in year 2020. The dominant land cover type is vegetation, covering approximately 53.76% of the area. Built-up areas account for 42.10%, indicating some level of urbanization when compared to that of 2017. Bare land comprises 2.27% of the area, suggesting gradual reduction in exposed soil or rock. Water bodies occupy the smallest area of 1.87%, indicating limited water resources within the study region. This information provides insights into the spatial patterns and characteristics of the study area in year 2020 (Figure. 4.5 and 4.6 (a) and (b).

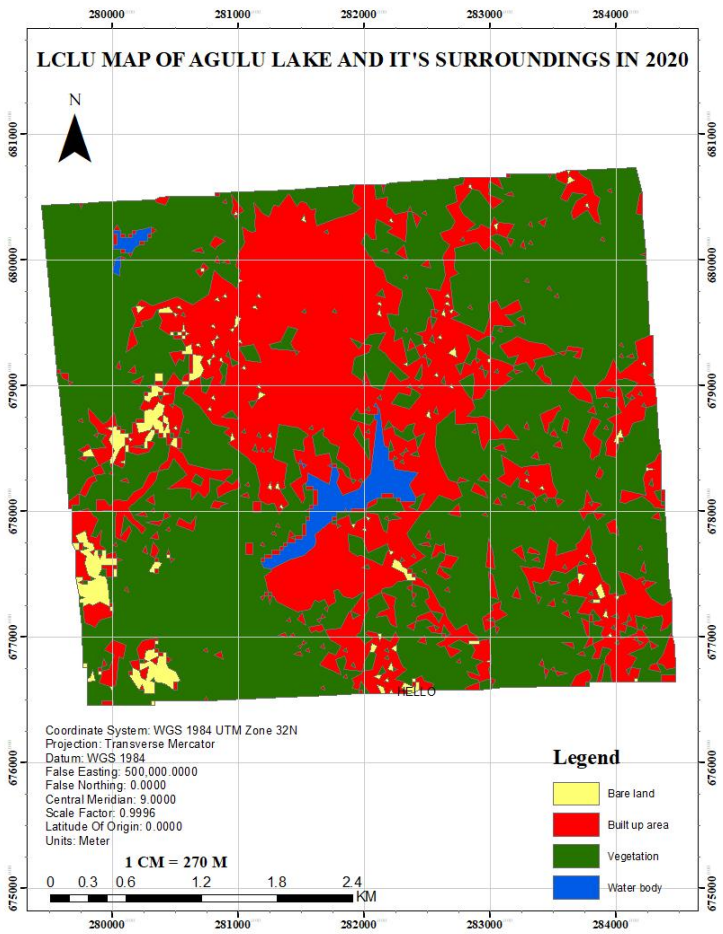
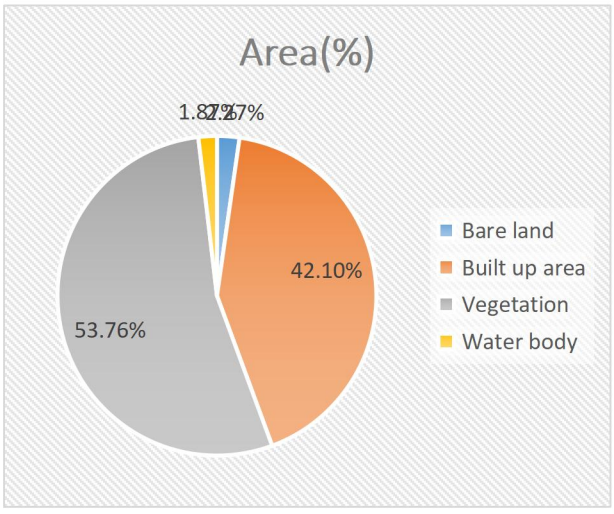


Figure 4.5: LULC Map for Agulu Lake and its Environ in 2020



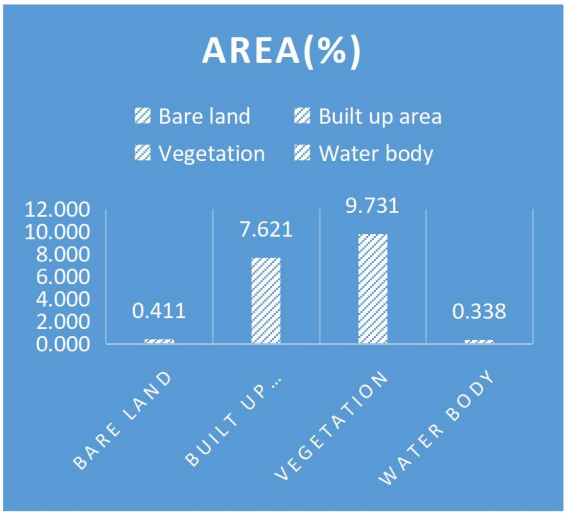


Figure 4.6 (a) Figure 4.6 (b)

Figures 4.6 (a): Pie Chart of LULC Map 2020 (b): Bar Chart of LULC Map 2020

4.1.4 Land Use/Land Cover (LULC) Distribution in the Study Area in 2023

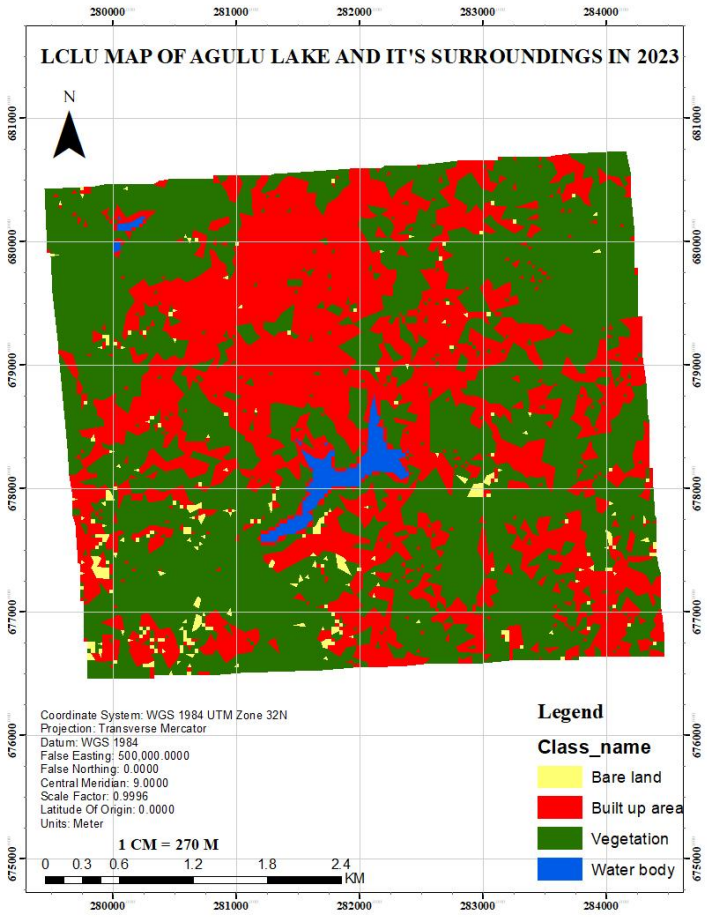
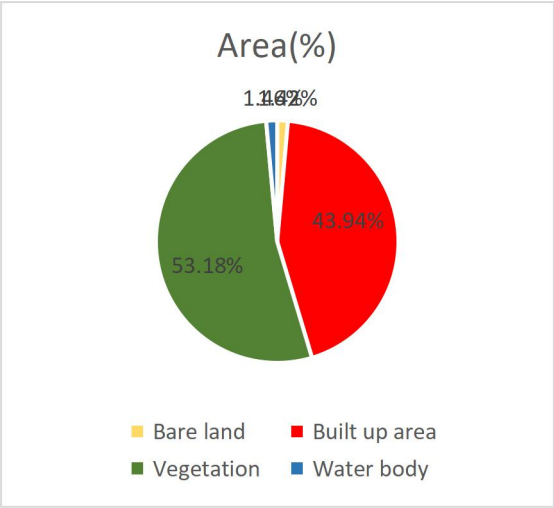


Figure 4.7: LULC Map for Agulu Lake and its Environ in 2023



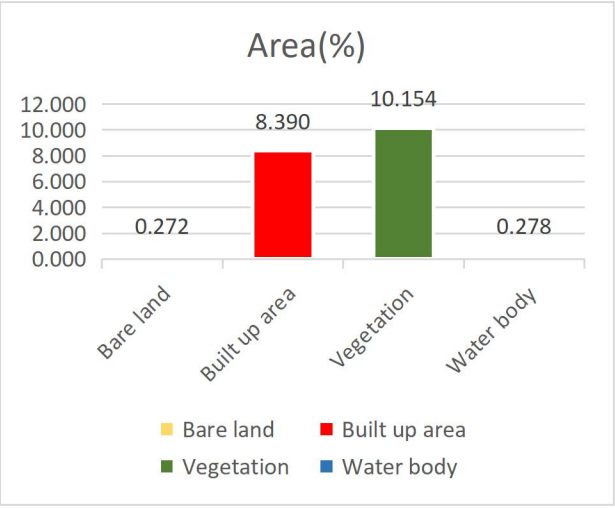


Figure 4.8 (a) Figure 4.8 (b)

Figures 4.8 (a): Pie Chart of LULC Map 2023 (b): Bar Chart of LULC Map 2023

The map shows the land use/land cover distribution in a study area. The dominant land cover type is vegetation, covering approximately 53.18% of the area. Built-up areas account for 43.94%, indicating some level of urbanization. Bare land comprises 1.42% of the area, suggesting exposed soil or rock. Water bodies occupy the smallest area at 1.46%, indicating limited water resources within the study region. This information provides insights into the spatial patterns and characteristics of the study area. These are seen in Fig. 4.7 and in Fig. 4.8 (a) and (b).

4.2 LULC Changes from 2014 to 2023

A more precise presentation of the classification of the satellite imageries of the study area into four major classes (Waterbody, Vegetation, Bare land and Built-up Area), presented in Square Kilometers for easy understanding are shown in table 4.1 and 4.2. These tables illustrate the spatial distribution of different land use categories over the study period of ten years (from 2014-2023).

Table 4.1: Area Covered by the Various Land Use Categories in Agulu Lake.

Year	**2014** (km^2)	**2017** (km^2)	**2020** (km^2)	**2023** (km^2)
Water bodies	0.347	0.299	0.338	0.278
Built-up Area	5.808	7.896	7.621	8.390
Vegetation	9.981	9.399	9.731	10.154
Bare land	2.965	1.508	0.411	0.272

Table 4.2: Percentage of the Area Covered by the Various Land Use Categories in Agulu Lake.

Year	**2014**	**2017**	**2020**	**2023**
	% of Land use			
Water bodies	1.82	1.57	1.87	1.46
Built-up Area	30	41	42	44
Vegetation	52	49	54	53
Bare land	16	8	2	1

4.2.1 Water Bodies

The water bodies within Agulu Lake and its immediate environs from 2014 to 2023 show some reduction or negative changes. In 2014, waterbodies covered 0.347 km^2 (1.82% of the study area). This decreased slightly to 0.299 km^2 (1.57%) in 2017. It then increased marginally to 0.338 km^2 (1.87%) in 2020, but decreased too low to 0.278 km^2 (1.46%) in 2023. This decrease in water bodies between 2014 from 0.347 km^2 (1.82% of the study area) when the study started to 0.278 km^2 (1.46%) in 2023, when the study

ended, show a serious reduction in the lake size. The decrease here of such area shown in kilometres square is highly alarming. These changes suggest that the surface area of Agulu Lake and its associated water bodies has reduced drastically over the decade.

4.2.2 Built-Up Areas

The analysis of built-up areas around Agulu Lake from 2014 to 2024 shows a notable increase in urbanization. In 2014, built-up areas covered 5.808 km^2, representing 30% of the study area. This increased significantly to 7.896 km^2 (41%) in 2017, then increased to 7.621 km^2 (42%) in 2020, and finally increased to 8.390 km^2 (44%) in 2023 (Figure. 4.1and 4.2).

This increase in the built-up area when considering the beginning of the study (2014) and the end of the study (2023), indicates a high trend of urban expansion and development over the area. The increase in built-up area suggests ongoing construction and infrastructural development in the region. This is also the major cause of the reduction in bare land noticed from the study. Such an alarming growth is inimical to the existence of the lake. This trend may be driven by the pressures of population growth, economic development, and increased demand for housing and commercial spaces. While urbanization can bring economic benefits and improved infrastructure, it also poses several environmental challenges. The expansion of built-up areas often leads to habitat loss, increased surface runoff and greater pollution levels. These impacts can negatively affect the local ecosystem, water quality, and biodiversity around Agulu Lake.

4.2.3 Vegetation

The analysis of vegetation covers around Agulu Lake and its immediate environs from 2014 to 2023 indicates a very high increase. In 2014, vegetation covered 9.981 km^2, accounting for 52% of the study area. This decreased to 9.399 km^2 (49%) in 2017, increased again to 9.731 km^2 (54%) in 2020 and finally increased so high to 10.154 km^2 (53%) in 2023 (Figure. 4.1 and 4.2). These changes suggest a substantial increment in vegetation cover over the decade. These increase in vegetation cover from 9.981 km^2 to 10.154 km^2, between the start of the study in 2014 and the end of the study in 2023, may be attributed to several factors, such as eutrophication of the lake, agricultural expansion. This result shows that part of the lake is gradually being claimed by vegetation. Thus, the lake is shrinking in size while the vegetation is increasing (Table 4.1 and 4.2). If nothing is done about this rate, the lake may turn to a dry valley occupied by grasses in future in the nearby future (Table. 4.1 and 4.2).

4.2.4 Bare land

The analysis of bare land around Agulu Lake and its environ from 2014 to 2023 shows a notable decrease in the bare land (Table. 4.1 and 4.2). In 2014, the built-up areas covered the total area of 2.965 km^2, representing 16% of the study area. This decreased significantly to 1.508 km^2 (8%) in 2017, and later declined to 0.411 km^2 (2%) in 2020 and finally decreased slightly to 0.272 km^2 (1%) in 2023. The cause of this decrease from 2.965 km^2 in 2014 representing 16% of the study area to 0.272 km^2 (1%) in 2023 is alarming. This is not far from increase in the built up areas or urbanization around the lake. Water droplets from the roof of buildings draining through the ground is likely to carry much sand into the lake. This is likely to be the reason why the lake size is reducing but the vegetation size is increasing. This calls for the management effort to ensure proper measures are taken to preserve the lake from total drying up.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Application of remote sensing and GIS has proven to be a very reliable and useful tool in the study of the patterns of dynamics in any environmental unit. This study assessed the spatio-temporal changes within Agulu Lake (of Anambra state of Nigeria) and its immediate environs through the use of remote sensing and GIS techniques. This study has yielded a good and efficient result as it has given a valuable insight into the dynamics of the LULC features and characteristic in the region. The satellite image classification of the LULC classes into Waterbody, Vegetation, Bare land and Built-up Area in the study area has revealed that Agulu lake (belonging to the water bodies in the LULC classification) is drastically shrinking from its initial size. The study reveals that there is a notable reduction in the available water space within Agulu lake and its environs between 2014 (when the duration of the study started), from 0.347 km^2 (1.82% of the study area) to 0.278 km^2 (1.46% of the study area) in 2023 (when the study duration ended). This reduction shows that the size of the lake is decreasing at a noticeable rate, and that if no immediate control measures is taken, the deadness of Agulu lake may be a future occurrence. The reason for the decrease in size of the lake is mostly due to urbanization and eutrophication (a process where there is much nutrient in the water from land source causing more plants to grow in the water). The high rate of urbanization and coastal agriculture also contributes to sand deposition from the runoff. The lake may need to be dredged to regain its initial size.

Built-up area on the other hand has increased from 5.808 km^2, representing 30% of the study area in 2014 to 8.390 km^2 (representing 44%) in 2023. The increase in urbanization and built-up areas around the Agulu lake environs by 14% within the study duration is highly alarming and cannot go without a negative impact on the lake. Automatically, part of the lake's wetland must go for it. Apart from this, there is going to be waste dumping into the lake. And some of the residents will block the sources of ground waters feeding the lake. Human impact also will lead to high rate of erosion and sedimentation, and consequently, filling of the lakes with the eroded soils.

The temporal dynamics and modifications of the vegetation around Agulu lake and its immediate environ shows and alarming warning. The study reveals that there is an increase in vegetation cover from 9.981 km^2 in 2014 to 10.154 km^2, in 2023. This increment is a kind of red line warning to the Agulu lake management authority. One may be tempted to think that since there is an increment in vegetation cover around the lake region, it is welcoming change. But that is not so, because at the same time, the available water space in the lake is reducing. The main cause of this increase in vegetation cover and a decrease in the water body is likely to be due to siltation of the water from sand carried into the lake by flood. Another major reason is mostly due to a eutrophication process whereby nutrients from the coastal agriculture are washed into the lake cause the growth of plant in the lake, mostly at the peripheries where heavy sand is deposited.

The study equally reveals that Bareland is reducing drastically between 2014 and 2023. Within the period, bareland from the classified result shows a decrease from 2.965 km^2 in 2014 representing 16% of the study area to 0.272 km^2 (representing 1% of the same study area) in 2023. This shows that residential buildings have taken much of the former available bareland spaces.

5.2 Recommendations

This study recommends that more researcher should carry out practical bathymetric study on the depth of Agulu lake to know when it is necessary to dredge the lake to avoid its deadness in the a sooner future. There shoulda lso be a joint effort of the Agulu lake management authority and the government of Anambra state, with the task of developing measures to ensure that urbanization and

shoreline agriculture around the lake and its environs is under control and regulations.

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