Wetlands Mapping and AI-driven insights for enhanced Climate-Resilient Land Management in Rivers State, Nigeria. (SDG 11 & 15)

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Key words: Wetland; Mapping; Land Management, Coastal Zone Management; Land management;

SUMMARY

Wetlands mapping for assessing wetland conversions and land use classification using satellite imagery and remote sensing techniques will pave the way for significant improvements in the management of wetlands in Rivers State, Nigeria. Rivers State is spatially located in the Niger Delta coastal region of Nigeria with a population of about 5,185,400 people and approximate size of 11,077km^2. The area is changing rapidly due to urbanization where significant wetlands have been converted for other purposes posing consequences such as flooding, detrimental to the socio-economic well-being of the people and hinders the capacity of the state to have resilient cities. Therefore, efforts for conservation are being made to optimize the use of wetlands in the state. The aim of this work was to access the conversion of wetlands over 30years, from satellite derived spectral indices and Land Use classifications in parts of Rivers State from 1995-2025 and to determine the features existing on the lands. This was assessed linking the sustainable development goals and the available national wetland laws. Data acquisition from LandSat 4, 7 and 8 were acquired from the United State Geological Surveys (USGS) Earth explorer and data preprocessing was done on the imageries acquired using QGIS 3.34.9 to correct for atmospheric and radiometric issues in the datasets. Ground control spatial data were acquired for verification. LU/LC image supervised classification adopting the machine learning algorithm to provide enhanced results for the available wetlands area in 2025 was done using ArcGIS Pro, GeoAI tools. These provided the temporal changes over 30years. This change detection served as basis for informed decisions regarding this natural resource in line with national and international laws, having defined the specific drivers to be considered in the wise and optimal use of wetlands for environmental sustainability, enhanced Land Administration and Management.

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1.0 INTRODUCTION

1.1 Background

Rivers State is characterized by significant wetland areas especially in Port Harcourt, and the coastal areas. However, the state is rapidly changing due to urbanization, real estate development, constructions activities, which have the potential to significantly impact these wetland areas. The region is exceptionally rich in flora and fauna, hosting endangered species like the Niger Delta Red colobus monkey. The state houses one of the eleven Ramsar Internationally recognized wetland sites in the Upper Orashi Forests, a protected area of international importance. The mangrove and peatfalls in the Deltaic areas of the state are highly effective as 'blue carbon' sinks, storing large amounts of carbon in their biomass and soils. This is important for enhancing more climate change mitigation efforts. The wetlands are natural filters, that purify ground water by trapping sediments and pollutants from surface water. This effortlessly helps maintain the health of aquatic ecosystems and provide the communities with clean drinking water.

The wetlands are also rich in nutrients serving as breeding grounds for a wide variety of fish, crustaceans (prawn) and mollucks, which are primarily sources of food security, income and employment for the local populace. The wetlands also provide non-timber forests products including plant medicine, fuel woods, craft materials and timber for building.

This work should provide significant information that considers aspects impacting on the Sustainable Development Goals (SDG's) 15; biodiversity loss, pollution and climate change. The SDG 15, which aims at the protecting, restoring and promoting the sustainable use of terrestrial ecosystems, sustainably managing forests, combating desertification, halting and reversing land degradation, and halting bio-diversity loss, is therefore a significant basis for this work. The implication is that the well-being of the people in the state is guaranteed, livelihood is supported, improving the quality of life of the people which should align to SDG 11: Life on Land.

There is increase in the awareness of the importance of wetlands to man and his environment resulting in many studies about wetlands, but developing countries like, Nigeria, where this study area is situated requires that policies about the protection and restoration of wetlands should be enhanced. This means that the agencies responsible for wetland preservations in the state should have specific governing policies that are based on current spatial information about the use of these wetlands. Therefore, the use of the wetlands requires policies for proper Land Administration and management.

The allocation of Landed properties in and around wetlands or the reclamation and conversion of lands in wetland areas are activities that the government must begin to consider for the enhancement of Land Administration and Management. Now, if the wetlands are not

preserved, the value of Lands in and around wetland areas is altered as such. It is therefore important that specific studies are done to bring to the fore the dynamics and changes over time.
Effective conservation efforts and strategies hinge on the collection of high- quality information derived from the comprehensive assessment of wetland conversion in the state, considering key factors and drivers that influence land use decisions (Turner et al, 2018). These conservation efforts are enhanced by making quality studies about the indices that represent the reflective capacities of features in the environment and the wetlands under study. To understand the Land use types that may be replacing the wetlands, it is crucial that we analyze Land Use/Land Cover (LU/LC) data to first map the spatial distribution of landed features (Huang, Chen & Liu, 2020). The outcome of all, of these studies is vital for informed decision-making.

1.2 The Problem

The problem faced in Rivers State is the rapid conversion of wetland ecosystems exacerbated by anthropogenic activities springing from rapid urbanization. The conversion of the wetlands for other uses is degrading them, and threatening their ability to provide ecosystem services like flood control, water purification and carbon sequestration services crucial for urban and city sustainability and resilience to climate change (Out, *et al.* 2020). The state is in the verge of improving her land management policies and wetland management is core considering the rapid development in the region. In addition, one of the primary causes of global warming; the burning of fossil fuels, which releases carbon dioxide into the atmosphere is prevalent in the region. The carbon dioxide emitted which should be absorbed by the presence of wetland is now a concern as the wetlands are threatened with rapid urbanization creating urban heat. Land Administration processes in the state requires that current wetland change dynamics are derived to aid insightful policies and strategic approaches that will enhance land use. The potential of AI in enhancing the accuracy and efficiency of wetland mapping and monitoring remains underexplored in the state. Artificial (AI) Intelligence merged with Geospatial Data processing enhances data processing and analyses of wetlands in time and accuracy Traditional methods of wetland management adopted in the region often reliant on manual surveys are limited in scope and lack the precision necessary for strategic and quick decisions making amidst the rapid urban trends. This underscores the need for innovative technologies that offer detailed, real-time insights into wetland dynamics (Olalekan, 2021).

1.3 Aim of the Study

The aim of the study is to map the Wetlands imploring AI-driven insights for enhanced Climate-Resilient Land Management in Rivers State, Nigeria in line with the SDG 11 and SDG 15.

1.3.1 <u>Objectives of the Study</u>

1. To determine the spatial extent of wetlands within the study area for the period under study.
2. To generate the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) values to detect wetlands.

3. To quantify the extent of wetland conversion over a 20 years period using supervised classification and AI classification algorithms.
4. To determine the main drivers for the wetland conversion providing geospatial data of features on the wetlands converted over a period in the study area.
5. To provide actionable insights that can guide environmental management and policy development in the region.

1.4 The Study Area

Rivers State, located in the vibrant Niger Delta area of southern Nigeria, with Port Harcourt as its capital. The state is positioned between latitudes 4° 35' through 5° 10' North and longitudes 6° 55' through 7° 55' East, and strategically bounded by Imo and Anambra to the north, Abia and Akwa Ibom to the east, Bayelsa and Delta to the west, and the Atlantic Ocean to the south (see figure 1) Covering an area of approximately 11,077 km², the state has a population of around 5.2 million. It was officially established on 27 May 1967, breaking away from the former Eastern Region, and now comprises 23 Local Government Areas (LGAs).
There are 11 Ramsar wetland sites internationally recognized in Nigeria and one of such is located in the study area; the Orashi Area in Rivers State (see figure 2 below). The major water body that influences the State is the Bonny River about 66 kilometers upstream from the Gulf of Guinea in south-western Nigeria. The Bonny River serves as an important waterway for transportation and commerce, connecting Port Harcourt to the Bonny Island and the Atlantic Ocean. It supports various economic activities, including shipping, fishing, and oil exploration. The Niger Delta region which houses the State is renowned for its complex system of creeks, rivers, and wetlands. These water bodies contribute to the region's unique ecological diversity and provide habitats for a wide range of flora and fauna.

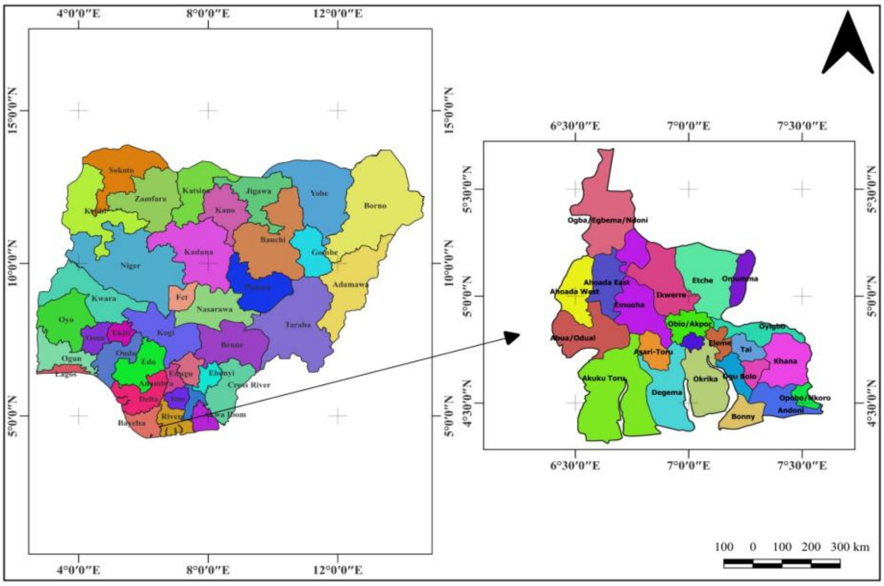


Figure 1: Study Area Map.

Figure 2: Aerial View of Orashi Region Ramsar site in Rivers State.

2.0 BRIEF LITERATURE

According to Dienye, Dagogo and Pepple (2019), when wetlands are altered without considering their full value, the negative consequences such as flooding and increased carbon in the atmosphere can be felt immediately by the local people. This is because although it is a natural resource, its mismanagement can result in disasters (Costanza 2021; Hoag et al, 2001; Abubakar & Abdusalam, 2024); and therefore, hinder sustainable development. It is on this premise that the Ramsar Convention was signed, which aimed at the wise use of all wetlands through local, national and international actions and cooperation as a contribution towards achieving sustainable development all over the world. Nigeria became a contracting party, giving her assertion to the Ramsar Convention on the 2nd February 2001 where eleven (11) Ramsar sites were identified (Nwankwoala, 2009).

There are various definitions of wetlands which mostly relates to the aim of the research or the type of wetland under study. As defined by Zedler & Kercher, (2005) and adopted for this study, a wetland is an area where water covers the soil or is present either at the surface or near the surface of the soil all year round or for varying periods of time during the year even during the growing seasons. The Ramsar Convention states that wetlands include all lakes, rivers, underground aquifers, swamps, marshes, wet grasslands, peat lands, oasis, estuaries, deltas and tidal flats, coral reefs and all man-made sites such as fish ponds, rice paddies, reservoirs, and salt pens. (Ramsar Convention, 2018 in Dienye & Fubara 2019). Again, the US Army Corps of Engineers and the Environmental Protection Agency (EPA) defined wetlands as “those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support a prevalence of vegetation typically adapted for life in saturated soil conditions” (EPA, 2008).

Most wetlands are defined by a typical vegetation type and always wet soils, so their conversion or otherwise could be assessed from the temporal analyses over a period of time of the variations in the water content and the typical vegetation losses.

spectrum, as NDVI uses the red band and NDWI uses the green bands.

The spectral indices are mathematical algorithms applied in digital image processing by combining pixel (picture element) values from the different spectral bands of an image in order to define the specific feature properties of objects on the earth. Spectral Index is an equation that combines pixel values from two or more spectral bands in a multispectral image using various algorithms, mainly focusing on the band ratio or feature scaling (Tran, Reef, & Zhu, 2022). The data obtained about the spectral reflectance bands for features are combined in the classification processes to define a mathematical model that represents feature characteristics. This is what is known as Band Combination in digital image processing.

2.1 Importance of the Study

The integration of AI with remote sensing technologies presents an opportunity to improve in the management of wetlands in the state by providing comprehensive data-driven insights. The AI algorithms can process and analyses large datasets from satellite imageries, identifying patterns and predicting changes with greater accuracy compared to traditional methods adopted by the state previously (Geller et al, 2022). This capability makes the method very essential in developing climate resilient land management strategies that align with the SDG.s 11 and 15, as so fostering urban resilient cities in the region.

2.2 Wetland land management using AI-driven insights

AI-driven Mapping enhances land management precision by transforming reactive processes into proactive, data-rich strategies. The integration of Deep Learning Algorithms and Geospatial analytics, known as GeoAI, has enhanced feature classification accuracies up to 95% for high resolution mapping of wetlands and 90% for low resolution mapping.

Random Forest and Convolutional Neural Network (CNN) processed large data sets that deals with the whole state. The AI models differentiate complex categories of nypa palm, mangroves, degraded wetlands, urban sprawl, water bodies, bare earth, vegetation types, by analyzing pixel-level spectral signatures.

The deep learning process detects hidden wetlands obscured by the canopy trees in the rain forest areas, which normal feature extraction cannot achieve. AI-driven insights identify infrastructure vulnerabilities in coastal cities like Port Harcourt, guiding "no-build" zoning to protect natural stormwater buffers.

Traditional mapping is often outdated before publication. AI enables continuous updates, so results are published quicker for the government or relevant authorities to act fast. Cloud-based AI processing allows smaller firms to handle large datasets without expensive local hardware, reducing overall project investment by up to 30%.

Sustainable and resilient cities, which aims at achieving SDG’s 11 and 15.

2.3 Automated Wetland Detection Algorithms

These algorithms primarily focus on land-cover classification and semantic segmentation using satellite imagery and LiDAR data.

- Convolutional Neural Networks (CNNs): Architectures such as **U-Net** and **DeepLabV3** are widely used for pixel-level semantic segmentation to identify wetland boundaries and distinguish them from similar terrain.
- Random Forest (RF): A dominant machine learning technique for geospatial analysis, used to classify landforms based on elevation, soil characteristics, and moisture retention.

– Support Vector Machines (SVM): Frequently employed for binary classification (e.g., wetland vs. non-wetland) due to their effectiveness in handling complex, high-dimensional datasets with limited training samples.
– Deep Forest (DF): Emerging as a superior alternative to traditional tree-based models, providing higher accuracy for multi-class wetland mapping.
– Transformers: Used for large-scale ecological analysis, especially when integrating multi-spectral and thermal data to refine boundary delineation.

2.4 Wetland Mapping and AI Integration

The traditional GIS mapping has transitioned into modern AI technology adopting Geospatial AI (GeoAI) -AI powered geo-spatial systems that use Machine learning to predict patterns of wetland conversions in the region. The models generated integrate vegetation and water (Moisture) indices and elevation date to categorize the features within the region into 4 classes; built up, water body, vegetation and wetland (Mangroves and Nypa palm) enabling proactive wetland conversion risks.

3.0 MATERILAS AND METHODS

3.1 System Requirement

In assessing the wetland areas converted in the study area, the following software and hardware were utilized namely:
(a) ESRI's ArcGIS 10.3 was used for the clipping of the images used in the study, and for map compilation.
(b) QGIS 3.34.9 software was adopted for image processing.
(c) Laptop computer with processor Intel® Core (TM2) Duo CPU P9700, 4.00GB RAM, and 64-bit operating system.
d) Python used to merge the images from the two scenes Band by band

3.1.1 Data Source

Sensor Type	Path/ Raw	Imagery Date	Spatial Resolution	Band Used	Wavelength (µm)
TM	188/57	07/01/1991	30m	B3	0.52-0.60
				B4	0.63-0.69
				B5	0.69-0.90
ETM+	188/57	31/12/2005	30m	B3	0.63-0.69
				B4	0.69-0.90
				B5	1.55-1.75
OLI	188/57	03/12/2015	30m	B4	0.636-0.673
				B5	0.851-0.879
				B6	1.566-1.651
OLI_TIRS	188/57	01/03/2025	30m	B4	0.63-0.69
				B5	0.69-0.90
				B6	1.55-1.75

3.2 Remote Sensing Applications in Wetland Assessment

Remote sensing is a very valuable tool for wetland monitoring as it provides data on wetland extents, vegetation health, and water quality. Satellite imagery and aerial photography are combined with Geospatial Information System (GIS) to enhance mapping, detect changes, and assess wetland ecosystems. Data obtained from Remote Sensing methods can be used to obtain the spectral Indices from objects in the environment based on their reflectance capacities in the electromagnetic spectrum, and hence monitor features like vegetation indices, water levels, water quality, land cover changes, etc. The application of Remote Sensing therefore aids in conservation efforts and sustainable management practices.

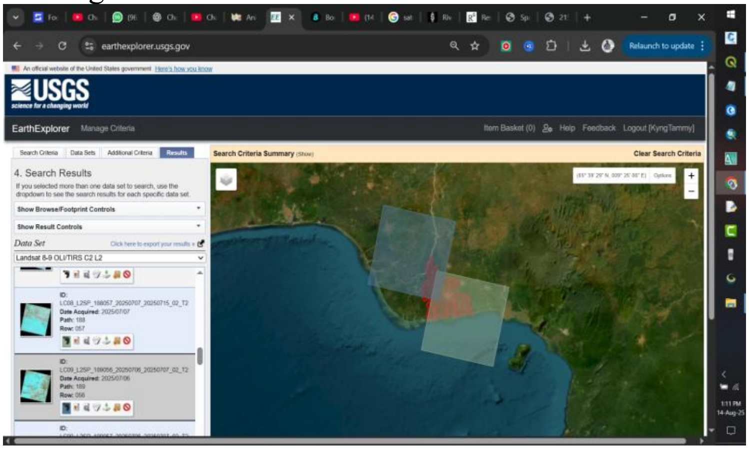


Figure 3: Staellite Imagry of the study area

3.3 Remote Sensing in Wetland Mapping

Remote Sensing methods are beneficial for monitoring essential biodiversity variables because they are cost effective and allow for coverage of large areas with a quick turnaround time. To conserve wetland resources, manage wetland programs, and evaluate performance of existing programs, it is important to identify and monitor wetlands and their adjacent uplands. Satellite remote sensing data, especially free remote sensing data have many advantages for wetland monitoring. Ozesmi and Bauer in 2002 stated that satellite remote sensing data are relatively less costly and less time-consuming to acquire and use, especially for the analysis of large geographic areas (as cited in Yue Gu, 2015). Brivio in 2002 also stated that the digital format of remote sensing data makes it easy to integrate into the Geographic Information System (GIS) (as cited in Yue Gu, 2015). Satellite can regularly monitor wetland conditions, for instance, Landsat-7 sensors overpass and monitor the same area every 16 days. Moreover, based on the policy made in 2008, the United States Geological Survey (USGS) has been providing all LandSat data over the internet for free (Woodcock *et al,* 2008). However, satellite imagery and geospatial analysis methods also have some limitations (Ozesmi & Bauer, 2002; Zhu & Woodcock 2012). The overlapped spectral signatures of different wetland types make it difficult in separation (Zhu & Woodcock, 2012)

3.4 Data Manipulation and Pre-Processing

3.4.1 Band Combination/Band Stacking

In delineating wetland areas, it is important that the various bands of the acquired imagery are combined. Therefore, he different bands in the imageries used were imported to the GIS because the objects in the environment have different spectral reflectance that are visible in either of the bands in the visible region of the electromagnetic spectrum (Dienye, 2013). The color composite of the study area was performed from the raster processing tool by adding the bands. This combination of near-IR (Band 4), mid-IR (Band 5) and red (Band 3) offers added definition of land-water boundaries and highlights subtle details not readily apparent in the visible bands alone

3.4.2 Image Clipping

In order to focus on the Area of Interest (AoI), generalization process was done to reduce the large dataset associated with the AoI. Using the ‘clip raster by marked layer tool’, the image is added to the GIS Software. A vector layer was then created that defined the clipping boundary. In doing this we ensured that the image and layer are on the same reference system as well as maintaining the study area boundary. The study area extent was defined using the image clipping operation tool in ArcGIS toolbox –The clipped image was exported in TIFF to ENVI and here it was resaved in GeoTIFF that is readable.

3.5.3 Image Classification

To interpret and identify of reflectance of image features, supervised image classification was done where the Land use/Land cover are extracted from the satellite imageries of the study area as defined from the clipped data. Maximum Likelihood approach (MLC), using a vector layer containing training polygons. The objective of the image classification is to correct/compensate for data errors, enhance the image and to rectify the image for further extraction of needed information. It involved grouping of the pixels representing the feature classes within the study area. This resulted in the various datasets including the area of the various land use and land cover.

During image classification level I classification scheme was adopted in which four land cover types (water body, built up, vegetation and wetland) were identified and classified. This process was carried out for all the bands of the imageries, using the ROI tool. The MLC assumed that the pixel is assigned to the class to which it has the highest probability. The operation was performed using QGIS Semi-automatic classification plug in.

3.5 Advantage of Real-Time Monitoring and Change Detection

3.5.1 Traditional mapping is often outdated before publication. AI enables continuous updates:

- **Rapid Alerts:** Systems now generate alerts when a wetland shrinks by a certain threshold (e.g., 20%) or when illegal logging is detected in real-time.
- **Spatio-Temporal Analysis:** AI analyzes 30+ years of historical data to distinguish normal seasonal flooding from permanent habitat loss caused by human encroachment.

3.5.2 Supporting SDG 11 & 15 Targets

- **SDG 11 (Sustainable Cities):** AI-driven insights identify infrastructure vulnerabilities in coastal cities like Port Harcourt, guiding "no-build" zoning to protect natural stormwater buffers.
- **SDG 15 (Life on Land):** By automating species identification via camera traps and acoustic sensors, AI monitors biodiversity health within wetlands more accurately than manual surveys.

3.5.3 Operational Efficiency needed in Nigeria

AI-driven tools offer significant resource savings and can provide meaningful management of fiscal resources.

- **Field Safety:** Monitors can document evidence of land degradation or illegal activities from safe distances using satellite and drone data rather than risking physical confrontation.

4.0 RESULTS

4.1 Reflective Indices for Water Content and Vegetation

This model was developed which satsfies the range of swctral values of -1 to 1 for water and vegetation in remote sensing mapping.
The results of Indicators for wetland identification in the State using the Water and Vegetation Indices provided insights to the areas that have wetlands in the various yeasr. Therefore, the actual wetlands were derived from the spectral indices of classified features and their elevation data.

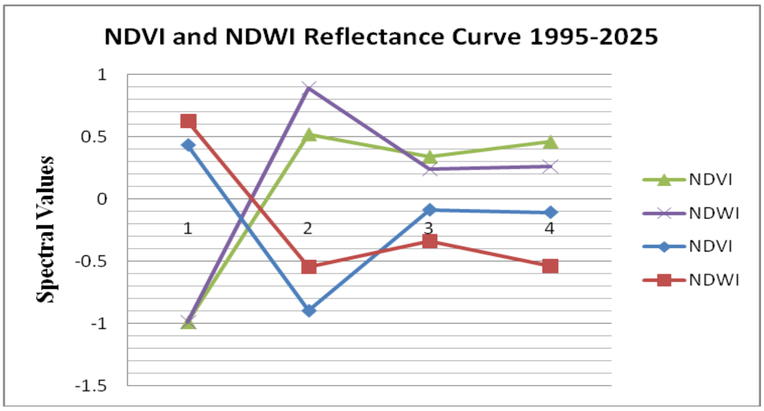


Figure 4: Mathematical Model showing the Vegetation and Water Indices in Rivers state.
The features range of the spectral indices were used to generate thematic map of the state as shown in Figur 5a & b.

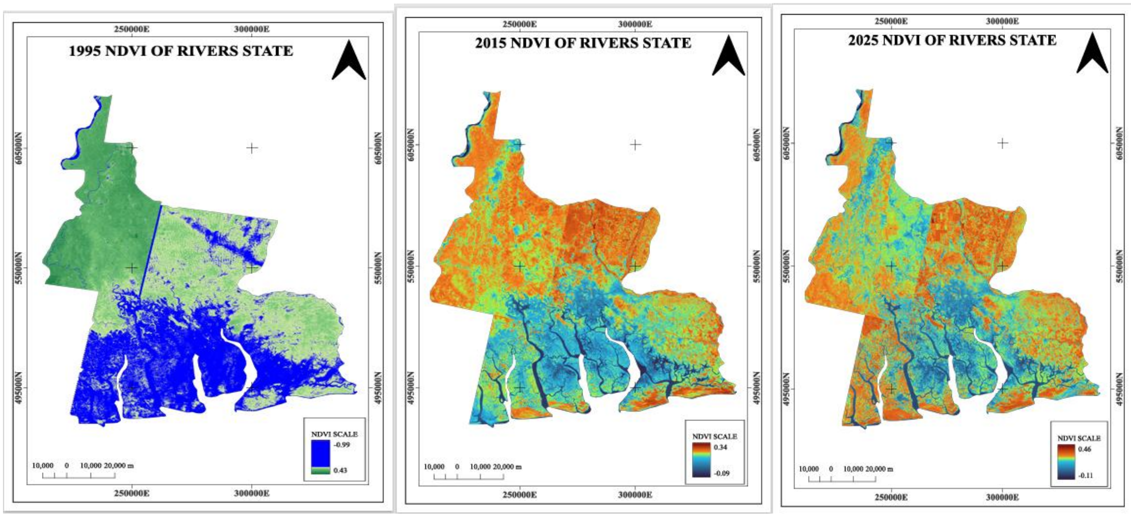


Figure 5a: NDVI and NDWI for the study period.

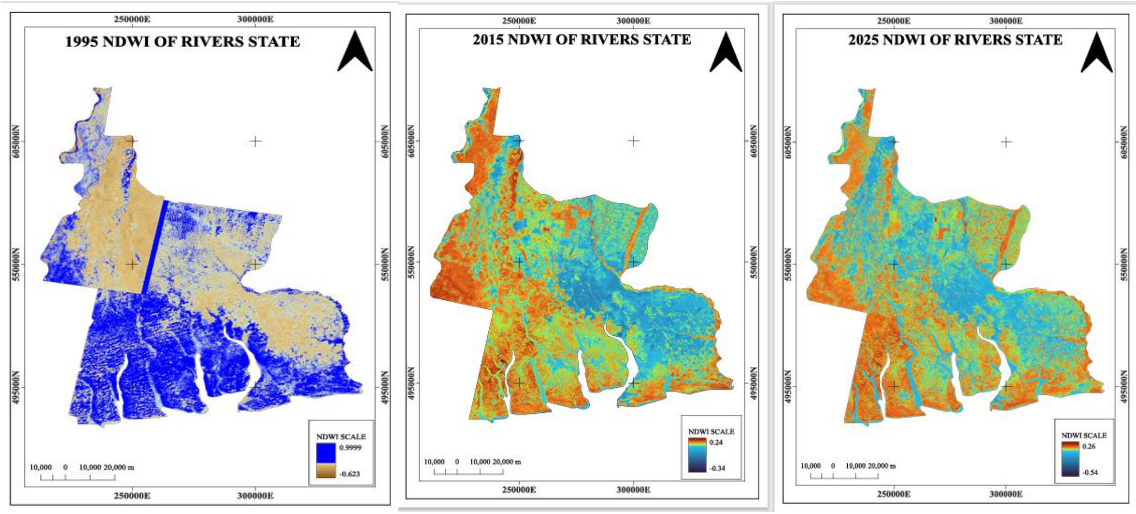
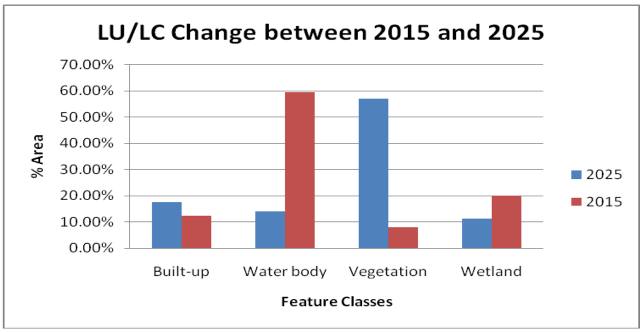


Figure 5b: NDVI and NDWI for the study period.

Based on the two scenes used that covered the study area, the total area classified was 9.766km^2. According to Ibama, Ogundaro & Akue (2025) the wetlands in Obio-Akpor are reducing due to anthropogenic activities. Now, these anthropogenic activities could be building development, land reclamation, farming, and these activities are specific drivers to be considered in the wise and optimal use of wetlands for environmental sustainability, enhanced Land Administration and Management. This work brings to bare the current sizes of the classified features which gives recent scenario of the wetland area compared to the area defined by Ibama, Ogundaro & Akue (2025) where results showed 2020 scenario of wetland loss. The basis for proper decision on wetlands justifies the need for quality spatial information; hence one must consider the relevance of time as a factor for quality geospatial information if we must enhance Land Administration and Management. This result therefore, shows current LU/LC for 2025 were four (4) classes, Built-up, Water Body, Vegetation and Wetland were classified. The results showed the area of wetlands left in the study area in 2025 as 1,103.84km^2 which is11.30%, and 1,956.03km^2 in 2015 which is 20.10%. The charts below show the statistical presentation for the classified data.



Bar chart Showing the LU/LC Changes

4.2 Results of Wetland derived from Spectral Indices

The table and figures show the amount of wetland in the study area. This satisfies the study aim

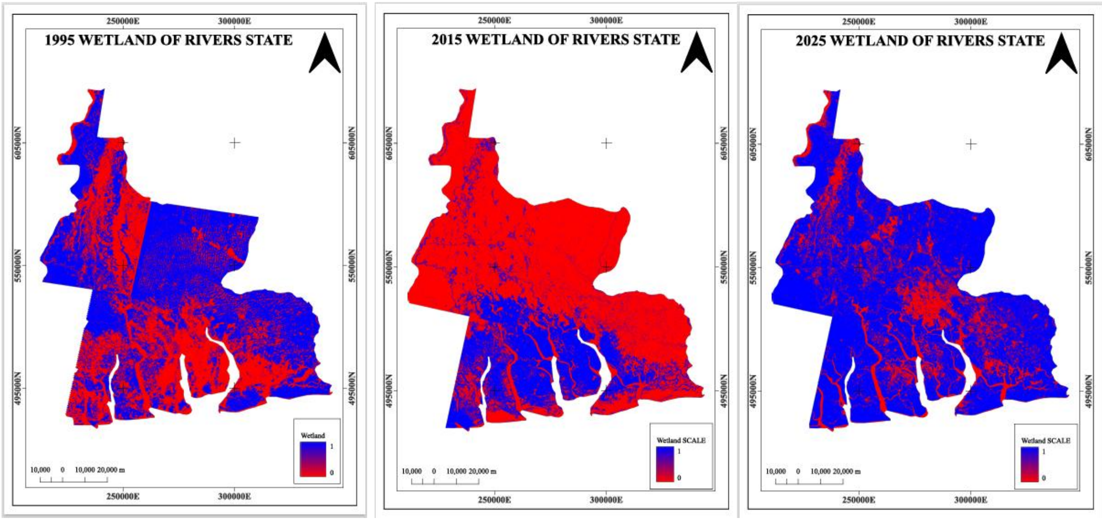


Figure 6: Temporal Changes in Wetland 1996, 2015 and 2025 *Source: Author's Work 2025*

4.3 Results from the Land use/Land Cover classification

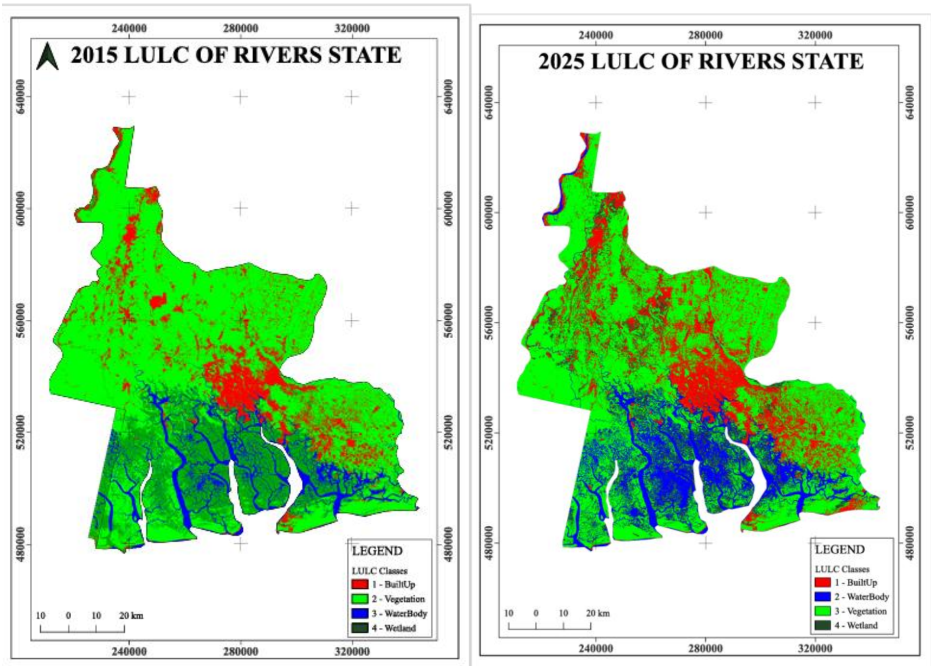


Table 1 Classification Results

Class	Value	Pixel Count	Area (m²)	Area (km²)	Area (%)
Built-up	1	1,344,613	1,210,151,700	1,210.15	12.43%
Vegetation	2	6,441,968	5,797,771,200	5,797.77	59.55%
Water body	3	856,529	770,876,100	770.88	7.92%
Wetland	4	2,173,367	1,956,030,300	1,956.03	20.10%
Total	–	10,816,477	9,734,829,300	9,734.83	100.00%

Figure 2 Classification Results

Class	Value	Pixel count	Area (m²)	Area (km²)	Area (%)
Built-up	1	1,904,915	1,714,423,500	1,714.42	17.55%
Water body	2	1,513,934	1,362,540,600	1,362.54	13.95%
Vegetation	3	6,206,443	5,585,798,700	5,585.80	57.19%
Wetland	4	1,226,486	1,103,837,400	1,103.84	11.30%
Total		10,851,778	9,766,600,200	9,766.60	100.00%

4.4 Field verification

The field verification also known as ground truthing is a critical component of the remote sensing approach which involves ground-based observations to validate the data derived from satellite sensor systems and enhance remote sensing interpretation. This process enhances the reliability of data. The Spatial coordinates of sample locations of wetlands were obtained using GPS receivers. This process minimizes the gaps between the spectral signatures in the imageries and the actual land use/land cover on the ground. It is important to confirm that the classification results are correct.

5.0 CONCLUSION

In Rivers State, Nigeria, the integration of Artificial Intelligence (AI) and geospatial mapping as at 2025, has become a cornerstone for achieving the Sustainable Development Goals (SDG’s) 11 and 15. SDG 11 focuses on sustainable cities and communities and SDG 15 focuses on achieving Life on Land. There are critical challenges that have risen due to the rapid growth the state is experiencing directly related to rapid urbanization and coastal erosion that threatens the ecosystem in the Niger Delta Region of Nigeria.The importance for adopting the current technology in advancing and enhancing wetland mapping cannot be over emphasized. The results are quick and accurate creating the room for data driven decisions for Land Administration in the face of rapid urbanization.

Rather than people setting before planning, planning can be done before people settle. AI-driven data analyses enable proactive steps in Land Management. The results provide insights in policy generation for the state. Wetlands are natural ecosystems that are good for making, but as urbanization increases on a rapid scale, GeoAI's adoption closes the gaps that the ordinary traditional mapping processes create.

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