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Wetland Depletion Assessment in Marine Local Government Areas of Rivers State

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ABSTRACT

Wetlands are considered to be one of the most productive yet disappearing ecosystems, providing critical ecological, social (livelihood, water supply, floods regulation) and economic services. But once depleted these vital supporting functions are lost or diminished to a great degree. The prime aim of this paper is therefore to provide cost-effective, accurate and spatially-explicit information that supports appropriate policy decisions and actual wetland conservation in the Marine LGAs of Rivers State, Nigeria.

Three specific questions were addressed: (i) Spatial identification and delineation of wetlands in the LGAs based on Landsat-7 images from 2004–2024 in ≥5-year period; (ii) Quantification of the variation of their spatial extent and depletion rate; and (iii)Examination of the spatio-temporal variation of land use/land cover (LULC). Preprocessed multi-temporal Landsat-7 imageries were spectral-enhanced using indices (NDVI, NDWI), digested with DEM, classified into wetlands and non-wetlands based on threshold technique and changes were spatio-temporally quantified through image differencing; while status, distribution and dynamics of LULC were analyzed. Classifications schemes for the selected LULC categories; built-up, vegetation, water bodies and bare earth were derived according to the nature of the area, spectral characteristics of Landsat-7 image and their potential roles in the hydrological and Ecological functioning of the wetlands. These schemes were respectively rooted on indices, boundaries, spectral characteristics, and extent of the variables. The maximum likelihood supervised classification was consecutively employed on the focused area for the multi-temporal datasets image-sets for the years (2004, 2009, 2014, 2019 and 2024) to ensure homogeneity in classification and accordingly, consistency in change detection accuracy.

The temporal prevalence of wetland extent in years (2004, 2009, 2014 and 2024) indicated gain of +153% just before the onset of observed decline within the period (2014–2024) by ≈51%, which explained the trend of increase in exploitation of wetlands in the last decade. The classification of LGAs landsat images revealed a significant gain in built-up lands area between the two endpoints (2004 and 2024) from 1000km^2 to 3420Km^2 (341% increase), which is indicative of a significant increase in anthropogenic intervention. A significant loss was observed between 2004 and 2009 (N=−61%), before a recovery period with a gain of 37% in 2019, followed by an accelerated depletion with a loss in area of −73% in 2024 (N=−73%). Intermedium-year variations were affected by the clouds ratio and scanning errors of Landsat 7 visible bands, which induced inaccuracies in imagery classification. Nonetheless, these findings did also report a relative stability in water body surface areas in the study area. This was countered with fluctuations in bare lands with a magnitude of −99%, from 651 km^2 in 2004 to 6 km^2 in 2024 as well as a continuous increase in urbanized lands from 1000 km^2 in 2004 to 3420 Km^2 in 2024. It was concluded that the loss in the values of 2004 exhibited wetlands dynamic could be tackled to ensure sustainable development if immediate actions are taken. These could include setting up GIS-based monitoring and controlling framework, establishing effective regulations on land uses & implementation, and providing participatorily active role for local communities & authorities in wetland conservation.

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INTRODUCTION

Background to the Study

The United States Fish and Wildlife Service has described wetlands as lands that exist in a transitional state between terrestrial and aquatic systems, with water levels either near the surface or covering the land with shallow water (Cowardin et al., 1979, U.S. Fish and Wildlife Service, 1993). As part of the natural ecosystem, wetlands where they occur in the landscape are valued for their crucial contribution to ecological balance and biodiversity (Obiefuna, Nwilo, Atagbaza, & Okolie, 2023). Wetlands play an integral role in sustaining life both within and outside their immediate environments by providing a wide range of ecosystem goods and services that support ecological integrity and human well-being. Wetland goods include tangible resources such as fish and shellfish, freshwater, fuelwood, reeds, and other biological materials. In addition, wetlands provide services including flood attenuation and water storage, groundwater recharge, nutrient and sediment retention, pollution control, water purification, shoreline stabilization, as well as cultural, aesthetic, and educational benefits (Wala et al., 2023; Nwankwoala & Okujagu, 2021). Ironically, in terms of their significance as natural resource base, wetlands are the world 's most threatened ecosystems. Once these are lost, their numerous functions are lost, and the remaining ones are greatly reduced, thus negatively affecting the integrity of the ecological environment and the quality of human life (Adekola & Mitchell, 2011). Wetlands have been closely associated with human settlements, especially in coastal and estuary areas, since the beginning of human civilization.

Statement of the Problem

Wetlands provide valuable ecological services such as water purification, flood control, carbon-hold, and habitat for many species yet these ecosystems are being depleted at a fast rate. These depletions are caused mainly by urbanization agricultural expansion. Drainage, reclamation and filling of wetlands are some of the activities that have been undertaken in order to create room for other infrastructural development, settlements and farming. For instance, in the coastal metropolis of Port Harcourt, urbanization, reclamation and oil-related industries have affected the hydrological and Ecological character of the wetlands.

Pollution from farming chemicals, industrial waste and urban sewage further expediates the destruction of wetlands through the pollution of water sources and modification of soil composition. For instance, in the Ogoni area, (Bonny Island & Port Harcourt) oil spills and waste discharge from industrial development has led to large scale destruction of aquatic environment and depletion of the wetlands natural regenerative power (Amnesty International 2011).

In addition, climate change exerts additional and widespread stress on wetlands via rising sea levels, soaring temperatures, shifting rain regimes and saline intrusion. These processes undermine the ecological balance of wetlands and lead to imbalance and increase cover loss, and especially in the low-lying coastal areas such as the estuarine and marine LGA of Rivers State in the Niger Delta (IPCC, 2023). Wetland depletion in the period covered by this study poses severe threats to human lifestyles and biotic diversity. Species dependent on moist environment for key biological processes such as spawning, feeding, and cover are increasingly under pressure, while collected communities through which people directly use related resources such as fish pond farming and aqua sources encounter national market increased socio- economic difficulties. Therefore, this study seeks to fill scientific and spatial lack of explicit information on the area extent, rate and patterns of wetlands loss and undelimitated effects on ecosystem services.

Aim and Objectives of the study

Aim of the study

The aim of this study is to carry out a wetland depletion assessment in Marine Local Government of Rivers State, Nigeria.Objectives of the study

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The objectives of this study are to:

Carryout Epoch-based identification and delineation of wetlands in the study area.

Determine the spatial extent and analyze the extent of depletion of the wetlands

To examine the spatio-temporal dynamics of LULC changes in the study area.

Significance of the Study

By delineating the wetlands in the areas, the study provides a reliable spatial database that can support informed decisions making on Land-use Planning, Ecosystem Conservation, and Sustainable Resource Management.

By analyzing the extent of depletion, the study generates evidence on the rate and pattern of wetland loss, offering critical information for environmental monitoring.

By analyzing spatio-temporal LULC changes, this study provides evidence of wetland conversion patterns in the study areas, and by so doing, it supports policymakers and planners in monitoring loss, and guides sustainable land-use and conservation strategies.

MATERIALS AND METHOD

Concise description of the study Area

For the purpose of this study, "Marine LGAs" refers to the Local Government Areas of Rivers State that are located within the coastal and estuarine belt of Rivers State, characterized by extensive wetlands, mangrove ecosystems, tidal influence, creeks, river networks, and proximity to the Atlantic Ocean. This classification is adopted in an environmental and geographical context rather than as an official administrative designation.

The study focuses on LGAs of Rivers State which include Akuku-Toru, Degema, Bonny, Ogu/Bolo, Okrika, Asari-Toru, Andoni, Opobo/Nkoro, Tai, Gokana, Eleme, and Abua/Odual. The areas are characterized by low-lying terrain, extensive wetlands, mangrove vegetation, tidal creeks, floodplains, and strong hydrological interaction with the Atlantic coastline.

Location and Geographic Features

The Marine LGAs of Rivers State are situated within the Niger Delta region of southern Nigeria. While several of these LGAs, including Akuku-Toru, Degema, Bonny, Ogu/Bolo, Okrika, Asari-Toru, and Andoni, are located along the coastal and estuarine belt, others such as Abua/Odual, Eleme, Gokana, and Tai are primarily inland but riverine, forming part of the delta's extensive wetland and river network (Udom et al., 2022; Obi et al., 2021). This region is low-lying plains, situated below 20m above the mean sea level. The plain has been dissected by countless number of rivers, creeks and estuaries which sustains the ecosystem and the economy of the region. The main rivers included are the Bonny River, New Calabar River and the Orashi River (Nwankwoala & Amadi, 2013).

Specifically, Port Harcourt metropolis itself is located about 25km away from Atlantic Ocean and is surrounded by the following significant water bodies; Dockyard Creek, Bonny River and Amadi Creek. The wider area is defined by the coordinates Longitude 6 40"20′E in the East, 7 15"40′E in the West, Latitude 4 25"15′N in the South and 5 16"20′N in the North.

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These ecological features make the areas highly sensitive to wetland depletion and suitable for wetland-related geospatial analysis. Consequently, the term “Marine LGAs” is adopted in this study to describe LGAs that exhibit dominant coastal, estuarine, and wetland environmental characteristics.

Rainfall is very high, periodic and sporadic in time in Rivers State. Precipitation occurs throughout the year, with time distribution and range varying from place to place. The State receives very high amount of annual rainfall with the amount gradually dropping from about 4, 698mm for the coast line to about 1, 862 for the extreme North. Bonny has an average of 4698 mm while Degema 1862mm in a year of rainfall. In Port Harcourt, there are an average of 182 days of rainy days (NiMET, 2021). Temperature patterns are relatively stable, the winter mean maximum monthly temperatures are kept between 28°C and 33°C and the mean value of minimum monthly mean temperatures are between 17°C and 24°C. The mean value of monthly temperatures is between 25°C and 28°C, and the overall mean annual temperature value is about 26°C while between February and May are the hottest months. The temperature difference between the dry and rainy season is averaging about 2°C. The humidity is high peak at all the year along time slowly decreasing in the dry season (NiMET,2022).

The study area can be divided into three major hydro-vegetation zones: the beach ridge zone, the saltwater zone, and the freshwater zone.

The beach ridge zone is characterized by freshwater swamp trees, palms, and shrubs growing on sandy ridges, while mangroves occupy the intervening valleys and tidal flats. The saltwater zone comprises tidal flats and swamps dominated by the red stilt-rooted mangrove (Rhizophora racemosa), along with two other mangrove species. The freshwater zone encompasses the Upper and Lower Delta floodplains of the Niger River, where freshwater forest species which are considered edaphic variants of the rainforest, predominate. Typical vegetation in this zone includes the Abura tree, oil palm, raffia palm, various shrubs, lianas, ferns, as well as floating grasses and reeds (Niger Delta Budget Monitoring Group, 2021)

According to the 2006 National Population Census conducted by the National Population Commission, the population distribution varies across the study areas as shown in table 1.1.

Table1.1: Population distribution of the study area.

LGA (Study Area)	**2006 Census Population**
Port Harcourt	541,115
Bonny	215,358
Okrika	222,026
Degema	249,773
Andoni	211,009
Akuku-Toru	156,006
Asari-Toru	220,100
Ogu/Bolo	74,683
Opobo/Nkoro	151,511
Abua/Odual	282,988

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Tai	117,797
Gokana	228,828
Eleme	190,884
TOTAL	**2,862,078**

Source: Author, 2026.

The economy of the study area is diverse and driven by several major sectors.

Firstly, the oil and gas industry dominate the economic landscape.

Secondly, trade and commerce are vital to the region's economy.

Despite increasing urbanization, agriculture continues to play an important role. Additionally, the extensive mangrove and freshwater ecosystems support vibrant fishing activities, which are a major source of livelihood for many coastal communities (Food and Agriculture Organization, 2022)

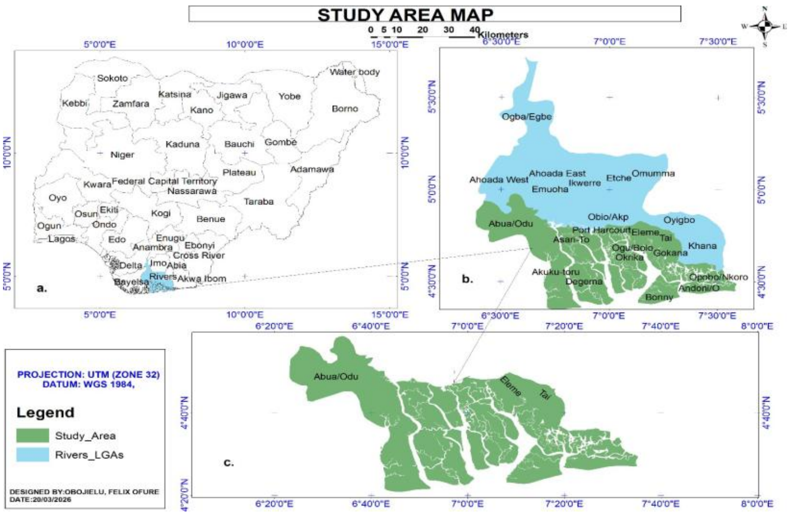

Figure 1.1: Detailed Map of the Study Area. (Source: Author, 2026)

The composite map consists of (a) Map of Nigeria, (c) Map of Rivers State, and (c) Study Area.

Data acquisition

Landsat 7 satellite imagery for five epochs (2004, 2009, 2014, 2019, and 2024) was obtained from the United States Geological Survey(USGS) Earth Explorer platform. This imagery was used to generate the land use and land cover map. The Digital Elevation Model (DEM) and LGA boundary shapefiles were acquired from open Street Map (OSP) for spatial analysis. The imagery was selected based on minimal cloud cover and consistent spatial coverage over the study area to provide the temporal basis for wetland change analysis

METHODOLOGY

This study employed a remote sensing and GIS-based approach, a quantitative research design grounded in a positivist research philosophy. Following this philosophy, the study adopts both descriptive and quantitative research approaches. The descriptive approach provides insight into the nature, distribution, and observable

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changes in wetlands over time, while the quantitative approach involves the analytical application of Remote Sensing (RS) and Geographic Information System (GIS) techniques to measure and evaluate wetland dynamics.

The methodology combined:

Satellite image analysis for wetland delineation.

Index-based classification for wetland detection.

Change detection techniques for temporal analysis (2004–2024).

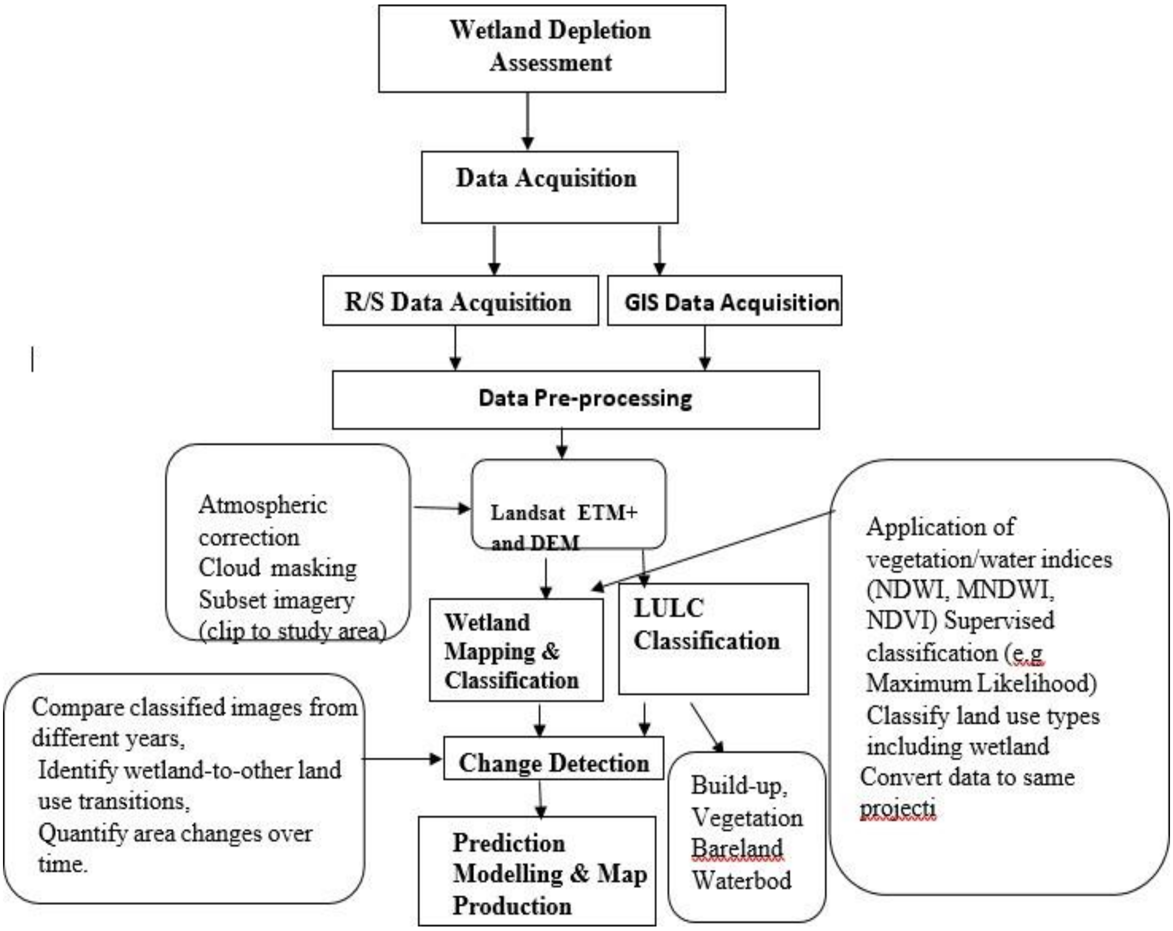

Figure 2.1: Workflow Chart of research design (Source: Author, 2026)

Research Workflow

The methodological framework adopted for this study follows the structured workflow presented in Figure 3.1. The workflow begins with data acquisition, followed by preprocessing, wetland mapping and classification, change detection, map production. Each stage is discussed in detail below in accordance with the sequence illustrated in the workflow chart.

Wetland Depletion Assessment (Top of Figure 3.1)

As illustrated at the top of Figure 3.1, the overall objective of this research is wetland depletion assessment in the marine LGAs of Rivers State. This objective guided the sequential methodological phases presented in the workflow.

Data Acquisition (2nd Box in Figure 3.1)

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The first stage of the workflow (Figure 3.1) involved Data Acquisition, comprising both Remote Sensing (R/S) and GIS data acquisition.

a. R/S Data Acquisition → Landsat imagery

b. GIS Data Acquisition → DEM + LGA boundary

Landsat satellite imagery for five epochs (2004, 2009, 2014, 2019, and 2024) was obtained from the USGS Earth Explorer platform, while the Digital Elevation Model (DEM) and LGA boundary shapefiles were acquired for spatial analysis. The imagery was selected based on minimal cloud cover to reduce atmospheric interference and consistent spatial coverage over the study area to provide the temporal basis for wetland change analysis. Where small areas of residual cloud remained,overlapping scenes acquired within the same Epoch were used during mosaicking to improve spatial coverage.

Data Processing and Analysis Workflow

The second phase of the workflow (Figure 3.1) involved Data Pre-processing to ensure spatial consistency and analytical readiness of all datasets. The following pre-processing

The analytical procedure for wetland mapping and change detection involved a sequence of geospatial processing steps as outlined below:

Preprocessing

Pre-classification analytical procedure (Index Generation):

Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Digital Elevation Model (DEM) layers were derived to enhance wetland feature extraction and reduce classification ambiguity.

Classification: A binary classification scheme was implemented, distinguishing wetlands (class 1) from non-wetlands (class 0). This allowed for accurate delineation of wetland extents across time periods.

Change Detection: Post-classification comparison was applied to detect and quantify temporal changes in wetland extent between epochs, thereby revealing depletion patterns and transition dynamics.

Data Preprocessing

Preprocessing ensured the imagery was analysis-ready and spatially consistent. The key steps included:

Atmospheric and Geometric Correction: Level-2 Surface Reflectance products, which have been radiometrically, atmospherically, and geometrically corrected by the United States Geological Survey (USGS), were used to minimize the effects of atmospheric scattering, absorption, haze, and aerosols, thereby ensuring that the spectral values more accurately represented the Earth's surface.

Image Selection and Cloud Cover Management: Landsat imagery was selected based on minimal cloud cover and consistent spatial coverage over the study area to ensure high-quality image analysis. Where small areas of residual cloud cover remained, multiple overlapping scenes acquired within the same study epoch were mosaicked so that cloud-obscured areas in one scene were supplemented with valid observations from another scene. This approach minimized the influence of cloud cover on image classification.

Re-projection: All datasets were projected to WGS 84 / UTM Zone 32N (EPSG:32632) for spatial uniformity.

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Mosaicking and Sub-setting: Image tiles were mosaicked and clipped to the study boundary using QGIS.

Re-sampling: All imagery was standardized to a spatial resolution of 30m × 30m, consistent with Landsat sensor characteristics, to maintain uniformity across datasets. Masking:

The study area boundary was applied to clip imagery, thereby restricting analysis strictly to the extent of the marine-inclined LGAs under investigation.

Landsat-7 SLC-off and NoData Handling: Since the study utilized Landsat-7 ETM+ imagery acquired after the Scan Line Corrector (SLC) failure of May 2003; some images contained characteristic data gaps (SLC-off errors). To reduce the effect of these gaps, multiple overlapping scenes that were acquired within the same period were used. Where one scene contained missing data, information from another overlapping scene was used during the mosaicking process to provide coverage of the affected areas. Remaining No Data pixels outside the study boundary were masked and excluded from subsequent analyses to prevent bias in image classification and statistical calculations. This approach minimized the influence of SLC-off gaps on the wetland mapping results, although a small degree of uncertainty may still remain.

Image Classification (Wetland Mapping & Classification)

As illustrated in Figure 3.1, after the data preprocessing stage, the next step was Wetland Mapping & Classification. In this phase, threshold values were applied to the derived indices (NDWI, NDVI, DEM) to classify the pixels into two categories: wetlands (class 1) and non- wetlands (class 0). This binary classification ensured accurate separation between wetland and non-wetland areas, which was crucial for the subsequent change detection analysis. The procedure involved applying threshold values to the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Digital Elevation Model (DEM) to isolate wetland features. The classification rules for each epoch were:

2004: ("NDWI_2004" ≥ -0.08816) AND ("NDVI_2004" ≤ 0.0535495) AND ("DEM" ≤ 9.5)

2009: ("NDWI_2009"≥ -0.053496) AND ("NDVI_2009" ≤ -0.086114) AND ("DEM" ≤ 9.5)

2014: ("NDWI_2014"≥ -0.1061365) AND ("NDVI_2014" ≤ 0.23160785) AND ("DEM" ≤ 9.5)

2019: ("NDWI_2019" ≥ -0.0148315) AND ("NDVI_2019" ≤ 0.1347466) AND ("DEM" ≤ 9.5)

2024: ("NDWI_2024"≥ -0.0753225) AND ("NDVI_2024" ≤ 0.16498275) AND ("DEM" ≤ 9.5)

1) Binary Raster Outputs:

a) Value 1 → Wetland

b) Value 0 → Non-wetland.

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This binary classification provided a clear separation between wetland and non-wetland areas, thereby simplifying subsequent change detection analysis.

Pixel Counting: Area Calculation:

a) Each Landsat pixel = 30 m × 30 m = 900 m^2.

a. Wetland area (m^2) = Wetland pixels × 900 m^2.

b. Then converted into Km^2 by dividing by 1,000,000.

LULC Classification and Analysis

Land Use/Land Cover (LULC) classification was carried out to identify and analyze the spatial distribution and temporal dynamics of major land cover types within the study area. The classification scheme was developed based on the characteristics of the study area, the spectral properties of Landsat-7 imagery, and relevance to wetland depletion processes. The following LULC classes were adopted: (i) Built-up Areas: Urban settlements, roads, industrial areas, and other impervious surfaces. (ii) Vegetation: Forests, mangroves, shrubs, and other green cover excluding wetlands. (iii)Water Bodies: Rivers, creeks, and open water surfaces. (iv) Bare Land: Exposed soil surfaces, sand, dredged areas, and degraded lands with little or no vegetation cover. This classification scheme enabled the assessment of land cover transitions and the identification of major drivers of wetland depletion.

Classification Method (Supervised Maximum Likelihood)

A supervised classification approach was employed using the Maximum Likelihood Algorithm (MLC) to categorize the satellite imagery into the defined LULC classes. The Maximum Likelihood classifier was chosen due to its effectiveness in handling multi-spectral data and its ability to incorporate class variance and covariance in classification decisions. The algorithm assumes that the statistical distribution of each class in each band is normally distributed and assigns each pixel to the class with the highest probability of membership. The classification process was carried out for all selected epochs (2004, 2009, 2014, 2019, and 2024) to ensure consistency in temporal analysis.

Classification Accuracy Assessment

In order to evaluate the dependability of the classified 2024 LULC map, a classification accuracy assessment was performed with the use of an error (confusion) matrix generated from reference samples. The classified image was compared with corresponding reference data, from which Producer's Accuracy (PA), User's Accuracy (UA), Overall Accuracy (OA), and the Kappa coefficient were computed. The statistics were used to measure the agreement level between the classified map and the reference data and to assess the suitability of the classification for future wetland change detection and prediction analyses.

Change Detection Analysis

Post-classification comparison was used to analyze changes in wetland extent or area over two successive Epochs. The change formula given below was used.

The rate of change was calculated using the formula (Muttitanon & Tripathi, 2005):

$$\%\Delta = \frac{At2 - At1}{At1} \times 100 \qquad (3.1)$$

Where:

i. At_2 = Wetland area at the later epoch

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ii. At1 = Wetland area at the earlier epoch

iii. Δt = Time interval (years)

RESULTS AND DISCUSSION

i. The results are organized into four sections:

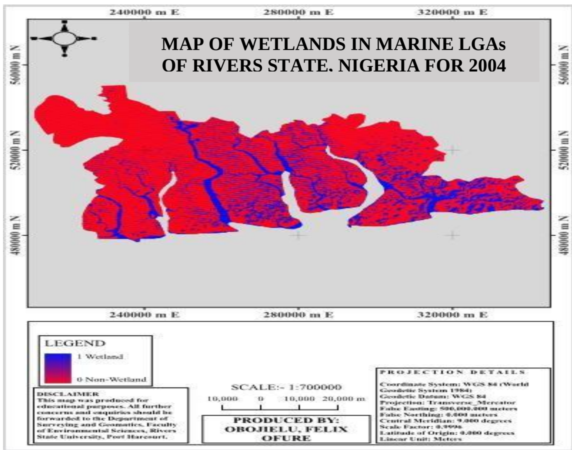
ii. identification and delineation of wetlands,

iii. determination of the spatial extent and extent of depletion of the wetland,

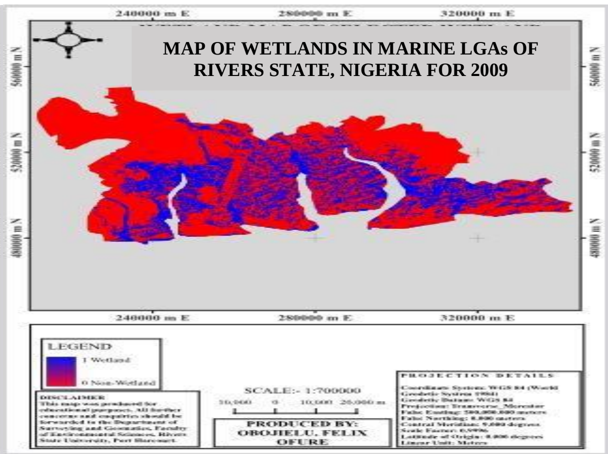
iv. LULC change analysis,

Delineation of Wetlands (2004–2024) (Objective 1)

Wetlands within the study area were successfully delineated for five epochs (2004, 2009, 2014, 2019, and 2024) using combined spectral and terrain indices, namely: The Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Digital Elevation Model (DEM) thresholds. See fig. 4.1 (a, b, c,d, and e)



(a)



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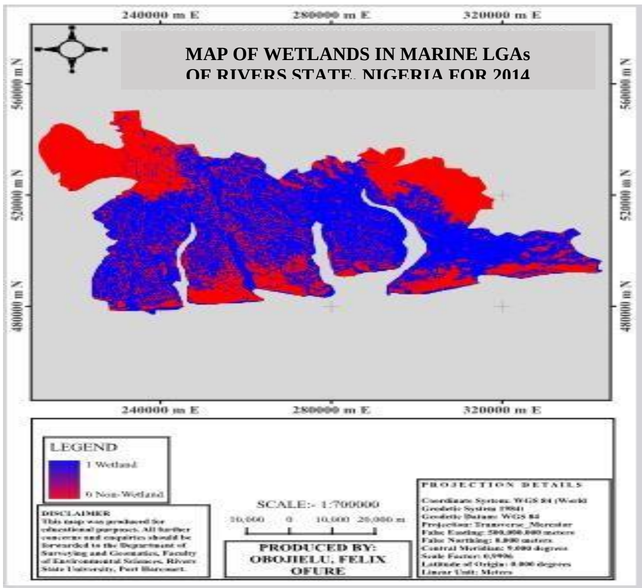

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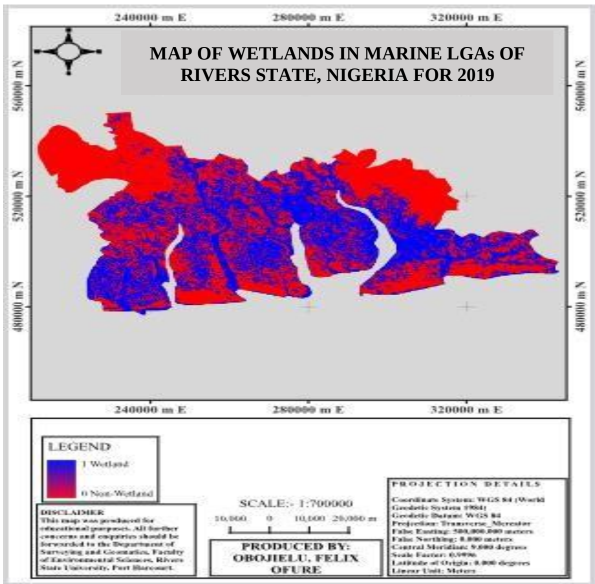

(b)

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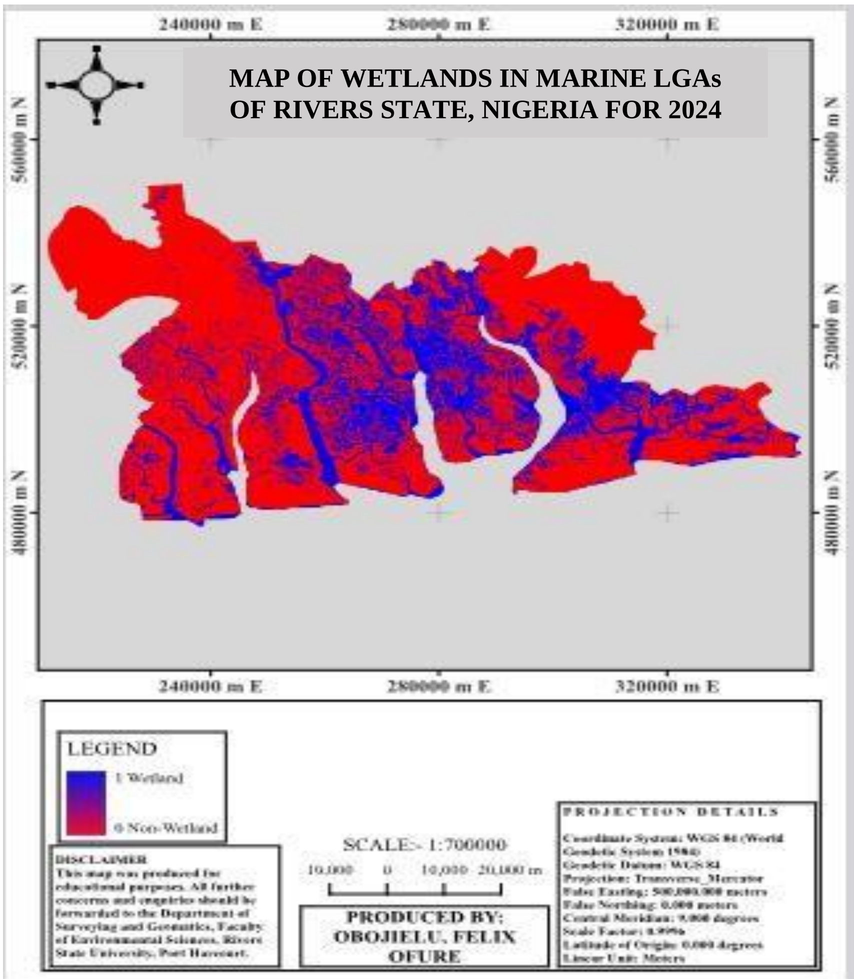

(e)

Figure 3.1: Delineation of wetland areas (2004 – 2024). Source: Author, 2026.

The table 3.1 and 3.2 show wetland and non-wetland extent across the different epoch

Table 3.1: Wetland Extent across Epochs (2004–2024)

Year	Wetland Pixels	Wetland Area (Km^2)	Non-wetland Pixels	Non-wetland Area (Km^2)	Area in ($Hectares^2$)
2004	641,625	577.46	3,463,659	3,117.29	5774.63 ha
2009	1,621,266	1,459.14	3,835,952	3,452.36	1459.14 ha
2014	3,129,144	2,816.23	2,327,993	2,095.19	2816.23 ha
2019	2,389,805	2,150.82	3,067,341	2,760.61	2150.82 ha
2024	1,538,818	1,384.94	3,918,395	3,526.56	1384.94a

In the table, column 2 shows number of pixels for each epoch. Each pixel size is 30m x 30m = $900m^2$. In 2004, for instance, there are 641,625 pixels. Multiplying this by $900m^2$ gives an area of $577,462,500m^2$. This value was then converted to Km^2 by dividing the value by $1000000m^2$ resulting in $577.46Km^2$. The wetland areas were

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further converted to hectares (1 ha = 10,000 m²) and are presented in Table 4.1.

Objective Two: Analysis of Wetland Depletion (Change Detection Analysis)

The change analysis revealed alternating patterns of gain and loss, with net depletion dominating the latter period as shown in table 4.2.

Table 3.2: Comparative Table

Year	Wetland Area (m²)	Wetland Area (km²)	% Change from Previous	Trend
2004	577,462,500	577.46	–	Baseline
2009	1,459,139,400	1459.14	+153%	Major increase
2014	2,816,229,600	2816.23	+93%	Peak expansion
2019	2,150,824,500	2150.82	-24%	Decline starts
2024	1,384,936,200	1384.94	-36%	Continued depletion

Source: Author,2026.

Explanation of change detected:

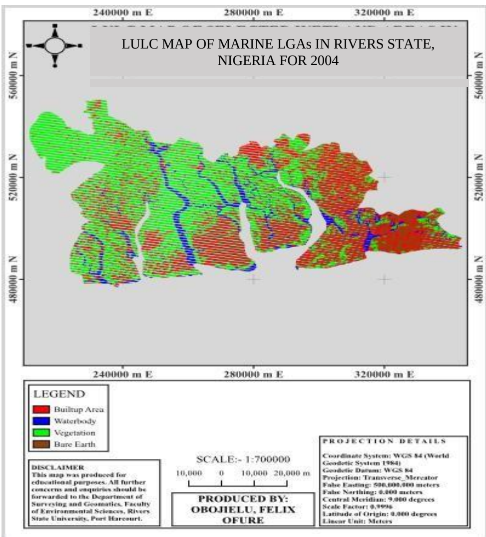
i. From 2004 → 2014, wetlands expanded massively (likely due to classification sensitivity, flooding, or vegetation recovery).

ii. From 2014 → 2024, wetlands show a sharp depletion trend, losing nearly 143,000 ha (≈51%) in just 10 years.

iii. The peak year = 2014 → after which wetlands are on a steady decline.

Objective Three: S p a t i o -Temporal Dynamics of Land Use/Land Cover (LULC) Analysis (2004–2024)

LULC Classification Results by Epoch



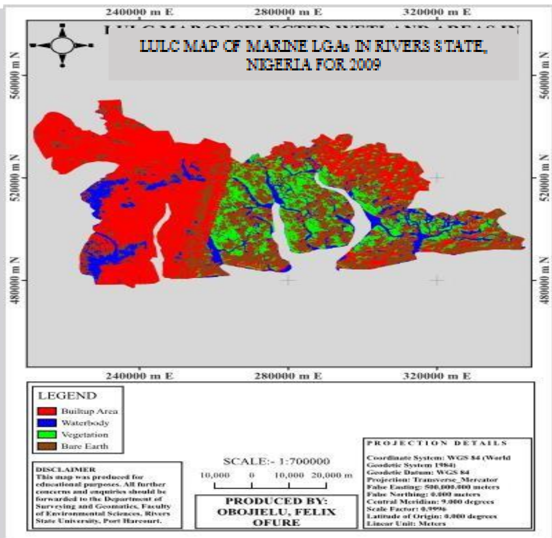


Figure3.2c **Figures 3.2d**

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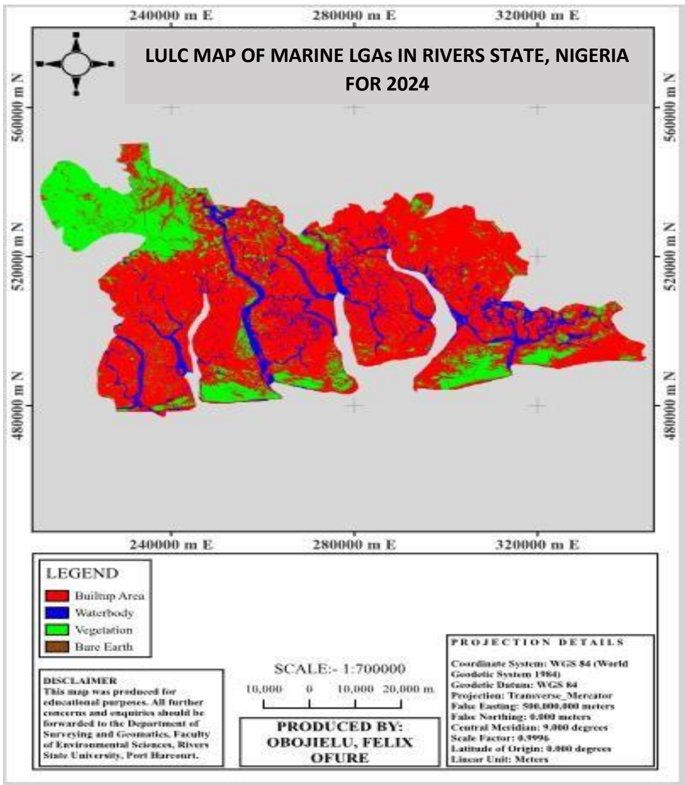

Figures 3.2e

Figures (3.2a – 3.2e): LULC Spatial distribution maps

Table 3.3: Summary of Land Use/Land Cover Distribution (2004–2024)

Class	**2004 (km²)**	**2009 (km²)**	**2014 (km²)**	**2019 (km²)**	**2024 (km²)**
Built-up	1001.75	2362.55	1396.43	417.49	3417.47
Waterbody	272.88	519.90	329.95	735.51	481.85
Vegetation	1771.55	692.52	2742.90	3760.35	1011.92
Bare Earth	648.58	1340.21	435.20	3.77	5.94

Analysis of LULC Changes 2004 Baseline Condition

The 2004 epoch represents the baseline condition of the study area, with vegetation (1771.55 km²) as the dominant land cover, followed by built-up areas (1001.75 km²) and bare earth (648.58 km²). However, this distribution should be interpreted with caution due to the scan line error associated with Landsat 7 imagery, which may have introduced classification inaccuracies.

2004–2009 Changes

Between 2004 and 2009:

Built-up area increased significantly from 1001.75 km² to 2362.55 km², indicating rapid urban expansion.

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Vegetation decreased sharply from 1771.55 km² to 692.52 km².

Bare earth increased from 648.58 km² to 1340.21 km².

i. Waterbodies showed moderate increase.

These changes suggest extensive land conversion; however, cloud contamination in the 2009 imagery likely contributed to misclassification, particularly overestimating bare earth and underestimating vegetation.

2009–2014 Changes

From 2009 to 2014:

i. Vegetation increased significantly to 2742.90 km².

ii. Built-up area reduced to 1396.43 km².

iii. Bare earth declined.

This apparent ecological recovery is likely influenced by classification inconsistencies caused by cloud interference and image merging issues, rather than representing true environmental change.

2014–2019 Changes

Between 2014 and 2019:

i. Vegetation became overwhelmingly dominant (3760.35 km²).

ii. Built-up area dropped drastically (417.49 km²).

iii. Bare earth nearly disappeared.

This pattern is unrealistic and is attributed to cloud cover, which likely caused non-vegetated surfaces to be misclassified as vegetation.

2019–2024 Changes

From 2019 to 2024:

i. Built-up area increased dramatically from 417.49 km² to 3417.47 km².

ii. Vegetation declined sharply from 3760.35 km² to 1011.92 km².

iii. Waterbodies slightly decreased.

iv. Bare earth remained minimal.

This epoch is considered the most reliable due to minimal cloud interference, providing a more accurate representation of actual land cover dynamics.

Relationship Between LULC Changes and Wetland Depletion

The LULC analysis provides critical insight into the drivers of wetland depletion observed in the study area.

Although wetland extent showed an increase between 2004 and 2014, this does not contradict the LULC findings. The apparent increase in wetlands during this period may be attributed to:

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i. Classification uncertainties due to cloud cover

ii. Inclusion of wetland vegetation within general vegetation classes

iii. Landsat 7 scanline error in early datasets

However, the 2019–2024 epoch provides a clearer and more reliable picture:

i. Built-up areas expanded significantly

ii. Vegetation declined sharply

iii. Wetland extent also reduced considerably

This strongly suggests that wetlands are being converted primarily into built-up areas and anthropogenic land uses.

SUMMARY OF RESULTS

The results of this study reveal a progressive decline in wetland extent across the study area between 2014 and 2024. From 2004 to 2014, the delineation and change-detection analyses showed an apparent expansion in wetland coverage which could be attributed to temporary flooding, vegetation regeneration following periods of reduced disturbance. However, from 2014 to 2024, a sharp contraction of wetland area was observed. This signifies intensified human interference and conversion of wetlands to non-wetland uses.

Results of LULC analysis showed that wetland extent increased by **+**153% between 2004 and 2014, followed by a **≈**51% decline from 2014 to 2024, indicating accelerated depletion in recent years. LULC analysis (2004–2024) revealed rapid urban expansion accompanied by vegetation decline. Built-up areas increased from 100 Km² in 2004 to 3420Km² in 2024 (+241%)**,** indicating intensified anthropogenic land transformation. Vegetation exhibited significant fluctuations, decreasing from 1770 Km² in 2004 to 690 Km² in 2009 (−61%)**,** rebounding to 3760 Km² in 2019 (+37%), and declining sharply to 1.010 Km² in 2024 (−73%)**.** Intermediate-year variations (2009–2019) were strongly influenced by data quality issues, including cloud cover and Landsat-7 scan line errors. Water bodies remained relatively stable, increasing moderately from 270 Km² in 2004 to 480 Km² in 2024(+76%)**,** whereas bare earth showed extreme fluctuations, declining overall from 650 Km² in 2004 to 6 Km² in 2024 (−99%) due to classification uncertainties.

Predictive modeling indicated a continued decline in wetland area from 1,384.9 km² in 2024 to –20,026.03 km² in 2054 (−86%)**,** suggesting near-total collapse by 2054 if current trends persisted. The study concludes that without immediate and sustained conservation efforts, the ecological integrity and socio-economic benefits of wetlands in the selected areas will be severely compromised. It recommends the adoption of GIS-based monitoring frameworks, stricter land-use regulations, and active community participation to preserve these critical ecosystems.

The overall LULC trends indicate:

A long-term increase in built-up areas, reflecting rapid urbanization.

Vegetation fluctuations, largely influenced by data quality issues in intermediate years.

Waterbodies remain relatively stable with minor variations.

Bare earth shows inconsistency, suggesting classification uncertainty.

The most reliable comparison (2004 vs 2024) clearly indicates a transition from vegetation- dominated landscape to built-up dominance.

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Classification Accuracy Assessment

Raster Value	**Reference**	**Classification**	**Pixel Sum**	**Area [metre^2]**		
1	1	1	201	180900		
2	2	1	8	7200		
3	3	1	2	1800		
4	2	2	71	63900		
5	3	3	129	116100		
6	1	4	3	2700		
7	4	4	16	14400		
ERROR MATRIX [pixel count]						
	> Reference					
V_Classified	1	2	3	4	Total	
1	201	8	2	0	211	
2	0	71	0	0	71	
3	0	0	129	0	129	
4	3	0	0	16	19	
Total	204	79	131	16	430	
AREA BASED ERROR MATRIX						
	> Reference					
V_Classified	1	2	3	4	Area	Wi
1	0.6621	0.0264	0.0066	0	3417467400	0.695
2	0	0.098	0	0	481851900	0.098
3	0	0	0.2058	0	1011924000	0.2058
4	0.0002	0	0	0.001	5937300	0.0012
Total	0.6623	0.1243	0.2124	0.001	4917180600	0

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Estimated area	3256439589	611424123.7	1044317056	4999831.58	4917180600	
SE	0.0102	0.0092	0.0046	0.0001		
SE area	50110971.85	45040716.46	22850747.88	510293.17		
95% CI area	98217504.84	88279804.27	44787465.85	1000174.62		
PA [%]	99.9712	78.8081	96.8982	100		
UA [%]	95.2607	100	100	84.2105		
Kappa hat	0.8597	1	1	0.8419		

Overall accuracy [%] = 96.6871

Kappa hat classification = 0.9315

Area unit = metre^2

SE = standard error

CI = confidence interval

PA = producer's accuracy

UA = user's accuracy

The classification accuracy evaluation produced an Overall Accuracy of 96.69% and a Kappa coefficient of 0.9315, and it indicates an excellent level of agreement between the classified map and the reference data. The Producer's Accuracy ranged from 78.81% to 100.00%**,** while the User's Accuracy ranged from 84.21% to 100.00%**,** this demonstrates that the classified LULC map is highly reliable for wetland delineation and subsequent change analysis.

Validation of Prediction

Validation using historical epochs gave:

% Correctness = 76.23%

Kappa Overall = 0.54 (moderate agreement)

Kappa Histogram = 0.61 (good agreement on class proportions)

Kappa Location = 0.88 (very high spatial accuracy)

This indicates the model is reasonably reliable, though uncertainties remain.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The study has shown that the extent of depltion of wetlands within the study area is dire and has the propensity to escalate. Further depletion of the wetlands will be principally through human interventions with urbanization the chief architect.

Recommendations

Based on the findings of this study, the following recommendations are proposed to address the objectives of the study:

Wetland Protection Policies (Objective ii & iii)

Government and planning authorities should also prepare and implement policies to delineate, control and prevent the expansion of forest areas into wetlands. This can be supported by evidence of pattern of over-exploitation and spatio-temporal variation of land use.

Integration of GIS in Environmental Planning (Objective i & ii)

Decision-makers should strive to employ GIS-based monitoring systems on an ongoing basis to track changes in wetlands extent and to monitor early degradation trends. The availability of GIS will help to precisely recognize and demarcate wetlands in order to Plan based on the available evidence and implement effective management interventions in the appropriate time frame.

Sustainable Land Use Practices (Objective iii & iv)

Control of urban growth and agriculture expansion in the vicinity of wetlands by land use zoning, creation of buffer areas and water ring enforcement of EIAs has to be implemented these would help to minimize adverse effects of land cover changes on wetlands and would be helpful in modeling and forecasting depletion over the next three decades.

Community Awareness and Participation (Objective ii & iii)

Local peoples should be made aware of the ecologic, economic and cultural importance of wetlands, which would lead to more concerted community effort in wetland conservation. Community involvement in the effort of wetland conservation would reinforce policy measures, which is required due to the spatio-temporal pattern of wetland loss observed in this study.

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