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Spatio-Temporal Land-Cover Change Analysis of the Imo River Estuarine Wetlands and its Implication on the Mangrove Ecosystem

Lois E. Obuba[a]*, Mohammed S. Ozigis[b]

[a]*Department of Fisheries and Aquatic Resource Management, College of Natural Resources and Environmental Management. Michael Okpara University of Agriculture, Umudike*
[b]*Department of Geography, University of Leicester. United Kingdom*
[b]*Department of Strategic Space Application, National Space Research and Development Agency, Nigeria*
[a]*Email: zeobuba@gmail.com* , [b]*Email: msjo1@leicester.ac.uk* , [b]*Email: mohammed.ozigis@gmail.com*

Abstract

Land-cover in coastal areas determines to an extent the degree its surrounding water bodies differ from their pristine nature. Change mapping within coastal wetlands especially in areas prone to anthropogenic activities will help protect these fragile habitats. A land-cover change analysis was carried out on the Imo River estuary covering about 724 hectares of the estuarine wetlands, using 3 satellite images of the area acquired from Landsat 5TM (1986), Landsat 7 ETM (2000) and Landsat 8 OLI (2016) for a period of 30 years. Results showed that mangrove vegetation decreased by 17.5%, crop and grassland increased by 17% while total coverage of settlements increased by 3.4%. This implies that mangrove vegetation has significantly depleted over time and if this trend is not checked could lead to increase siltation of the river through runoff as a result of deforestation. There is also a likelihood of increase waste discharge directly or indirectly into the river by neighboring communities. It is recommended that proper waste management practices be adopted to suit urban growth within these communities and constant monitoring should be carried out using high resolution images to monitor coastal wetlands to protect fishes and other endangered species.

Keywords: Wetlands; Waste Discharge; Land-cover change; Fisheries Management.

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* Corresponding author.

1. Introduction

Over the years, the effects of anthropogenic activities have become the change drivers in coastal ecosystems and the environment as a whole. Changes in regenerated habitats caused by mangrove deforestation and destruction of wetlands bring about the introduction of non-native species which alter these communities and declination of flora and fauna. These salt-tolerant tidal evergreen forests play a prominent role in tropical and subtropical coastal habitats as they fuel the trophic web with withered leaves and detrital matter. They have been found to enhance and sustain the natural biomass of coral reef fish as well as breeding grounds for many fish fauna. Furthermore, mangrove forests enhance water quality by trapping nutrients and heavy metals [19]. Nonetheless, all over the world mangrove ecosystems and the hydrological integrity of coastal systems are threatened with destruction through various forms of anthropogenic activities utilization of coastal resources, pollution, and land reclamation [16]. Within the lists of human-induced pressure on the mangrove forests in Nigeria, pollution from crude oil activities tops the chart and is still a source of concern for ecologists [17,18]. However, the presence of vast expanse of wetland vegetation within a coastal environment serves as a sink for these heavy metals and therefore a mitigating factor [11]. Species richness of mangroves in many geographical areas have decreased over time as a result of socio-economic activities bringing about overexploitation by traditional users. Replacement and degradation because of development are all major problems of mangrove environments and have been predicted by the Intergovernmental Panel on Climate Change (IPCC) that climate change will have more effect in Sub-Saharan Africa. Thus, the need to use natural resource management tools like Remote sensing which analyze vast expanse of land-cover with little or no contact to the sites. Data acquisition and observation from these space-borne\airborne sensor system have profoundly changed the practice, monitoring, and understanding of the dynamics of coastal environments. It has become increasingly important to identify and inventory the current extent and condition of coastal wetlands and its river basins, especially in Nigeria where spatial and in-situ data on wetlands are relatively scarce and still evolving. Estuarine ecosystems comprise of various flora and fauna habitats which vary according to geographical region, biomes, and land-use of the catchment. While agriculture remains the mainland-use around most coastal catchments, urban centres and industries have also become a major land-use around these coastal areas especially within southern Nigeria [14]. The development of urban centres and other activities which are tied to urbanization have led to significant changes in the quantity and quality of water discharged into the sea through the estuaries. It becomes therefore imperative to leverage on the available vast earth observation data from satellite remote sensing to establish the contribution from both urban and peri-urban land use activities into the estuarine ecosystem. This study aimed at implementing a land-cover change analysis of the Imo River estuary covering about 724 hectares of wetlands. The specific objective of the study was to assess the impact of the adjoining land cover on the river estuarine using satellite remote sensing. To achieve this, three (3) satellite images spanning a period of 30 years were collected and analyzed to show changes in the land cover composition.

2. Methodology

2.1. General Methodology

The Imo River estuary rises from the Achi Okigwe highlands in the Udi hills [1]. It flows through different eastern Nigerian states and empties into the Atlantic Ocean at bight of Bonny, where it is bounded by Akwa-

Ibom and Rivers States at Ikot-Abasi and Opobo. It is characterized by the presence of dysfunctional Aluminum plants and abandoned oil wells. The estuary has about 26,000 hectares of wetland [4,2,9] and located between latitude 06°50' and 07°40' E and longitude 04° 25' and 06° 25' N of the South Eastern coastline.

2.2. Data

The satellite images used were obtained from the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov/). Image downloaded were the Landsat 5 Thematic Mapper (TM) image, Landsat 7 Enhanced Thematic Mapper (ETM) and Landsat 8 Operational Land Imager (OLI) for 1986, 2000 and 2016, respectively. The images used for this study were dry season images acquired in the month of December. The rationale for the choice of images chosen were to reduce the influence and impact of haze and cloud cover during the wet season.

Table 1: List of Images Used in the Study

Data	Date of Acquisition	Spatial Resolution	Number of Bands
Landsat 5 TM	1986-12-19	30 meters	4
Landsat 7 ETM	2000-12-17	30 meters	8
Landsat 8 OLI	2016-01-04	30 meters	11

2.3. Field Data

Field data were obtained in the course of this study for ground data accuracy. The estuary in the study area was surveyed using a speed boat hired from local transporters, while a GPS unit (Garmin eTrex 10) was used to get coordinates for 45 points. These points were used to determine ground truth for accuracy assessment purpose as prescribed by [6].

2.4. Image Analysis

The satellite image process was carried out in the Environment for Visualizing Images (ENVI 5.3) software environment, obtained under the license of the University of Leicester United Kingdom. In other to analyze for change, a classification process was carried out on the 3 images after all the necessary image pre-processing operations (i.e. atmospheric and geometric corrections) were concluded. Unsupervised classification methodology was used to classify image pixels into classes. This was further used to extract the final land-cover classes within the estuary and tidal creeks. Nine (9) land cover classes ranging from clear water, turbid water, settlement (urban surface), mud plains, mangrove vegetation, Nypa palm, crop/grassland, bare surface (soil surface type 1) and alluvium (soil surface type 2) were investigated in this study. Unsupervised classification was used based on its potential for a better class delineation within the geographical context of study as implemented in [10,15]. The ENVI software was calibrated to find the best optimal class using an ISODATA algorithm and 75 iterations to give a good result. A comparison of the three decades was done to analyze Spatio-temporal change in land-cover for the wetlands directly bounded by the river flowing into the ocean.

3. Results

3.1. Image Classification and Landcover

Figure 1 shows the result of the image classification process. Nine land cover classes which represented the major land cover in the estuary and within its neighboring wetlands were adopted in this study as seen in different color codes of the classified images. The results indicate that true mangroves were predominant and had the highest percentage of land-cover within the estuary and its wetlands in 1986 at 31 percent. This figure reduced drastically by 2016 to 14.6 percent, showing that over half of the mangrove forest within the banks of the river have depleted over the years. Areas of clear water had 4.6 percent coverage in 1986, this later increased in 2000 by 5.2 percent (Table 1). The areas classified as turbid waters are situated within the creeks and riverbeds. This decreased by 4.9 percent. However, prior to this decrease, water body had an area coverage of 17.2 percent hectares of clear water and 12.3 percent hectares of turbid water (Shallow creeks and riverbeds) in 1986. The total urban land cover presence increased from 3.5 to 6.9 percent between 1986 and 2000 [12], reported that coastal wetlands provide lots of environmental and socio-economic importance, and that the destruction of mangroves in West and Central Africa is attributed to urban development, land conversion to agriculture and aquaculture, oil and gas extraction as well as pollution from waste.

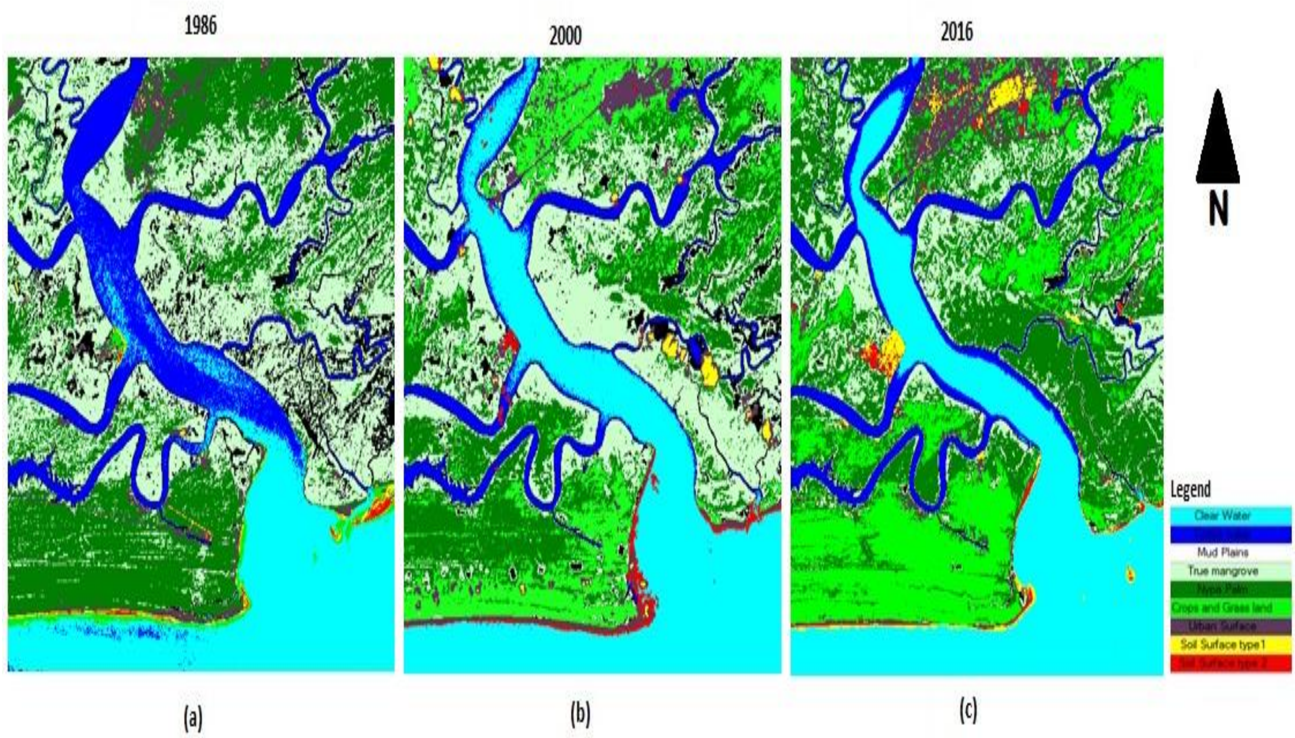

Figure 1: Result of the image classification showing the Landcover maps of the Imo River Estuary. (a) 1986 Landcover Map (b) 2000 Landcover Map (c) 2016 Landcover map

Table 2: Land-cover in Hectares and Percentage Change by Year, in the Imo River Estuary.

Landcover	Area (h) 1986	Area (h) 2000	Area (h) 2016	Change 1986 – 2000 (%)	Change 2000 – 2016 (%)	Change 1986 – 2016 (%)
Unclassified	-	-	-	-	-	-
Clear water	124.376	162.297	157.851	5.2	-0.6	4.5
Turbid water	88.277	46.227	53.766	-6.0	1.0	-4.9
Mud plains	63.407	40.827	18.246	-3.3	-3.1	-6.4
True mangrove	226.455	186.480	105.642	-5.5	-11.1	-17.0
Nypa palm	183.588	161.130	199.755	-3.1	5.3	2.2
Crops & grassland	10.931	85.683	137.334	10.3	7.1	17.4
Urban surface	20.514	28.152	34.170	1.1	0.8	1.9
Soil surface 1	3.978	3.786	11.232	-0.03	1.0	1.0
Soil surface 2	1.971	8.874	5.460	1.0	-0.5	0.5
Total	**723.497**	**723.456**	**723.455**	-	-	-

3.2. Accuracy Assessment

The Kappa coefficient (*K*) was derived to evaluate the accuracy of the image classification. Kappa statistic close to one indicate that classification is significantly better than random and are accurate [13]. This usually range from -1 to +1. Table 3 shows that $K = 0.864$ was obtained for the 1986 image which had 86% accuracy. A kappa statistic of $K = 0.867$ with 88% overall accuracy was recorded for the year 2000 classified image (as shown in Table 4). In addition, results for the 2016 image (as shown in Table 5) shows that $K = 0.94$ with 95% overall accuracy was recorded. In general, the Kappa coefficients from the classification showed that land cover classes attributed to the pixels are accurate and thereby valid for the results obtained.

Table 3: Confusion Matrix for 1986 Image.

Class Category	Reference Totals	Classified Totals	Number Correct	Producers Accuracy %	Consumers Accuracy%	*K* Statistic
Clear Water	6	5	5	83.00%	100.00%	1.0000
Turbid Water	5	5	4	100.00%	80.00%	0.7970
Mud Plains	5	5	4	100.00%	80.00%	0.8100
True Mangrove	5	5	4	100.00%	80.00%	0.8000
Nypa Palm	4	5	5	80.00%	100.00%	1.0000
Crop & Grassland	6	5	4	83.00%	80.00%	0.8200
Urban Surfaces	6	5	5	83.00%	100.00%	1.0000
Soil Surface Type 1	4	5	4	80.00%	80.00%	0.7719
Soil Surface Type 2	4	5	4	80.00%	80.00%	0.7900
Unclassified	0	0	0	---	---	0.0000
Total	**45**	**45**	**39**			

Overall Classification Accuracy = 86.66%

Overall Kappa Statistics = 0.8644

Table 4: Confusion Matrix, Computed for 2000 Image.

Class Category	Reference Totals	Classified Totals	Number Correct	Producers Accuracy %	Consumers Accuracy%	*K* Statistic
Clear Water	6	5	5	85.00%	100.00%	1.0000
Turbid Water	5	5	3	100.00%	60.00%	0.5409
Mud Plains	5	5	4	100.00%	80.00%	0.7600
True Mangrove	5	5	4	100.00%	80.00%	0.7619
Nypa Palm	4	5	5	80.00%	100.00%	1.0000
Crop & Grassland	6	5	4	85.00%	80.00%	0.7500
Urban Surfaces	6	5	5	85.00%	100.00%	1.0000
Soil Surface Type 1	4	5	5	80.00%	100.00%	1.0000
Soil Surface Type 2	4	5	5	80.00%	100.00%	1.0000
Unclassified	0	0	0	---	---	0.0000
Total	45	45	40			

Overall Classification Accuracy = 88.00%

Overall Kappa Statistics = 0.8670

Table 5: 2016 Image Classification Error Matrix

Class Category	Reference Totals	Classified Totals	Number Correct	Producers Accuracy %	Consumers Accuracy%	*K* Statistic
Clear Water	6	5	5	83.00%	100.00%	1.0000
Turbid Water	5	5	5	100.00%	100.00%	1.0000
Mud Plains	5	5	5	100.00%	100.00%	1.0000
True Mangrove	5	5	5	100.00%	100.00%	1.0000
Nypa Palm	4	5	4	80.00%	80.00%	0.7660
Crop & Grassland	6	5	5	83.00%	100.00%	1.0000
Urban Surfaces	6	5	5	83.00%	100.00%	1.0000
Soil Surface Type 1	4	5	5	80.00%	100.00%	1.0000
Soil Surface Type 2	4	5	4	80.00%	80.00%	0.7660
Unclassified	0	0	0	---	---	0.0000
Total	45	45	43			

Overall Classification Accuracy = 95.55%

Overall Kappa Statistics = 0.9480

4. Discussion

This study demonstrated the potential of remote sensing in showing and quantifying the true extents of different land cover types within a wetland estuary. Of interest is the fact that the change dynamics among the estuarine land cover types can be held responsible for the rapid changes observed in the water body as shown in figure 1. The depletion of the true mangroves may have also occurred through bank erosion, socio-cultural activities and urbanization [12]. The increase in urban areas from 20 to 34 hectares as well as increase seen in soil surfaces show expected changes which occur around coastal areas, as migration to these environments are always on the increase in search for resources. The increase in human settlements observed in the results could be attributed to the industrial boom around this estuary in the past 15years. Though in recent times, most of these industrial activities such as oil exploration, and Aluminum Smelter Company of Nigeria (ALSCON) have been halted, but the effect on the environment are still very much visible from the satellite images. Furthermore, increase in areas with clearer water observed can be attributed to the dredging of the estuary by ALSCON earlier in the year 2000 as reported by [20]. The economic importance of dredging rivers is also juxtaposed with hydrological changes in rivers and riverbeds which can cause destruction of habitats and eventually change in biodiversity [3]. Clearer water nevertheless implies lower suspended sediment loads and deeper riverbeds, which allows enough light penetration to support photosynthesis. This positive change ameliorates the turbid effects of sediments produced by erosion and runoff from upstream areas and wetlands. The most enhanced change within this wetland is the increase in crop and grassland, from 11 hectares in 1986 to 137 hectares in 2016, while the true mangroves decreased from 226 hectares to 106 hectares. This 17 percent increase in grassland showed that more of the mangrove forest have become croplands or regenerated into grassland. This may, therefore, affect the nutrient load of a water body, especially in the rainy season when runoff transports sediments and nutrients such as fertilizers from the farms to the river, increasing the organic matter content, Biochemical Oxygen Demand, pH and transparency of the river. The Avicennia Africana and Rhizophora racemose were the predominant mangroves distributed in this ecosystem [7]. These plants are however being displaced by the Nypa palm (Nypa fruticans), which has been introduced to Nigeria and Cameroon since the early 20th century and have become an invasive species [20]. The Nypa Palm constitute significant detriment to the native mangrove species, which are now sparsely distributed within this environment. Nypa palm (Nypa fruticans), is a native shrub of the Indo-Pacific waters, its spread has had a major negative impact on the native mangrove macrophytes (Rhizophora spp.) of the Imo river estuary. [20], reported that this invasive species suppressed the native macrophytes and taken over in most of the estuary. However, its effect is not completely negative on the estuarine habitat as it increases species richness through heterogeneity. [5] also reported that Nypa palm has been found as a mitigation factor against bank erosion as the coastal areas suffer threats from land clearing for shrimp farms and industrial urbanization, being one of the few plants that grow well in mangrove tidal areas. These plants have been seen to take over the riparian zones of the Imo River estuaries following the decline of true mangroves which includes the native Rhizophora spp. The implication of this mangrove decline is a possible decline in recruitment of fish species which in the long run affects fish abundance as they serve as refuge grounds to aquatic fauna which protects them from overfishing as well as serves as breeding grounds. A comparative analysis of the fisheries of the estuary within these 30 years would have been ideal to ascertain the possible effect of the land-cover changes on the relative abundance of fish fauna, however, the dearth of past fisheries data remains a limitation. Another limitation is the lack of high-resolution images to delineate surfaces prevalent in urban settlements such as the different soil types seen, and the high cost of commanding them.

5. Conclusion

The results of this study revealed that the most enhanced change area within this wetland is the increase in crop and grassland, from 1.5% hectares in 1986 to 18.9% hectares in 2016. This 17% increase showed that more of the mangrove forest have become deforested crop and grassland. The resultant effect of this land-cover change type is an increase in the nutrient load of the river affected, especially in the rainy season when runoff transports sediments and nutrients from the farms and grasslands to the river. It can therefore be concluded that the integrity of the estuary and its surrounding wetlands have been affected by urbanisation, agriculture and loss of mangrove vegetation. These anthropogenic perturbations influence the varying nature of the abiotic factors which in turn affects plankton and fish catch, the hydrology of the estuary and over time eutrophication of these environments. It is therefore recommended that proper waste management strategies be put in place to curb waste disposal into the estuary by the increasing urban population also high spatial resolution image capturing of Nigerian coastal waters, should be carried out as a priority for artisanal and commercial fisheries management. The unavailability of high-resolution images makes it difficult and expensive for researchers to analyze catch per unit effort, chlorophyll-a production as well as surface and water temperature which can affect fish growth easily, especially on a large expanse of water.

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