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A Long-Term Assessment of Habitat Fragmentation in Coastal Wetlands, Niger Delta, Nigeria

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Abstract

The landscape of the Niger Delta is under threat because of rapid population increase and a thriving oil industry. This threat has necessitated many studies in the area to investigate the rapid changes occurring in different part of the Niger Delta. However, there has been limited focus on the changes taking place in the coastal areas of the Niger Delta. This study examined the pattern of landscape fragmentation in the coastal wetlands of the Niger Delta using remote sensing data of 1987, 2002 and 2017. The data were classified into five dominant landuse classes viz settlement, forest, mangrove, cultivation and water. The assessment of habitat fragmentation was carried out using FRAGSTAT v.4.2 to determine the level of habitat fragmentation in the area. The results showed that freshwater forest increased by more than 28% while mangrove forest and cultivation lost 5% and approximately 20% respectively. Landscape metrics showed an increasing mean patch size (3.37 ha in 1987, 6.48 ha in 2017), reducing number of patches (1340663 in 1987, 683926 in 2017), and patch density (7.68 in 1987, 3.92 in 2017), suggesting landscape homogenization in the area between 1987 and 2017. Therefore, although current conservation efforts may be succeeding, the fragile nature of the Niger Delta wetlands calls for sustainable utilization of the available resources in the wetlands. The pattern of change observed in this study provides a basis for the development of ecological conservation strategies for planning, monitoring and management of these resources.

Keywords: Rainforest; coastal wetland; remote sensing; tropical deforestation; landscape metrics; Niger Delta

Introduction

The earth's ecosystem is under pressure from human-induced changes associated with rapid population growth, industrial and technological advancement and climate change impacts (Jones *et al.*, 2017; Wu *et al.*, 2017). Though the tropical rainforest is a reservoir of ecosystem goods and services, anthropogenic pressure is leading to forest fragmentation, degradation and loss (Armstrong, 2017) through the conversion of the rainforest to non-forest land uses (Enaruvbe and Ige-Olumide, 2015; Dezecache *et al.*, 2017; Asubonteng *et al.*, 2018; Minaei *et al.*, 2018).

Coastal wetlands are biodiversity hotspots, rich in flora and fauna species. Much of these wetlands are however, at risk of conversion to non-forest use which pose threats to biodiversity and ecosystem goods and services (Huang *et al.*, 2012;

Wu *et al.*, 2017). In the Niger Delta region of Nigeria, oil exploration and exploitation activities have resulted in a complex relationship between man and the environment leading to severe ecological stress (Ochege *et al.*, 2017). The increasing anthropogenic disturbance of the coastal area is a major contributor to the heterogeneity and alteration of the composition and configuration of the Niger Delta landscape (Enaruvbe and Ige-Olumide, 2015). These activities also disrupt many aspects of the natural environment including water availability and quality, air and soil quality (van Hall *et al.*, 2017; Wohlfart *et al.*, 2017). The disruption of environmental processes can hinder ecological functions (McGarigal, 2013) and has prompted a call for sustainable use of terrestrial ecosystem as part of the United Nations sustainable development goals (SDGs) agenda. SDG agenda 15 aims to "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss". The attainment of this goal requires an understanding of the processes and impacts of land use changes resulting from human activities as input for ecological analysis, planning and management (Vogt and Riitters, 2017).

The Niger Delta is a fragile, ecologically sensitive area that supports a diverse assemblage of flora and fauna. It is the largest mangrove wetland in Africa and is composed of different ecological zones (Kuenzer *et al.*, 2014; Ayanlade and Drake, 2015) including freshwater forest and mangrove forest. The Niger Delta wetlands have remained vulnerable to degradation and loss in spite of efforts to conserve wetlands around the world (Kuenzer *et al.*, 2014; Enaruvbe and Ige-Olumide, 2015). The vulnerability of the Niger Delta wetlands to degradation and loss is a threat to biodiversity and ecosystem goods and services (Ewel, 2010; Tomaselli *et al.*, 2012). This is worsened by the influence of oil extraction activities and the resultant pollution coupled with rapid population growth (Adekola and Mitchell, 2011; Kuenzer *et al.*, 2014; Ochege *et al.*, 2017).

The processes leading to the observed land use/cover pattern and the resulting landscape configuration can influence environmental health, biodiversity and ecosystem products and services (Tomaselli *et al.*, 2012). The need for understanding land use change processes on ecological landscape structure and the availability of time-series satellite remote sensing data have promoted the development of new methods for land use change and landscape assessment. Intensity Analysis (Aldwaik and Pontius, 2012), fragstat (McGarigal, 2013) and morphological spatial pattern analysis (Vogt and Riitters, 2017) are examples of tools that are now available for land use analysis and landscape assessment. These methods and techniques depend on post-classification categorical comparison of remote sensing data at two or more time points (Zhang and Xu, 2014; Wohlfart *et al.*, 2017).

Land use change analysis and modeling tools have gained widespread interest as tools for understanding environmental change processes and rates among ecologists and land change scientists (Vogt *et al.*, 2006; Saura *et al.*, 2011; Zhou *et al.*, 2014; Akinyemi *et al.*, 2017; Hasani *et al.*, 2017). Landscape metrics are commonly used for quantifying ecological landscape structure. Adade *et al.* (2017), and Ke *et al.* (2010) have used landscape metrics for fragmentation analysis in coastal savanna in Ghana and coastal wetland change in Yanchang National Nature Reserve in China. Though landscape metrics have been extensively used for landscape fragmentation analysis around the world, landscape studies on the changing nature of the coastal wetlands in the Niger Delta appear to be lacking. The Niger Delta, especially around the coast wetlands, is rich in biodiversity and provides several ecological services that are important for the livelihood of the local population and the efficient functioning of the environment. Landscape fragmentation poses a threat to the continued existence of the coastal wetlands ecosystem. Therefore, this study seeks to characterize landscape fragmentation in the coastal wetlands of the Niger Delta as input for sustainable landscape planning and utilization of wetland resources in coastal wetland environments.

Materials and method
The study area

The coastal area of the Niger Delta cuts across six coastal States in Nigeria: Ondo, Delta, Bayelsa, Rivers, Akwa-Ibom and Cross River States (Figure 1). The area is rich in flora and fauna species diversity and is composed of a dense network of rivers and creeks majority of which are distributaries of the River Niger. Akpoborie (2011), discussed the hydrology of the area while the geology of the Niger Delta was the focus of a study by Short and Stauble (1967) who noted that the Niger Delta coastal area is composed of sedimentary deposits which has undergone at least three depositional phases. The three phases began with a marine incursion in the middle Cretaceous which was terminated by a mild folding phase in Santonian time.The second included the growth of a proto-Niger delta during the Late Cretaceous and ended in a major Paleocene marine transgression. The third cycle, from Eocene to Recent, marked the continuous growth of the main Niger delta.

The climate of the Niger Delta is characterized by a double-maximal rainfall regime which starts in April and ends in October. Annual mean rainfall of over 2000 mm is usually recorded in many part of the region with high relative humidity of above 80% in most periods of the year (Odjugo, 2010). The vegetation of the Niger Delta can be broadly divided into two major zones: freshwater forest in the northern part and the mangrove forest in the coastal belt (Ite *et al.*, 2013). Some vegetation species in the area include Nypa palm (*Nypa fruitican*), red mangrove (*Rhizophoraceae*) and *Aurea cedrata.* Many rare animal species and varieties of water bird species are also common in the area.

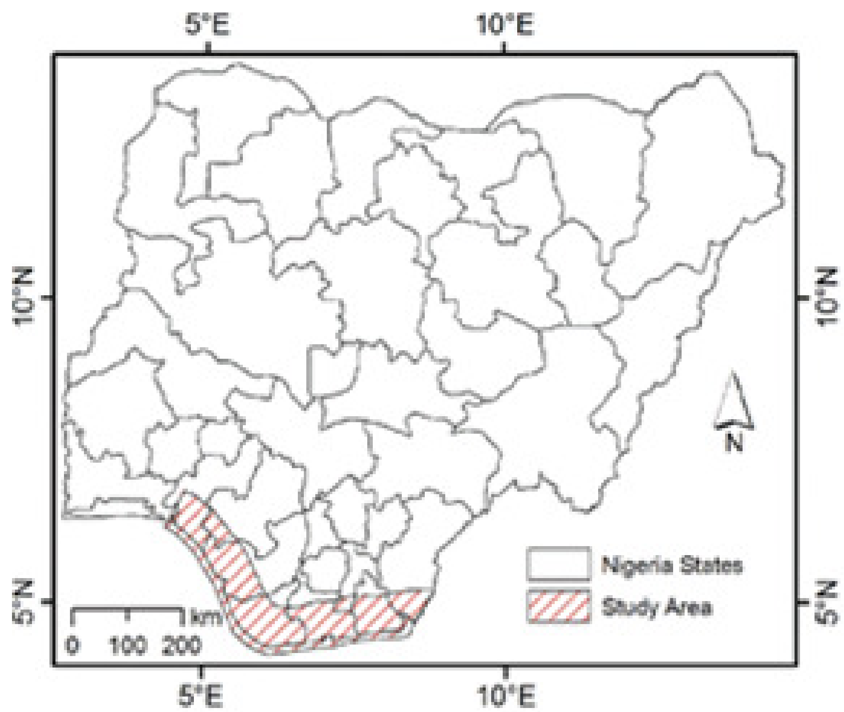

Figure 1: Location of the study area in Nigeria

Data sources, characteristics and image classification

A major constraint encountered with image data in the Niger Delta is cloud cover. This is because there is scarcely a month without rainfall which leads to almost year-round cloudiness in the area (Kuenzer *et al.*, 2014). Despite the desire to obtain images acquired between December and February of successive years, the difficulty of obtaining cloud-free data was a major determinant in the selection of the data used for this study. Seven scenes of Landsat images covering the coastal area from Ondo State in the west to Cross-River State in the east were obtained from the achieves of the United States Geological Surveys (USGS) during the dry season between December and February when clouds are at its minimum. The characteristics of the data are shown in Table 1.

The data were subjected to radiometric correction (conversion of digital numbers (DN) to surface reflectance followed by dark object subtraction) to account for differences in sensor, solar and atmospheric effects. This process ensures that the data are comparable over space and time (Young et al., 2017). The study area was extracted from the pre-processed images and image mosaicking was done before classification was carried out.

Table 1: Characteristics of Landsat images

Year	Path/Row	Sensor	Date
1986/87	187/057	Landsat 5 TM	13-Jan-1987
	188/056	Landsat 5 TM	19-Dec-1986
	188/057	Landsat 5 TM	19-Dec-1986
	189/056	Landsat 4 TM	21-Dec-1987
	189/057	Landsat 4 TM	21-Dec-1987
	190/055	Landsat 5 TM	15-Jan-1986
	190/056	Landsat 5 TM	15-Jan-1986
2002/03	187/057	Landsat 7 ETM^+	30-Jan-2002
	188/056	Landsat 7 ETM^+	08-Jan-2003
	188/057	Landsat 7 ETM^+	08-Jan-2003
	189/056	Landsat 7 ETM^+	30-Dec-2002
	189/057	Landsat 7 ETM^+	30-Dec-2002
	190/055	Landsat 7 ETM^+	03-Jan-2002
	190/056	Landsat 7 ETM^+	17-Feb-2001
2016/17	187/057	Landsat 8 OLI_TIRS	30-Dec-2016
	188/056	Landsat 8 OLI_TIRS	06-Jan-2017
	188/057	Landsat 8 OLI_TIRS	06-Jan-2017
	189/056	Landsat 8 OLI_TIRS	28-Dec-2016
	189/057	Landsat 8 OLI_TIRS	28-Dec-2016
	190/055	Landsat 8 OLI_TIRS	04-Jan-2017
	190/056	Landsat 8 OLI_TIRS	04-Jan-2017

Image classification and analysis

Supervised classification technique was used for extracting five dominant land use/cover categories in the study area. The categories are water (rivers, streams and water-logged areas), cultivation (cultivated farmlands, abandoned farmlands, secondary vegetation), settlement (towns, villages and cities, bare surfaces and cleared vegetation), freshwater forest (swamps with tree canopy greater than 40% cover and mature plantation forest in areas that are not perpetually flooded) and mangrove forest (swampy areas dominated by mangrove species). Maximum likelihood algorithm was used in ENVI 5.1 software. Earlier images (2002 and 1986) were classified based on 2017 field data (Enaruvbe and Pontius Jr., 2015; Akinyemi *et al.*, 2017). Square contingency tables were obtained by overlaying image pairs of subsequent years (1986 and 2002, 2002 and 2016).

Accuracy assessment of classified images

Accuracy of the maps derived from image classification were assessed based on information derived from field survey, existing maps and google earth images at 127 randomly selected sample points across the study area. The same information were also used for the accuracy assessment of maps derived from images of earlier years (Enaruvbe and Pontius Jr., 2015; Akinyemi *et al.*, 2017). Fragstat spatial metrics were computed using maps derived from classification of the satellite image data. The accuracy of the maps derived from the classification of the images is a determinant of the accuracy of landscape metrics derived from landscape analysis (Shao and Wu, 2008).

Landscape fragmentation and statistical analysis

Because of the size and nature of the landscape under investigation and for ease of interpretation, six landscape metrics that describe patch and shape characteristics at the class and landscape levels were computed. These are number of patches (NP), patch density (PD), mean patch size (MPS), largest patch index (LPI), largest shape index (LSI) and mean shape index (MSI) (Table 2). Landscape metrics were computed using the publicly available FRAGSTATS v. 4.2 (2015) software for the land use at each period in 1987, 2002 and 2017.

Table 2: Characteristics and description of landscape metrics

Landscape metric	Equation	Description
Number of Patches (NP)	n_i	Number of patches in the landscape type (class) *i*
Patch Density (PD)	$\frac{n_i}{A}$ x (10,000)(100)	Number of patches of the corresponding class type divided by the total landscape area (m2), multiplied by 10,000 and 100 to convert to hectares
Mean Patch Size (MPS)	$\frac{\sum_{j=1}^{n}(S_{ij})}{N}$	Sum of all Patches in a landscape divided by the total number of patches
Largest Patch Index (LPI)	$\frac{\sum_{j=1}^{n}(a_{ij})}{A}$ x 100%	Area (m^2) of the largest Patch of the corresponding patch type divided by total landscape area (m^2) multiplied by 100
Landscape Shape Index (LSI)	$\frac{.25\sum_{k=1}^{m}e_{ik}^{*}}{\sqrt{A}}$	0.25 (adjustment for raster format) times the sum of the entire landscape boundary and all edge segments (m) within the landscape boundary involving the corresponding patch type, including some or all of those boundary background divided by the square-root of the total landscape area (m^2)
Mean Shape Index (MSI)	$\frac{LSI}{N}$	Sum of shape index of all patches divided by the total number of patches in the landscape

n_i = Number of patches (class *i*) in the landscape; N= Total number of patches in the landscape; S_i= Size of patch *i* in a landscape; A = Total landscape area; m = sum of edge segment with a landscape boundary; a_{ij} = area (m^2) of patch *ij*; e_{ik} = total length (m) of edge in landscape involving patch (class *i*)

Source: Adopted from McGarigal (2015)

Results

Accuracy of land use/cover maps

The overall classification accuracy of the maps ranges between 90.19 % in 1987 and 99.21 % in 2017 (Table 3). Though overall accuracy were above 85% for all the maps, the producer's accuracy of freshwater forest and user's accuracy of cultivation were low (<50%) in 2002 and 1987
.

Table 3: Accuracy of land use maps

	Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)
Class	2017		2002		1987	
Settlement	99.88	96.16	92.26	90.60	85.70	92.92
Freshwater	97.71	98.35	48.66	85.82	23.54	39.51
Mangrove	98.56	92.40	91.35	83.59	95.13	71.83
Cultivation	96.48	97.17	87.48	37.61	86.64	29.17
Water	99.98	98.76	96.78	91.58	92.71	93.48

Overall classification accuracy: 2017 = 99.21 %; 2002 = 94.10 %; 1987 = 90.19 %

Land use and cover in the coastal wetland

Forest increased from about 5% in 1987 to 34% in 2017 (Table 4). Mangrove declined slightly from 26% in 1987 to 21% in 2002 and has remained stable since 2002. Similarly, water remained unchanged. Cultivated land however, declined from 37% in 1987 to 15% in 2017. Settlements reduced from 10% in 1987 to 4% in 2002 but increased to 8% by 2017.

Table 4: Land use and land cover changes in the Niger Delta coastal wetlands, 1987-2017

Land Cover	2017 (km^2)	%	2002 (km^2)	%	1987 (km^2)	%
Settlement	3985.98	8.65	2195.92	4.76	4769.09	10.34
Freshwater	15760.95	34.19	9400.38	20.39	2663.57	5.78
Mangrove	9774.58	21.20	10059.81	21.82	12210.45	26.49
Cultivation	6977.86	15.14	14697.90	31.88	17338.06	37.61
Water	7788.65	16.89	8519.32	18.48	8253.93	17.90
Unclassified	1814.66	3.94	1229.35	2.67	867.58	1.88

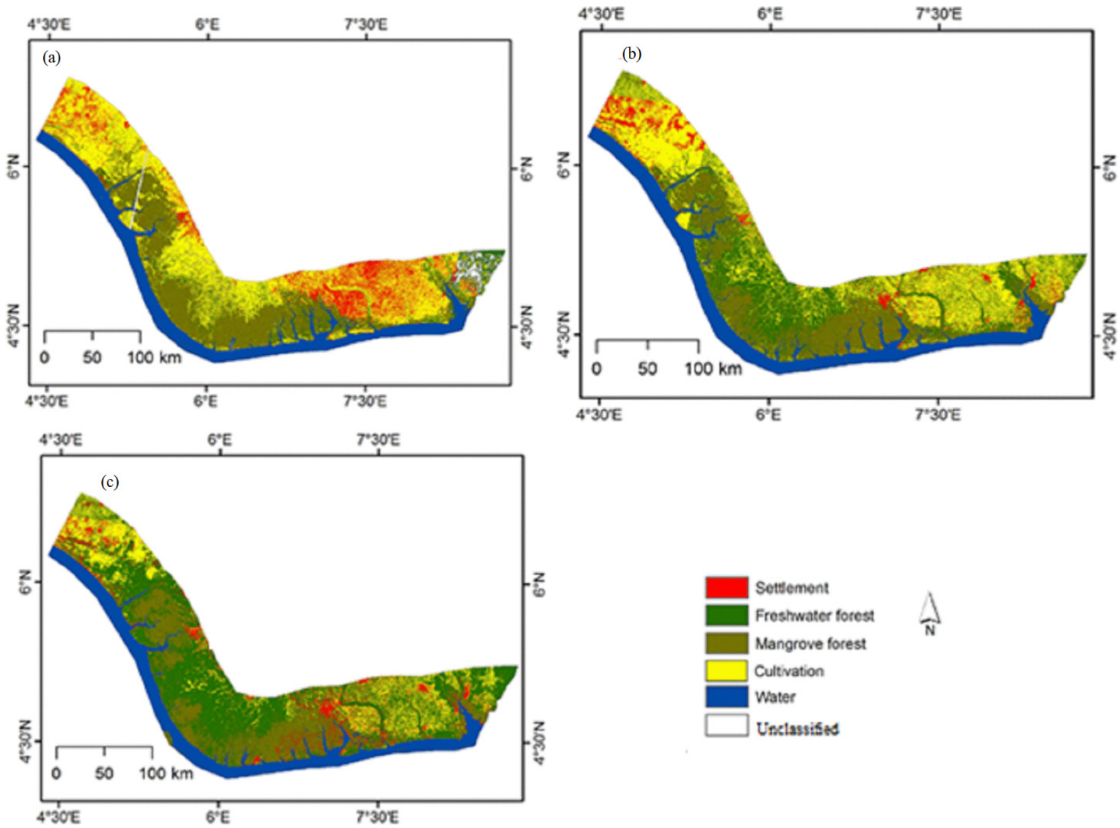

Figure 2: (a) land use/cover in 1987; (b) land use/cover in 2002 and (c) land use/cover in 2017

Landscape fragmentation in coastal wetlands of the Niger Delta

The number of patches (NP) at the class level are lower in 2017 than in previous years (Table 5). However, apart from mangrove forest category that decreased progressively from 1987, NP values are higher in 2002 for all classes. Similarly, despite a general decrease in patch density (PD), values were higher in 2002 for cultivation, freshwater forest and water categories. Mean patch size (MPS) of cultivation decreased over the years while freshwater forest, mangrove forest, settlement and water categories increased. In contrast, the largest patch index (LPI) of freshwater forest increased over the years while the values of other categories fell. In terms of shape complexity, the largest shape index (LSI) decreased while mean shape index (MSI) changed marginally.

Landscape metrics at the landscape level show higher values in 2002 for NP, PD and LSI (Table 6). The landscape level showed similar results with the class level. However, except for MPS, there is a general decrease in landscape metrics in the coastal wetlands.

Table 5: Landscape pattern metrics of land use categories in coastal wetlands, Niger Delta

	NP			PD			MPS (ha)		
	1987	2002	2017	1987	2002	2017	1987	2002	2017
Cultivation	249114	306292	204422	1.43	1.76	1.17	6.96	4.8	3.41
Freshwater	452167	850068	218004	2.59	4.87	1.25	0.59	1.11	7.23
Mangrove forest	373237	288128	104289	2.14	1.65	0.6	3.27	3.49	9.37
Settlement	251618	153125	149351	1.44	0.88	0.86	1.9	1.43	2.67
Water	14527	17873	7860	0.08	0.1	0.05	56.82	47.67	99.09

Table 5contd.

	LPI (%)			LSI			MSI		
	1987	2002	2017	1987	2002	2017	1987	2002	2017
Cultivation	2.58	2.69	1.58	716.5	765.92	514.05	1.24	1.2	1.22
Freshwater	0.35	1.81	1.12	716.21	1233.94	454.5	1.14	1.22	1.22
Mangrove forest	5.4	2.32	4.7	496.65	490.79	245.89	1.16	1.19	1.16
Settlement	0.81	0.08	0.62	581.19	404.15	424.74	1.21	1.19	1.24
Water	4.67	4.79	2.74	48.2	45.66	28.71	1.17	1.19	1.16

Table 6: Landscape pattern metrics of coastal wetlands, Niger Delta 1987-2017

	NP	PD	MPS(ha)	LPI	LSI	MSI
1987	1340663	7.68	3.37	5.40	271.12	1.18
2002	1615486	9.26	2.78	4.79	331.93	1.21
2017	683926	3.92	6248	4.70	180.22	1.21

Discussion

This study shows that freshwater forest ecosystem in the coastal wetlands of the Niger Delta increased more than six-folds in the last three decades. In contrast, cultivation decreased by half while mangrove forest and settlement reduced by 5% and 2% respectively (Table 4). Landscape metrics such as NP, PD, LPI and LSI reduced but MPS increased (Tables 5 and 6).

The increase in freshwater forest may be accounted for by a number of factors including the cultivation of perennial tree crops such as oil palm, cocoa, rubber and other tree plantations that are commonly cultivated for economic reasons in the Niger Delta (Onojeghuo and Blackburn, 2011; Enaruvbe and Ige-Olumide, 2015). In addition, the creation of parks for conservation areas, such as Bayelsa National Forest, Orashi National Forest and Cross River National Park, limits access to these forests. The swampy nature of the forest and the activities of oil exploitation companies that regularly pollute the landscape through oil spills also make farming difficult and unattractive in the area. Also, with the exception of Warri, Port Harcourt, Uyo and Calabar, large areas of the coastal wetlands are dotted with small and medium-size towns with low population densities. Onojeghuo and Blackburn (2011), observed that areas that have considerably low population density in the Niger Delta witnessed forest increase compared with those with high population concentration. In contrast, Wu *et al.* (2017), reported that freshwater wetland was decreasing in the coastal area of the eastern part of Shanghai, China. The high population density of the Shanghai area in contrast with the mostly sparsely populated Niger Delta coastal area, may explain the observed differences.

The general idea that rural dwellers may abandon their villages for urban areas in search of better opportunities and standard of living in cities (Çakir *et al.*, 2007), may however, not be the case in the Niger Delta. The 2% decrease in settlement may have been caused by error in the data or classification inaccuracy. Low agricultural productivity due to polluted soils and water and the attraction of working in oil servicing companies may however, lure young adults from rural communities of the Niger Delta to cities. The quest for better standard of living in cities may explain the decrease in cultivated areas over the years, the relative stability of the mangrove forest and the declining rate of forest loss in the Niger Delta wetlands. In addition, those engaged in agricultural activities may prefer to work in large plantations. Similar assertion was made by Zhang *et al.* (2010), who posited that agricultural development influence wetland dynamics in northeast China.

Mineral and timber extraction activities in the region also exert a huge pressure on the natural environment. Chidumeje *et al.* (2015) and Ayanlade and Drake (2015) reported the impact of anthropogenic activities, including agriculture and the oil industry, on the ecology dynamics of the Niger Delta. Similarly, Enaruvbe and Ige-Olumide (2015), observed a spatial and temporal variation in the rate of land use change in the Niger Delta region. The freshwater forest is generally more accessible for cultivation and for other anthropogenic activities than the difficult terrain of the mangrove swamp forest. In addition, accessibility may account for the differences in the landscape parameters between freshwater and mangrove forest. Ayanlade and Drake (2015), observed that freshwater forest lost more than 30% of its area while mangrove forest loss was only 11% in the Niger Delta between 1984 and 2011.

The values of the landscape metrics are an indication of the status of ecological conditions in the coastal wetlands of the Niger Delta (Table 5). Landscape metrics appears to be general improving indicating improvement in the ecological status of the coastal area of the Niger Delta. However, there is spatial variation in the pattern of fragmentation. For instance, as earlier indicated by the pattern of land use change (figure 2), MPS value of cultivation reduced by about 50% over the years suggesting a decrease in the size of farms in the study area (Table 5). This reduction in farm size may have been caused by scarcity of farm labour as many young adults would prefer city life than be engaged in farming activities in the rural communities. They therefore leave farming to the elderly who may not be able to cultivate large areas (Opukri and Ibaba, 2008). In addition, high frequency of oil spill because of the activities of oil exploitation and exploration companies may make farming unattractive as crop yields are adversely affected by the resulting pollution (Uyigue and Agho, 2007).

The mean patch size of freshwater forest, mangrove forest and settlement however increased indicating that these land use categories are expanding in size. Similar trends are observed in 1987 - 2002 and 2002 - 2017 intervals (Table 5). The declining landscape fragmentation in the coastal wetland may be due to conservation efforts by local and international agencies such as the Ramsar sites (Apoi creek and Orashi forest) and the creation of National Parks aimed at promoting forest and biodiversity conservation. In addition, the northern part of the Niger Delta which is primarily freshwater forest is more accessible and therefore more attractive for agricultural purpose which is a major driver of deforestation and landscape fragmentation than the swampy mangrove forest around the coastal belt.

Conclusion

The Niger Delta area of Nigeria remains an important part of the country's economy as it is home to several oil and gas installations. However, the management of these facilities in relation to environmental concerns has left much to be desired. The influence of economic activities on the environment of the area and especially around the coastal wetlands has been a source of concern from environmental and ecological conservation stand point. This study examined the state of habitat fragmentation in the coastal areas of the Niger Delta using remote sensing and GIS techniques. This study has shown that though deforestation in the Niger Delta may be high because of anthropogenic pressure on available resources, the area of freshwater forest in the coastal wetlands has increased over the years probably because of the cultivation of perennial tree crops such as oil palm and rubber plantations. In spite of this, however, the freshwater forest is more fragmented because it is more accessible and suitability for cultivation. In addition, the landscape is, in general, becoming more homogenous as many indicators of landscape fragmentation show improvement. The results of this study implies that the though a holistic planning strategy for the Niger Delta is desired, there is also the need to consider the pattern of land use and landscape changes in the coastal wetland of the Niger Delta. This is important because the unique characteristics of the area needs to be considered when making planning decisions so as to account for the sensitivity of specific ecosystems such as the coastal zone. The pattern of landscape and land use change, therefore, provides a basis for the development of ecological conservation strategies in the planning, monitoring and management of specific aspects of the landscape for sustainable utilization of ecological resources.

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