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Assessing the Changes in the Mangrove Ecosystem of Oron and Eastern Obolo Estauries

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Studies were carried out to assess the impact of nipa palm (*Nypa fruticans*) population on the sustainability of the mangrove forest of Oron and Eastern Obolo estuaries in Akwa Ibom state for a period of 30 years. Assessment of the land use change of Oron and Eastern obolo mangrove forests revealed a progressive succession of the nipa palms over the mangroves within a period of three decades (1986- 2018). The result showed a significant reduction (P > 0.05) in the population of mangrove, from 7610 in 2000 to 5540 in 2018 and an increase in the population of nipa palm from 3411 to 6229 within the same period. Satellite imageries obtained for both Oron and Eastern Obolo showed a decrease (P > 0.05) in the land area covered by mangroves while there was an increase (P > 0.05) in the area of land covered by nipa palms. These observed changes resulted in the loss of 1.9km^2 and 4.8km^2 of mangroves in Oron and Eastern Obolo respectively as well as an increase of 2.5km^2 and 7.4km^2 respectively (P > 0.05) in nipa palms. In summary, the outcome of

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the research shows a progressive succession of nipa palm over the mangroves. This calls for urgent action to mitigate the impact caused by the alarming succession that is currently on-going in the mangrove forest of Oron and Eastern Obolo, and by extension other mangrove forests across Nigeria and the world at large, if the ecosystem services performed by these mangroves will have to be sustained.

Keywords: Mangrove ecosystem; nipa palm; land use change; satellite image.

1. INTRODUCTION

“A mangrove is a shrub or tree that primarily thrives in brackish or salty coastal waters. Mangroves often grow along coasts and tidal rivers in an equatorial climate. They have unique characteristics that allow them to absorb more oxygen and expel salt, allowing them to withstand conditions that would kill most plants. The phrase is also applied to such species-rich tropical coastal vegetation. As a result of convergent evolution in multiple plant groups, mangroves are taxonomically diverse. The largest mangrove area is found within 5° of the equator, and they are found all over the world in the tropics and subtropics as well as some temperate coastal areas, primarily between latitudes 30° N and 30° S” [1,2].

10 of the 17 West African nations, from Senegal to Nigeria, have mangroves. Nigeria has the greatest mangrove area in Africa, with an estimated 10,515 km2, or 5.8% of the world's total mangrove area; the majority of this area is in the Niger delta. “Along with Indonesia, Brazil, and Australia, Nigeria is among the eight nations with extensive mangrove reserves that are still in existence. All nine of the coastal states—Lagos, Ogun, Ondo, Edo, Delta, Bayelsa, Rivers, Akwa Ibom, and Cross River—have forests. Mangroves make up around 18% of the land area, and these regions are protected by national and international laws but only a few of the declared protected sites are actively managed” [3]. In Akwa Ibom State, according to BDCP [4], the left overs of some healthy mangrove stands are found in Oron, Udunguko, Mbo, Urue-offong Oruko, Opobo, Uruan, IkotAbasi, Esit Eket, Ibeno, Eastern Obolo, and Parrot Island.

Mangroves provide a wide range of benefits including the provision of food and fisheries; biodiversity preservation [5]; medicinal values [6]; coastal/shoreline protection [7]; soil formation [8]; carbon sink [9,10], improvement of water quality [11], as well as nutrient cycling. “Mangrove restoration is an issue of concern for a number of reasons. Mangroves help maintain healthy marine and coastal environments. They shield the surrounding areas from weather extremes and tsunamis. Mangrove forests are also good in storing and sequestering carbon, which helps to slow down global warming” [2].

“Mangrove ecosystems have an outstanding relevance ecologically and economically, for this reason there is an urgent demand for conservation and restoration measures. Therefore, retrieving up-to-date information with regard to the extent and condition of mangrove ecosystems is an essential aid to management and policy- and decision-making processes. Typical mangrove habitats are temporarily inundated and often located in inaccessible regions; consequently, traditional field observation and survey methods are extremely time-consuming and cost intensive. To address these issues, large-scale, long-term, cost-effective monitoring and mapping tools are required, which are available by means of remote-sensing technology” [12,13,14,15].

“Mangroves also have a crucial role in addressing climate change by both mitigating and adapting to its effects. Their high primary productivity leads to the removal of significant amounts of carbon dioxide from the atmosphere” [16]. “The majority of this carbon, reaching up to 90 percent, is stored in the waterlogged and anaerobic conditions of mangrove soils, which minimize microbial respiration” [10,17]. When left undisturbed, mangroves have the potential to serve as a carbon sink for thousands of years.

Despite the importance of ecosystem services provided by mangroves (e. g. Timber, non-wood forest products, carbon sequestration, biodiversity conservation, coastal disaster mitigation, etc.), mangroves continue to be lost and converted to other uses, including aquaculture, agriculture, urban development and infrastructure. Natural retraction, at least in part a likely consequence of the impacts of climate change, is also a key driver of mangrove loss.

FAO [18] reports that between 2000 and 2020, 677 thousand ha of mangroves were lost, which was partially offset by the expansion of 393 thousand ha of mangroves, resulting in net loss of 284 thousand ha over the 20-year period. This highlights the dynamic nature of mangroves, with coastal ecosystems transitioning from one form to another as environmental conditions change.

Remote sensing has been widely proven to be essential in monitoring and mapping highly threatened mangrove ecosystems [19,20]. “Many research studies on this subject have been carried out around the globe. Tropical and subtropical coastal mangroves are among the most threatened and vulnerable ecosystems worldwide” [21]. The habitat area loss during the last two decades is estimated to be about 36% of the total global mangrove area. Although the rate of decrease has slowed since the 1980s, the average annual loss rate of mangroves of 0.66% during the years 2000–2005 is still alarming [22].

This research was carried out in order to assess the changes in the formation of the mangrove ecosystem of Oron and Eastern Obolo over time as well as determine the changes in the population of mangrove species in relation to the nipa palm in the two estuaries over a period of thirty years (between 1986- 2018).

2. MATERIALS AND METHODS

2.1 Study Area and Description of Sampling Sites

The study was undertaken in 2 estuaries, Eastern Obolo and Oron. Eastern Obolo is located in the Niger Delta fringe between Imo and Qua Iboe Rivers estuaries and lies between latitudes $4^{o}33'N$ - 4° 50`N and longitudes 7° 45` - 7° 55` E; and about 650m above sea level in the tropical mangrove forest belt, east of the Niger Delta.. It is bounded to the north by Mkpat Enin Local Government Area, northeast by Onna, west by Ikot Abasi, southeast by Ibeno Local Government Area all in Akwa Ibom state, and in the south by the Atlantic Ocean. It has a total landmass of 117,008square kilometers with an estimated shoreline of about 184 km long and a population of 60,543 people, according to 2006 population census. The tidal range in the area is about 0.8m at neap tides and 2.20m during spring tides with little fresh water input joined by numerous tributaries as they empty into the Atlantic Ocean [23]. The climate of the area is tropical with distinct rainy (April to October) and dry seasons (November to March) with a high annual rainfall averaging about 2500mm [24].

“Eastern Obolo estuary is a unique aquatic environment in the tropical belt with marked maritime influence characterized with riverine inflow, vertical mixing, coastal nutrient enrichment, oil pollution and other anthropogenic sources. It is also one of the ecologically and economically rich transitory marine ecosystems in the Niger Delta region of Nigeria with mangrove and saline water providing breeding grounds for a variety of fish and shrimp species. The area is characterized by an extensive mangrove swamp with inter-tidal mud flats influenced by the semi- diurnal tidal regime of the estuary. Numerous activities such as oil exploitation and exploration, laundry, fuel wood exploitation, boat transportation and capture fisheries take place along the estuary/watershed” [25]. Fishing and farming are the main economic activities in this study area.

A study by Fimsco Surveys [26] reported that Eastern Obolo ecosystem was rich in biodiversity and wildlife population before oil exploration. According to history, the Eastern Obolo people, migrated into the area from Western Obolo over 300 years ago and enjoyed a functional environment of unpolluted air, water and land [27].

Oron is located between 40^{0} 50’ 0’ latitude 5^{o} North and longitude 9^{o} East at the right bank of the lower estuary of the Cross River. It is the third largest city in Akwa Ibom State with an area of 70 km^2 and a population of 156,461 according to 2006 population census. The region is extremely fertile and is known for its topographical Oil Palm Belt, tropical rainforest, swamps, and beaches. There are also deposits of solid minerals such as iron, free silica or glass sand and gravel. Seafoods such as crayfish, snipers, oyster and periwinkle abound richly in Oron as in all coastal areas. The tidal range in Esuk Oron is between 2.01m (6.6ft) and 2.06m (6.8ft), by which time it brings high saline water and adds nutrients to the estuary, flushing away waste products, impurities, or even pollution. As the high tide gradually falls to its lowest point, it becomes the low tide, and the cycle starts over again [28]. Oron is in the tropical region and has a uniformly high temperature all the year round. The two main seasons are the dry- which spans between October and April and wet- season which starts around May and ends in September. The people of Oron are predominantly fishermen, farmers and traders who trade across the Gulf of Guinea frontiers.

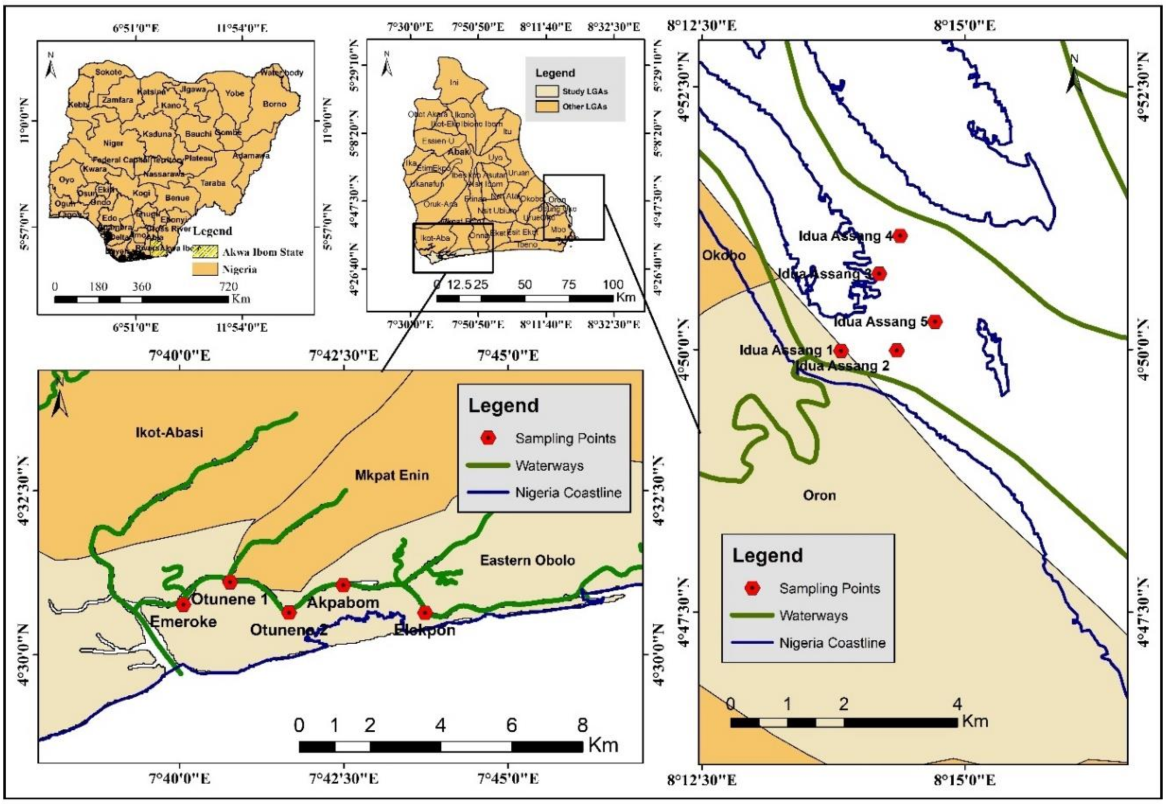

Fig. 1. Map of Akwa Ibom State showing the study areas, Oron and Eastern Obolo Local Government Areas

2.2 Methods

2.2.1 Identification of the study area and mangrove species

Some of the true mangrove species found in the study area were *Rhizophora mangle, R. racemosa, Avicennia africana as well as the mangrove associates- Nypa fruticans, Elaeis guinensis,* among other plant species. Identification of the mangrove species were done in the herbarium of the department of Botany and Ecological Studies, University of Uyo.

Reconnaissance survey was carried out to identify areas of pure mangroves and those dominated by invasive nipa palms. Cordinates of the different locations were taken and used for the remote sensing. This made it possible for the true mangroves to be differentiated from the nipa palms in the remotely sensed data, this offered some form of ground-truthing.

In the study, five sampling locations- A, B, C, D and E were selected each from Oron and Eastern Obolo estuaries on the basis of the presence and density of the mangrove or nipa populations. At each location, five 40m line transects were established from the low tide level at 1.5m interval. Location A was an area of purely mangrove trees with no nipa palm, situated at 04^{0} 49'59.2''N and 008^{0}13'49.2'E, with an elevation of 3m.

Location B was an area dominated by nipa palm with few mangroves (about 30 percent). It lies at coordinate 04^{0}49'59.4N and 008^{0}14'21.1''E with an elevation of -1m.

Location C was also dominated by nipa palm, with very few mangroves stands. Its coordinate was 04^{0}50'43.2N and 008^{0}1411.0" E with zero (0) elevation.

TRANSECT-D (Idua Asang 4 or site 3): this area was dominated by mangroves, with only few nipa stands; located at coordinate 04^{0}51'04.9" N and 008^{0}14'23.0E, with 2m elevation.

TRANSECT-E (Idua Asang5 or site 4): this was a transect of purely nipa palm with no mangrove plants, situated at 04^{0}50'15.9" N and 008^{0}14'42.9E, with 2m elevation.

2.2.2 Eastern Obolo Estuary

In this location, transects A- E were identified as Elekpon (EP), Emeroke (EK), Otunene 1(OT1), Otunene 2 (OT 2), and Akpabom (AK) respectively.

TRANSECT-A (Elekpon- Control): Elekpon is a fishing settlement situated at 04^{0}30'38.2N and 007^{0}43'44.3E, with an elevation of 4m. It is an area with luxurious mangrove stands without nipa interference and was thus used as the control for Eastern Obolo sampling location.

TRANSECT-B: Emeroke is the location of the oil well belonging to NPDC. This transect is located at coordinate 04^{0}30'45.7'N and 007^{0}40'03.4' E; with 7m elevation. The area is dominated by nipa palm, with only few mangrove stands.

TRANSECT-C: Otunene1 is also dominated by nipa palm. It has a coordinate of 04^{0}31'06.3'N and 007^{0}40'46.2'E; with an elevation of 9m.

TRANSECT-D: Otunene 2 lies within 04^{0}30'38.3N and 007^{0}41'40.0"; and has an elevation of 3m. This area also has an abandoned oil well head.

TRANSECT-E: Akpabom is an area of purely nipa palm with a coordinate of 04^{0}31'03.3N and 007^{0}42'29.5" E, with zero (0) elevation.

2.2.3 Remote sensing

The raw spatial images were acquired from United States Geological Survey (USGS), on www.earthexplorer.usgs.gov for Landsat 5TM, Landsat 7ETM and Landsat 8 OLI for 1986 to 2018. Three images of the study area were acquired within a time frame of 30years. The final process employed the use of the empirical radiometric calibration coefficients to transform the data into reflectance values. A set of control points were acquired as training sites for classification and validation to cover the study area. A GPS unit was used to get coordinates for the sampling points (transects). Appropriate enhancement techniques were applied to the images to make the mangroves appear better on the images as described by Green et al. [29]. In addition to the individual spectral bands of Landsat images, vegetation indices such as Normalized Difference Vegetation Index (NDVI), Green Atmospherically Resistant Index (GARI), and Normalized Difference Infrared Index (NDII) were also derived from the images to improve quality of classification.

2.4 Analytical Techniques

Data collected were subjected to descriptive statistics such percentages, frequency distribution and proportions of responses from which some inferences were drawn. ANOVA and SPSS were also used to carry out a wide range of data manipulation to achieve desired results. Bar chart and least significant difference (LSD) where used to determine changes in mangrove size as well as the land use change.

3. RESULTS

A critical examination of the result of analysis for Oron estuary as presented in Table 2 shows that in 1986 mangroves occupied the largest area of 6.8km^2 with a pixel count of 7610, representing 12.7% of the entire forest, while nipa palm covered an area of 3.1km^2 with a pixel count of 3411 (5.7%). Other features in the forest were as follows: built up 5442 (4.9km^2), water body 1752 (1.6km^2), shrubs 14168 (12.8km^2) while forest and farmland occupied 9279 (8.4km^2) and 17954 (16.2km^2) respectively. However, in 2000, mangrove forest reduced from its initial of 7610 (6.8km^2) to 6682 (6.0km^2) and later 5540(4.9km^2) in 2018 while nipa palm increased from 3411 (3.1km^2) in 1986 to 4624 (4.2km^2) in 2000 and then 6229 (5.6km^2) in 2018.

The results for remote count of features and land use in the mangrove forests of Oron are shown on Tables 1a, b and Figs. 2 a,b.

Similarly, analysis of Eastern Obolo estuary shows a consistent decrease in land area covered by the mangrove forest from 48.78km^2 in 1986 to 43.98 km^2 in 2018 while the land area cover for nipa palm increased from 11.91 in 1986 to 19.29 in 2018, implying a loss of 4.8 km^2 of mangrove forest and an increase of 7.38 km^2 of nipa forest.

The results for remote count of features in the mangrove forests of Eastern Obolo are shown on Tables 2 a,b and Fig. 2. Satellite imageries for Oron and Eastern Obolo LGA for the period between 1986 and 2018 (30 years) are shown in Figs. 4 a-c and 5 a-c.

Table 1a. Pixel counts of features of land use and land cover of Oron in Akwa Ibom State

Features	1986	2000	2018	$LSD_{(0.05)}$
Built Up	5442.0^{c}	5831.0^{b}	5844.0^{a}	3.6056
Water Body	1752.0^{c}	5114.0^{b}	9554.0^{a}	57.9828
Mangrove	7610.0^{a}	6682.0^{b}	5540.0^{c}	30.4631
NIPA	3411.0^{c}	4624.0^{b}	6229.0^{a}	34.8281
Shrub	14168.0^{a}	11541.0^{c}	13048.0^{b}	33.4664
Forest	9279.0^{c}	10673.0^{b}	11324.0^{a}	25.5147
Farmland	17954.0^{a}	15151.0^{b}	8077.0^{c}	52.9434

The mean value in each row followed by different superscripts is statistically different at ($P < 0.05$). Mean separation was done using Least Square Difference (LSD) without replicates derived from QI Macros 2018 excel add in statistical package

Table 1b. Pixel counts of features of land use and land cover of Oron in Akwa Ibom State

Features	1986	2000	2018	$LSD_{(0.05)}$
Built Up	1658.0^{c}	4232.0^{b}	8904.0^{a}	50.7346
Water Body	14422.0^{c}	14904.0^{b}	15272.0^{a}	19.1833
Mangrove	54197.0^{a}	51888.0^{b}	48870.0^{c}	48.0521
Nipa	13231.0^{c}	18395.0^{b}	21432.0^{a}	55.1090
Shrub	6888.0^{c}	8924.0^{b}	14492.0^{a}	45.1221
Forest	34903.0^{a}	23970.0^{b}	15411.0^{c}	92.5149
Farmland	8594.0^{c}	11580.0^{a}	9512.0^{b}	30.2985

The mean value in each row followed by different superscripts is statistically different at ($P < 0.05$). Mean separation was done using Least Square Difference (LSD) without replicates derived from QI Macros 2018 excel add in statistical package

Table 2a. Area (km^2) of land use and land cover of Oron in Akwa Ibom State

Features	1986	% of total Area covered	2000	% of total Area overed	2018	% of total Area covered	$LSD_{(0.05)}$
Built up	4.9^{b}	9.13	5.25	9.78	5.26	9.80	0.1082
Water body	1.58^{c}	2.94	4.60	8.57	8.60	16.03	1.7395
Mangrove	6.85^{a}	12.76	6.01	11.20	4.99	9.29	0.9139
Nipa	3.07^{c}	5.72	4.16	7.75	5.61	10.45	1.0448
Shrub	12.75^{a}	23.76	10.39	19.36	11.74	21.88	1.0040
Forest	8.35^{c}	15.56	9.61	17.90	10.19	18.99	0.7654
Farmland	16.16^{a}	30.12	13.64	25.42	7.27	13.55	1.5883

Total area covered 53. 66km^2. The mean value in each row followed by different superscripts is statistically different at ($P < 0.05$). Mean separation was done using Least Square Difference (LSD) without replicates derived from QI Macros 2018 excel add in statistical package

Table 2b. Area (km^2) of land use and land cover of Eastern Obolo in Akwa Ibom State

Features	1986	% of total Area covered	2000	% of total Area covered	2018	% of total Area covered	$LSD_{(0.05)}$
Built up	1.49^{c}	1.24	3.81^{b}	3.16	8.01^{a}	6.65	1.5232
Water body	12.98^{c}	10.77	13.41^{b}	11.13	13.74^{a}	11.40	0.5745
Mangrove	48.78^{a}	40.48	46.70^{b}	38.76	43.98^{c}	36.49	1.4422
Nipa	11.91^{c}	9.88	16.56^{b}	13.74	19.29^{a}	16.01	1.6523
Shrub	6.20^{c}	5.14	8.03^{b}	6.66	13.04^{a}	10.82	1.3528
Forest	31.41^{a}	26.07	21.57^{b}	17.90	13.87^{c}	11.51	2.7749
Farmland	7.73^{c}	6.41	10.42^{a}	8.65	8.56^{b}	7.10	0.9110

Total area covered 120.5km^2. The mean value in each row followed by different superscripts is statistically different at ($P < 0.05$). Mean separation was done using Least Square Difference (LSD) without replicates derived from QI Macros 2018 excel add in statistical package

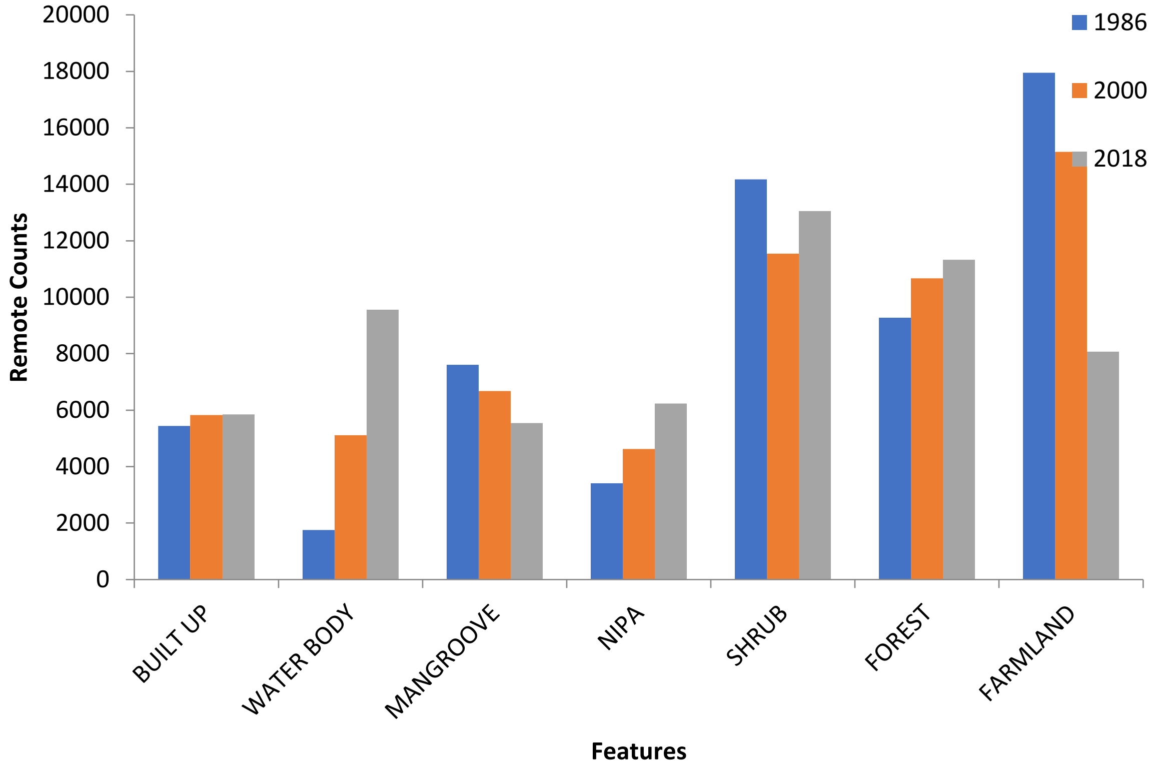

Fig. 2a. Pixel counts of land use and land cover in Oron - Akwa Ibom State

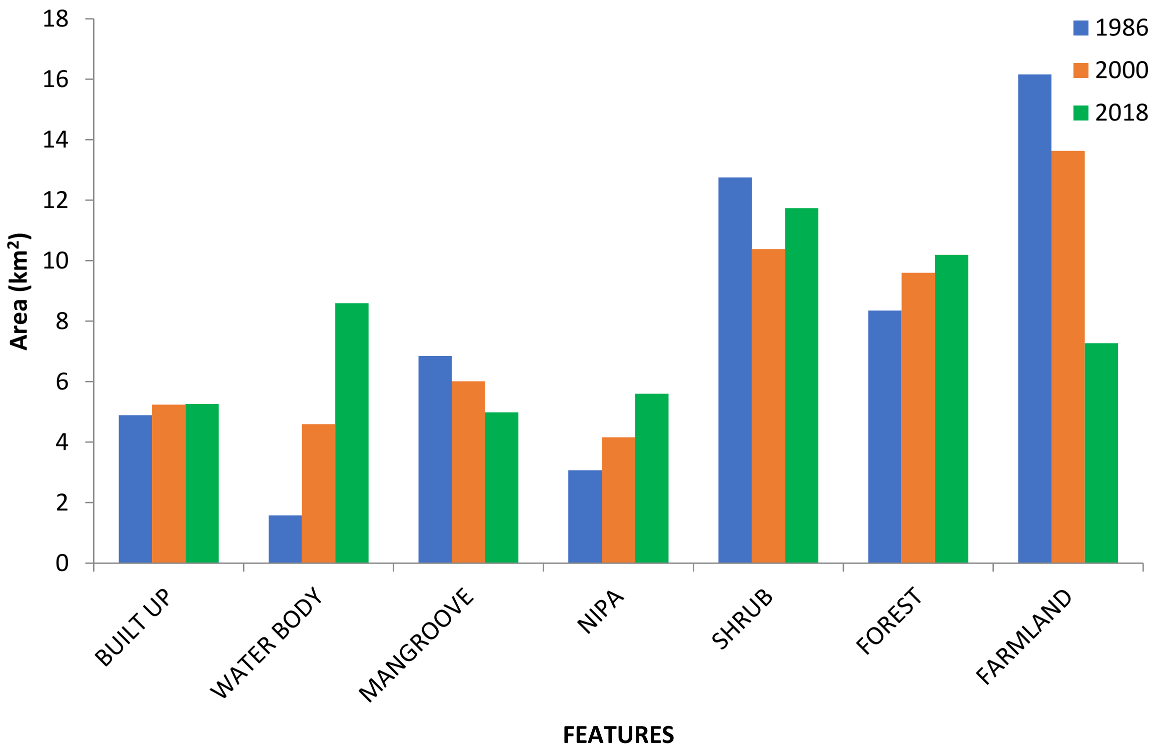

Fig. 2b. Area (km^2) of land use and land cover of Oron - Akwa Ibom State

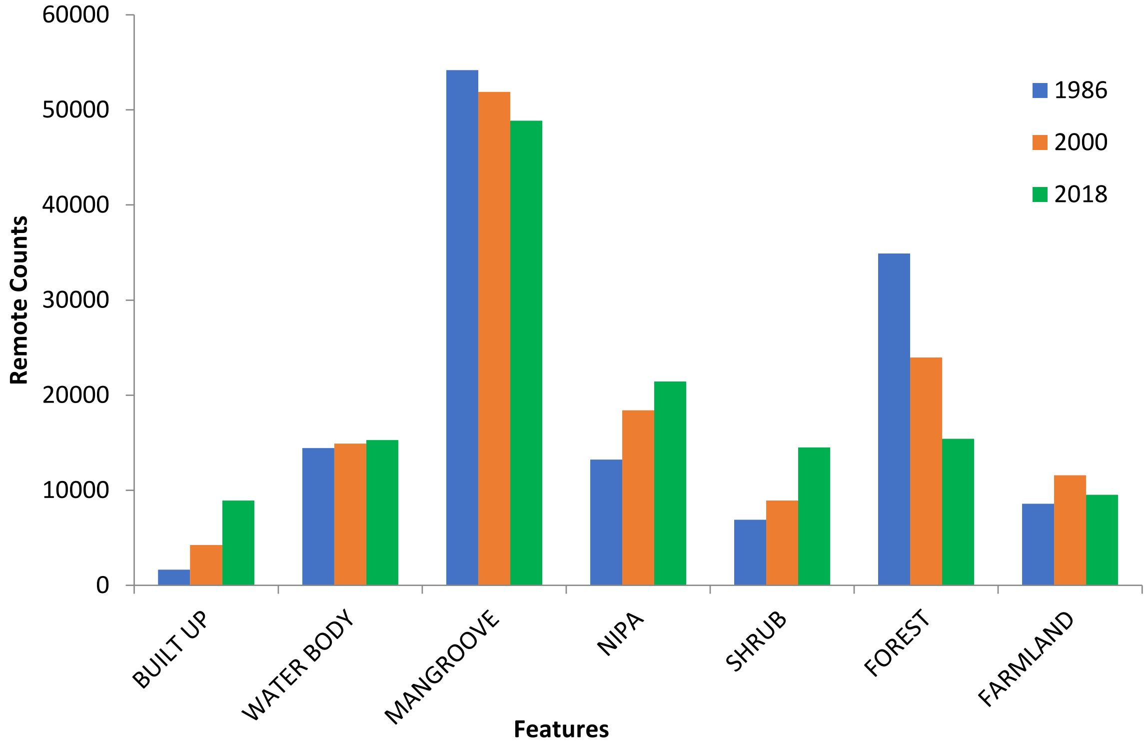

Fig. 3a. Pixel counts of land use and land cover in Eastern Obolo - Akwa Ibom State

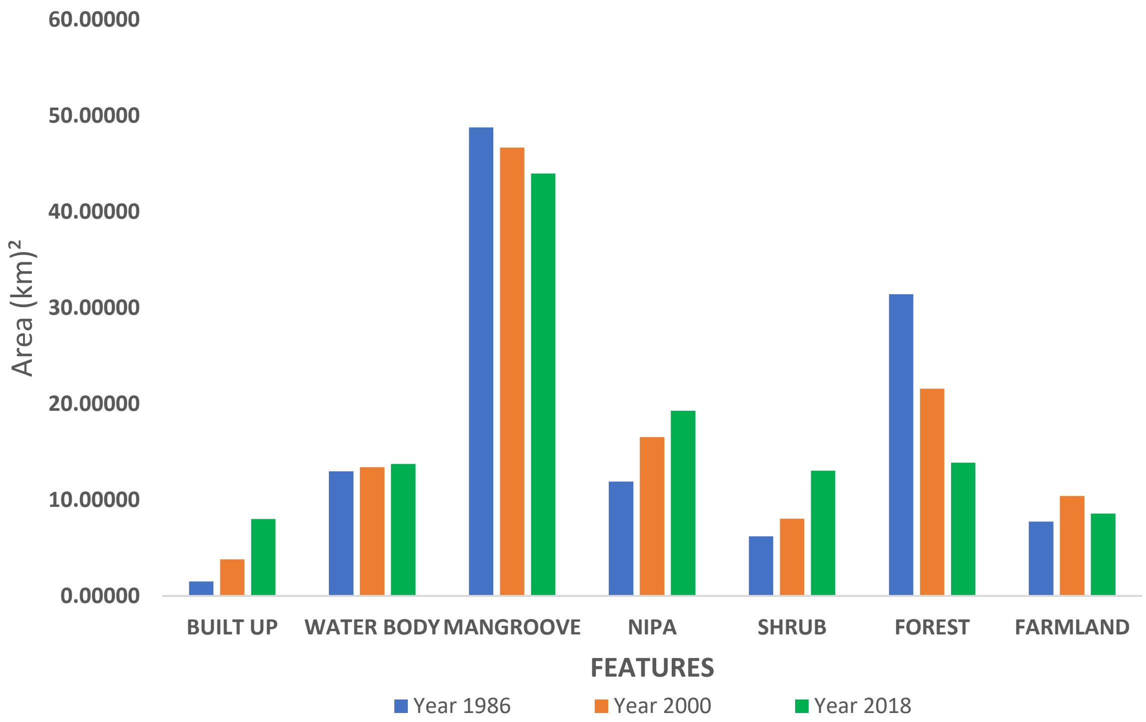

Fig. 3b. Area (km^2) of land use and land cover of Eastern Obolo - Akwa Ibom State

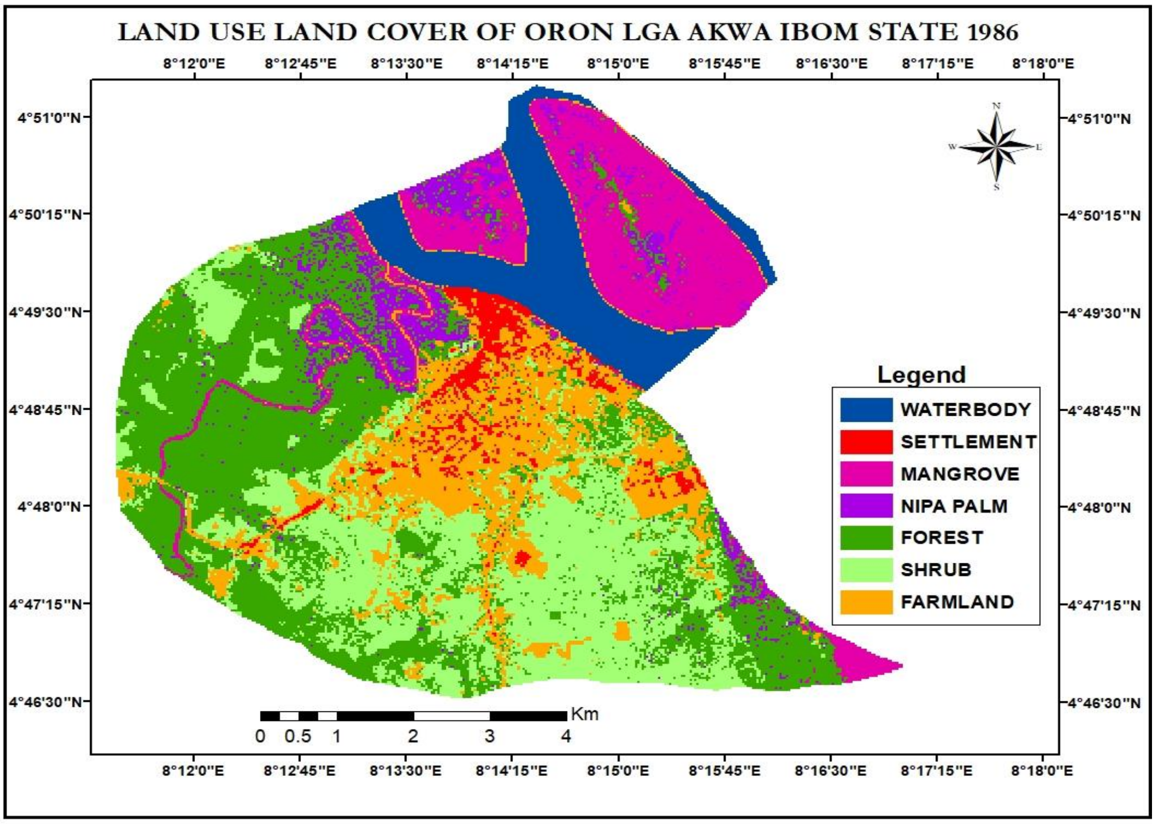

Fig. 4a. Satellite Image showing Land use cover of Oron LGA in 1986

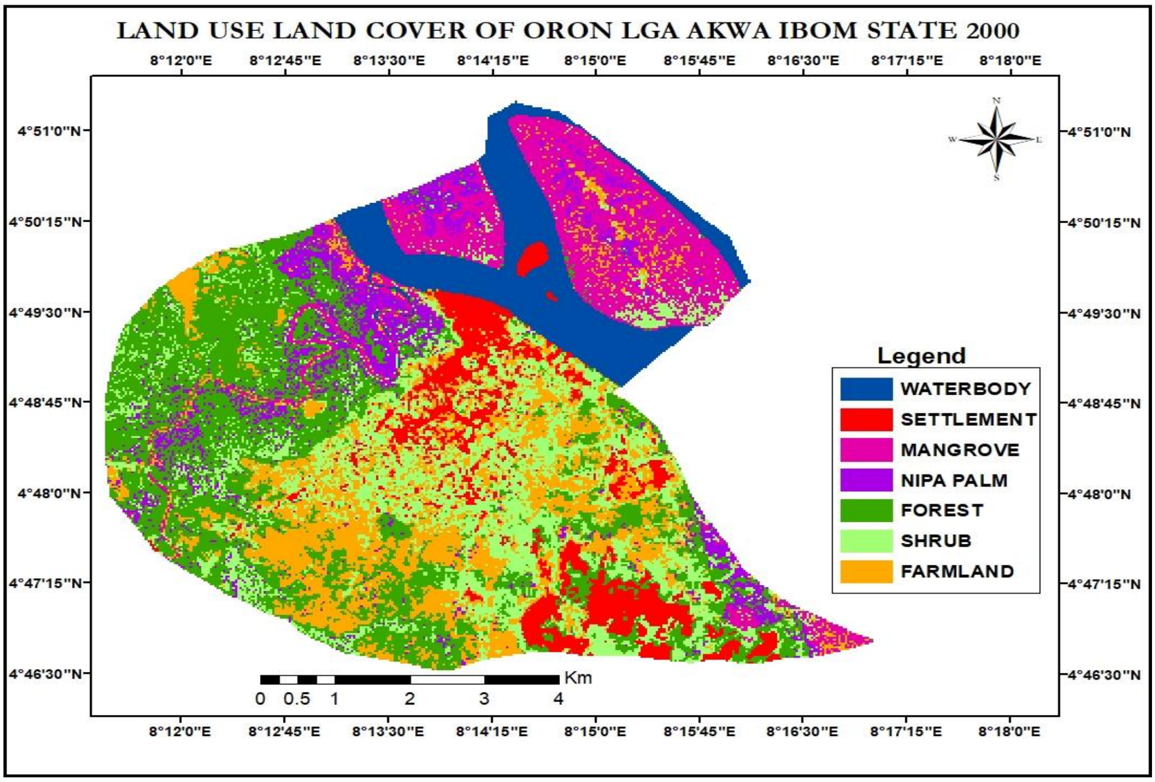

Fig. 4b. Satellite Image showing Land use cover of Oron LGA in 2000

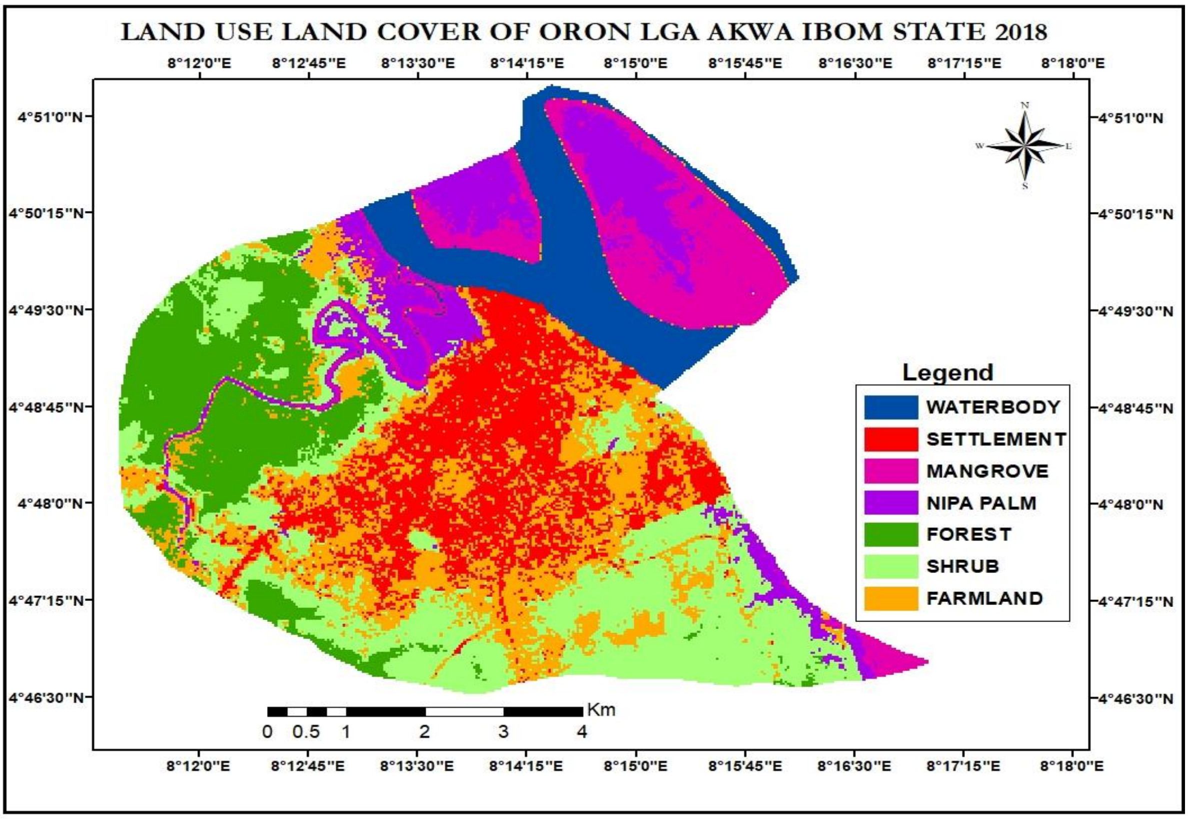

Fig. 4c. Satellite Image showing Land use cover of Oron LGA in 2018

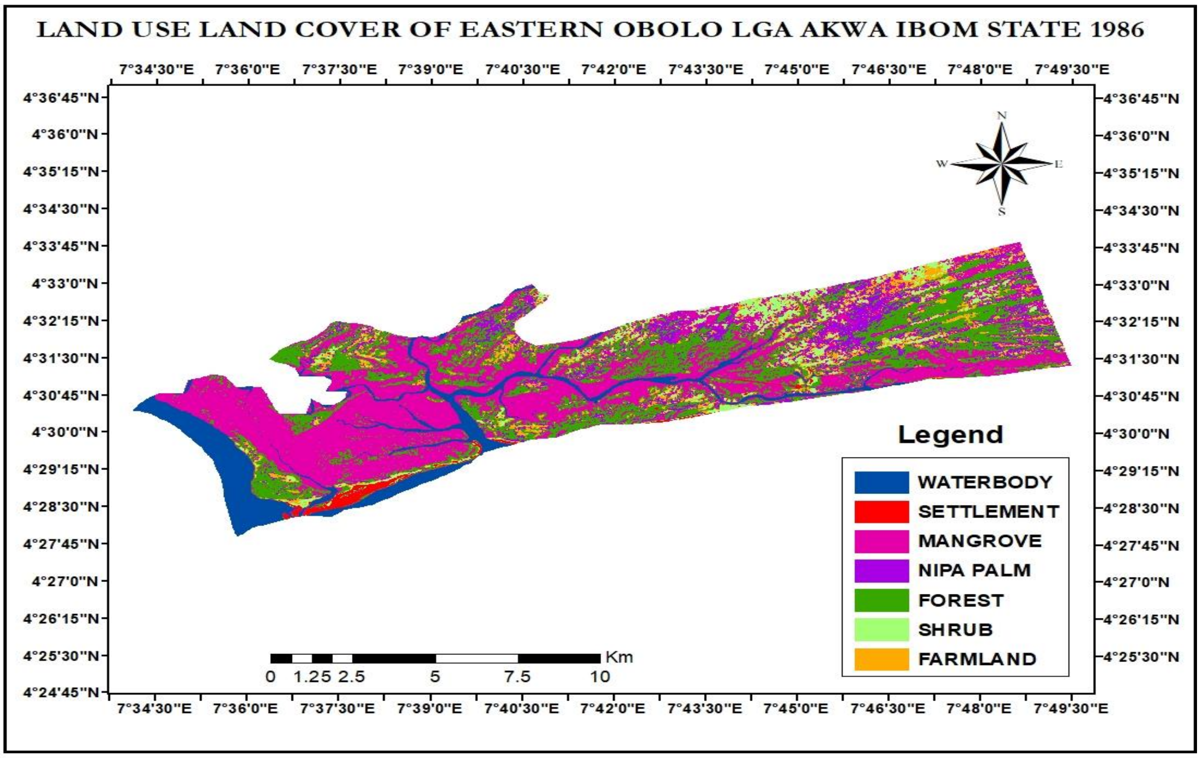

Fig. 5a. Satellite Image showing Land use cover of Eastern Obolo LGA in 1986

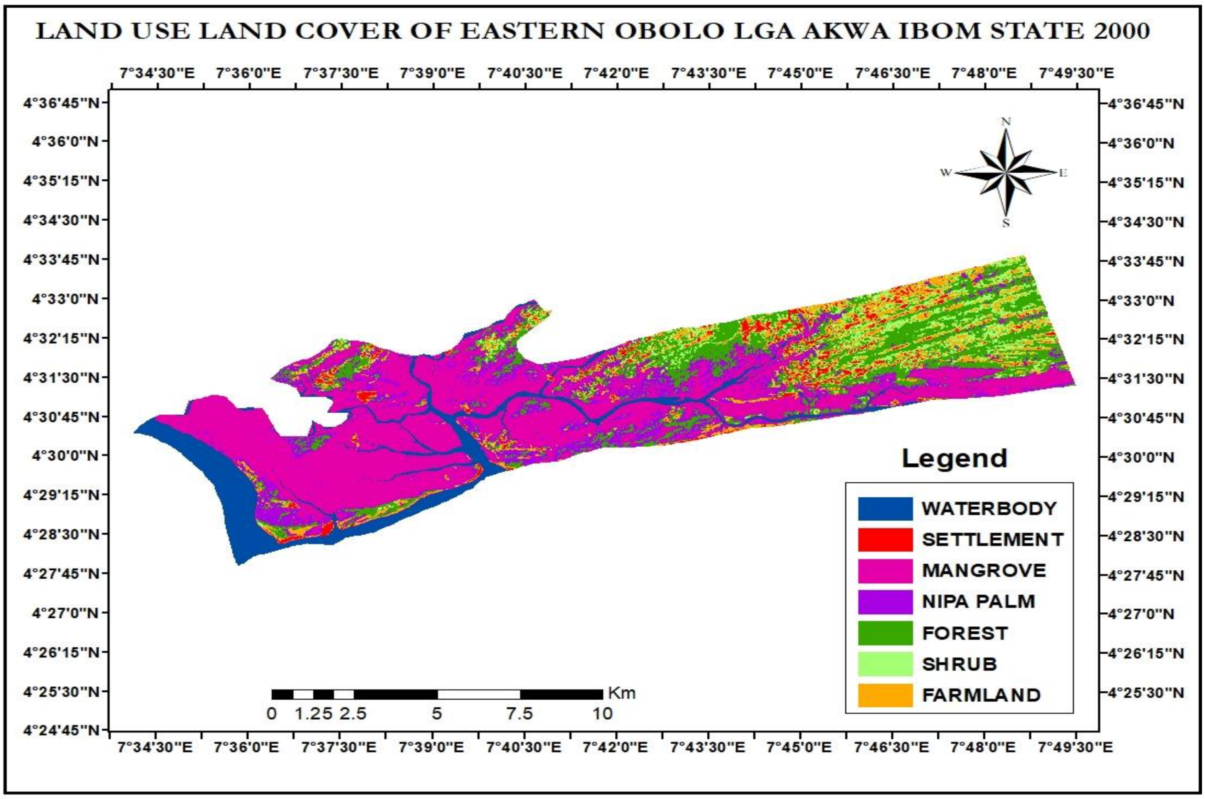

Fig. 5b. Satellite Image showing Land use cover of Eastern Obolo LGA in 2000

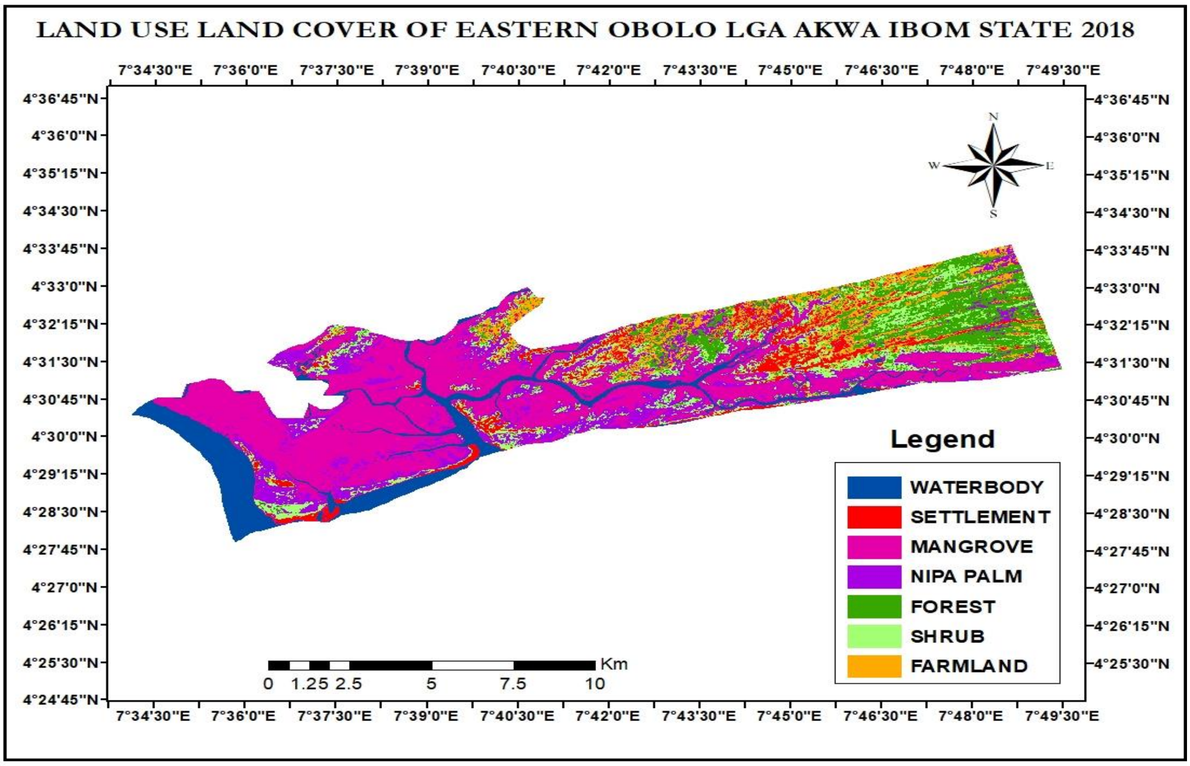

Fig. 5c. Satellite Image showing Land use cover of Eastern Obolo LGA in 2018

4. DISCUSSION

A number of authors have noted that mangrove habitat inventories, change detection and monitoring, success in conservation and reforestation, silviculture, and the development of aquaculture all benefit from the knowledge that may be obtained via mangrove remote sensing, including Green et al. [30], Aschbacher et al. [12], Manson et al. [31], Giri et al. [32], and Wang et al. [33]. According to them, support for ecosystem evaluation, productivity assessment (biomass estimation), estimation of regeneration capacity, multiple management requests (fisheries, aquaculture activities, conservation management, management guidelines and strategies), field survey planning, water-quality assessment, prompt information supply for disaster management, and delivery are all ways to better understand ecological and biological relations and processes, functions, and relationships.

The changes observed in the mangrove forests from 1986 to 2018 (30 year period) resulted in the loss of 2070 stands of mangrove, representing 1.9km^2 of the mangrove forest to other land use/cover types, while nipa palm increased by 2818 stands equivalent to a land area of 2.5km^2.

The result shows that the percentage and land area covered by mangrove forest kept decreasing while that of nipa palm increased over the period under review. In 1986 for instance, the mangrove count was 12.7% but decreased to 11.2% in year 2000 and subsequently to 9.3% in 2018; while nipa palm had a 5.7% in 1986 but increased to 7.7 % in 2000 and 10.4% in 2018. Similarly, the land area covered by mangrove forest decreased from 6.8km^2 in 1986 to 4.9km^2 in 2018 while that of nipa palm increased from 3.1km^2 in 1986 to 5.6km^2 in 2018.

This remote sensing result agrees with various authors such as Dahdouh-Guebas [14] and Cunha-Lignon et al. [34] who noted that the use of aerial photographs and other remote sensing technologies Pin combination with geographic information systems (GIS) offers a useful tool for monitoring changes in mangrove forests and assessing anthropogenic impacts on them. Aerial photographs have been widely used in the mapping and assessment of mangrove forests [35], allowing long-term decadal retrospection on the basis of spatio-temporal imagery analyses [36]. The outcome shows clearly a gradual succession of the nipa palm over the mangrove forest.

Remi et al., 2024 reports a decline in the mangrove area in Madagascar from 2935 km^2 in 1972 to 2699 km^2 in 2019, a total of −8.04% and also a decline from 2734 km^2 to 2627 km^2 between 1989 and 1999, and then down to 2571 km^2 in 2009, their lowest level over the study period and later an increase to 2699 km^2 in 2019. they further noted that mangrove loss has slowed over time, with annual rates of 0.4% from 1972 to 1999, and 0.2% from 1999 to 2009. Similarly, Spalding et al. [37] and Giri et al. [1] estimated Madagascar's mangrove extent as respectively 3006 km^2 in 2003, and 2377 km^2 in 2000, a difference of about 600 km^2. They also noted that Nigerian mangrove forest has been depleted to a little above 7,000 km2 by the year 2000 from its initial 10,515km2in the 1960's. Olaniyi [38], reported that out of 20,884 ha in 1996, Akwa Ibom lost 88ha over the 20 year period (1996 - 2016) with an annual loss of 4.4ha/annum.

5. CONCLUSION

Evidence from remote sensing suggest a decline in the mangrove forests of Oron and Eastern Obolo and a concomitant increase in nipa palm population. The use of remotely sensed data and application of Geographic Information System to determine the change in mangrove forest distribution was carried out for a period of 30 years (2000 and 2018). Based on the findings of the study, it was concluded that there has been a significant decrease in the mangrove forest area in Oron and Eastern estuaries Akwa Ibom State. In Oron for instance, the area had changed from 6.85km^2 in 1986 to 4.99 km^2 in 2018; while nipa palm area had increased from 3.07km^2 to 5.61km^2 within the same period. This change resulted in a loss of 1.86km^2 of mangrove forest and an increase of 2.54km2 of nipa palm. Thus, the study concludes that the rate of mangrove forest destruction over the years has been alarming and thus requires urgent attention to recover these environments if the ecosystem functions performed by mangroves are to be sustained.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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