Remote Sensing for Environmental Monitoring and Change Detection (Proceedings of Symposium HS3007 at IUGG2007, Perugia, July 2007). IAHS Publ. 316, 2007.

Mapping land degradation and forest resource loss from fused Landsat TM and Nigeriasat-1 images in some parts of the southwest coast of Nigeria

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Abstract This research quantifies forest resources and describes its spatial pattern, configuration and arrangement in parts of the southwest coast of Nigeria. Band 1 and 7 of Landsat TM were fused with band 2 of NigeriaSat-1 to generate a hybrid image. Unsupervised image classes were vectorized and allocated into information classes. From the results, human interference is on the increase, with about 25% of the land under cultivation, about 800 km^2 (40%) of forest is still standing, and 7% accounted for by forest degradation. Landscape pattern indices suggest the area presently consists of several variable, irregular, jointed, but rich patches. The level of disturbance has not significantly affected the connectivity and feedback functions of the ecosystems. Considering the anticipated increase in demand for agricultural land in the near future, designating the area an ecological reserve for eco-tourism is suggested as probably the only way to protect the remaining forest stands.

Key words forest resources; fragmentation; image fusion; land degradation; Nigeria

INTRODUCTION

Ecosystems are facing increasing perturbations from the influence of natural and anthropogenic processes. While the demands for ecosystems services have been on the increase, at the same time natural degradation processes and human demands are diminishing the capability of ecosystems to provide these services. The coastal ecosystems are particularly vulnerable. They are home to a large and growing population, and an area of intense natural and human processes (Pernetta & Milliman, 1995; PRB, 2003). Ke (2004) is of the opinion that ecological disruptions in the coastal environment are more serious than environmental pollution in most developing countries. The coastal environment of Nigeria typifies this.

The coastal zone of Nigeria is rich in ecology and biodiversity. It is also rich in non-renewable resources, especially crude oil and bitumen deposits. It has thus recorded intense human activities and unsustainable land practices resulting in widespread modification of the natural systems. Some of the consequences of these modifications include loss of forests and wetlands, saline water inflow into land areas and permanent inundation of lands, subsidence, ecosystems fragmentation, and loss of biodiversity and wildlife. These problems are even more disturbing as recent studies elsewhere have suggested strong linkages between environmental degradation, rural livelihood, rural poverty, and vulnerability to other hazards (Rao, 1990; Eyre, 1990; Verstappen, 1999, PRB, 2001; Okali, 2004; UNEP/GRID-Arendal, 2005; Mascarenhas, 2006; Chung, 2006, and www.maweb.org).

Remote sensing provides a consistent spatial and temporal scale for ecosystems health and natural resources assessment at meso scales, which is very important for comparison and analysis. The integration of geographic information system (GIS) and remote sensing has made it possible to perform systematic inventory and assessment of land resources and land degradation over space and time so that intervention strategies can be put in place to halt the deteriorating health of ecosystems. Landscape ecology is found on the notion that environmental patterns strongly influence ecological processes (MacGarigal & Marks, 1994; www.umass.edu). This, coupled with the fact that knowledge of the structure of landscapes is directly related to their functional capability and overall environmental quality (DeMers, 2000) is drawing the investigation of landscape patterns—spatial arrangement of land uses—into the mainstream of landcover change research. Remote sensing potentially offers data needed for measuring temporal change both in ecosystems and in landscape characteristics, while GIS is important for ecosystems temporal change and landscape fragmentation analysis (Onyeahialam, 2003).

Landsat TM and Nigeriasat-1 provide medium resolution images that are useful for natural resources assessment. They possess nominal spatial resolutions of 30 m and 32 m, respectively. Depending on the band combinations for creating a composite Landsat image, there should not be much difference between the ability of the two images to differentiate terrain features. But in practise, this was not so. It was discovered that while the 3 band composite Landsat TM data can support mapping up to 1:50 000, the Nigeriasat-1 image with 3 bands cannot be used for mapping beyond 1:100 000. Hence, this throws up a challenge to improve the quality and mapping capability of Nigeriasat-1 data, especially for natural resources inventory by fusing it with bands from Landsat TM imagery.

Thus, the objective of this study is to assess the state of forest resources, land degradation and forest resource loss in the study area based on data generated by fusing, and analysing selected bands of Landsat TM and Nigeriasat-1 data for indices of ecosystems disturbance within a GIS.

STUDY AREA

The study area lies approximately between longitudes 4º30' and 4º56' east and latitudes 6º12' and 6º30' north. The area which covers approximately 2000 km^2 extends along a coastline distance of about 21 km and an inland distance of about 30 km from the coast. It falls within the mahin mud beach coast of the Nigerian coastline. The study area covered parts of Ilaje and Ese-Odo, Okitipupa and Irele local government (LGAs) areas of Ondo State and small portions of Ovia Southwest and Ogun waterside LGAs in Edo and Ogun States, respectively (Fig. 1).

The study area is part of the sedimentary basin of the Niger Delta. The major geological classes are: alluvium in general; lagoonal marshes, abandoned beach ridges

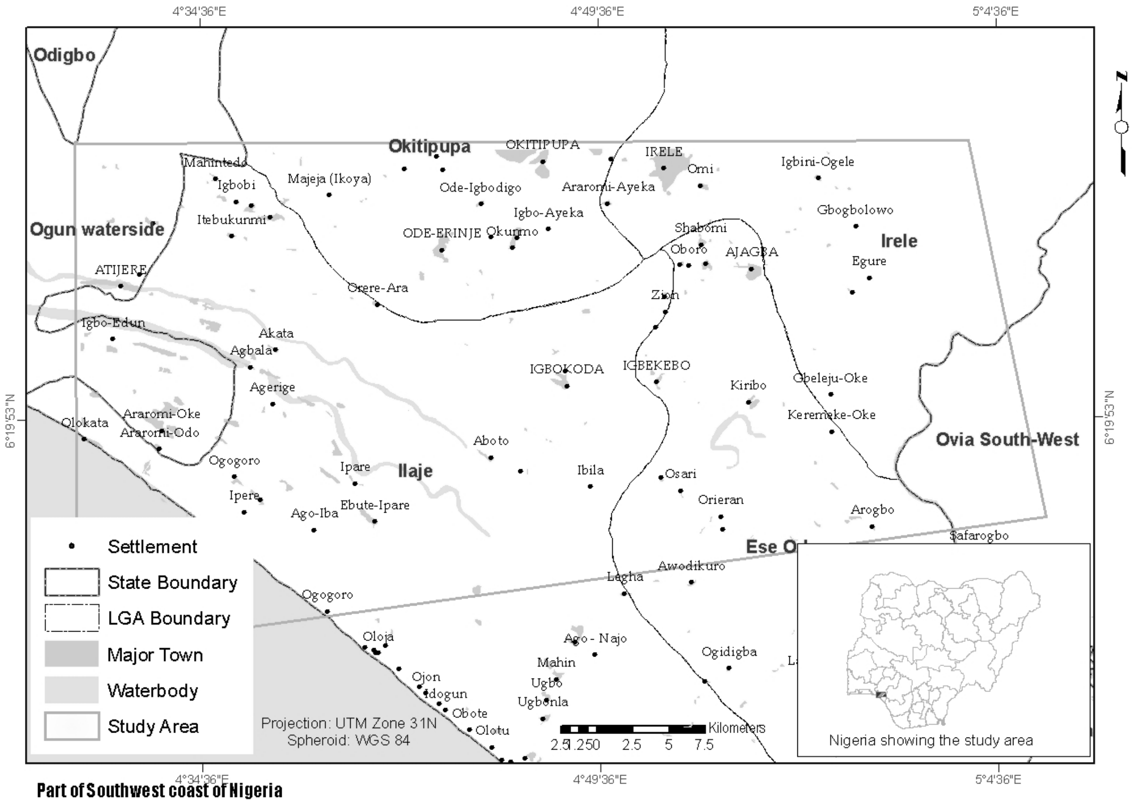

Fig. 1 The study area.

and some coastal plains sand all of the lower deltaic plain. The area slopes gently into the coast. The elevation ranges from about 50–55 m around upland settlements to 1–1.5 m around the coastline. It also consists of deep to very deep poorly-drained hydromorphic soils and mud in the lower parts to deep, drained to well-drained soil in the upland areas. Surface drainage is very sparse. Mean annual rainfall approaching 3000 mm, and mean annual temperature is ~27.8ºC. The area is densely settled with peasant inhabitants whose livelihoods depend on land resources.

METHODOLOGY

Data and image classification scheme

The adopted framework methodology is shown at Fig. 2. Three–band composite Landsat TM and Nigeriasat-1 images were acquired from the University of Lagos Geography Department. The characteristics of the imagery are as shown in Table 1.

The archival composite Landsat ETM+ (band 1,2,7) image was acquired in February 2001 and the Nigeriasat-1 (band 1,2,3) image acquired in December 2003. Both images were orthorectified and georectified to UTM Zone 31 Projection, WGS 84 datum. The study area is very familiar and a field reconnaissance was conducted to get a quick update about the landcover characteristics. Based on existing knowledge and field update, a landcover classification schema (Table 2) was developed.

Table 1 Characteristics of data used.

Characteristics	Landsat ETM+	Nigeriasat-1
Spatial resolution	30 m (Pan–15 m, Band 6–60 m)	32 m (all bands)
Spectral resolution	8 bands	3 bands (G,R,NIR)
Band utilized	1 (blue), 7 (FIR)	2 (red)
Temporal resolution	16 days	1–4 days
Radiometric resolution	8 bit	8bit
Swath size	180 km	600 km
Space vehicle	Landsat 7	Nigeriasat-1
Year launch	1998	2003

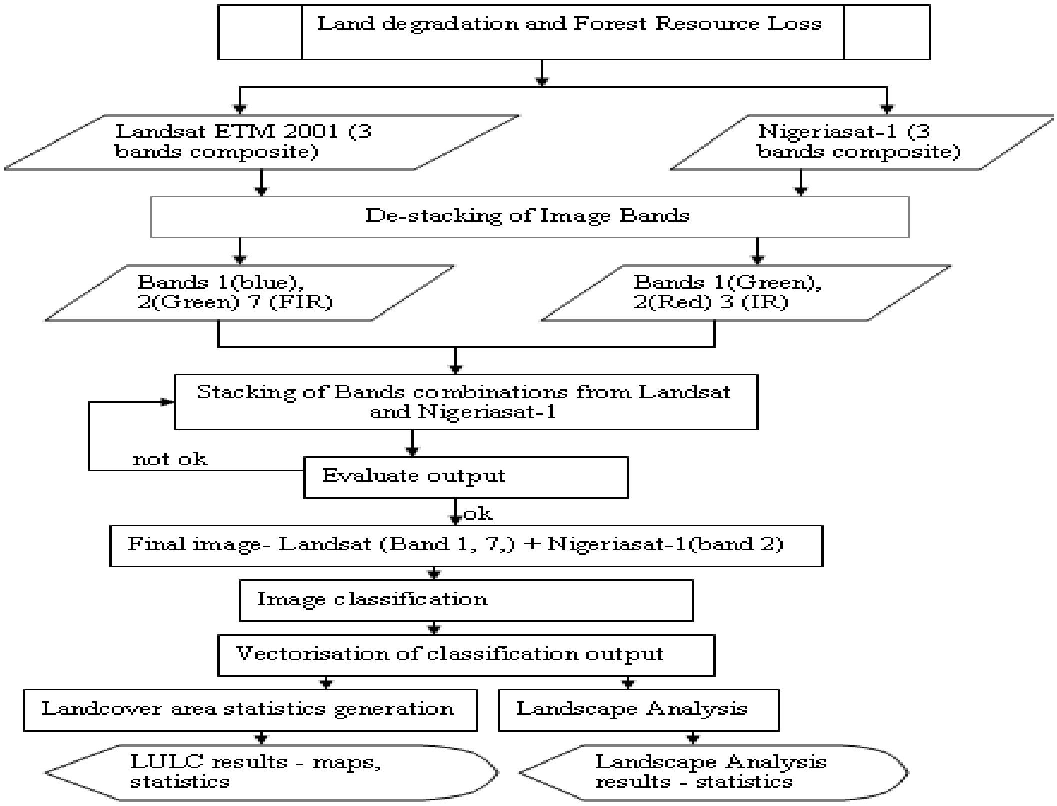

Fig. 2 Framework methodology for the study.

Table 2 Classification scheme utilized.

Code	Primary class
1	Built up areas
2	Water
3	Degraded areas
4	Agriculture
5	Forest
6	Grassland
7	Shrub and thickets

Image fusion, classification and landscape pattern analysis

Image de-stacking (disaggregating the images into their constituent bands) was performed using the image analyst extension. Different 3-band combinations from both images were fused (aggregated) together and evaluated. The idea was to generate a composite image that would yield a better product for forest resource assessment than the original Nigeriasat-1 image. After careful consideration, the combination L_Sat (1,7)+N_Sat (2) was selected, resulting in the use of the Blue and Far-infrared bands from Landsat and Red band from the Nigeriasat-1 image. The new image was adequate for mapping at 1:50 000 and it also clearly depicted, for visual analysis, the forest resources, degraded areas, and other human constructions (especially roads) better than what was interpretable for both the original Landsat and Nigeriasat-1 data. The new composite image was classified into 15 classes using unsupervised classification algorithm. These were further reclassified into 7 classes based on the prepared classification schema. The classified image was converted into vectors within Arcview GIS for generation of area statistics.

Landscape metrics were generated using the Patch Analyst 2.3 that runs as an extension to Arcview GIS version 3x. The landscape metrics were generated at landscape level and the metrics generated include area, shape and diversity (composition) metrics. The computations for the indices are compiled from MacGarigal & Marks (1994); www.innovativegis.com/products/fragstatsarc/manual/manpatch.htm and www.geog.umd.edu/resac/anacos1.htm

RESULTS

Areal coverage of land use and landcover classes

The total extent of the study area is about 2000 km^2. Figure 3 shows the vector land use/landcover interpreted from the new image. The coverage of the landcover classes is shown in Table 3.

The forest class which consists of heavy forest and galleria swamps and palms dominated the ecology. It covers about 790 km^2 (39.5%) of the area. Agricultural areas (cultivated farmlands and fallows) account for about 496 km^2 or 24.8% of the area.

Table 3 Extent of Land use/landcover classes.

SN	Ecological Class	Area (km^2)	Percent
1	Agriculture	496.4	24.8
2	Degraded Areas	142.0	7.1
3	Forest	790.3	39.5
4	Grassland	101.0	5.1
5	Shrub and Thickets	235.4	11.8
6	Water	202.0	10.1
7	Built up area	33.01	1.7
		2000.3	100.0

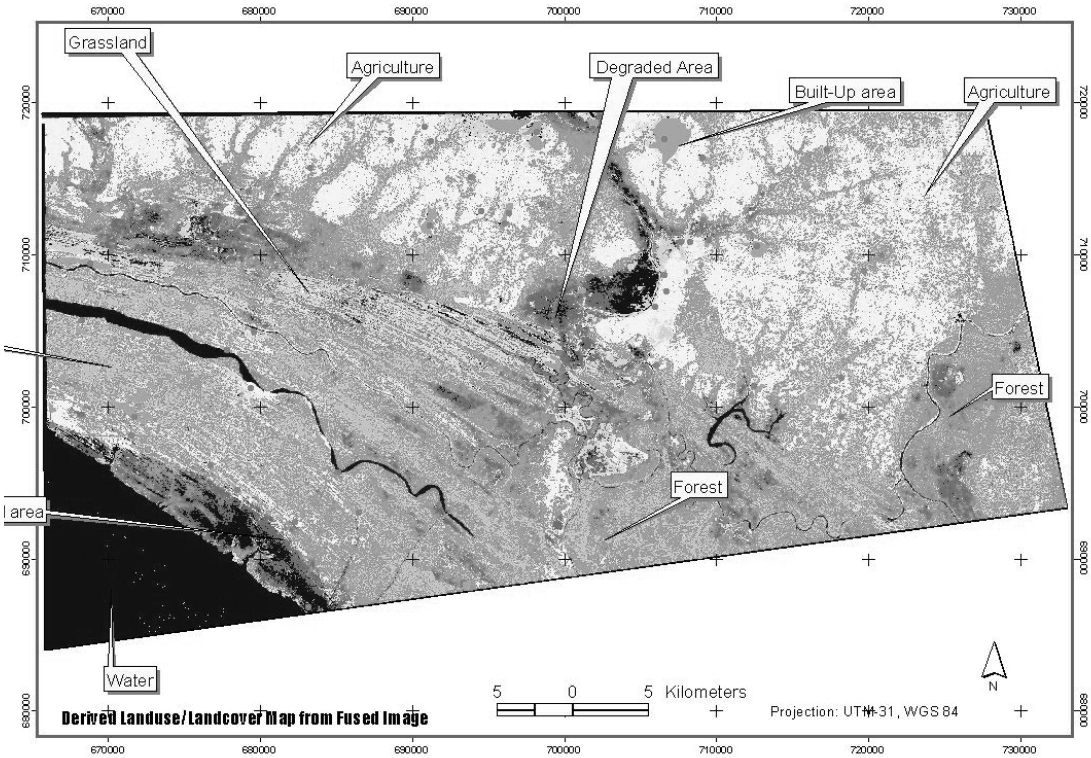

Fig. 3 Derived land use/land cover map from fused image.

Other landcover classes include shrubs and woodlands accounting for 235 km^2 (11.8%), water (including the ocean) 202 km^2 (10%), and degraded lands (devegetated areas where intensive forest removal and logging activities are taking place) accounts for 142 km^2 (7%). Coastal grassland (including areas of marsh and mangrove loss and intensively cultivated lands that have lost the power of regeneration) accounts for 101 km^2 (5%), and built-up areas (human settlements and other constructions) account for 33 km^2 (1.7%).

Landscape pattern analysis

Landscape metrics refer to those indices that give clue to ecological function of the land. They are indicators of ecosystems fragmentation, which by implication, indicate the rate and extent of ecosystems connectivity, disturbance and degradation. It has several implications for natural resources management. Table 4 shows the landscape metrics for the categorical map data for the area.

The Class Area (CA), the Total Landscape Area (TLA) and the Number of Patches (NUMP) gave aggregate quantitative description of the data extents. Mean Patch Size (MPS), Patch Size Coefficient of Variation (PSSCOV), Patch Size Standard Deviation (PSSD), Mean Shape Index (MSI), Area Weighted Mean Shape Index (AWMSI), and Mean Patch Fractal Dimension (AWMPFD) quantify the spatial configuration of patches; while Shannon's Diversity Index (SHDI) and Shannon's Evenness Index (SHEI) quantify the composition of map data without reference to spatial attribute.

Table 4 Landscape metrics generated.

S/n	Metric	Value
1	Class Area (CA in Ha)	200 035.8
2	Total Landscape Area (TLA in Ha)	200 035.8
3	Number of Patches (NUMP)	359 820.0
4	Mean Patch Size (MPS in Ha)	0.6
5	Patch Size Coefficient of Variation (PSSCOV)	3137.9
6	Patch Size Standard Deviation (PSSD)	17.4
7	Mean Shape Index (MSI)	1.3
8	Area Weighted Mean Shape Index (AWMSI)	4.1
9	Mean Patch Fractal Dimension (MPFD)	1.4
10	Area weighted Mean Patch Fractal Dimension (AWMPFD)	1.4
11	Shannon's Diversity Index (SHDI)	1.4
12	Shannon's Evenness Index (SHEI)	0.7

Both the CA and TLA correspond to the summation of area of all individual land use/landcover classes within the Polygon Attribute Table (PAT) and NUMP is equivalent to the number of polygons in the PAT.

The MPS is 0.6 ha. The small size of MPS and the corresponding large number for NUMP (359 820) is an indication that the landscape is fragmented into several patches. The PSSD and PSCOV are indices of variation and the higher the figure, the higher the variability in patch size. The PSCOV and PSSD for the area are 3137.9 and 17.4, respectively. The high figure for PSCOV indicates high variability in the size of the several patches.

The MSI and AWMSI are shape complexity metrics (indices of regularity). The figure equals 1 when all patches are regular and becomes higher as the patches become more irregular and contorted. The MSI and AWMSI figures for the study area are 1.3 and 4.1, respectively. These figures suggest the preponderance of irregular patches which is an indication of modification of patches by human activities which translates into disturbance and fragmentation of patches. The MPFD and AWMPFD are also shape metrics which approach 1 for simple shapes and 2 for highly contorted shapes. MPFD (1.4) and WMPFD (1.4) for the area confirm deductions from MSI and AWMSI, which suggest increasing perturbation. SHDI measures patches diversity (a composite measure of richness and evenness). Richness indicates the number of patch types and evenness indicates the distribution of the area among the different patch types. SHDI thus increases as the patch type increases and proportional distribution of area among patch types becomes more equitable. 0 indicates no diversity. The SHDI (1.4) here suggests progressive increase in diversity, which means the patches are becoming richer. SHEI measures patch evenness (the distribution of area among the patch types). As the evenness index approaches 1, the observed diversity approaches perfect evenness, and approaches 0 as the distribution of area among the patch types becomes increasingly uneven. The SHEI (0.7) suggests the patches are progressively tending towards perfect evenness.

In summary, landscape metrics suggest that the study area consists of several but jointed patches which are highly variable in size. The patches are also very irregular, which probably suggests increased human interference that may lead to disturbance and perturbation. The level of disturbance has not significantly impacted ecosystems functions and processes. The patches are also becoming diverse and richer and the distributions of area among the patches are also tending towards uniform.

DISCUSSION

Degradation of the ecosystems has several implications and dimensions on rural livelihoods and natural resource management. Hence, preventing natural resource degradation is fundamental towards reducing rural poverty, preventing rural livelihood impairment and sustainable resource management. The study area is dominated by rural communities that depend on land resources for survival. This is manifested in about 25% of land that is devoted for agricultural land use. Forested lands in the upland area are swamp forests and galleria vegetation on soils, which the people presently find very difficult to work. There are chances that these forests may not be spared if there is a significant increase in demand for agricultural lands. It is also clear that forest loss and degradation have already set in as a result of lumbering and tree felling. Something has to be done now to prevent additional loss of forest in the near future. Saline water inflow into the land areas caused by dredging activities has also led to decimation of marsh ecosystems along the shoreline. If something is not urgently done, more delicate ecosystems may be impacted, with severe implications for the local fauna species and livelihoods of rural communities.

The level of ecosystem disturbance in the area is still very minimal when compared with some other parts of the Nigerian coast. The large forest stands also suggest that the area can serve the purpose of eco-tourism. A forest area of about 800 km^2 is large enough to be protected for eco-tourism. This is probably the only way the remaining forest stands can be saved from further loss and degradation, while also contributing to national development.

CONCLUSIONS

Although there are statutory policies and plans in Nigeria to address forest loss and degradation of coastal resources, these have not worked because there are no data and information about critical variables and indicators on natural resources to be compared with threshold values for assessing the state-of-being. Such data are generated from remotely sensed imagery. However, the mapping capability of the Nigeriasat-1 image data can be improved by fusing with relevant bands of other satellite imagery for inventory and mapping of Nigeria's natural resources and to generate critical variables required for their management. Only then can we move ahead to build a natural resource information system that is critically required for management of our natural resources.

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