Remote sensing of vegetation cover changes in the humid tropical rainforests of Southeastern Nigeria (1984–2014)

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Friday Uchenna Ochege¹,²* and Chukwunonyelum Okpala-Okaka²

Abstract: This study demonstrates a 30-year multi-temporal variations in vegetation cover changes as a means of filling the vegetation knowledge gap in the humid tropical forests of southeastern Nigeria. Landsats 4TM, 5TM and 7ETM+ data-sets were accessed and analysed using the Maximum Likelihood Classification algorithm to discriminate and geovisualize the spatiotemporal variations in the general vegetation and other land cover types, from 1984 to 2014. This was supported with detailed field surveys in dry and rainy seasons of 2011 and 2014 to ascertain the status of wide-ranging vegetation cover stands. A 44% vegetation decline was recorded given the reduction in dense vegetation spatial extent from 330.63 km² in 1984 to 170.87 km² in 2014. Sparse vegetation equally increased in spatial extent by 25% given the variations registered from 6.86 km² in 1984 to 97.16 km² in 2014. The reduction in vegetation cover was found to have been replaced by increase in other land cover types—residential (18.97 km²) and industrial areas (39.87 km²). Suggesting that, heterogeneity in the spatial distribution of land resources, in addition to weak concerns towards preserving the accruing benefits of vegetation resources attracted anthropogenic phenomenon (e.g. urbanization) to vegetated...
areas. As such, strengthening institutional monitoring and urban planning frameworks would help to improve sustainable governance of the tropical rainforests.

**Subjects: Vegetation; Environmental Studies & Management; GIS, Remote Sensing & Cartography**

**Keywords: remote sensing; vegetation cover changes; tropical rainforest; Southeastern Nigeria**

**1. Introduction**

Vegetation is the general plant life or the total plant cover forming parts of the biological system and it is the primary producer of any ecosystem (Ochege, 2014b). Local and regional wide-ranging natural vegetations are important component on earth and they govern all forms of life (Millennium Ecosystem Assessment, 2005). They provide food, oxygen, fertility and finally enhance survival of all living beings (Matlack, 1994; Mckey, Waterman, Gartlan, & Struhsaker, 1978; Newbold et al., 2014). For the earth’s environment, natural vegetation constitutes the biologically richest ecosystems and play vital roles in regional hydrology, carbon storage and the global climate dynamics (Du et al., 2015; Forkel et al., 2013; Igbagwua, Zhang, Chang, & Yao, 2016).

The benefits accruing to humankind from the natural functioning of a healthy and productive vegetation system cannot be over emphasized. Because, the natural vegetation provides not only the basic needs of life (i.e. food, clothing and shelter), but enables purification of water bodies (Friberg et al., 2011), manages diseases (Fisher & Turner, 2008), regulates climate and the functioning of biosphere (Millennium Ecosystem Assessment, 2005) and provides mankind with spiritual fulfilment that contributes to improving quality of life (Food & Agriculture Organisation, 2013). As such, vegetation remains the lifeblood of human societies around the world (United Nations Environment Programme & the International Institute for Sustainable Development, 2004).

Nevertheless, human being has long distinguished himself from other species by shaping ecosystem forms and processes using fire, tools and technologies that are beyond the capacity of other organisms including natural vegetation stands (Smith, 2007). As a result, man is inextricably and unavoidably attached to the environment, which often time gives him the nerve to impact negatively on forests and natural vegetations resulting in other land uses.

Based on the considerations of the Intergovernmental Panel on Climate Change (IPCC), land use and land cover are not technically synonymous. Land cover is the observed physical and biological cover of the Earth’s land, such as vegetation or man-made features, whilst the total arrangements, activities and inputs undertaken in a certain land cover type (e.g. a set of human actions) for both social and economic purposes (e.g. grazing, timber extraction, conservation) are referred to as land use (Watson et al., 2000). Since vegetation is continuously changing—alteration in the surface components of the vegetation cover, the rate of change can either be dramatic and or abrupt—as exemplified by fire, subtle and or gradual (Lund, 1983; Milne, 1988). This is a common global scenario, especially, with regard to forest cover and biomass accumulation or mass deforestation (Hansen et al., 2013).

Africa has been observed to be experiencing the fastest rate of vegetation change and most of its segments are already evidently been impacted and plagued with diverse ecological problems (Erika et al., 2015; Ofori, Owusu, & Attuquayefio, 2014; Yeshaneh, Wagner, Exner-Kittridge, Legesse, & Blöschl, 2013). Especially, as land use remains a significant driver of habitat degradation and removal and associated losses in biodiversity and vegetation resources (Lucas et al., 2015). According to Odjugo and Ikuhia (2003), these problems, though anthropogenic in context, do have a direct link with the ongoing global climatic and environmental change. Nevertheless, natural vegetation equally suffers from these consequences, as they are profoundly been altered by human activities, and so, few natural stands remain (FAO, 2012).
In Nigeria, a wide range of vegetation types exist, and they reflect past and present climatic variations (Federal Republic of Nigeria, 1977; Igbawua et al., 2016; Odjugo, 2010). Generally, the southern part of the country is flanked by maritime stretches where the sandy uniformity is occasionally broken by mangrove ecosystem, bushes, lush vegetation, hardy trees and putrid water, while the northern part displays segments of croplands and rangelands that are heavily populated by grasses of varied species (Igbozurike, 1975). The global land cover map by DIVA-GIS (2016) reveals Nigeria’s current vegetation cover belts (see Figure 1(A)). From top to bottom indicate Sahel Savannah, Sudan Savannah, Guinea Savannah and Forest vegetation (Igbawua et al., 2016).

Based on the obvious reasons of regional vegetation dynamics which has been influenced by global environmental change (Igbawua et al., 2016), the natural vegetation of Nigeria has ever since been under considerable threat like those of most other parts of tropical Africa (Adekunle, Olagoke, & Ogundare, 2013; FAO, 2012; Federal Republic of Nigeria, 1977). The World Resources Institute (WRI) did identify Nigeria’s humid tropical rainforests as one of the most ecologically vibrant places on the planet because it is home to over 4,850 different plants and tree species, 1,340 species of animals, among which are 274 mammals, 860 birds (Meduna, Ogunjimi, & Onadeko, 2009; World resources, 1987). Despite these rich and abundant vegetation resources, the country is highly rated for unsustainable exploitations, deforestation and forest degradation among others (Momoh, 2014). Yet, the country lack adequate monitoring framework (Erika et al., 2015) especially, in those steadily urbanizing locations of the humid tropical rainforest belts (Ofori et al., 2014) including southeastern Nigeria i.e. Umuahia.

Prior to Umuahia been declared a headquarter city in Nigeria by the national government on the 27 August 1991, Umuahia was previously known to be home to ecological parks, protected forests, unprotected and undeveloped forest areas and trees growing amidst scattered residential settlements. These natural green covers provide different benefits, ecosystem services and support to well-being, ecosystem health, urban livelihoods and other advantages to the society at large. Notwithstanding these recognized benefits to sustainable development and environmental sustainability to the area, spatial quantification of local vegetation changes has been lacking for this part of Nigeria.
Remote sensing technology has proven essentially relevant in establishing land use and land cover monitoring frameworks at different scales (Hansen et al., 2013; Loveland & Dwyer, 2012). It is the science by which information about an object is obtained from electromagnetic radiation reflected from the surface of that object (Jensen, 2014; Lillesand, Kiefer, & Chipman, 2015). Its mechanisms have revolutionized traditional mapping methods (Ariti, van Vliet, & Verburg, 2015; Newbold et al., 2014; Okpala-Okaka & Igbokwe, 2010; Scull et al., 2016; White & Oates, 1999), by advancing and characterizing the spatiotemporal distribution of environmental phenomena using air-borne sensor platforms and image processing and interpretation techniques or packages (Chen, Lu, Luo, & Huang, 2015; Dubula, Tesfamichael, & Rampedi, 2016; Forkel et al., 2013; Hansen et al., 2013; Loveland & Dwyer, 2012; Luo, Zhou, Chen, & Li, 2008). The advent of remote sensing paved way for improved methodological mapping of vegetation cover changes since the establishment of Landsat mission in 1972 (Coppin & Bauer, 1996; Coppin, Jonckheere, Nackaerts, & Muys, 2004; Loveland & Dwyer, 2012).

Several researchers have comprehensively used Landsat imageries, with its extensive data archive at no cost and suitable spectral and spatial resolutions to detect and quantify vegetation cover changes (Chen et al., 2015; Luo & Dai, 2012; Luo et al., 2008; Omo-Irabor et al., 2011; Zhu, Liu, & Chen, 2012). But literature search, with focus on the Umuahia segment of the tropical rainforest belt of Nigeria shows a dearth of information about the dynamics of vegetation cover changes in the area, probably due to limited accessible monitoring data and a lack of appropriate research methods.

This paper, therefore, initiated a remote sensing-based vegetation baseline assessment that is nonexistent in the study area (Erika et al., 2015), as a strategy for informing the non-technical and expert policy makers involved in the sustainable governance and development of the region.

This is necessary to understand the dynamic nature of emerging regional and local vegetation and land cover types that may have been impacted over time. The information will be useful in streamlining policy efforts towards sustainable urban growth in the long-term, land cover recovery, agricultural resilience and carbon storage/sequestration in the face of increasing changing climate. The following specific objectives have been addressed:

1. to estimate the spatial extent of the vegetation cover changes using remotely sensed satellite data;
2. to quantify the temporal changes based on spatial extent of the vegetation cover, before and after 1991 (the year the study area was officially created) to a near present date—2014; and,
3. to identify and document responsible factors for the changes in terms of areal extent of the study area.

The results generated in this study would, thus, show the spatial variations and pattern of vegetation cover distribution of different vegetation classes. While their validation helped to reveal interclass confusion than could be resolved with the use of other biased information (Foody, 2002), especially as it had been established that the region lacked adequate vegetation monitoring data (see, for example, Erika et al., 2015). In this way, appropriate place-specific reinvestigations and or decisions can be achieved, such as rapid identification of alternatives where necessary, and to incorporate same in the formulation of sound policies required in the governance and natural resources management framework of the region (see, for example, Larcom, van Gevelt, & Zabala, 2016; Obydenkova, Nazarov, & Salahodjaev, 2016).
2. Materials and method

2.1. Case study area

Geographically referred to as Umuahia, the study area (latitude 5°26′ 06.00″ N to 05°36′ 04.00″ N and longitude 07°21′ 50.00″ E to 7°34′ 03.00″ E) covered the administrative boundary of the present day Umuahia North and Umuahia South local government areas in Abia State. It lies entirely in the southeastern segment of the humid tropical rainforest in Nigeria (Figure 1(B)). It covers an area of about 363.13 km² amidst a constellation of scattered villages and towns within a 15 km radius, while the total area covered by the metropolis is about 71 km² (Ejenma, 2013).

The climate is humid tropical rainforest—Koppen Af (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006). Daily average insolation is generally low—4.8 h, nevertheless the area experiences mean annual maximum temperature of 31°C with little daily variations (Iloeje, 2007). Meteorologically, Umuahia experiences an annual mean rainfall of 2,278 mm, with eight months of precipitation, which extends from early March to late October (Figure 2). Meaning, that, the study area witnesses two major seasons—dry season and rainy season. The dry season is dominated by a period of short spell of dry/cool season referred to as harmattan. Usually, the heaviest of monthly total of rains → 363 mm (Figure 2), is experienced more in September, while the month with the lowest rainfall fluctuates between January and December, except for recent climatic anomalies with random variance of precipitation in other locations (e.g. Nsukka & Ogbudu) (Campling, Gobin, & Feyen, 2001).

The soils of Umuahia have been greatly influenced by different ancient geologic formations, climate, vegetation, and general topographic configuration of the area (Onu, Opara, & Ehirim, 2012). The major rivers that drain the catchment area of Umuahia are the Imo river on the west axis, Kwa-Ibo river draining southwardly and Enyong creek on the east axis. River Eme with it various tributaries in Ohuhu flows into the Imo river while the Ofenyi river tributaries transverse the Ibeku landscape to deposit into the Enyong creek. These rivers and streams are ephemeral and dry up after the cessation of rainfall. The study area currently serves as one of the nation’s commercial hubs for economic development, with high potentials for growth and development.

2.2. Field observations

Validation of remotely sensed data through field surveys, documented information and discussions with the local people has proven useful in several land use/land cover (LU/LC) studies (see, for example, Ariti et al., 2015; Scull et al., 2016; Yeshaneh et al., 2013). In this study, vegetation of the study area was carefully observed by extensive field surveys conducted during rainy season, and the early dry season in 2011 and 2014 respectively. Ground truth of relevant land cover types in the study area were collected alongside plant species and other landscape features. A Garmin 62s Global Positioning System (GPS) with 3 m accuracy was used to identify infrastructural facilities that were relocated to
previously vegetated areas. Likewise, certain geographical features, ranging from landscape configurations to vegetation types, were equally identified. This was necessary, to complement and affirm the relationship and variations that may be there, would have occurred and the rationale behind the changes.

As such, the study area lies in the lowland rainforest vegetation belt typified by almost continuous cover of riparian forest along stream valleys. Tilling, in most cases, for agriculture and road construction, has resulted in an ecological situation where the normal development of vegetation is markedly retarded (Onu et al., 2012). Although, most of these locations have been drastically affected by human activity so much, large sections of the upper rain forest zone may be called an “oil palm bush”. However, the observed vegetation of the area is characterized by an abundance of seed-bearing plants species, such as *Brachystegia eurycoma*, *Carya* spp., *Steroula*, *Canarium*, *Cassia siame*, *Triplochitan scleroxylong*, *Meliaceae*, *Mitragyna ciliate*, *Khaya* spp., *Entandrophrayma* spp., *Lova trichiloideas*, *Nauclea diderrichii*, *Gmelina arborea*, *Neliaceae*, *Acacia nilotica* and *Gum arabi*. Others include *Cauarea and Terminalia*. Many times, they occur in about 100 species per hectare. It is this great abundance of species that makes the area rich in terms of biomass productivity of all terrestrial ecosystems, therefore, requiring a periodic assessment.

2.3. Satellite remote sensing data
Remote sensing offers priceless source of geospatial information for ecological and vegetation resource management (Hagenlocher, Long, & Tiede, 2012; Hansen et al., 2013; Lillesand et al., 2015; Luo & Dai, 2012). With reference to complex terrain, data unavailability, area coverage, data obtained by remote sensing can be timely, cost-effective, and objectively presented and demonstrated for either specific or post assessment—spatiotemporal investigations (Hagenlocher et al., 2012; Omo-Irabor et al., 2011). In this study, vegetation variation in Umuahia was mapped and visualized from Landsat data covering the total extent occupied by the study area.

Given the different software algorithm-based platforms available for ecological studies (Coppin et al., 2004), ERDAS Imagine 2014 and ArcGIS 10.1 were used for image pre-processing so as to maintain data spatial reference consistency to the georectified format—the Universal Transverse Mercator (UTM) zone 32 North and the World Geodetic System 1984 datum, at the various stages. As such, classification challenges (Huang, Lu, Zhang, & Plaza, 2014; Lillesand et al., 2015) were minimized by selecting suitable dates—1984, 1991 and 2014. This was necessary for maintaining seasonal uniformity as an a priori for increased ground vegetation and cloud cover during the wet season (Churches, Wampler, Sun, & Smith, 2014; Schwartz, 2003). More importantly, the 1991 data equally served as a second baseline date for the reason of the study area’s official pronouncement as headquarter to a major state in southeastern Nigeria. A scan line corrector (SLC) error experienced by the Landsat 7/ETM+ was corrected with a gap fill function (Zhu et al., 2012) in ERDAS Imagine 2014.

Datasets of 1984, 1991 and 2014 (path 188, row 56 with a spatial resolution of 30 × 30 m) were obtained from the United States Geological Survey (USGS) archives at www.earthexplorer.usgs.gov. After image acquisition, bands 5 (mid-IR): 1.55–1.75 μm, 4 (NIR): 0.76–0.90 μm and 3 (red): 0.63–0.69 μm in each of the image scene were stacked together to form a single multispectral image data-set using the “layer stack” function in ERDAS Imagine.

The United Nations Fund for Population Activities (UNPFA) had recognized that population growth and its resultant human influence constitute serious pressures on global natural resources especially on local and regional forests ecosystems and natural vegetation (United Nations Population Fund, 1991). Using the annual population growth rate of 2.83%, (Abia State of Nigeria, 2005), the population of the area was projected to present to determine the influence of population growth on vegetation resources.

So, the resulting multispectral images based on the layer-stacked data-sets were used as the baseline data—before impact imagery (1984–1991—marked year of population influx in the study
Figure 3. Vegetation cover mapping workflow.

While the analysed data-sets served as the post impact assessment imagery (1991–2014). The process allowed for straightforward detection of changes and human-induced impacts on the landscape/vegetation cover over the period of study—30 years. The vegetation classification workflow for the study consists of several other steps and stages, as illustrated in Figure 3.

3. Data analysis

3.1. Image classification

Since land use cover change is a continues issues (Watson et al., 2000), detecting spatial and temporal patterns of vegetation cover changes with satellite data depends largely on pixel-based spectral signatures or vegetation indices (Chen et al., 2015). Based on their spectral signatures or vegetation intensity values, the Landsat image pixels covering the study area were organized into a finite set of classes that represents surface types. This can be done in two ways; supervised and unsupervised classification (Lillesand et al., 2015). This study used the maximum likelihood classification (MLC) method of the set of the supervised classification algorithms in grouping vegetation cover changes. Several other methods do exist (Minimum distance technique, Mahalanobis distance technique and Parallelepiped classification methods (Soofi, 2005), but the maximum likelihood
method is preferred because it required field observation to aid the classification procedure which tends towards accurate data analysis. The analysis was performed with ERDAS Imagine.

Using the (MLC) on ERDAS Imagine (Congalton & Green, 1999), the enhanced false colour composite bands 5, 4 and 3 of the different years depicting the vegetation image pixels were trained and categorized into appropriate classes. A total of five classes were discriminated (i.e. densely vegetated and sparsely vegetated areas, water bodies, congested residential and built-up industrial areas). The same five classes have been adopted in this work. This classification pattern is in accordance with the 2010 updated version of the global ecological zones for forest reporting by FAO (2012).

The supervised classification maps, showing the spatial extent and variations in forest cover across the study area, are presented in Figure 5. For effective visual interpretation, suitable colour patterns have been used to identify and show the various classes. A class name is assigned to a colour. Thick green represents dense vegetation, light green is for sparse vegetation (Ochege, 2014a), ox-blood is used to show congested sections in the study area, light brown represents built-up areas while blue is used to show the presence of any kind of water body in the area. This pattern is acceptable according to the vegetation classification standard as modified by Anderson, Hardy, Roach, and Witmer (1976).

3.2. Accuracy assessment
It is usually very important to ensure the correctness of the classification analyses because it seeks to measure the quality of results shown on the classification maps (Banko, 1998; Congalton & Green, 1999). The accuracy assessment can either be quantitative or qualitative. In this study, we evaluated the accuracy process of vegetation classification by visual inspection of the classified image in ERDAS Imagine using Kappa statistics function on a scale range of −0.1 to 1 (Congalton, 1991). Kappa statistics is calculated as in Equation (1):

\[
K = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{it} \times x_{ti})}{N^2 - \sum_{i=1}^{r} (x_{ti} \times x_{it})}
\]

where \(N\) is the total number of samples in the matrix, \(r\) corresponds to the number of rows in the matrix, \(x_{ii}\) is the number in row \(i\) and column \(i\), \(x_{it}\) = is the total for row \(i\), and \(x_{ti}\) = is the total for column \(i\).

We had generated 150 (30 for each class) reference sites (Figure 4) which were based on the simple random sampling technique (Lins & Kleckner, 1996).

Each sample point was assigned the ideal class value during field observations, and was used to enhance geovisual inspections. These points were further superimposed on the classified images. Features of the representing land use pixels (class) that correspond with each point were compared with the features that existed on the ground by also using the federal government approved national vegetation atlas base map of Nigeria (Federal Republic of Nigeria, 1977), Google Earth pro web-based GIS, in addition to other reference information obtained from field observations. Then, the following accuracy assessment estimators: the error matrix, overall accuracy, producer’s accuracy, user’s accuracy and the kappa coefficient, were computed in ERDAS for each of the year under-studied—1984, 1991, 2014 (see Section 4.5).
4. Results and discussion

4.1. Spatio-temporal dynamics of vegetation cover changes

Results from this study include a vegetation cover statistics and land-cover classification maps of the years understudied—1984, 1991 and 2014. From 1984 to 1991, dense vegetation (healthy vegetation) had reduced in percentage by 21.2%. Between 1991 and 2014, it further reduced by 22.8%. While sparse vegetation (disturbed or unhealthy vegetation cover) increased by 18.32% (1984–1991) and 6.64 (1991–2014). Likewise, residential and built-up areas increased by 0.09% and 2.76% in 1991, and 5.13 and 8.94% in 2014, respectively (Table 1).

4.2. Vegetation and other land cover stands as at 1984

The 1984 classification map clearly shows that dense vegetation covered most of the fragments in the study area followed by patches of other cover types—sparse vegetation, water bodies, congested and built-up areas (Figure 5(A)). As such, vegetation resources in the study area may not be adjudged to be entirely untouched or referred to as pristine because of the scattered pattern of sparse vegetation which indicates disturbances and stress on vegetation canopies and phenology (Ochege, 2014a). In this regard, there are chances that most vegetation fragments in the humid tropical rainforests of southeastern Nigeria have experienced one form of human or natural interruptions.

Often times, fragments of tropical forests are considered primary or virgin, whereas, in the actual sense, they have passed through a number of stages to become secondary forests (Aubreville, 1938;
Table 1. Changes in vegetation and other land cover types in Umuahia

| Land cover                | Total area covered | % change  |
|---------------------------|--------------------|-----------|
|                           | 1984 (%)           | 1991 (%)  | 2014 (%) | 1984–1991 | 1991–2014 | 1984–2014 |
| Dense vegetation          | 330.63 (91.05)     | 253.65 (69.85) | 170.87 (47.05) | −21.2     | −22.8     | −44       |
| Sparse vegetation         | 6.86 (1.8)         | 73.05 (20.12)  | 97.16 (26.76)  | 18.32     | 6.64      | 24.87     |
| Congested (residential)   | 9.69 (2.67)        | 10.04 (2.76)   | 28.66 (7.89)   | 0.09      | 5.13      | 5.22      |
| Built-up (industrial)     | 15.07 (4.15)       | 25.09 (6.91)   | 54.94 (15.13)  | 2.76      | 8.94      | 10.98     |
| Water body                | 0.87 (0.24)        | 1.30 (0.36)    | 10.46 (2.88)   | 0.12      | 2.52      | 2.64      |

Notes: Total area occupied by each cover type was calculated as follows: (CT/SA) × 100%; where CT = area occupied by each cover type of year under consideration, SA = 363.13 km² is the area covered by the study area; while the percentage change (1984–2014) for each cover type was derived by subtracting the percentage change of each cover type in 1984 from those in 2014, likewise for time interval of 1984–1991 and 1991–2014. In furtherance of this exploratory analysis, Table 1 is summarized as follows: dense vegetation and sparse vegetation covers represent vegetation resources, congested (residential) and Built-up (industrial) areas represent urban encroachment, while water body represents Water (see Appendix 2).

Figure 5. Vegetation classification of the study area (A) in 1984, (B) in 1991, and (C) in 2014.
Budowski, 1970; Bush & Colinvaux, 1994). For instance, the Okomu Forest Reserve in southwest Nigeria was considered to be a primary forest by Richards (1939), but later studies by Jones (1956) revealed extensive charcoal and pottery deposits and a tree population structure reflecting “second growth” vegetation. Recent studies now provide evidence that the forests of Okomu can be traced back to a period soon after 700 years ago, following a period of intensive human use (White & Oates, 1999).

Conducting interviews or discussions with the local people is one way of ascertaining age long anthropogenic impacts on past vegetation status, vegetation loss and their root causes (Ariti et al., 2015; Ofori et al., 2014; Yeshaneh et al., 2013). Critical information obtained through informal discussions with some indigenous people of the area during the field observations, suggests that: most rural dwellers in the study area depend to a large extent on wood fuel energy for cooking and timber logging for furniture and other kinds of woodwork. Figure 6 show harvested wood fuel from the Ibeku axis of the study area, intended for domestic energy consumption. This practice is neither new nor exclusive to the Umuahia ecological zone of the humid tropical rainforest, but is obtainable in most parts of the country (Anyiro, Ezeh, Osondu, & Nduka, 2013; Food & Agriculture Organization of the United Nations, 1981; Jones, 1956; Tee, Ancha, & Asue, 2009; White & Oates, 1999).

Likewise, forests and vegetation of the study area may be of similar secondary growth vegetation with those of Okomu forests, as shown by the scattered distribution of stressed vegetation which is an indication of human influence (Figure 5). To say the least, wood fuel harvests are on the increase and constitute a major factor to vegetation cover changes in the humid tropical rainforests of Nigeria and the entire sub-Saharan Africa (Sulaiman, Abdul-Rahim, Mohd-Shahwahid, & Chin, 2017).

Statistical report generated from the 1984 image pixel training show that, dense vegetation dominated a greater portion and occupied a spatial extent of 330.63 km² out of the 385 km² of the entire study area, while sparse vegetation fragments occupied a spatial extent of about 6.86 km². As at 1984, built-up and congested areas occupied 15.07 and 9.69 km², respectively. Given the total study area size of 385 km², the classification analysis accounted for 94.32% of the total land cover. About 5.68% of the study area’s land cover was unclassified, and so is unaccounted for. Out of the new land area (i.e. 363.13 km²), dense vegetation totalled 91%, while sparse vegetation, congested and built-up areas occupied 2, 3 and 4%, respectively (Figure 7(A)).

4.3. Vegetation and other land cover changes in 1991

Figure 5(B) shows that increased population among other factors have had significant impact and probably, some negative implication on the spatial extent of vegetation cover changes on the Umuahia segment of the humid tropical rainforest. The statistical report generated from the
classification analysis carried out on the 1991 data-set shows that land area covered by dense vegetation decreased from 330.63 km² (91%) in 1984 to 253.65 km² (69.7%) in 1991, while every other land cover types, i.e. sparse vegetation, congested and built up areas increased in spatial extent (Table 1). As such, 76.98 km² which is about 20% of dense vegetation cover was lost between 1984 and 1991. Then fragments occupied by sparse vegetation increased by 18% given the initial 2% as at 1984. Though, congested sections maintained its size, but built-up areas gained by 3% (Figure 7(B)).

It is obvious that population growth is associated with increased demand for land and economic spaces and or exploitation of natural resources—including forest and non-forest products (Obeta, Aujara, Ochege, & Shehu, 2013; United Nations Population Fund, 1991). In this study, data analyses reveal a strong correlation between population growth and vegetation resource depletion. Projected population of Umuahia, which is currently 438,992 rose from 220,104 in 1991 to 359,230 in 2006 (Federal Republic of Nigeria, 2007) show that the area is rapidly urbanizing. Consequently, observations from field surveys revealed serious spread of urban infrastructure and socio-economic activities to previously vegetated sections.

Pieces of information gathered from the indigenous people by preliminary random discussions in 2014 confirm that: (1) urban encroachments (Figure 8) were often not coordinated, (2) have been ongoing since the 1980s, and (3) did significantly accelerate after the study area became state capital in 1991. The people further indicated that: “past methodologies that saw to the sitting and relocation of urban infrastructure to forest-rich zones derided adequate ecological unit accounting and or impact assessment. They maintain that some ecological units of already destroyed forest corridors (e.g. Ibeku and Olokoro) were natural habitats to certain endemic vegetation resources (e.g. Nauclea diderrichii, Myrianthus arboreus P. Beauv., K. Schum., Canarium schweinfurhii, Dialium guineense Wild)”. Unfortunately, most of the species are now difficult to come by even within other sections of the study area (See, for example, Meregini, 2005).
These assertions by the local people shows that heterogeneity in the spatial distribution of land resources, in addition to weak concerns towards preserving the accruing benefits of vegetation resources made certain vegetated sites in the study area more attractive for anthropogenic functions of population and urbanization dynamics (Osemeobo, 1988). Thereby, leading to “mixed patterns of land-use and land-cover changes” which are the resultant effect of long-term gaps and or ambiguity in the implementation of urban development plan (Niemelä, 1999; Rojas, Pino, Basnou, & Vivanco, 2013). Suggesting that, before now, it is not unlikely that urban planning actions in the humid tropical rainforest of southeastern Nigeria were perceived as ecologically unsustainable and developmentally biased.

4.4. Vegetation and other land cover changes in 2014

Like the previous result, the 2014 classification map yet shows reduced fragments of dense vegetation on one hand, and on the other hand increased fragments of sparse vegetation, built-up and congested areas and even the water bodies. Indeed, the 2014 classification result is a near-perfect representation of the current vegetation status in the study area as observed during field surveys. It portrays some distinct variations from the previously classified images of 1984, 1991 and 2014, respectively (Figure 5(C)).

The 2014 image classification analysis indicates a serious decline in the phonological quantity and characteristics of general vegetation resources, judging from the spatial dominance of the sparse vegetation. Since 1984, dense vegetation has been decreasing, while other land cover types gain from these losses (Appendices 1 and 2, Table 1, and Figure 8). Initially, dense vegetation occupied about 330.63 km², but today it only maintains just about half of that green space i.e. 170.87 km². This shows a 44% decrease in its spatial extent. Sparse/unhealthy vegetation on the other hand rose from 2% in 1984 to 27% in 2014; thereby occupying as much as 97.161 km² in spatial extent (Figure 7(C)). Built-up and congested areas—urbanization have also grown to sustain a steady growth pattern (Figure 8), especially because of the rising population and increasing quest to satisfy human need for urban occupancy in the area.

In 1984, built-up and congested areas occupied 15 and 9.69 km², respectively, but the 2014 results show that they currently occupy about 54.94 and 28.66 km², in that order. Consequently, the built up area increased by 14% over a period of 30 years while the congested central business district experienced a steady 5% increase over the same period of years. It therefore suggests that Umuahia axis of the humid tropical rainforest is experiencing more of urban diffusion as shown by fragmented patches of other land cover types.

The marked influx of people since 1991 induced urban congestion and increased need for living spaces. Thereby, introducing opportunities for urban planning interventions aimed at sustainable governance of natural resources. The state government did relocate some urban infrastructural facilities e.g. markets, to previously vegetated areas. Yet, the level of increased disturbances as shown
by the classification analyses of 1991 and 2014 suggests increased human impacts on the region’s ecological landscape. Regrettably, deforestation and habitat loss are the greatest threat to terrestrial biodiversity and ecosystem health which equally leads to species extinction at the time of occurrence and in the future (Millennium Ecosystem Assessment, 2005).

4.5. Accuracy assessment

Using the mapped data against 150 reference data obtained during field observations, the image analysis in this study were subjected to automated quantitative accuracy assessment using the Cohen Kappa’s statistics function in ERDAS Imagine, on the scale of 0 to 1 (i.e. Kappa is a value less than or equal to 1, where 1 corresponds to a perfect agreement) (Congalton & Green, 1999). The acceptable standard of overall accuracy for land cover map is set between 80% (Anderson et al., 1976) and 100% (Lins & Kleckner, 1996). In this study, the results of the accuracy assessment obtained for the classified images of 1984, 1991 and 2014 are presented in a standard summaries report in Table 2(a)–(c). The error matrices quantitatively compared the relationship between the classified images with the reference data obtained from field observations. All the classified images—1984, 1991 and 2014 returned high percentage of overall accuracy and Kappa values as follows: 92% (0.92), 94%

| Vegetation cover | Water | Sparsely vegetated | Densely vegetated | Industrial | Residential | Row total | User accuracy (%) |
|------------------|-------|--------------------|-------------------|------------|-------------|----------|-------------------|
| (a) Confusion matrix for 1984 classification | | | | | | | |
| Water            | 32    | 1                  | 0                 | 2          | 0           | 35       | 91                |
| Sparsely vegetated | 1     | 38                 | 1                 | 1          | 0           | 41       | 93                |
| Densely vegetated | 0     | 2                  | 36                | 1          | 0           | 39       | 92                |
| Industrial       | 0     | 1                  | 2                 | 34         | 0           | 37       | 92                |
| Residential      | 0     | 0                  | 0                 | 2          | 21          | 23       | 91                |
| Column total     | 33    | 42                 | 39                | 40         | 21          | 175      |                   |
| Producers accuracy (%) | 97  | 90                 | 92                | 85         | 100         |          |                   |

| (b) Confusion matrix for 1991 classification | | | | | | | |
| Water            | 31    | 0                  | 2                 | 0          | 0           | 33       | 94                |
| Sparsely vegetated | 0     | 37                 | 1                 | 1          | 0           | 39       | 95                |
| Densely vegetated | 1     | 0                  | 38                | 1          | 0           | 40       | 95                |
| Industrial       | 0     | 0                  | 1                 | 34         | 1           | 36       | 94                |
| Residential      | 1     | 0                  | 0                 | 1          | 25          | 27       | 93                |
| Column total     | 33    | 37                 | 42                | 37         | 26          | 175      |                   |
| Producers accuracy (%) | 94  | 100                | 90                | 92         | 96          |          |                   |

| (c) Confusion matrix for 2014 classification | | | | | | | |
| Water            | 35    | 0                  | 0                 | 0          | 0           | 35       | 100               |
| Sparsely vegetated | 0     | 42                 | 0                 | 0          | 0           | 42       | 100               |
| Densely vegetated | 0     | 0                  | 38                | 0          | 0           | 38       | 100               |
| Industrial       | 0     | 0                  | 1                 | 32         | 0           | 33       | 96                |
| Residential      | 0     | 1                  | 0                 | 2          | 24          | 27       | 89                |
| Column total     | 35    | 43                 | 39                | 34         | 24          | 175      |                   |
| Producers accuracy (%) | 100 | 98                 | 97                | 94         | 100         |          |                   |

(a) Overall accuracy = 92%; Kappa coefficient = 0.92.
(b) Overall accuracy = 94%; Kappa coefficient = 0.94.
(c) Overall accuracy = 97%; Kappa coefficient = 0.97.
(0.94) and 97% (0.97), respectively. This show a high level of conformity with the supervised classification analysis carried out in the study (Table 2).

4.6. Factors responsible for vegetation cover changes in the study area
This study identified four major factors responsible for vegetation cover changes in the humid tropical rainforest segment of Umuahia. (1) Unchecked and increased local demand for forest and non-forest products, (2) Rapidly growing population induced by the reason of the study area’s centrality and official recognition as state capital in 1991, (3) Urban diffusion influenced by increased demand for land and economic spaces (i.e. urbanization), (4) Long-term gaps in the implementation of vegetation monitoring frameworks (see, for example, Erika et al., 2015).

Field observations conducted in 2011 and 2014 reveal that the humid tropical rainforest of southeastern Nigeria is a biodiversity rich belt, with abundance of several endemic vegetation resources that provides various benefits to the indigenous people and uphold useful potentials for posterity. Yet, this rich ecologically vibrant area is considered one of the most rapidly urbanizing and endangered areas in Nigeria.

In 1991, the study area was officially declared a headquarters city in southeastern Nigeria. The action trickled-down a ripple cause-effect response of vegetation resources to anthropogenic phenomenon of urbanization. The rising population initiated increased demand for land and economic spaces, which in turn, affected vegetated areas by increased exploitation of natural resources—including forest and non-forest products.

Data extracted from the analyses in this study (Table 1 and Appendix 2) showed increased human impact on vegetation cover. This is indicated by fragmented sparsely vegetated areas, growth of industrial and residential land uses (Figure 8). One of the understudied geographies of population impact on natural resources is the role of institutional governance in monitoring deforestation and vegetation loss in Africa (Erika et al., 2015; Larcom et al., 2016). Nevertheless, like most other regions, the study area continues to experience unrestrained exploitation of natural resources by virtue of domestic need and industrial demand for fuel wood and timber, respectively.

Also, the spatiotemporal extent maps generated in this study show that built-up and residential areas had become fragmented given the accelerated rate of vegetation reduction since 1991 to 2014. Generally, this kind of situation is often attributed to the concentration of built-up patches or new infrastructural developments along emerging economic corridors (Müller, Griffiths, & Hostert, 2016; Simmons et al., 2016).

Based on the foregoing, Umuahia section of the tropical rainforest is currently witnessing its middle phase of urbanization process. This is exemplified by the area experiencing more of urban diffusion, urban growth (Figure 8) and less of vegetation resilience and forest recovery (Table 1, Appendix 1). As such, vegetation reduction in the area is highly correlated with anthropogenic functions from population dynamics.

5. Conclusion and recommendation
This study shows that remote sensing of vegetation is a consistent methodology in ascertaining changes and phenological characteristics in the humid tropical rainforests. The change detection covered a 30-year period, starting from 1984 to 2014, and revealed a reduction in size of healthy vegetation by 159.76 km² which indicates a 44% vegetation loss. Composite replacement of healthy vegetation cover in the area is impacted by other land use cover types as follows; 90.3 km² (unhealthy vegetation), 18.97 km² (congested/residential), 39.87 km² (built-up/industrial area), 9.59 km² (Water-body). Thereby, indicating a gross encroachment of urban land use of about 23.02% into vegetated areas, and reduced it from 93.03% in 1984 to 73.8% in 2014.
The most significant changes in the spatiotemporal dynamics of land use cover in the study area accelerated after the area became capital city in 1991. Similarly, the much higher percentage of vegetation losses recorded before 1991 (i.e. mid-1980s) is attributed to the persistent unsustainable exploitation of vegetation resources resulting from lack of adequate vegetation monitoring frameworks. Imposing that, unsustainable exploitation of vegetation resources, increased economic activities in need of industrial and residential occupancies, in addition to uncoordinated urban expansions constitutes the anthropogenic functions of urbanization currently experienced in the study area. These, therefore suggest that, there is need to strengthen institutional monitoring frameworks that should account for all ecological units in the humid tropical rainforests.

Though limited by data availability, this study provides the baseline information about vegetation depletion in the humid tropical rainforests of Nigeria, and recommends periodic integration of high-resolution satellite images with urban afforestation strategies in natural resources governance through public engagements. Stakeholders and the local people, whom the vegetation resources are domiciled in their communities, can be adequately consulted, sensitized and integrated into every activity that may directly or indirectly affect ecological heritage. This will increase rates of vegetation resilience and forest recovery, such that, developments that disregard ecological losses and urban greening can be monitored effectively.

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Author details

Friday Uchenna Ochege1 2  
E-mail: uchenna.ochege@uniport.edu.ng  
ORCID ID: http://orcid.org/0000-0002-6661-0966  
Chukwunonyelum Okpala-Okaka2  
E-mail: chukwunonyelum.okpala-okaka@unn.edu.ng  
1 Laboratory for Cartography and GIS, Department of Geography & Environmental Management, University of Port Harcourt, Choba, Rivers State, Nigeria.  
2 Faculty of Environmental Studies, Department of Surveying and Geoinformatics, University of Nigeria, Enugu, Nigeria.

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Appendix 1

Trend of land cover changes (%) in the study area

![Graph showing land cover changes](image)

Appendix 2

**Temporal pattern**

| Land use cover          | 1984  | 1991  | 2014  |
|-------------------------|-------|-------|-------|
| Vegetation resources    | 93.03 | 89.97 | 73.81 |
| Urban encroachment      | 6.82  | 9.67  | 23.02 |
| Water                   | 0.24  | 0.36  | 2.88  |

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