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Building a Resilient Climate Regulatory Ecosystem for Nigeria

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ABSTRACT

Terrestrial ecosystems, which store more carbon than the atmosphere, are vital in influencing carbon dioxide-driven climate change. Climate and land-use change are critical and interlinked components of the carbon budget in human-dominated landscape. Using InVEST model, maps of land use and stocks in four carbon pools (aboveground biomass, belowground biomass, soil and dead organic matter) are used to estimate the amount of carbon currently stored in the landscape and the amount of carbon sequestered over time. InVEST model was integrated with Geographic Information System (GIS) techniques in building a resilient climate regulatory ecosystem for Nigeria based on REDD policy scenario. The result reveals that there is a reduction in forest land by 68.00% in 1984, 52.00% in 2003, and 48.00% in 2035. This has led to a decrease in total carbon stored from 15594440704.00Mgha^{-1}yr^{-1} in 1984 to 11968108544.00Mgha^{-1}yr^{-1} in 2003 and then to 11115581440Mg ha^{-1}yr^{-1} in 2035. Also, total carbon sequestered decrease by 4856430592.00Mgha^{-1}yr^{-1}in 1984 to 2018537728.00Mgha^{-1}yr^{-1} in 2003, and then to 82727.99Mgha^{-1}yr^{-1} in 2035. Based on these findings, REDD policy scenario was designed to increase carbon storage credits in all land useland cover through sustained forest protection and enhancement of forest carbon stocks, and the following can be achieved, 4619.97 Mgha^{-1}yr^{-1} of carbon can be stored for 2003 and 2035. For carbon sequestered, 1707.79Mgha^{-1}yr^{-1} was stored between 1984 and 2003, while between 2003 and 2035, 912.85Mgha^{-1}yr^{-1} was stored. A greater resilient is achieved by adopting the REDD policy because carbon stored can cut down emission by 89.00% and 87.00% in 2003 and 2035, while sequestered carbon by 33.00% between 1984 to 2003 and 2003 to 2035 unconditionally under the Business-As-Usual (BAU) scenario.

Introduction

Terrestrial ecosystems, which store more carbon than the atmosphere, are vital in influencing carbon dioxide-driven climate change (Tallis et al., 2013). Ecosystems regulate earth's climate by adding and removing greenhouse gases (GHG) such as carbon dioxide (CO_2) from the atmosphere. In fact, forests, grasslands, peat swamps, and other terrestrial ecosystems collectively store much more carbon than the atmosphere (Lal, 2004). By storing this carbon in wood, other biomass, and soil, the ecosystems keep CO_2 out of the atmosphere, where it would contribute to climate change. Beyond just storing carbon, many systems also continue to accumulate it in plants and soil over time, thereby "sequestering" additional carbon each year. Disturbing these systems with fire, disease, or vegetation conversion (e.g., land use / land cover (LULC) conversion) can release large amounts of CO_2. Other management changes, like forest restoration or alternative agricultural practices, can lead to the storage of large amounts of CO_2. Therefore, the ways in which we manage the terrestrial ecosystems are critical to regulating our climate (Tallis et al., 2013).

Amongst the many aspects of global change, land use change has been highlighted as a key human-induced effect on the ecosystems (Turner et al., 1995; Lambin et al., 2001). For example, forest area in the tropics is declining (Geist & Lambin, 2002), and the rising atmospheric carbon dioxide results in global warming (IPCC, 2001a; IPCC, 2001b). The land cover classes most heavily impacted by land conversion are the state's terrestrial carbon (C) sinks—most prominently forests, but also green fields, soils, and above and below ground biomass. While the environmental role of these C sinks to climate regulation is well understood, methods to quantify their contribution to regional C budgets to date have largely been ignored due to the absence of reliable C accounting (Tomasso & Leighton, 2014). Research on emissions increases from development-related land cover change supports, the proposition is that LUCF (Land Use, Change and Forest) should play a greater role in GHG reduction strategies (Solecki & Oliveri, 2004; Jo et al., 2009; Mashayekh et al., 2012; Heres-Del-Valle & Niemeier, 2011). From an ecological perspective, land converted from both forests and farmland implies loss of wildlife habitat, habitat fragmentation, deterioration of air and water quality, groundwater run-off from fertilizers and pesticide, impeded groundwater recharge with the expansion of impervious surfaces, and disappearance of farmland. From a global warming perspective, land use characterized by low development density impacts the region's GHG profile, raising emissions from lengthened car travel, deterring public transit use, and increasing the minimum zoning requirements for property and, often in consequence, the C footprint of individual households. From a social equity standpoint, the continued trend toward outlier development diverts state and federal monies away from existing infrastructural improvement in older, inner-core communities in need of reinvestment toward peripheral development, fueling the cycle of sprawl through newly-lain access to low-density areas (Sierra Club, 2000; Willson & Brown, 2008; Rudel et al., 2011).

Voluntary carbon markets allow carbon emitters to offset their unavoidable emissions by purchasing carbon credits emitted by projects targeted at removing or reducing GHG from the atmosphere (Favasuli & Sebastian, 2021). Carbon credits (often referred to as "offsets") have an important dual role to play in the battle against climate change (Blaufelder et al., 2020). Currently these markets only apply to carbon sequestration (i.e., the additional storage of carbon over time), but there is increased interest in financial incentives to avoid release of carbon from the ecosystems in the first place, so called "reduced emissions from deforestation and degradation" or "REDD" (Gibbs et al., 2007; Mollicone et al., 2007; Mackey et al., 2008). Payments for REDD would financially reward forest owners for reversing their planned deforesting and thinning actions (Sedjo and Sohngen 2007; Sohngen et al., 2008). Issues of accounting and verification have slowed the emergence of REDD markets, but many are anticipating them with private transactions (Tallis et al., 2013).

Terrestrial-based carbon sequestration and storage is perhaps the most widely recognized of all environmental services (Stern, 2007; IPCC, 2006; Canadell & Raupach, 2008; Capoor & Ambrosi, 2008; Hamilton et al., 2008; Pagiola 2008). For this study, InVEST model aims at building a resilient climate regulatory ecosystem using REDD policy scenario by estimating the amount of carbon stored and sequestrated as well as the social value of carbon sequestrated in Nigeria. Using InVEST model and socio economic variables, a REDD market-based system will be used to attempt to reduce CO_2 emissions by 33% in 2035 or more. Attempts have been made to reduce and cut down on carbon by implementing 30% cut on emission by 2025 in Australia (Murphy, 2015), 30% by 2030 in Kenya (Bournagui, 2015). However, Nigeria pledges to reduce CO_2 emission by 20% unconditionally and 45% conditionally, compared to the business–as–usual levels by 2030 (Pearce, 2015).This, along with increased pressure on all sectors, is the motivation needed by regional planners to accommodate their decisions to reduce the impact of carbon emissions (Mika et al., 2010) in Nigeria and how changes in land use land cover(LULC) between 1984 and 2035 affect this. This study will help in addressing how climate regulates its ours urban and rural centers specifically in Nigeria through its ability to anticipate, absorb, accommodate, or recover from the hazardous effect (Rodriguez-Llanes et al., 2013) of carbon, by ensured preservation, restoration, or improvement of its essential basic structures and functions (Mendiluce, 2014) using InVEST model integrated with GIS.

Methodology

This research integrates InVEST model with Geographic Information System (GIS) techniques and remote sensing data in building a resilient climate regulatory ecosystem for Nigeria. The research procedure adopted includes:

Data acquired and sources

Data acquired for this study includes mosaic Landsat satellite imagery which covers Nigeria from U.S. Geological Survey(USGS) Earth Explorer, Thematic Mapper(TM) 5 for 1984 and Enhanced Thematic Mapper plus (ETM+) 7 for 2003 was used, with an area extent covering Path 191 to 185 and Row 51 to 57. While, Ikonos satellite imagery was acquired from USGS Earth Explorer with a resolution of 1meter covering parts of Nigeria (such as Lagos state) for 2010. Also, map of Nigeria (vector GIS shapefile format) showing state boundary was acquired from the Department of Geography, University of Lagos, Nigeria as well as the review of relevant and current literatures on the research subject. The study area covers Nigeria which lies between 4° N to 14° N and 3° E to 15° E (Figure 1). It has a land mass of 923,768 sq.km. It is bordered to the north by the Republics of Niger and Chad; it shares borders to the west with the Republic of Benin, while the Republic of Cameroun shares the eastern borders right down to the shores of the Atlantic ocean which forms the southern limits of Nigerian territory (NHC, 2022). Currently, Nigeria is divided into thirty-six states. Nigeria is the most densely populated country in West Africa with 140,431,790 residents according to 2006 census (NBS, 2012), 182,202,000 residents (WHO, 2018) in 2015 and 211,400,708 residents (WPP, 2022) in 2021.

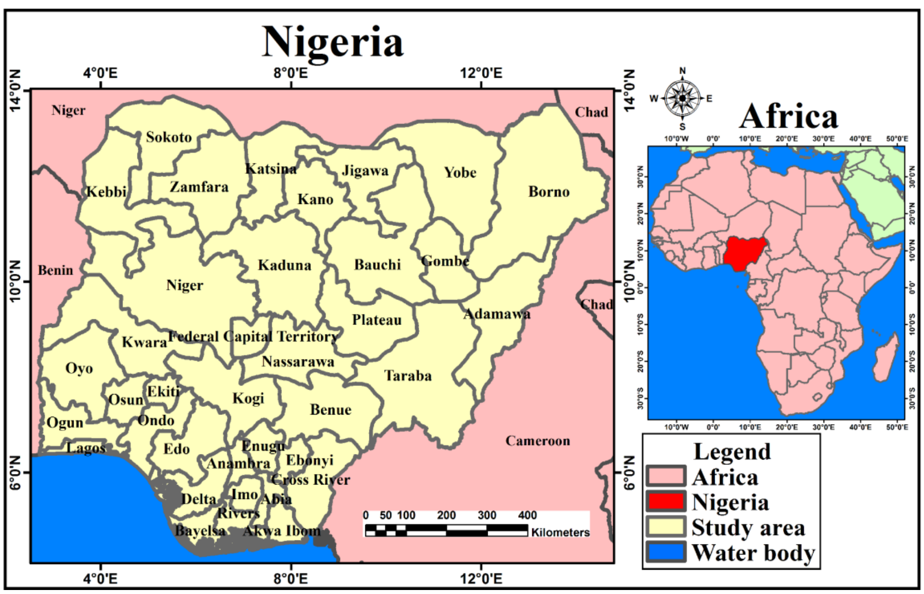

Fig. 1. Location of Nigeria.

Mapping changes in Forest resources of Nigeria

Land use land cover (LULC) maps were classified for 1984 and 2003 from mosaic Landsat TM and ETM+ scenes, provided by U.S. Geological Survey (USGS). Band 4, 5 and 7 acquired from mosaic Landsat TM and ETM+ imagery was enhanced which involves stretching of bands. This was used to create a (false color) composite image. In this research, supervised classification was used with Maximum Likelihood Classification (MLC) method to classify Landsat imagery in Idrisi Selva software. The adopted land use land cover (LULC) classification scheme includes: (a) *Forest area*, (b) *Non-forest area* and (c) *Water body*. GIS reclassification procedure was employed to recode the imagery into correct land use classes, due to misclassification and spectral confusion errors. Accuracy assessment was performed using Ikonos satellite imagery and the results reveals that the land use land cover map classified from ETM+ image yield a better accuracy. In all, the map classified is 48.6% in 2003 better than would have occurred strictly by chance. CA-MARKOV (Cellular Automata and Markov) chain land cover prediction procedure was adopted to predict spatial and temporal changes in land use land cover (LULC) for 2035 using Idrisi Selva software. LULC statistics were used to identify changes between 1984 to 2003 and 2003 to 2035 for forest and non-forest areas. This was used to map forest and non-forest resources in Nigeria. LULC data was used as input in InVEST model.

Mapping changes in Carbon Stored and Sequestrated using InVEST model

Adopting the business-as-usual approach, carbon sequestration and storage was mapped using InVEST model (version 2.6, a toolset of ArcGIS 10 software), and this was implemented using the following procedures:

Modeling changes in Carbon Stored and Sequestrated using InVEST model

LULC component ideally reflects localized data gathered through satellite mapping similar to the type used under the REDD mechanism (Reducing Emissions from Deforestation in Developing Countries) to document avoided deforestation as input. To employ the REDD approach locally, InVEST model utilizes LULC data (for 1984, 2003 and 2035) on timber harvest rates, harvested product degradation rates, and stocks in four carbon pools (aboveground biomass, belowground biomass, soil, and dead organic matter) to estimate the amount of carbon currently stored in a landscape or the amount of carbon sequestered over time (Tallis et al., 2013). Also, this approach adopts business - as - usual (BAU) scenario in estimating carbon stored and sequestrated in Nigeria between 1984 and 2035. Using InVEST model, carbon storage and sequestration computer model quantify and track terrestrial carbon storage and sequestration in Nigeria. InVEST model uses a raster dataset drawn from LULC maps of the type produced in ArcGIS format. A second required dataset for modeling changes in sequestered carbon is estimating carbon pool values for each of the LULC class, assembled from scientific literature on carbon density and terrestrial carbon capture specific to the Nigerian forest eco-systems.

Estimating changes over time in Land Use Land Cover and Carbon Stocks

GIS raster dataset of land use land cover (LULC) was used to capture three measurement intervals across the period of 1984, 2003 and 2035, with a LULC code for each cell. An elaborate matrix of LULC classes was used to evaluate carbon stored in each of the four fundamental pools for each class: above-ground biomass, below-ground biomass, soil and dead organic matter (Tallis et al., 2013). Carbon stock values were prepared for the four carbon pools in accordance with the methodology given by InVEST model and IPCC (2006). Measured hectares of the different LULC classes are plotted against carbon estimates made for terrestrial carbon pool sizes for Nigeria. The table of carbon pools was compiled from evaluation of published scientific literature on carbon storage and sequestration, and values assigned to the various LULC class of the study area. Data reclassification to a double band file format allowed the overlay of Landsat raster files onto a vector-based ArcGIS program to create LULC change.

Dynamics of Carbon Sequestration

Using the same methodology, the levels of carbon sequestration for previous LULC change were modeled and compared with the results of carbon sequestered. For this comparison, the future carbon stock values and the past LULC raster were paired as input data for InVEST model to simulate the amount of biomass growth that would have contributed to sequestration levels in the absence of land use change. To estimate this change in carbon sequestration over time, the model is simply applied to the current landscape and projected future landscape, and difference in storage is calculated. For multiple future scenarios in InVEST model, the differences between the current and each alternate future landscape can be compared (Tallis et al., 2013).

Building a resilient climate regulatory ecosystem using REDD policy scenario

Carbon model perform scenario analysis according to the framework of Reducing Emissions from Forest Degradation and Deforestation (REDD). REDD scenario analysis was performed using: one for the current scenario LULC map, one for the future baseline scenario LULC map, and one for a future scenario LULC map under the REDD policy. The future baseline scenario is used to compute a reference level of emissions against which the REDD scenario can be compared. Based on these three LULC maps for current, baseline, and REDD policy scenario, the carbon biophysical model produces a number of outputs. First, it produces raster for total carbon storage for each of the three LULC maps. Second, it produces two sequestration raster. The other sequestration raster indicates sequestration from the current scenario to the REDD policy scenario (Tallis et al., 2013). The current market value of carbon was computed for this study, the social value of carbon per metric ton was then found by multiplying the market value by \$3.67×Y (Year) (Tallis et al., 2013). The market discount in price of carbon was left at the model's default value of 7%, as recommended by the U.S. government for cost-benefit evaluation of environmental projects (Tallis et al., 2013).

Finally, upon successful completion of the model, a summary html is produced which presents a summary of all data computed by the model. It also includes descriptions of all output files produced by the model (Tallis et al., 2013). Also, data of carbon stored, carbon sequestrated, economic value of carbon sequestrated and economic value of carbon sequestrated in the REDD policy scenario, carbon stored and sequestrated in the REDD policy scenario generated were published as maps while the minimum, maximum and mean value was presented in graph for the LULC type for Nigeria. While, carbon stored was used as input in computing radiative forcing and surface temperature for Nigeria in 1984, 2003 and 2035. Also, carbon sequestrated for the REDD policy was used to design a REDD policy beneficiaries using the sum total value for the difference states in Nigeria between 1984 to 2003 and 2003 to 2035. Economic value of carbon sequestrated in the REDD policy was used to design the economic value gained and lost over time in Nigeria between 1984 to 2003 and 2003 to 2035. Graphs and table presented were executed in Microsoft excel 2010 and maps in ArcGIS 10 software.

Cumulative effect of Carbon induced change on the Climate system of Nigeria

Radiative forcing was used to estimate a subsequent change in equilibrium of surface temperature (ΔT_s) arising from the forcing (Myhre et al., 2008), this was calculated via the following equation as:

$$\Delta T_S = \lambda \Delta F \qquad (1)$$

Where, λ is the Climate Sensitivity (K/ (W/m^{-2})), and ΔF is the Radiative Forcing (IPCC, 2007). A typical value of λ is 0.8 K/ (W/m^{-2}), which gives a warming of 3K for doubling of CO_2. The radiative forcing of a simplified first-order approximation expression for carbon dioxide is:

$$\Delta F = 5.35 \times \ln C/C_0 \; (units: Wm^{-2}) \qquad (2)$$

Where, C is the CO_2 concentration in parts per million by volume and C_0 is the reference concentration. The relationship between carbon dioxide and radiative forcing is logarithmic (Huang & Shahabadi, 2014) and thus, increase in concentrations has a progressively larger warming effect. The cumulative effect over time of carbon stored on radiative forcing and surface temperature was ascertained for the different LULC type. Non-forest area was picked for further analysis because non-forest areas are source of carbon leakage and emission. Based on this, the mean value of surface temperature and radiative forcing was used to study the distribution and changes in trend over time. The distribution of surface temperature and radiative forcing was studied using the mean values plotted on graphs in Microsoft excel 2010 software. To study the trend, time series analysis was used to study observations made between 1980 and 2040 by forecasting changes in surface temperature and radiative forcing based on variations in 1984, 2003 and 2035 using Microsoft excel 2010 software. While the mean value of carbon was plotted against radiative forcing and surface temperature to study the influence of carbon in altering radiative forcing and increase temperature in the climate system. Adopting the curve estimation procedure, logarithmic regression was used to study the relationship between: (1) carbon and radiative forcing, and (2) carbon and surface temperature. This was implemented using SPSS 20 software.

Results and Discussion

Mapping changes in Forest resources of Nigeria

Based on the adopted land use land cover (LULC) classification scheme, figure 2 shows changes in LULC of Nigeria for 1984, 2003 and 2035. Forest area covers 627864.30Km^2 while non-forest area covers 295135.71Km^2 of Nigeria in 1984. Also, forest area covers 482527.21Km^2 while non-forest area covers 440472.79Km^2 of Nigeria in 2003. While In 2035, forest area covers 448122.65Km^2 and non-forest area covers 474877.36Km^2 of Nigeria. For projected changes in land use land cover under the

BAU scenario for 2035 in figure 2, the edges of surrounding forest area seem to have been filled up by developments leaving noticeable changes around non-forest areas. The result reveals that there is a high level of compactness around the non-forest areas in Nigeria for 2035. This trend suggests an increase in non-forest area, and reduction in forest area and water body in the study area between 2003 and 2035. The result reveals that there is a drastic reduction in forest land by 68.00% in 1984, 52.00% in 2003, and 48.00% in 2035, while non-forest area increased by 32.00% in 1984, 48.00% in 2003, and 52.00% in 2035. Also, there is a rapid depletion of the natural vegetation cover which represents forest resources and acts as storage for carbon. There is a corresponding increase in non-forest resources which in-turn increases carbon emission in Nigeria, and this is significant between 1984 and 2035. Thus, with no efforts made to balance up this upset at the present, this changes shows daring future consequences for Nigeria's climate system.

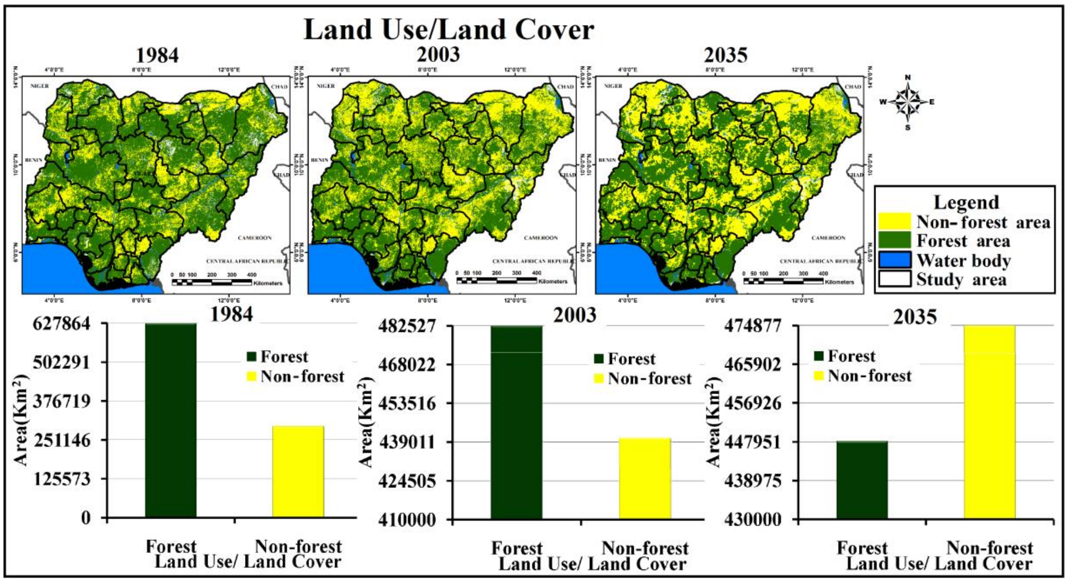

Fig. 2. Map and graph of land use land cover (LULC) change for Nigeria in 1984, 2003 and 2035.

Mapping changes in Carbon Storage, Sequestration and Emission for Nigeria

Based on the land use land cover (LULC) using InVEST model, figure 3 shows the map and graph of total carbon stored for 1984, 2003 and 2035 in Nigeria. Carbon stored in forest area recorded a minimum, maximum and mean value of 5343.95Mgha^{-1}yr^{-1} for 1984, 2003 and 2035. While, carbon stored in non-forest area recorded a minimum value of 561.42Mgha^{-1}yr^{-1} and maximum value of 1746.66Mgha^{-1}yr^{-1} with a mean value of 673.20Mgha^{-1}yr^{-1}, 785.09Mg ha^{-1}yr^{-1} and 799.65Mg ha^{-1}yr^{-1} for 1984, 2003 and 2035. It was observed that total carbon stored decrease from 15594440704.00Mgha^{-1}yr^{-1} in 1984 to 11968108544.00Mgha^{-1}yr^{-1} in 2003 and then to 11115581440.00Mgha^{-1}yr^{-1} in 2035 for Nigeria.

Figure 4 shows the map and graph of total carbon sequestrated between 1984 to 2003 and 2003 to 2035 for Nigeria. Sequestrated carbon in forest area recorded a minimum, maximum and mean value of 0.00Mgha^{-1}yr^{-1}, 4782.52Mgha^{-1}yr^{-1} and 1707.79Mgha^{-1}yr^{-1} between 1984 and 2003. Non-forest area recorded a minimum value of -4782.53Mgha^{-1}yr^{-1}, maximum value of 1185.23Mg ha^{-1}yr^{-1} and a mean value of -1432.29Mgha^{-1}yr^{-1} between 1984 and 2003. Between 2003 and 2035, sequestrated carbon in forest area recorded a minimum, maximum and mean value of 0.00Mgha^{-1}yr^{--1}, 4782.52Mgha^{-1}yr^{-1} and 912.85Mgha^{-1}yr^{-1}. While, non-forest area recorded a minimum value of -4782.53Mgha^{-1}yr^{-1}, maximum value of 1185.23Mg ha^{-1}yr^{-1} and mean value of -644.31Mgha^{-1}yr^{-1}. In figure 4, positive value indicates increase in carbon storage through sequestration and negative value indicates carbon emission from LULC change. Total carbon sequestered in Nigeria decrease from 4856430592.00Mgha^{-1}yr^{-1} in 1984 to 2018537728.00Mgha^{-1}yr^{-1} in 2003, and then to 826727.99 Mg ha^{-1}yr^{-1} for 2035.

Figure 5 shows the map and graph of economic value of sequestrated carbon between

1984 to 2003 and 2003 to 2035 for Nigeria. Based on the above sequestrated carbon, the economic (net present) value of sequestrated carbon in forest area recorded a minimum, maximum and mean of -$107283.00, $432895.80 and $220341.80 between 1984 and 2003. Non-forest area recorded a minimum of -$432896.00, maximum of $0.00 and mean of -$75482.30 between 1984 and 2003. While between 2003 and 2035, the economic value of sequestrated carbon in forest area recorded a minimum, maximum and mean of $0.00, $757901.75 and $144662.77. Non-forest area recorded a minimum of -$570073.94, a maximum of $187827.81 and mean of -$75752.68 between 2003 and 2035. In figure 5, positive value indicates increase in the net present value of carbon stored (gained) through sequestration and negative value indicates carbon lost (emission) from LULC change.

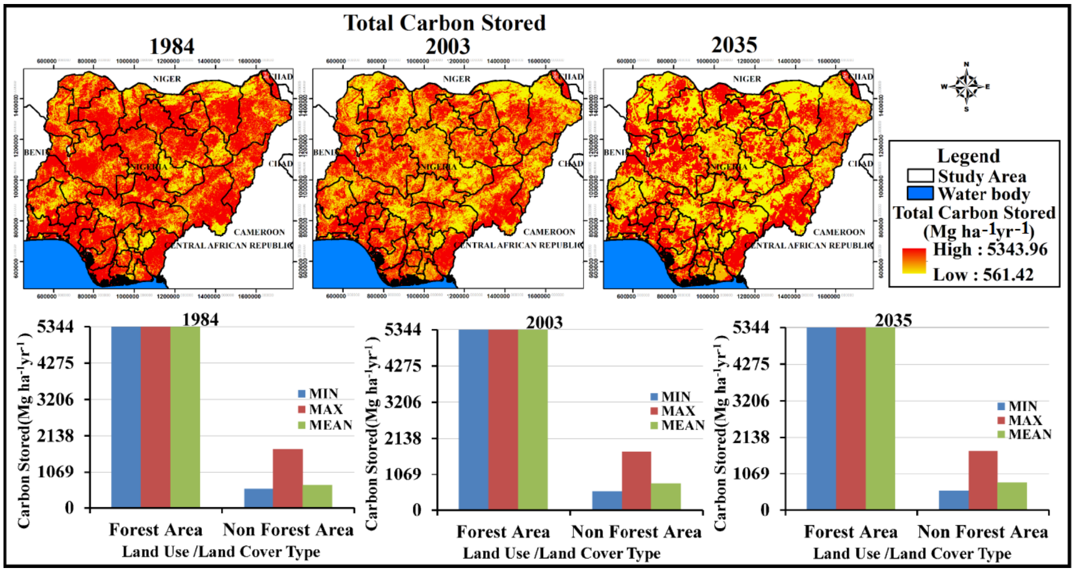

Fig. 3. Map and graph of total carbon stored for Nigeria in 1984, 2003 and 2035.

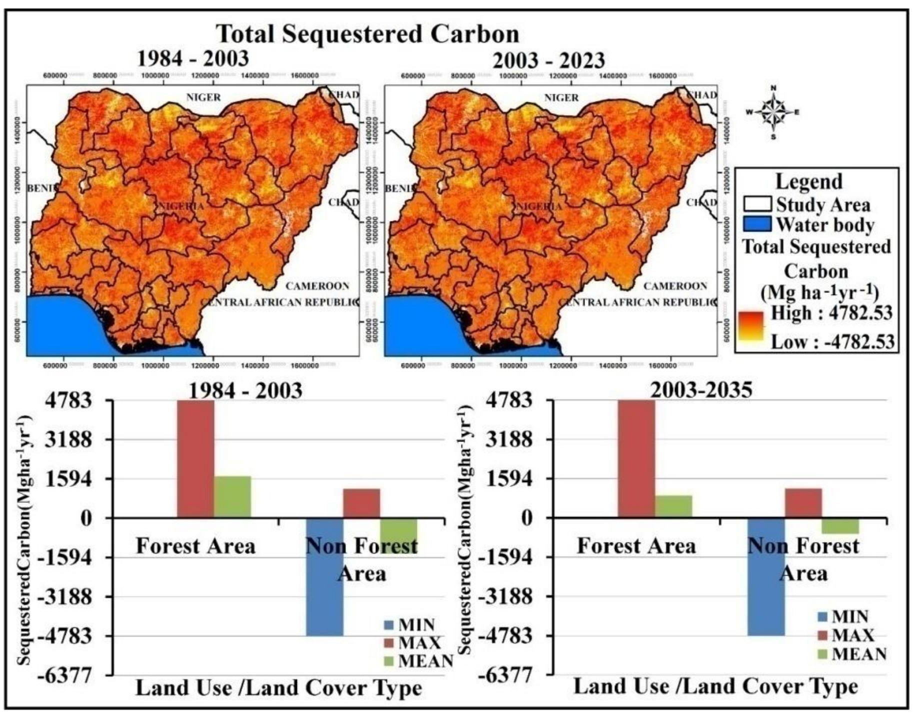

Fig. 4. Map and graph of total carbon sequestrated between 1984 to 2003 and 2003 to 2035 for Nigeria.

Economic value gained from carbon sequestration is decreasing over the years while the economic value lost and damage incurred from carbon emission is increasing.The net present value of total carbon sequestrated has decreased from $439585243136.00 in 1984 to $319883804672.00 in 2003, and then to $47693647038.15 in 2035. This decrease will in-turn hamper growth and cause major disruptions in economies across Nigeria. The result in figure 5 implies that the economic value lost and incurred over the years is high in abating global warming and climate change induced by carbon emission from LULC change in Nigeria.

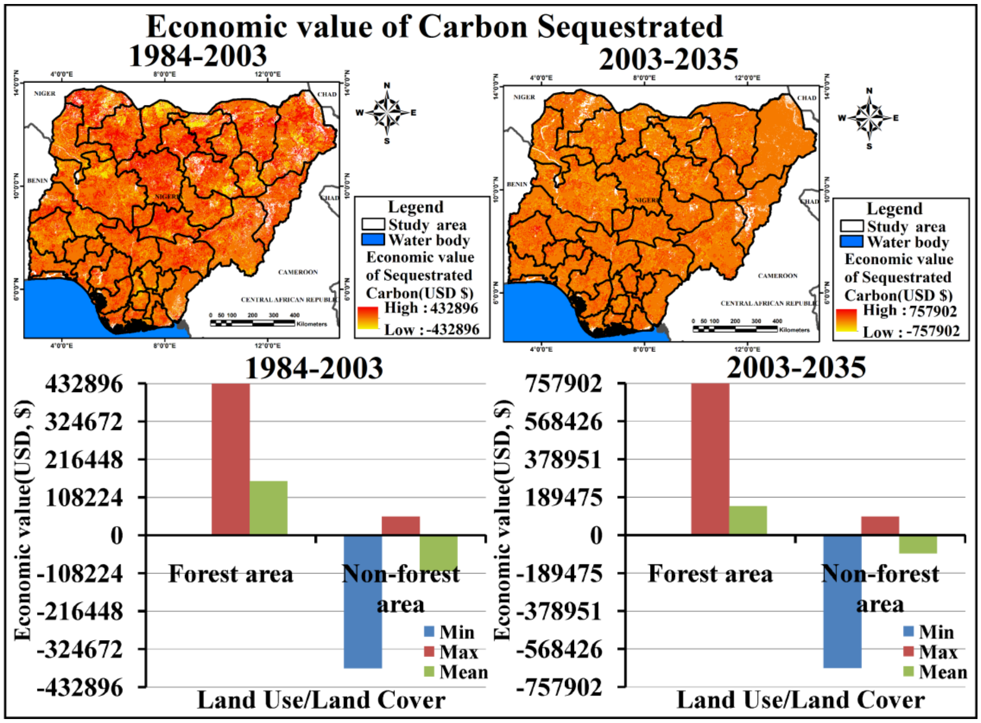

Fig. 5. Map and graph of economic value of carbon sequestrated between 1984 to 2003 and 2003 to 2035 for Nigeria.

Cumulative effect of Carbon induced change on the Climate system of Nigeria

In the study area, figure 6 shows the map and graph of radiative forcing for Nigeria in 1984, 2003 and 2035. Radiative forcing is a measure of the influence of carbon in altering the balance of incoming and outgoing energy in the earth-atmospheric system, and this is an index of importance, a potential climate change mechanism. Radiative forcing for forest area recorded a minimum, maximum and mean value of 15.78W/m^{-2} for 1984, while non-forest area recorded a minimum value of 3.72W/m^{-2}, maximum value of 9.79W/m^{-2} and mean value of 4.29W/m^{-2}. In 2003, radiative forcing for forest area recorded a minimum, maximum and mean value of 15.77W/m^{-2}, while non-forest area recorded a minimum value of 3.72W/m^{-2}, maximum value of 9.79W/m^{-2} and mean value of 4.86W/m^{-2}. In 2035, radiative forcing for forest area recorded a minimum, maximum and mean value of 15.776W/m^{-2}, while non-forest area recorded a minimum value of 3.72W/m^{-2}, maximum value of 9.79W/m^{-2} and mean value of 4.94W/m^{-2}. From the result presented in figure 6, using the map‘s legend, non-forest areas are located at the lower part of the legend on the color ramp while forest areas are located at the top of the color ramp of the legend. It is important to note that forest areas serve as storage to cut down and curtail unreleased, unutilized and untouched energy reserved, and non-forest areas serve as source of emission for radiative forcing. Using the mean value for non-forest area, radiative forcing for 1984 was found to be 4.29W/m^{-2}, 4.86W/m^{-2} for 2003 and a projected increase of 4.94 W/m^{-2} for 2035. A positive increase in radiative forcing over the years was observed for Nigeria, this implies that there is a high indication that climate change is fast encroaching into Nigeria. Also, a positively strong radiative forcing trend indicates an increase in the incoming energy and warming trend of the climate system resulting from global warming (R^2=0.71) (Figure 8). Again, it was observed that an increase in non-forest areas leads to an increase in radiative forcing.

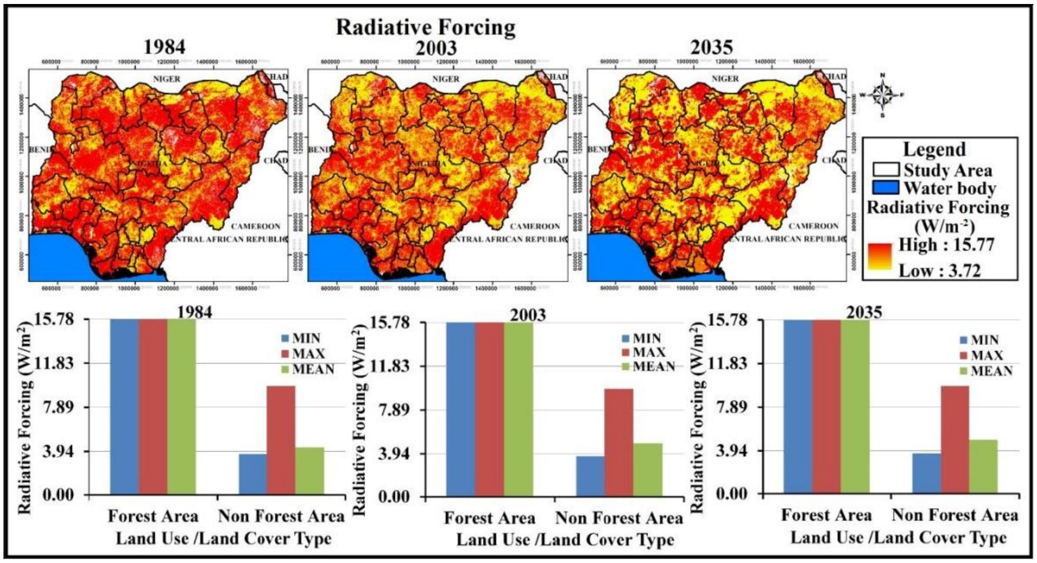

Fig. 6. Map and graph of radiative forcing for Nigeria in 1984, 2003 and 2035.

Figure 7 shows the map and graph of surface temperature for Nigeria in 1984, 2003 and 2035. Surface temperature for forest area recorded a minimum, maximum and mean value of 12.62ºC, while non-forest area recorded a minimum value of 2.97 ºC, maximum value of 7.83ºC and mean value of 3.44ºC for 1984. In 2003, surface temperature for forest area recorded a minimum, maximum and mean value of 12.62ºC, while non-forest area recorded a minimum value of 2.97ºC, maximum value of 7.83ºC and mean value of 3.89ºC.In 2035, surface temperature for forest area recorded a minimum, maximum and mean value of 12.62ºC, while non-forest area recorded a minimum value of 2.97ºC, maximum value of 7.83ºC and mean value of 3.95ºC. From the result presented in figure 7 (using the map's legend), non-forest area is located at the lower part of the color ramp on the legend, this are temperature values stored or used to heat the non-forest area while forest area are located at the upper part of the color ramp on the legend, this are temperature values stored and curtailed by the forest, this are unreleased and unutilized energy reserved. Using the mean value for non-forest area, a temperature increase of 3.40ºC was observed in 1984; 3.80ºC in 2003 and a projected increase of 3.90ºC in 2035 (Figure 8). The result observes a positively strong trend for temperature which is increasing over the years (with R^2=0.71), this impies that global warming is fast encroaching into Nigeria (Figure 8).

Radiative forcing was adopted as a useful way to compare between the different causes of perturbations in the climate system. Radiative forcing was used to estimate a subsequent change in equilibrium in surface temperature arising from the forcing. In the study area, between 1984 and 2035 using the mean value of radiative forcing and carbon emitted, a positive logarithmic relationship (with R^2 =0.99) was found to exist between both variables and thus, an increase in concentrations have a progressively larger warming effect on Nigeria's climate system (Figure 9). This approach also was adopted to study the relationship between carbon emitted and surface temperature. The result reveals that an increase in concentrations of carbon over the years influences changes in temperature and the relationship is positive (with R^2=0.99) (Figure 9). This confirms Intergovernmental Panel on Climate Change (IPCC)(2013) warning of a global average warming which lies between +1.50 and 4.50ºC. It was observed that increase in non-forest areas leads to an increase in surface temperature because the energy stored as temperature warms the climate system, thus making the non-forest areas warmer than its surrounding areas in Nigeria. It is widely believed that causes of radiative forcing and temperature increase arises from changes in insolation and the concentrations of radiatively active gases, commonly known as greenhouse gases (e.g. carbon) (Figure 9). It has been widely argued that GHG emissions need to be curtailed immediately to avoid crossing the GHG atmospheric concentration threshold that would lead to 3.00°C or greater change in global average temperature by 2100 (Figure 9). Some argue that such a temperature change would lead to major disruptions in economies across the world (Stern, 2007).

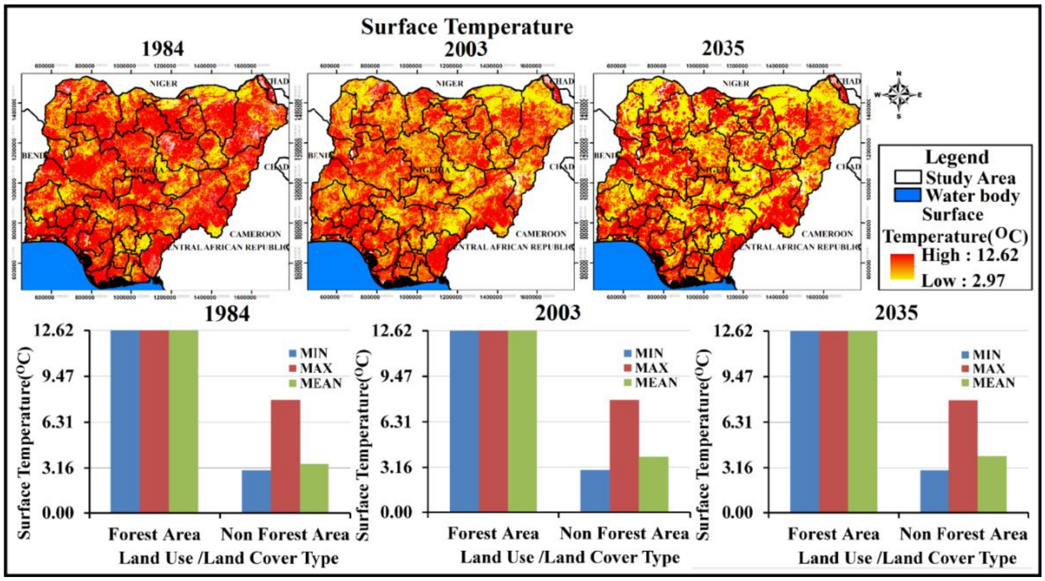

Fig. 7. Map and graph of surface temperature for Nigeria in 1984, 2003 and 2035.

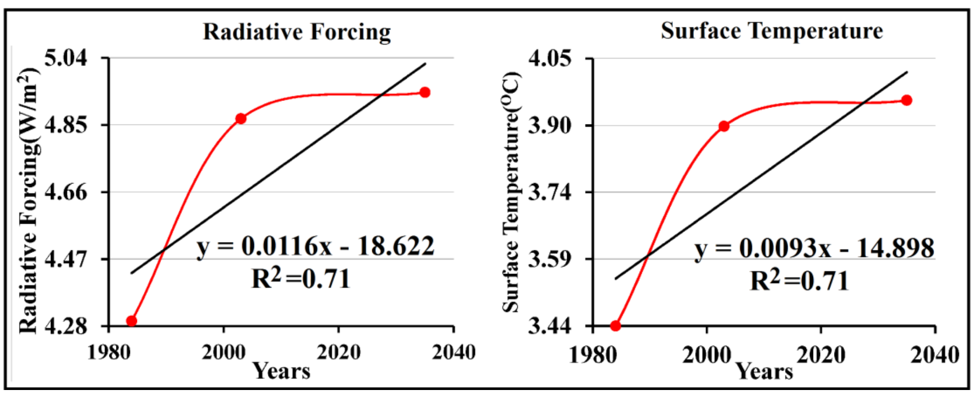

Fig. 8. Radiative forcing and surface temperature trend between 1980 and 2040 for Nigeria.

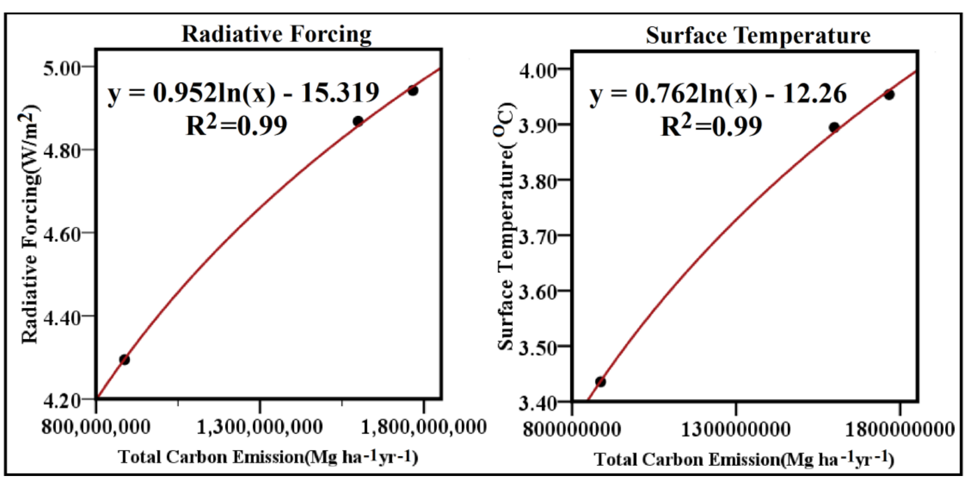

Fig. 9. Influence of carbon emission on radiative forcing and surface temperature in Nigeria.

In the study area, it is observed that between 1984 and 2035, GHG (carbon) atmospheric concentration threshold value for surface temperature is 2.90°C for non-forest area which includes built-up areas and bare ground which may cause major disruptions in economic activity and day to day life of the average Nigerian. While for forest area which includes primary and secondary forest serve as storage for 12.62°C with wetland included if untouched and agricultural land stores 7.80°C.

Building a resilient climate regulatory ecosystem using REDD Policy scenario for Nigeria

Carbon Stored and Sequestrated under the REDD Policy scenario for Nigeria

Figure 10 shows the map and graph of total carbon stored in the REDD policy for 2003 and 2035 in Nigeria. In 2003, a minimum of 561.43Mg $ha^{-1}yr^{-1}$, maximum of 5343.96Mg $ha^{-1}yr^{-1}$ and a mean of 4619.97Mg $ha^{-1}yr^{-1}$ of carbon was stored for forest areas with a total carbon of 15594440704.00 Mg $ha^{-1}yr^{-1}$ (89.00%). While, a minimum of 516.43 Mg $ha^{-1}yr^{-1}$, maximum of 5343.96 Mg $ha^{-1}yr^{-1}$ and a mean of 3051.29Mg $ha^{-1}yr^{-1}$ of carbon was stored for non-forest areas with a total carbon of 887287616.00 Mg $ha^{-1}yr^{-1}$ (11.00%) for 2003. A greater resilient is achieved because carbon stored in forest area is great than carbon emitted;this implies that carbon can be cut down by 89.00% per year unconditionally under the BAU scenario.

While for 2035, a minimum of 561.43Mg$ha^{-1}yr^{-1}$, maximum of 5343.96Mg$ha^{-1}yr^{-1}$ and a mean of 4679.19 Mg ha^{-1} yr^{-1} was stored for forest areas with a total carbon of 11968108,544Mg $ha^{-1}yr^{-1}$ (87%). For non-forest areas in 2035, a minimum carbon of 341.48Mg$ha^{-1}yr^{-1}$, maximum of 5343.96Mg$ha^{-1}yr^{-1}$ and a mean of 3127.76Mg$ha^{-1}yr^{-1}$ was stored with a total carbon of 1599485568.00 Mg$ha^{-1}yr^{-1}$ (13%). A greater resilient is achieved because carbon stored in forest area is great than carbon emitted; this implies that carbon can be cut down by 87% per year unconditionally under the BAU scenario. Under the REDD policy scenario, increase in carbon storage can be improved from 11.00% to 13.00% unconditionally between 2003 and 2035 for Nigeria using forest as the initiatives structured to cut down the mean and total carbon emitted (lost) from land use change and improve storage.

Figure 11 shows the map and graph of total carbon sequestrated in the REDD policy between 1984 to 2003 and 2003 to 2035 for Nigeria. For carbon sequestration, minimum of 0.00 Mg $ha^{-1}yr^{-1}$ and maximum of 4582.53 Mg $ha^{-1}yr^{-1}$ with a mean of 1707.79Mg $ha^{-1}yr^{-1}$ (33%) was sequestrated by forest area while, a minimum of -4782.53 Mg $ha^{-1}yr^{-1}$ and maximum of 1185.24 Mg $ha^{-1}yr^{-1}$ with a mean of -1432.29 Mg $ha^{-1}yr^{-1}$ was emitted by non-forest areas.

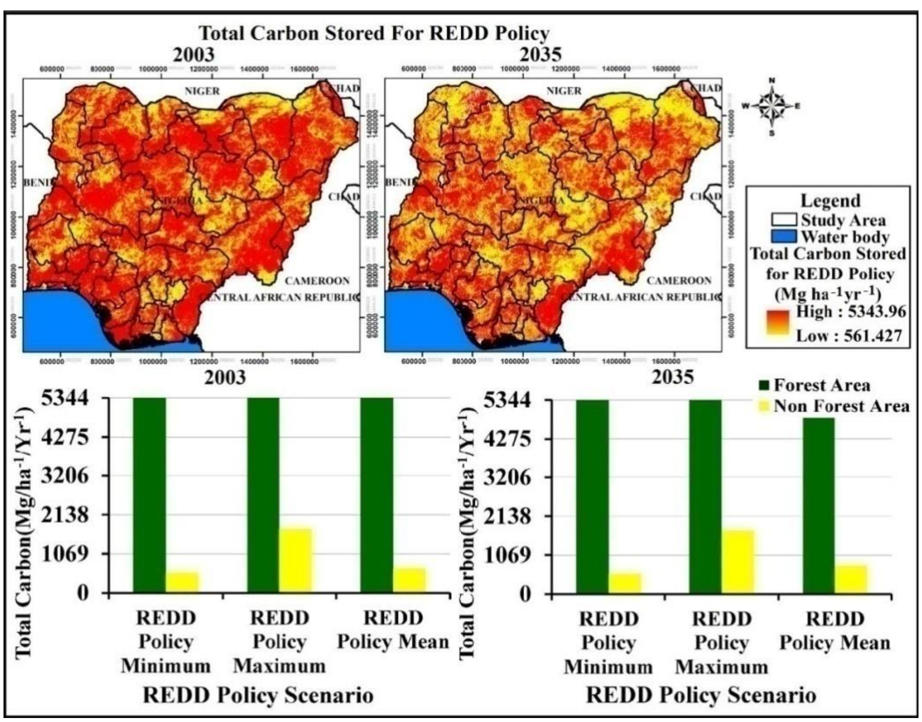

Fig. 10. Map and graph of total carbon stored in the REDD policy for Nigeria in 2003 and 2035.

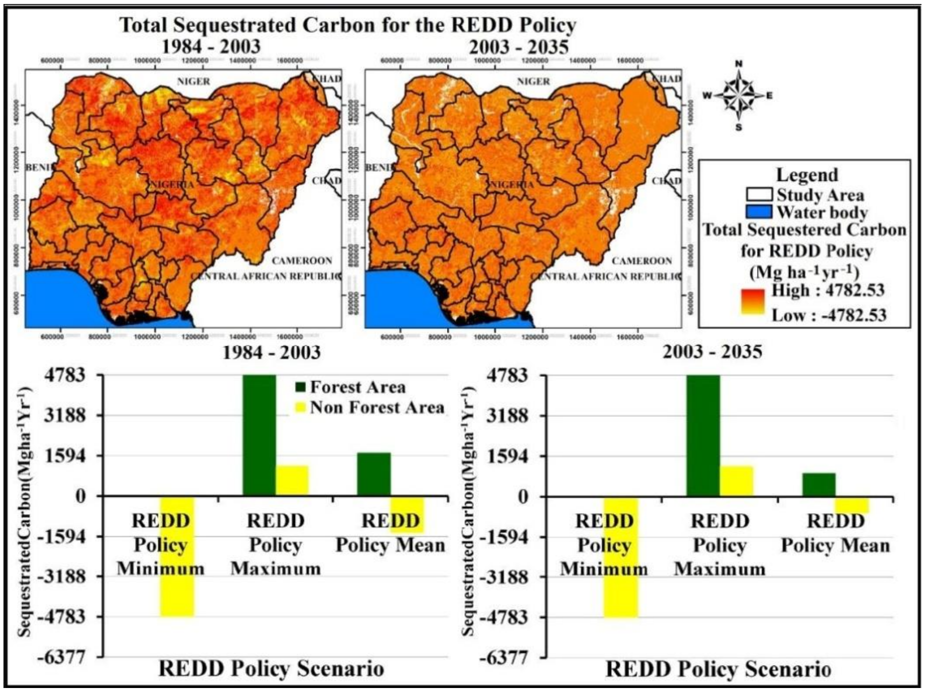

Fig. 11. Map and graph of total carbon sequestrated in the REDD Policy between 1984 to 2003 and 2003 to 2035 for Nigeria.

Between 2003 and 2035, a minimum of 0.00 Mg $ha^{-1}yr^{-1}$ and maximum of 4582.53 Mg $ha^{-1}yr^{-1}$ with a mean of 912.85 Mg $ha^{-1}yr^{-1}$ (33%) was sequestrated by forest areas while, a minimum of -4582.53Mg $ha^{-1}yr^{-1}$ and maximum of 644.32 Mg $ha^{-1}yr^{-1}$ with a mean of -644.18 Mg $ha^{-1}yr^{-1}$ was emitted by non-forest areas. A greater resilient is achieved because carbon can be cut down by 33% per year unconditionally under the BAU scenario between 1984 to 2003 and 2003 to 2035. In figure 11, a positive value indicates that carbon storage increases from sequestration under the REDD policy and a negative value indicates carbon loss(leakage) and emission from LULC change. REDD policy project implemented increases carbon storage credits in all LULC through sustained forest protection and enhancement of forest carbon stocks. REDD project should be encouraged in forest and non-forest areas (and more especially in urban areas). From the results the amount of carbon uptake and storage in the study area are relatively high for forest area. Carbon gained in forest area are relatively slow due to the low sequestration rate observed over time, so the REDD policy measure is to increase and encourage forest conservation by adding or restoring the loss sequestrated carbon back to the ecosystem. This plan acknowledged the importance of forests in addressing climate change, and the enormous potential boon REDD represents.

Beneficiaries and the Economic value gained under the REDD Policy scenario for Nigeria

Based on the mapped total carbon sequestrated in the REDD policy scenario in figure 11, REDD policy beneficiaries was designed for the different states in Nigeria were the impact and effect of REDD policy investment over time can be gained, and marked areas were offset intervention and remedial actions should be implemented. Total sequestrated carbon for the REDD policy was tabulated in Table 1 for the different states in Nigeria and used to defined REDD policy beneficiaries, top gainers include: Borno, Kaduna and Yobe state between 1984 and 2003, while top losers includes: Imo, Anambra, Ebonyi and Enugu state. While, between 2003 and 2035, Kaduna, Oyo, Taraba, and Yobe are ranked top gainers and top losers include: Imo, Jigawa, Kano, Katsina, Kebbi, and Niger state. Top gainers include areas with positive values, high capability to store carbon and emit less while top losers include areas with negative values, low capability to store carbon and emit more.

Based on the REDD policy actions to reduce deforestation and increase carbon sequestration above the economic value for the different land use land cover type in Nigeria using carbon sequestrated for the REDD policy, figure 12 shows the economic value of carbon sequestrated in the REDD policy between 1984 to 2003 and 2003 to 2035 for Nigeria.

Table 1. Total sequestered carbon (Mg $ha^{-1}yr^{-1}$) in the REDD policy scenario between 1984 to 2003 and 2003 to 2035 for Nigeria.

S/N	State	1984-2003	2003-2035	S/N	State	1984-2003	2003-2035
1	Abia	532378.93	14207830	20	Kano	132079176	-18000166
2	Adamawa	166792160	15067312	21	Katsina	33561724	-4810994
3	Akwa Ibom	21627528	13573500	22	Kebbi	52541412	-1171220
4	Anambra	-13629976	4706257	23	Kogi	97746824	33499820
5	Bauchi	180644368	29280466	24	Kwara	85451296	39380852
6	Bayelsa	26247074	859295.5	25	Lagos	6704959	4021524
7	Benue	150338592	33896540	26	Nassarawa	181545760	44179704
8	Borno	287929312	5380136	27	Niger	117840320	-6955688
9	Cross River	15322284	13748416	28	Ogun	38972340	7877551
10	Delta	48281052	23791018	29	Ondo	44925984	18286536
11	Ebonyi	-6891498	14623431	30	Osun	12326966	17050004
12	Edo	66916048	25897284	31	Oyo	44044692	74167504
13	Ekiti	8832789	12928836	32	Plateau	51091932	40389756
14	Enugu	-14961057	16134086	33	Rivers	16989348	13862511
15	Federal Capital Territory	26982336	11874767	34	Sokoto	168196624	18459768
16	Gombe	7326978	37463412	35	Taraba	129878504	61558308
17	Imo	-4418661	-35078.76	36	Yobe	215023808	55758452
18	Jigawa	80687504	-13070441	37	Zamfara	198129296	3167136
19	Kaduna	341097152	54768572				

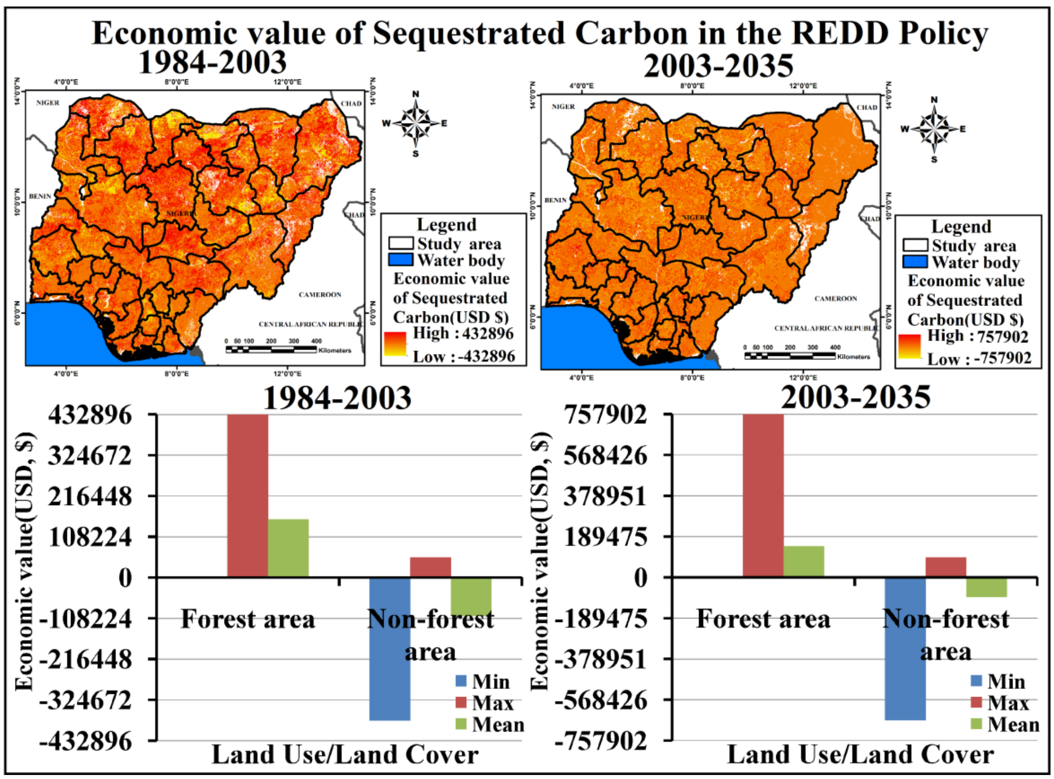

Fig. 12. Map and graph of economic value of sequestrated carbon in the REDD policy between 1984-2003 and 2003-2035 in Nigeria.

In figure 12, the negative net present value represents the cost of carbon emission (or economic value lost from carbon emission) while the positive net present value represents the economic value gained through carbon sequestration. For the study area, minimum of \$0.00 (this is the economic value neither gained nor lost), \$432895.84 maximum (economic value gained) and \$154582.58 mean (economic value gained) was observed between 1984 and 2003 for forest area. Between 2003 and

2035 for forest area, minimum of $0.00 (this is the economic value neither gained nor lost), $757901.75 maximum and $144662.77 mean was observed as the economic value gained. For non-forest area between 1984 and 2003, minimum of -$379254.40 (economic value lost), $53641.47 maximum (economic value gained), and -$102170.20 mean (economic value lost) was observed. While between 2003 and 2035 for non-forest area, minimum of -$663987.84 (economic value lost), $93913.91 maximum (economic value gained), and -$92020.13 mean (economic value lost) was observed (Figure 13). A greater resilient is achieved because economic value gained is greater than economic value lost; this implies that the economy can boon and flourish under REDD policy carbon cut down (due to land use change). Also,a greater resilient is achieved because the value gained over the years (between 2003 and 2035) is greater than the value lost using the mean value. The result further reveals that despite the cut down on carbon, high economic value will be spent on carbon sequestration in Nigeria but implementing the REDD policy will increase the economic value gained between 1984 to 2003 and 2003 to 2035 for forest area by $9919.81 and the economic value lost will decrease by -$10150.07 for non-forest area. Conclusively, the following assertions could be made about REDD policy: (1) Increasing carbon storage credits in forest and non-forest areas can regulate the climate system by implementing REDD policy. (2) Adopting REDD policy builds a resilient climate regulatory ecosystem by cutting down on carbon emission. (3) The gains in implementing REDD policy can regulate the climate system by addressing climate change and economic development, and enhancing the enormous potential boon REDD represents.

Conclusions

This study uses InVEST model to build a resilient climate regulatory ecosystem using REDD policy for Nigeria, principally from forestlands which comprise of high-density carbon storage pools. Landsat satellite imagery acquired for 1984 and 2003 was used to analyze LULC conversion and predict spatiotemporal changes in 2035 using GIS. The result reveals that there is a reduction in forest areas with corresponding increase in non-forest areas for Nigeria. This has led to a decrease in carbon stored and sequestrated with increase in carbon emitted and its economic value estimated using InVEST model between 1984 and 2035. This in-turn has altered the climate system's equilibrum such as increase in radiative forcing and surface temperature received in Nigeria. Based on these findings, REDD policy was implemented using InVEST model to increase carbon sequestration as well as carbon storage credits in the LULC through sustained forest protection and enhancement of forest carbon stocks which in-turn increase the economic value gained from carbon sequestration between 2003 and 2035. However, government, energy, transportation and environmental policy-makers can benefit from integrating REDD policy into policy-making aimed at combating climate change through maximizing carbon trade off principles in Nigeria.

Conflict of interest

The author declare that there is no conflict of interest.

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