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ORIGINAL ARTICLE

Land use/land cover change and statistical modelling of cultivated land change drivers in Nigeria

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Abstract In recent decades, human activities have significantly influenced land use/land cover. Identifying pattern changes in regional land use/land cover and their drivers is crucial for land use planning and management decision making. This study aims to (1) describe land use/land cover changes that have taken place in Nigeria in the study period of 10 years (2000–2010), (2) determine the factors that drive those changes with emphasis on transition to cultivated land use and (3) examine the spatiotemporal intensity of land use. The study utilized the GlobeLand30 land cover datasets produced by the National Geomatics Center of China. We used the spatial calculating analysis model to analyse land use/land cover change, logistic regression to model drivers of cultivated land expansion and land use intensity comprehensive index model to examine the intensity of land use. Our results revealed that (1) conversions to cultivated land dominate the land use/land cover change processes and expansion was largely at the detriment of the grassland, shrubland and forests; (2) biophysical, socio-economic and proximity factors are significant determinants of transition to cultivated land use. Population density is negatively related to cultivated land expansion, which suggests labour scarcity in the agricultural sector that can consequently result into low productivity and (3) significant discrepancies exist in the intensity of land use between the southern and northern regions of the country. Policy measures aimed at improving agricultural productivity remain one of the best ways to reduce pressure on increasingly scarce land resource and conserve natural ecosystems in Nigeria.

Keywords Cultivated land expansion · Land use intensity · Logistic regression · Determinants · Nigeria

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Introduction

Land use/land cover (LULC) change is probably the most significant of the earth's challenges over the next century (Mustard et al. 2004), when land cover transformations are expected to be the most rapid for many regions of the world (Lambin et al. 2005). As a result, LULC change is one of the most critical issues that are given top priority by a wide range of scientists and practitioners worldwide. The consequences of LULC change are vast and felt at local, regional and global scales. Among these numerous consequences are extinction of the indigenous species when land is changed from a relatively undisturbed state to more intensive uses like farming, livestock grazing and selective tree harvesting (Ellis and Pontius 2007); water, soil and air contamination (Girma and Hassan 2014); increased risks of natural disasters such as drought and flood (Nel et al. 2014); greenhouse gas emissions (Verburg et al. 2000) and alteration of the processes, structure and functioning of the ecosystem (Lambin et al. 2000), which impedes its ability to sustain human life (Vitousek et al. 1997).

LULC changes are the result of the interplay of a wide variety of factors which operate over a range of scales in space and time (Geist et al. 2005; Verburg et al. 2002). These factors are generally subdivided into two categories, namely, proximate and underlying factors. The proximate causes constitute human activities or immediate actions that originate from intended use of land and directly affect the land cover (Lambin et al. 2003). They include agricultural expansion, wood extraction, infrastructure extension and other activities that change the physical attributes of the land cover (Turner and Meyer 1994; Lambin et al. 2003). Underlying or indirect factors are the fundamental forces that underpin the more proximate causes of land cover change and include the social, demographic, political, economic, technological, biophysical and cultural factors (Geist and Lambin 2002; Lambin et al. 2003). While the proximate factors such as individual farms, households or communities often operate at the local level, the underlying factors may originate from either the regional or the global level (Lambin et al. 2003).

Major changes in human use of land particularly through extensive agriculture have significantly altered LULC patterns globally (Ademiluyi et al. 2008). Roughly 38.2% of the earth's terrestrial surface are used for either growing crops or livestock grazing, which is expected to rise to 60% in the next century if the trend is unabated (Wade et al. 2008). Agricultural expansion involving degradation of the natural vegetation has been established as the most dominant trajectory of LULC change in Africa (Brink and Eva 2009; Gibbs et al. 2010). During a period of 25 years (1975 to 2000), about 5 million hectares of both forest and natural non-forest vegetation is being lost annually to the development of new agricultural lands in sub-Saharan Africa (Brink and Eva 2009). A significant decline in vegetation density due to intensive land clearing for agriculture has equally been documented at smaller scales. Land area under cultivation in Senegal increased from 17% in 1960 to 21.4% in 2000 and occurred dominantly at the cost of the forests and savannah, which both decreased at an annual rate of 33,000 ha (Tappan et al. 2004). Ouedraogo et al. (2010) reported an annual increase of 0.96% in cropland land area between 1986 and 2006 for Sissili province in southern Burkina Faso, which occurred largely at the expense of the dense forestland estimated to decrease at a rate of 1.45% per year. With no exception in Nigeria, World Bank (1998) reported 84,073-km^2 increment in agricultural land area between 1976/1978 and 1993/1995 dominantly at the detriment of the natural vegetation and a more recent study (Abubakar 2015) showed an annualized growth of 12,995 km^2 in farmland area from 2001 to 2009 also found to involve a large reduction in the forest and savannah vegetation.

The aforementioned LULC change studies across Africa as well as studies at other local levels in the continent (e.g. Girma and Hassan (2014) for the Southern Nations, Nationalities, and Peoples' Region (SNNPR) of Ethiopia and Braimoh and Vlek (2004) for the Volta basin of Ghana) have done both qualitative and quantitative (e.g. using correlation, multivariate fractional logit and binary logit analyses) assessments of the underlying causes of land changes to agricultural use. These studies identified population size and density, road, water, market and credit access, topographic (elevation, slope and aspect), climate (temperature and rainfall), landscape, land suitability and land tenure variables as major drivers of agricultural expansion. However, none of the past national studies in Nigeria quantitatively examined the factors that drive LULC change. Indeed, many of the local studies (e.g. AC-Chukwuocha 2015; Shuaibu et al. 2014; Jibril and Liman 2014; Ejaro and Abdullahi 2013; Oyinloye and Oloukoi 2012; Njoku et al. 2010; Mengistu and Salami 2007) have equally focused mainly on quantifying the amount of change and a qualitative description of the factors causing the observed changes. In addition, land use intensity, which measures the extent to which the comprehensive activities of human on the land ecosystem impacts on its development and a vital component of LULC change analysis (Liu et al. 2003; Wang et al. 2010), has also been ignored in LULC change assessment studies in Nigeria.

Hence, building on the weakness of the previous national LULC change studies, as well as the emphasis laid on cultivated land expansion in Nigeria (Abubakar 2015; Abbas 2009; World Bank 1998), the present study aims at quantifying the determinants of the changes in LULC with special interest on transition to cultivated land use. Specifically, we addressed three questions: (1) what are the LULC changes that have taken place in Nigeria between 2000 and 2010? (2) what underlying factors drive conversions to cultivated land use? and (3) how do the intensity of land use varies with time and across regions? We hypothesised that both biophysical and human factors will be cogent drivers of cultivated land expansion in Nigeria.

Materials and methods

Study area

Nigeria is a sub-Saharan country situated on the south coast of West Africa between latitudes 4° 16′ 13.50″–13° 53′ 31.24″ N and longitudes 2° 40′ 6.35″–14° 40′ 35.09″ E. It borders Benin, Chad and Cameroon, and Niger in the west, east and north, respectively (Fig. 1) and has a land area of about 923,769 km^2 (FOS 1989). Since independence, Nigeria (the most populous country in Africa) has been experiencing a rapidly growing population (Online Resource 1). This by no doubt has profoundly influenced land use patterns and resulted into significant LULC changes. According to United Nations (2015) projections, Nigeria, which positioned no. 7 with an estimated 182 million people in 2015 (Online

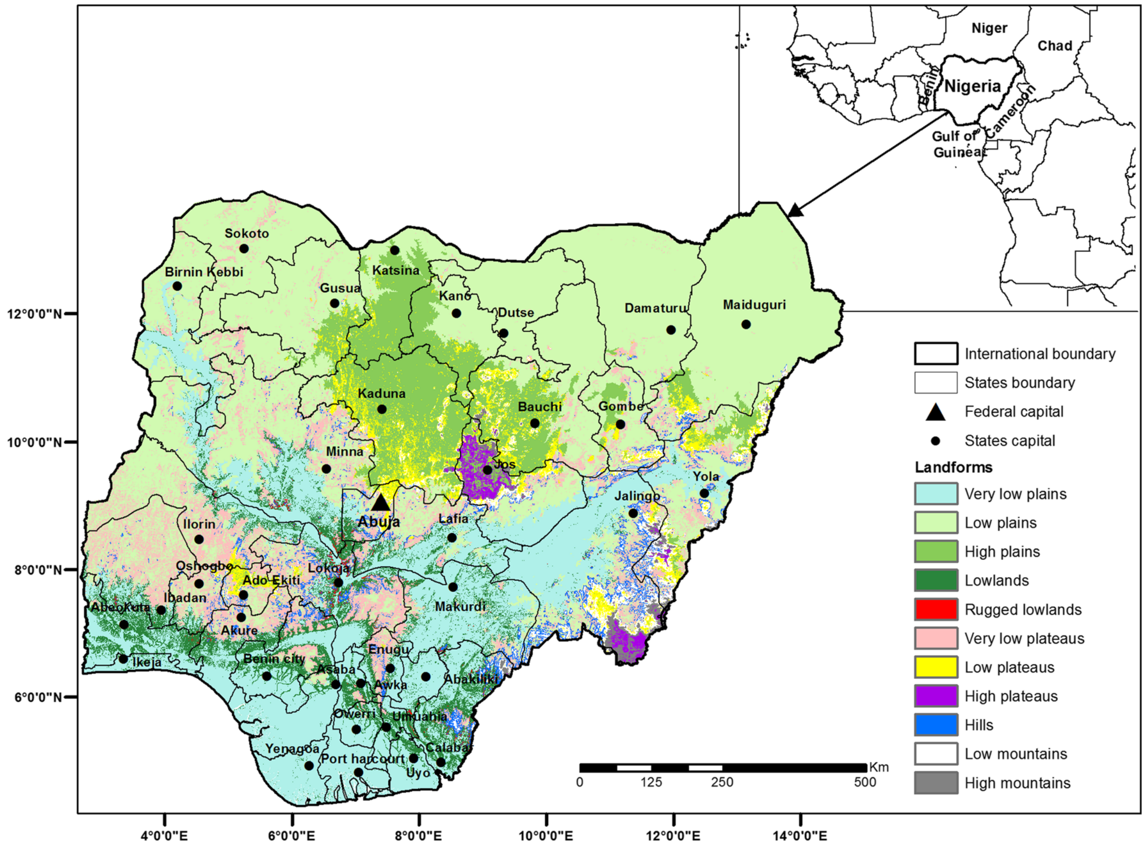

Fig. 1 Physiographic and administrative distribution of Nigeria

Resource 1), will be the third most populous country in the world by 2050 with estimated population of over 397 million people. This unprecedented rise in population will further escalate the existing human pressure on the finite land resource. Hence, monitoring past land use/land cover patterns, the change over time as well as its drivers is crucial for projection of future LULC change trajectory, its consequences and formulation of sustainable land use policies in Nigeria.

Nigeria has two main seasons: the wet season that lasts from mid-March to November in the south and from May to October in the north and the dry season, which occupies the rest of the year (Oyenuga 1967). The climatic regions are characterized by tropical rainforest in the south, tropical savanna in the centre and north, and highland (montane) climate in areas >1520 m above sea level (Iloeje 2001). Annual rainfall ranges from above 2000 mm in the south to less than 600 mm in the north (Oginni and Adebamowo 2013), and mean annual temperature ranges are 21–27 and >27 °C for the plateaus and inland areas, respectively (Iloeje 1981). Based on relief roughness and elevation, the plains, lowlands, plateaus, hills and mountains are the landforms typical in Nigeria (Meybeck et al. 2001; Fig. 1). With a wide range of climatic, vegetation and soil conditions, Nigeria possesses the potential for a wide range of food and cash crops. The staple food crops include cassava, yams, corn, cocoyams, cowpeas, beans, sweet potatoes, millet, plantains, bananas, rice, sorghum and a variety of fruits and vegetables.

Before the discovery of crude oil, the economy of Nigeria depended almost entirely on agriculture. The sector employed over 70% of the labour force, accounted for over 60% of its gross domestic product (GDP) and also served as the main source of foreign exchange earnings (Wahab 2011). However, the advent of oil boom in the 1970s led to the neglect of the agricultural sector, which ultimately resulted in a decline in agricultural output and in the overall contribution of the sector to the economy (Ogbalubi and Wokocha 2013; Online Resource 2). Nigeria also lost its status as a net exporter of cash crops such as cocoa, palm oil and groundnuts and became a major importer of food (Ogbalubi and Wokocha 2013; Online Resource 3). Though the land under cultivation has been shown to have increased considerably over the years (Abubakar 2015; Abbas 2009; World Bank 1998) in order to sustain the growing large population, food production has still not kept pace with population increase (Apata et al. 2010; Abdulrahaman 2013; Uma et al. 2014; Ahungwa et al. 2014).

Traditionally, land uses and distribution in Nigeria are governed by customary laws under which land was considered a community property. Individuals had rights to the land belonging to their family or the community for farming or any other purposes that will be beneficial to the society, but land could not be sold or mortgaged. Customary tenure was generally relevant for many rural areas and remained the major form of landholding until the early 1970s when population growth and increased urbanization led to commercialization of land and transaction on land became based on exchange value as opposed to use value (Braimoh and Onishi 2007). In response to the perceived inefficiencies in land distribution in the customary land tenure, the Federal Government of Nigeria promulgated the Land Use Act in 1978. The act vests all land comprised in the territory of a state in the hands of the state governor who holds in trust for the use and common benefit of the people. Under the Land Use Act system of land tenure, rights of occupancy form the basis upon which land is to be held. Statutory right of occupancy is granted by the state governor in respect of land in urban areas, and a customary right of occupancy is granted on rural lands by a local government. However, due to inefficiencies of land use and allocation committees in issuing certificates of occupancy, inconsistences in implementing the legislation and bureaucratic administrative requirements that tend to favour wealthy individuals (Braimoh and Onishi 2007), the act promoted land insecurity rather than equitable distribution of land. The low-income earners continue to attain land through the informal and commercialized process (Braimoh and Onishi 2007).

Datasets

In this paper, we used the GlobeLand30 land cover datasets of 30 m resolution produced by the National Geomatics Center of China for the years 2000 and 2010 (NGCC 2014). The datasets were generated using satellite images of the Landsat TM/ETM+, the Chinese Environmental Disaster Alleviation Satellite (HJ-1) and other ancillary data. The overall accuracy and kappa coefficient were, respectively, 79.6% and 0.81 in 2000 and 83.5% and 0.78 in 2010. Ten LULC types (Online Resource 7) were distinguished for both periods, eight of which are specific to Nigeria (Online Resource 4). To determine the suitability of the datasets for LULC change analysis in Nigeria, we conducted an accuracy assessment of the datasets using high-resolution Google Earth images. A total of 400 points (including 50 points for each LULC type) distributed over the study area was acquired through a random sampling method for both periods. These points were overlaid on the top of Google Earth satellite images, and the LULC type of each point was validated using the Google Earth images temporally around the GlobeLand30's production year. We achieved greater than 73 and 75% overall accuracy for 2000 and 2010, respectively. In addition, as shown in Online Resource 4, there is a high agreement in the spatial pattern of the Google Earth images and GlobeLand30 2010, giving credence to the suitability of the data for LULC change analysis in Nigeria. Although Sun et al. (2016) found the accuracy of GlobeLand30 to be 46% for Central Asia, high accuracy has been reported for other regions of the world. The overall accuracy of GlobeLand30 was found to be higher than 80% in Italy (Brovelli et al. 2015), up to 92% in Germany (Arsanjani et al. 2016a) and about 78% in Iran (Arsanjani et al. 2016b), and the accuracy of water bodies in Thessaly, Greece, is 91.9% (Manakos et al. 2014).

Based on previous LULC change studies and accessible data, we selected 13 variables to determine the potential driving factors of cultivated land expansion in Nigeria, which could be grouped into biophysical, socio-economic and proximity variables (Table 1; Online Resource 5). We consider this number of selected driving factors sufficient as demonstrated by related studies (Shu et al. 2014; Dong et al. 2016; Paudel et al. 2016). The landform data of 1 km resolution was provided by the Joint Research Centre (JRC) of the European Commission (Meybeck et al. 2001). The landform has 12 classes, which were reduced to 5 (Table 1; Online Resource 5) for use in logistic modelling. The agro-ecological zones (AEZs) data was obtained from the Global Trade and Analysis Project (GTAP) database (Ramankutty et al. 2007). Elevation and slope data were extracted from the 90 m resolution Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) (Jarvis et al. 2008), and the soil (pH and depth) data of 250 m resolution were obtained from the Africa Soil Information Service (AfSIS) Sentinel Site database (Hengl et al. 2015). Site-based observation data on temperatures and rainfall from 2000 to 2010 were provided by the Nigeria Meteorological Agency (NIMET 2015). The surface data for the climate variables were created using the spline interpolation algorithm (Hutchinson 2006) as the technique was identified as the optimal method for spatial interpolation of temperature and rainfall in Nigeria (Arowolo et al. 2017). State-wise population and GDP data were obtained from the National Bureau of Statistics, Nigeria (NBS 2016) and Canback Global Income Distribution Database (C-GIDD 2016), respectively. We used the 2010 road data released by the NASA Socioeconomic Data and Applications Center (SEDAC) (CIESIN/ITOS 2013). Data on water was acquired from the database of DIVA-GIS (2016), and we prepared the cities data based on topographic maps and Google Images.

Analytical tools

The rate of LULC change from 2000 to 2010 was determined using the spatial calculating analysis model (Zhang et al. 2008), given by:

$$\mathrm{CR}_i = \left[\frac{\left(\mathrm{LA}_{(i,\ t_1)} - \mathrm{ULA}_i\right) + \left(\mathrm{LA}_{(i,\ t_2)} - \mathrm{ULA}_i\right)}{\mathrm{LA}_{(i,\ t_1)}}\right] \times \frac{1}{t_2 - t_1} \times 100\%, \quad (1)$$

where CR_i is the changing rate of LULC type i during the observation period t_1 to t_2; $\left(\frac{LA_{(i,\ t_1)}-ULA_i}{LA_{(i,\ t_1)}}\right)\times\frac{1}{t_2-t_1}\times 100\%$, % and $\left(\frac{LA_{(i,\ t_2)}-ULA_i}{LA_{(i,\ t_1)}}\right)\times\frac{1}{t_2-t_1}\times 100\%$, are the decreasing and increasing rate of the ith type of LULC during the observation period, respectively; $\left(LA_{(i,\ t_1)}-ULA_i\right)$ and $\left(LA_{(i,\ t_2)}-ULA_i\right)$ are the total area of the LULC type i that is converted into (i.e. the decreased part) and gained from (i.e. increased part) other non-ith LULC types during the period of monitoring, respectively; $LA_{(i,\ t_1)}$ and $LA_{(i,\ t_2)}$ are the land area of the LULC type i at the initial and final monitoring periods t_1 and t_2 , respectively; and ULA_i is the unchanged area of the LULC type i from t_1 to t_2.

The magnitude of change (CM_i) from 2000 to 2010 for the ith LULC type can be computed as:

$$CM_i = \left(LA_{(i,\ t_2)}-ULA_i\right)-\left(LA_{(i,\ t_1)}-ULA_i\right). \tag{2}$$

A transition matrix was generated to capture the multidirectional change between the LULC types.

We examined the intensity of land use and its temporal change using regional land use intensity comprehensive index model (Wang et al. 2010; Di et al. 2015), given by:

$$\Delta I_{t_2-t_1} = I_{t_2}-I_{t_1} = 100\left[\left(\sum_{i=1}^{n} G_i\times A_{i,\ t_2}\right)-\left(\sum_{i=1}^{n} G_i\times A_{i,\ t_1}\right)\right]; I\in[100,400], \tag{3}$$

where l_{t_1} and l_{t_2} are the regional land use intensity comprehensive indexes at time t_1 and t_2, respectively, and range from 100 to 400 with larger values denoting a higher land use intensity; G_i is the grade value of the ith ranked LULC type; $A_{i,\ t_1}$ and $A_{i,\ t_2}$ are the area percentages of the ith ranked LULC type in t_1 and t_2, respectively; n is the number of land use grades and $\Delta l_{t_2-t_1}$ is the degree of change in land use intensity over time. When $\Delta l_{t_2-t_1} > 0$, land use is said to expanding, and regressing if otherwise. Adapting Wang et al. (2010) and Di et al. (2015) gradation systems in which land use is divided into four classes based on the degree of human disturbances of the land cover and ease of change to the natural equilibrium state, we attached a grade value of 1 to bare land; forest, grassland, shrubland, wetland and water bodies are attached a value of 2; cultivated land was given a value of 3 and built-up land was graded as 4.

The binary logistic regression (BLR) model was used to examine the determinants of LULC change with focus on the probability that a given location transited to cultivated land use relative to other land use options as a function of the hypothesised independent variables in Table 1. The dependent variable Y for the BLR takes a value of 1 if a given location j was converted to cultivated land use from 2000 to 2010 and 0 if otherwise. The BLR model is specified as:

$$\ln\left(\frac{p_j}{1-p_j}\right) = \beta_0+\beta_1X_{1,j}+\ldots+\beta_mX_{m,j}+\varepsilon, \tag{4}$$

where p_j is $\Pr(Y_j = 1 \quad X_j)$, i.e. the probability that Y takes a value of 1 conditioned on a vector of independent variables $X_{1,j}\ldots\ \ldots\ \ldots\ .\ .X_{m,j}$; βs are the model parameters to be estimated; ε is the residual; $\frac{p_j}{1-p_j}$ is referred to as the odds ratio and $\ln\left(\frac{P_j}{1-P_j}\right)$ is the logs of the odds ratios or 'logit'. The estimated probability $\hat{p}_j$ after the inverse transformation is expressed as:

$$\hat{p}_j = \frac{1}{1+\exp^{-\left(\hat{\beta}_0+\hat{\beta}_1X_{1,j}+\cdots+\hat{\beta}_mX_{m,j}\right)}}. \tag{5}$$

The predictors were checked for collinearity using the variance inflation factor (VIF). Each predictor was linearly regressed against the others, and a VIF (computed as: $1/1 - R^2$) of <10 was taken as the standard for removing collinear variables (Ozdemir 2011). The continuous predictors were also standardized to have a mean of zero and a unit standardization as these have been found to help improve computational efficiency (Dong-ku 2011) and interpretability of regression coefficients (Schielzeth 2010). The odds ratio (computed as the exponential of the estimated βs) quantifies the effect on the dependent variable if the independent variable is increased by one unit in the case of continuous variables or if the independent variable belongs to a category other than the reference category for categorical variables. Odds ratio varies from 0 to infinity; an odds ratio >1 indicates a positive effect, a ratio <1 indicates a negative effect and a value of 1 indicates that the predictor variable has no effect on the dependent variable. The model accuracy was assessed using the relative operating characteristics (ROC) which evaluates the predicted probabilities by comparing them with the observed values (Verburg et al. 2002) and ranges from 0.5, for a model that assigns probabilities at random, to 1 for a model that perfectly assigns the probability of land use change. ROC above 0.5 is considered to be statistically better than random. The logistic regression analysis was carried out at a resolution of 250 m due the large spatial extent of our study area, which makes the data extraction and statistical analysis more expensive.

Table 1 List of independent variables used in binary logistic regression modelling

Variables	Description	Unit	Minimum	Maximum	Mean	Stand. dev.
Biophysical variables						
Landform	Physiography					
	1: Plains[a]					
	2: Lowlands		–	–	–	–
	3: Plateaus	NA				
	4: Hills					
	5: Mountains					
AEZs	Agro-ecological zones (AEZs)					
	1: Arid					
	2: Dry semi-arid					
	3: Moist semi-arid	NA	–	–	–	–
	4: Sub-humid					
	5: Humid					
	6: Highly humid[a]					
Elevation	Digital elevation model (DEM)	m	−5	2346	331.71	221.30
Slope	Slope gradient derived from DEM	°C	0	49.25	1.82	2.98
Soil pH	pH values of soil.	NA	4.4	8.4	6.05	0.37
Soil depth	Depth of soil	cm	37	175	145.46	22.73
Mean annual temperature	Average mean temperature 2000–2010	°C	16.72	29.96	27.29	1.16
Mean annual rainfall	Average annual rainfall 2000–2010	mm	15.26	254.96	94.57	37.27
Socio-economic variables						
Population density	Change in population density 2000–2010	Persons/km^2	8.54	710.01	38.85	48.75
GDP per capita	Change in GDP per capita 2000–2010	US$	60.15	1609.12	418.80	352.10
Proximity variables						
Distance to city	Euclidean distance of each pixel to the closest major city	km	0	266.77	84.89	46.70
Distance to road	Euclidean distance of each pixel to the closest major road.	km	0	99.98	15.78	15.60
Distance to water	Euclidean distance of each pixel to the closest permanent water body	km	0	214.82	39.56	30.85

NA not applicable

[a] Reference category

Results

LULC change

The results of the direction, magnitude and rate of LULC change in Nigeria from 2000 to 2010 are presented in Table 2, and Online Resource 6 shows the spatial distribution of the change. From 2000 to 2010, cultivated land has a stable part of 19,203,641 ha, representing about 65.8% of the total area it occupied in 2010. The decreased part is 5,278,978 ha and the increased part is 9,968,227 ha, respectively, accounting for 18.1 and 34.2% of its total area in 2010. The increased part is 16.1% higher than the decreased part, indicating that cultivated land increased significantly during the study period, as equally evidenced by its increasing rate of 4.1% as against the decreasing rate of 2.2%. As for forests, the stable and decreased and increased parts accounted for about 80.5% (16,636,872 ha), 30.1% (6,217,676 ha) and 19.5% (4,024,052 ha) of its area in 2010, respectively. The decreased part being about 10.6% higher than the increased part signifies a remarkable reduction in forest cover as evidenced by its decreasing rate of 2.7% as against a 1.8% rate of increase. Grassland has a stable part of 21,249,067 ha, making up 68.6% of the total area it occupied in 2010. The decreased part is 11,991,735 ha, representing 38.7% of its total area in 2010, and its increased part is 9,721,590 ha, 31.4% of the total area accordingly. The decreased part is 7.3% higher than the increased part, which indicates that the net grassland area is decreasing.

With respect to shrubland, the decreased and increased parts are 4,602,820 and 4,656,035 ha, respectively, representing 54.6 and 55.2% of its total area in 2010,

Table 2 Direction, magnitude and rate of LULC change from 2000 to 2010

	Cultivated land	Forests	Grassland	Shrubland	Wetland	Water bodies	Built-up land	Bare land
LULC transition matrix (areas in hectare)								
Cultivated land	*19,203,641*	497,069	3,433,808	1,141,475	7226	12,700	78,527	108,172
Forests	1,395,608	*16,636,872*	3,342,151	1,281,250	102,711	31,343	35,971	28,643
Grassland	6,852,087	2,431,593	*21,249,067*	2,092,298	42,710	27,339	79,512	466,197
Shrubland	1,428,849	914,612	2,157,548	*3,779,415*	21,755	15,190	16,118	48,747
Wetland	7632	91,251	112,137	36,737	*1,228,493*	60,881	906	2584
Water bodies	27,732	47,813	66,246	28,984	106,240	*666,482*	717	32,929
Built-up land	35,084	20,950	34,980	14,003	935	654	*648,188*	3486
Bare land	221,235	20,763	574,720	61,288	13,024	17,080	3973	*423,911*
Magnitude of LULC change (areas in hectare)								
Decreased part	5,278,978	6,217,676	11,991,735	4,602,820	312,129	310,661	110,091	912,083
Increased part	9,968,227	4,024,052	9,721,590	4,656,035	294,601	165,187	215,723	690,758
Annual rate of LULC change (%)								
Decreasing rate	2.2	2.7	3.6	5.5	2.0	3.2	1.5	6.8
Increasing rate	4.1	1.8	2.9	5.6	1.9	1.7	2.8	5.2
Changing rate	6.3	4.5	6.5	11.1	3.9	4.9	4.3	12.0
LULC total area (ha)								
2000	24,482,619	22,854,548	33,240,801	8,382,236	1,540,622	977,144	758,280	1,335,994
2010	29,171,868	20,660,924	30,970,657	8,435,450	1,523,094	831,669	863,912	1,114,669

The diagonal values (in italics) represent the area of each LULC class that remained stable from 2000 to 2010 while the off-diagonal values represent the change area. The values along the row cells show the area converted from a particular LULC type *i* to other non-*i*th types and the sum gives the decreased part while those of the column cells indicate the area gained to the *i*th type of LULC from the non-*i*th types and the sum gives the increased part.

respectively. The stable part is 3,779,415 ha and accounts for less than half (44.8%) of its total area in 2010. The stable part of wetland is 1,228,293 ha, representing 80.7% of its total area in 2010. The decreased part, representing about 20.5% of its total area in 2010, is higher than the increased part, which accounts for 19.3% of the total area it occupied in 2010. This indicates that the net wetland area is decreasing. Water bodies land area decreased at a rate of 3.2% and its increasing rate was 1.7%, which shows a decreasing trend of water body land area. From 2000 to 2010, the water bodies land area had a net decrease of 145,475 ha.

As far as built-up land is concerned, the stable part is 648,188 ha, occupying 75% of its total area in 2010. The decreased and increased parts are 110,091 and 215,723 ha, respectively, making up 12.7 and 25.0% of the total area in 2010, respectively. The increased part is 12.3% higher than the decreased part, indicating that the net built-up land area is increasing. The stable part of bare land is 423,911 ha, representing only about 38% of the total area it occupied in 2010. The decreased and increased parts constituting about 81.8% (912,083 ha) and 62% (690,758 ha) of the total area in 2010, respectively, showed a decreasing trend of the bare land from 2000 to 2010.

The transition matrix revealed that land cover transformations significantly took place between cultivated land, forests, grassland and shrubland. Cultivated land was mainly converted to grassland, shrubland and forests with the area lost to them being 3,433,808 ha, 1,141,475 ha and 497,069 ha, respectively. In a similar vein, increment to cultivated land comes largely from grassland (6,852,087 ha), shrubland (1,428,849 ha) and forests (1,395,608 ha) conversions. These transformations between cultivated land and the LULC types of grassland, shrubland and forests showed net losses of 3,418,279, 287,374 and 898,539 ha, respectively, to grassland, shrubland and forests.

Driving factors of cultivated land use change

The result of the multicollinearity diagnostics indicates that the BLR model predictors are not highly correlated. Hence, they were all retained in the regression analysis and their maximum likelihood estimates are presented in Table 3. The table shows that the value of the area under the ROC curve (AUC) is greater than 0.70, which indicates a good explanatory power of the selected variables in explaining cultivated land expansion. The BLR model predicted that, as against the plain terrain, conversions to cultivated land use are 1.2 times more likely on the lowlands but 0.6, 0.5 and 0.2 times less likely on the plateaus, hills and mountains, respectively. Cultivated land expansion is one to three times more likely to occur in other AEZs compared to the highly humid zone (AEZ 6 in Online Resource 5). An increase in elevation by 1 standard deviation (that is 221 m) increased the odds of cultivated land expansion by only 1%, and the likelihood of conversions to cultivated land use decreased by 14% for every degree rise in slope. Conversions to cultivated land use are more likely with an increase in soil pH and depth. The odds of cultivated land expansion increased by 28% for every unit increase in the soil pH, reflecting the suitability of less acidic soils for farming purposes, and by 45% for every 23 cm increase in the depth of the soil. Annual mean temperature rise by 1.2 °C, and an increase in mean annual rainfall by 37 mm decreased the likelihood of cultivated land expansion by 32 and 21%, respectively.

In contrast to our expectation, the model predicts an inverse relationship between cultivated land expansion and population density. The likelihood of conversions to cultivated land use decreased by 7% for an increase in the number of persons per square kilometre by 49 people. GDP per capita (used as a proxy for income) also showed a negative relationship with cultivated land expansion. A US$352 increase in GDP per capita decreased the odds of transition to cultivated land use by 8%. Conversions to cultivated land use are more likely farther away from the cities and water bodies but closer to roads. The odds of cultivated land expansion decreased by 4 and 10% for every 47 and 31 km increase in distance to cities and water bodies, respectively, and increased by 6% for every 16 km increase in the distance to roads.

Land use intensity change

Figure 2 presents the results of the land use intensity comprehensive index and its temporal change. The value of I for the country as a whole was 226.36 and 231.83 in 2000 and 2010, respectively. The positive ΔI of 5.47 indicates that land use is expanding at the national level. Comparison of the I and ΔI for the administrative states revealed significant regional discrepancies. The majority of the states in the northern region have I of above 220 in both 2000 and 2010 except for Borno with an index of less than 220 in 2000 and Sokoto, Kwara and Kogi having indexes below 220 in both 2000 and 2010. On the contrary, I in both 2000 and 2010 is below 220 for the majority of the southern states except for Anambra, Ebonyi and Lagos states. I, was largest for the northern states of Kano in 2000 (277.85) and Katsina in 2010 (281.41) and lowest for Bayelsa state in both 2000 (201.20) and 2010 (201.07) in the southern region. Land use intensity increased from 2000 to 2010 for all the northern states with the exception of Taraba where land use tends to be regressing. Whereas, there is a decrease in the degree of human disturbances on the land ecosystem in the southern region as evidenced from the negative ΔI for majority of the states, with the exception of Abia, Ebonyi, Edo, Enugu and Lagos (with only a very slight increase) states.

Table 3 Maximum likelihood estimates of the binary logistic regression model for cultivated land expansion (2000–2010)

Variables	Coefficient (β)	Std. error (β)	Odds ratio
Landform: lowlands	0.166	0.006	1.180
Landform: plateaus	−0.485	0.004	0.616
Landform: hills	0.729	0.013	0.482
Landform: mountains	−1.765	0.014	0.171
AEZs: arid	0.832	0.022	2.299
AEZs: dry semi-arid	0.720	0.016	2.055
AEZs: moist semi-arid	1.193	0.015	3.297
AEZs: sub-humid	0.977	0.013	2.656
AEZs: humid	0.134	0.011	1.144
Elevation	0.010	0.004	1.010
Slope	−0.552	0.003	0.576
Soil pH	0.100	0.002	1.105
Soil depth	0.373	0.001	1.452
Mean annual temperature	−0.386	0.003	0.680
Mean annual rainfall	−0.241	0.003	0.786
Population density	−0.067	0.002	0.935
GDP per capita	−0.080	0.002	0.923
Distance to city	0.034	0.001	1.035
Distance to road	−0.064	0.001	0.938
Distance to water	0.092	0.001	1.096
Constant	−1.544	0.013	0.214
N = 4,695,406			
AUC = 0.71			

All variables are statistically significant at $p < 0.01$

N number of observations, *AUC* area under the ROC curve

Discussion

Agricultural expansion involving intensive clearing of the natural vegetation as a major cause of LULC change in Africa is no exception in Nigeria as evident from previous studies and corroborated by the present study. The net magnitude of LULC change in our study shows that cultivated land area increased considerably at the rate of 4689 km^2 per year (about 1.61% of its total area in 2010). The expansion largely involved conversions of the forests, grassland and shrubland, which in total, decreased at a rate of 4411 km^2 per year. In contrast, the most recent study of LULC change from 2001 to 2009 (Abubakar 2015) obtained a considerably higher results. LULC change estimates from the study indicated that farmland expanded at an annualized rate of 12,995 km^2, while the forests and savannas (equivalent to our forests, grassland and shrubland) decreased at a rate of 13,308 km^2 per annum. Our magnitude of LULC change is not directly comparable with that of Abubakar (2015) due to reasons such as differences in resolution of the datasets (Abubakar 2015 used MODIS data with a resolution of 250 m), image acquisition date and the number of study period. Nevertheless, our

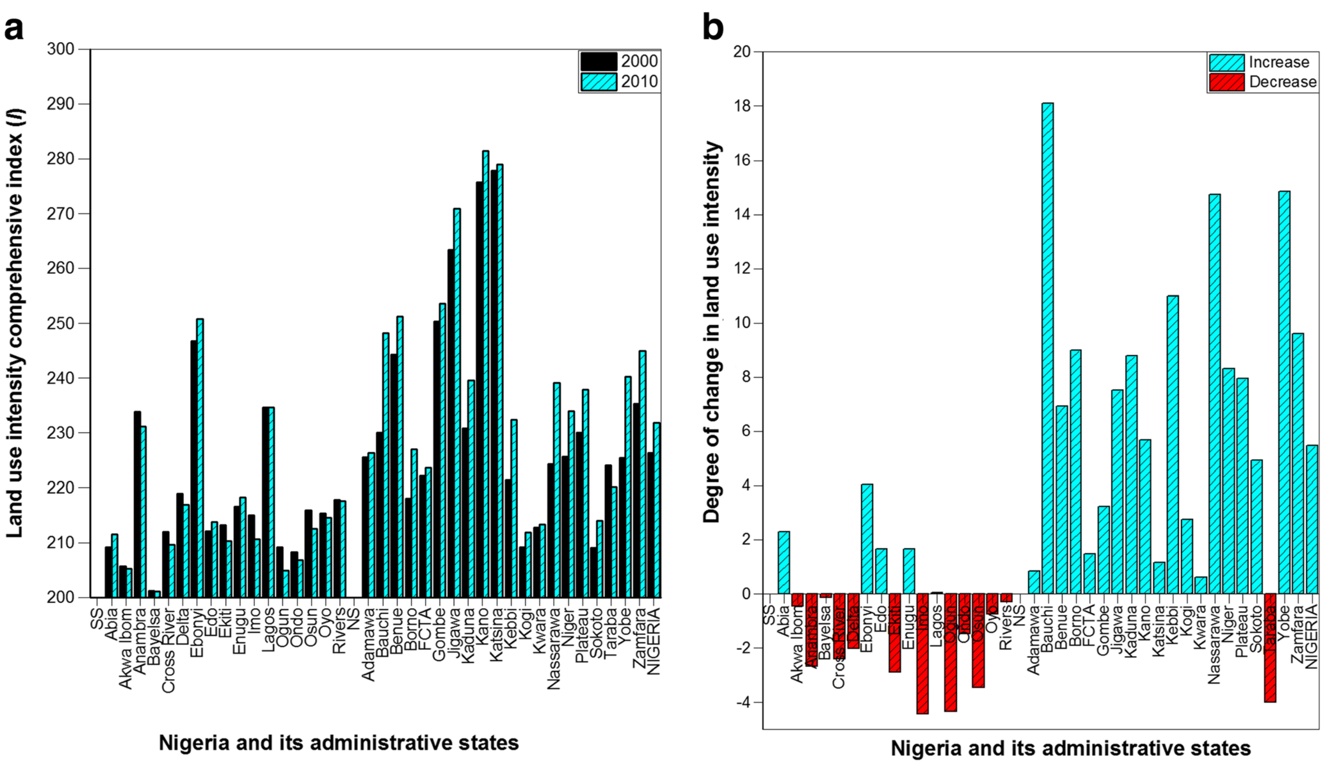

Fig. 2 **a** Temporal land use intensity comprehensive index (*I*). **b** Degree of change in intensity of land use (Δ*I*) from 2000 to 2010. *SS* southern states, *NS* northern states, *FCTA* Federal Capital Territory Abuja

observed dominant pattern of LULC change (i.e. expansion of cultivated land area at the expense of the forests and non-forests vegetation) corroborates the findings of Abubakar (2015) as well as those of earlier studies (Abbas 2009; World Bank 1998).

While artificial surfaces are very unlikely to change once established (Harper and Stein 2006), it was found that 1101 km^2 of built-up land changed to other LULC types. This instability on one hand could be due to some misclassification of the LULC types. On the other hand, several cases of demolition due to crisis and government land reclamation (AAAS 2011) as well as collapse of buildings as a result of rain storm, faulty construction, structural degeneration among others (Ayininuola and Olalusi 2004; Fakere 2005; Oke 2009; Ebehikhalu and Dawam 2014) have been reported in Nigeria. A significant proportion of these occurrences took place during our study period. Using satellite images, AAAS (2011) estimated that between 2008 and 2010, about 375 structures were removed from the Njemanze waterfront in Port Harcourt, following the redevelopment plan of the Rivers State government. AAAS (2011) also reported that the conflict in the Niger Delta region of Nigeria led to the destruction of more than 250 structures between 2009 and 2010. The conversions of built-up land into other LULC types have similarly been observed by previous local scale LULC change studies. Shuaibu et al. (2014) analysed LULC change in Bauchi, northeastern Nigeria, from 1994 to 2014 and found that 126 ha of built-up land area changed to farmland. Also, AC-Chukwuocha (2015) assessed LULC change between1977 and 2012 in Owerri, southeastern Nigeria, and found that 74.68 ha of built-up land area converted to other LULC types mainly farmland, vegetation and bare surfaces.

This present study has examined the determinants of land changes to agricultural uses and the spatiotemporal intensity of land use. Our BLR result showed that both biophysical and human factors drive cultivated land expansion in Nigeria. The BLR model predicts a higher likelihood of cultivated land expansion on lowlands and with decreasing slope, which reflects the suitability of flat areas for agricultural purposes, and it corroborates the findings of Hatna and Bakker (2011). Over the years, the mean temperature in Nigeria has been rising at a significant rate (Odjugo 2010). The trend between 1971 and 2005 showed a decadal increase of 0.4 °C (Bello et al. 2012); a warming rate evidently higher than the global rate of 0.74 °C that was recorded since temperature measurement commenced in 1860 (IPCC 2007; Spore 2008). Irregularity in rainfall pattern is also evident in Nigeria with increasing rainfalls in the majority of the coastal areas and decreasing rains in the continental interiors of the semi-arid region (Umoh 2007; Odjugo 2009). Although an increase in temperature will increase the yields of some crops, most crops are negatively affected by rising temperature. Likewise, excessive rainfall increases the risk of floods and crops susceptibility to various diseases. The effect of temperature rise and excessive rainfall on crop production is evident from our model's prediction of less likelihood of land conversions to agricultural use with increasing mean annual temperature and rainfall. A persistent increase in rainfall (induced by climate change) in the coastal areas (which falls to the highly humid zone, AEZ 6 in Online Resource 5) has resulted to floods (Nwafor 2007; Odjugo 2010), badly leached soils and severe erosion (Aregheore 2009). This poses serious threat to agricultural production and hence less likelihood of these areas transiting into cultivated land use as predicted by the BLR model.

The magnitude of effect of a meter increase in elevation on the likelihood of conversions to cultivated land use is relatively small and nearly negligible (0.005%), which further emphasized the suitability of low areas for agricultural purposes. However, the positive relationship between cultivated land expansion and elevation suggests the expansion of agriculture into high areas in the long run. This finding is similar to those observed in the Koshi River basin (KRB) of Nepal (Paudel et al. 2016), in the SNNPR of Ethiopia (Girma and Hassan 2014) and by Braimoh and Vlek (2004) in the Volta basin of Ghana who noted that this could exacerbate erosion problems. In contrast to the statistical findings from previous researches in other regions of the world that population density is a major cause of land conversions to agriculture (Girma and Hassan 2014 for the SNNPR of Ethiopia; Paudel et al. 2016 for the KRB of Nepal), population density is negatively related to cultivated land expansion from our statistical analysis. However, Braimoh and Vlek (2004) in their assessment of the determinants of cropland change in the Volta basin of Ghana found that the direction of effect of population density on cropland change varies with scale and over time. The observed negative relationship between population density and cultivated land expansion in our study suggests either labour scarcity in the agricultural sector or the substitution of labour for other inputs. However, scarcity of labour is evident in Nigeria's agricultural sector. Several constraints (such as climate warming, insecure land tenure, lack of access to credit, poor funding, heavy dependence on rain fed agriculture, poor irrigation facilities among others) militating against the sector have resulted in a decline in agricultural output and ultimately farmers switching to other sectors of the economy (Apata et al. 2010; Bello et al. 2012; Ladan 2014; Uma et al. 2014). Given these constraints, people find agriculture unattractive and, hence, opt for livelihoods in the metropolitan areas (Uma et al. 2014; Nwajiuba 2013), leading to scarcity of labour in the rural sector.

The negative relationship between cultivated land expansion and GDP per capita (used as a proxy for income) indicates a general tendency of farmers migrating to the cities to work in response to higher urban wages, resulting into less land conversions to agricultural use. The smaller likelihood of conversions to cultivated land use with rising income could also suggest investment in other activities with higher land productivity. The impact of urbanization on LULC change is evident from our statistical analysis through the positive effect of distance to cities on cultivated land expansion, which reflects the availability of new agricultural land areas in places remote from the city. The negative relationship between cultivated land expansion and distance to roads demonstrated the importance of road infrastructure on agricultural development. The availability of good transportation network aids the marketing of farm produce and stimulates economic growth (Tunde and Adeniyi 2012). The observed positive relationship between cultivated land expansion and distance to water is consistent with findings of farmers' reluctance to cultivate near permanent water bodies due to increased risks of flood damage, mosquitoes and waterborne diseases from a participatory rural appraisal in southeastern Nigeria (Gobin et al. 2002).

The result of the degree of change in land use intensity shows that human activities on the land ecosystem were more amplified in the northern region of the country during the study period and that most of the land cover transformations were from the natural ecosystems of forests, grassland and shrubland to more intensive uses of agriculture and urban. This is supported by the findings of local case LULC change studies (e.g. Ejaro and Abdullahi 2013; Suleiman et al. 2014) conducted within the region. The estimates of LULC change around our study period from these studies showed a significant increase in the artificial ecosystems (i.e. built-up land and farmland), which involves large reduction of the vegetation cover.

Conclusion

This study examined LULC change, determinants of transition to cultivated land use as well as temporal and regional variation in the intensity of land use in Nigeria from 2000 to 2010. Conversions to cultivated land use dominated the LULC change processes during the study period. Cultivated land expanded significantly by about 5% of the total area of the country, largely at the expense of grassland, shrubland and forests. The expansion was found to be driven by biophysical, socio-economic and accessibility factors. The factors that positively influence cultivated land expansion include lowland landform, agro-ecological zones, elevation, soil PH, soil depth as well as distance to cities and water, while plateaus, hill and mountain landforms, slope, mean annual temperature and rainfall, population density, GDP per capita and distance to road variables have negative effects. The intensity of land use varies significantly between the southern and northern regions. The degree of change in land use intensity indicates that most of the land conversions to agricultural uses occurred in the northern region. The negative relationship between population density and cultivated land expansion suggests scarcity of labour in the agricultural sector which could be attributed to the constraints to agriculture in Nigeria. Shortage in farm labour supply results in low farm productivity, and this could partly explain why expansion of cultivated land has not translated to enhanced food security among the citizens of the country. Climate adaptation measures, improvement of the agricultural sector through increased funding, more secure land access to improve farmers' access to credit, provision of irrigation facilities, access to farm inputs etc., which will help bring in more labour into the agricultural sector and improve agricultural productivity, are necessary. Measures aimed at improving agricultural productivity remain one of the best ways to reduce pressure on increasingly scarce land resources and conserve natural ecosystems in Nigeria.

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