

Toward achieving a sustainable management: characterization of land use/land cover in Sokoto Rima floodplain, Nigeria

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Received: 25 December 2014 / Accepted: 20 June 2016 / Published online: 30 June 2016
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Abstract Land use change is the main driving force of global environmental change and is considered as very central to the ongoing debate on sustainable development. Even though large volume of literature materials is available of land use/land cover (LU/LC) change for many areas, very little is known of it in the floodplain of the Sokoto Rima River Basin of Nigeria despite the basin's strategic importance. Thus, this study characterized the basin's LU/LC and its change using computer-based digital classification of near-anniversary Landsat 5 TM imagery of November 23, 1998, and Landsat 8 OLI of December 2, 2013. The results of the digital classification were complimented with field-based observations on major observable characteristics of every LU/LC identified. Thirteen classes (forest area, dense grassland, grassy fallow, grazed open grassland, open cultivation, open grain fallow farmland, pepper cultivation, rice farmland, scrubland, sugarcane farmland, dry bare land, sand deposit and wetland/water) were characterized and the nature and extent of their changes assessed. 40 % of the basin's uses is under cultivation, 22 % is under fallow, 27 % is either degraded or non-cultivable, while 11 % is forested. Change events include forest loss, increase in area cultivated, expansion of shrub/scrubland and pervasiveness of grazing. The changes were more pronounced in the upper than either the central and southern segments of the basin. In general LU/LC changes in the basin are reflection of increased human population pressure and effects of climate change. The LU/LC patterns and changes suggest underutilization and mismanagement of the floodplain which have impact on soil, hydrology and biodiversity with serious implication for livelihood and food security. The study recommends that interventions are needed to promote enhanced and sustainable management of land, water and vegetation resources in the basin, with

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particular emphasis on empowering the local land users to participate actively toward sustainable management of the floodplain.

Keywords Land · Use · Cover · Characterization · Sustainable · Management · Sokoto Rima · River Basin

1 Introduction

The current debate on sustainable development centers largely on understanding land use change (Shao et al. 2005), and to understand such a change the status of land use and land cover (LU/LC) needs to first be characterized. Where information is available on character of LU/LC, chances of taking appropriate steps toward achieving sustainable development becomes brighter.

Land use defines the human activities which are directly related to land, making use of its resources, or having an impact on them. In that context the emphasis is on the function or purpose for which the land is used (Meyer and Turner 1994; Turner II 1995; FAO 1997; Mather 1999). Land use may vary in nature and intensity according to the purpose it serves—whether it is food production, recreation, urban development, logging or mining, the biophysical characteristics of the land itself, technological level of the people as well as historical and existing government policies (Lambin et al. 2003). On the other hand, land cover refers to the observed physical and biological cover of the earth's land or immediately below it (as in soil), whether natural or man-made features (Meyer and Turner 1994; Turner et al. 1995; Mather 1999). Generally, while land use emphasizes on the socio-economic attributes of the land, land cover emphasizes particularly on the natural attributes of the soil.

LU/LC are linked to climate and other environmental changes in complex ways, such as the exchange of greenhouse gases between plants and soils and the atmosphere, the effects of changes in land use and land cover on Earth's heat balance and the impacts of changing environmental conditions on terrestrial ecosystems and biodiversity. Gaining a better understanding of the ways that land cover and land use practices are evolving is a priority concern of the global change research community. This is especially because the characteristics of land cover have important impacts on climate, biogeochemistry, hydrology, and the diversity and abundance of terrestrial species.

The growing pressure of population coupled with increasing variety of demands made on land resources has brought extra pressure on the available land resources all over the world. In order to use land optimally, it is necessary to have the information on existing land use/land cover. Conventional ground methods of land use mapping are labor intensive, time consuming and are done relatively infrequently. These maps soon become outdated with passage of time, particularly in a rapidly changing environment. In recent years, satellite remote sensing techniques have proved to be of immense value for preparing accurate land use/land cover maps. However, despite the role of this powerful technology in this regard, land use/land covers in many parts of earth's surface still remain to be identified and described. Thus, studies are required to regularly map different areas of the world so as to enable human kind have comprehensive and up-to-date information on global land use and land cover and their changes.

This study intends to contribute in this regard by employing remote sensing and field-based techniques to map out and characterize an economically and ecologically strategic area in Nigeria (Sokoto Rima Basin) for which, however, adequate information on land use

and land cover distribution and changes is not available. Though lying within the semi-arid part of Nigeria, the area has for over a century been supporting intensive dry season irrigation farming through which over half of the dry season fresh food demand (of especially vegetables) of the country is met (Yahaya 2002). Because of this strategic importance, the Federal Government of Nigeria established the Sokoto Rima Basin Development Authority (SRBDA) in 1979 to promote dry season agriculture so as to boost employment, food security, increase variety of crops, curtail annual dry season exodus of farmers and rural dwellers, as well as foster agro-allied industrial development, among others (Adeniyi 1993; Yahaya 2002; Ojo et al. 2009). The floodplain of the Basin is one of the most intensively cultivated areas in West Africa with potentially wide consequences on the area's land use and land cover characteristics (Swindell 1986; Iliya and Baba 2013).

2 Materials and methods

2.1 Study area

Sokoto Rima Basin is located in Sokoto State of Nigeria, covering an area within latitudes 13.04°–13.25°N and longitudes 5.1°–5.38°E (Fig. 1), stretching over 13,500 ha. While about 53 % of the landmass is agricultural land, 35 % is grassland, with forest and water bodies occupying about 2 and 1 %, respectively (Abdullahi et al. 2014).

The Rima Basin is an alluvial basin located in a relatively low lying area where high level of deposition is experienced (Ifabiyi and Eniolorunda 2012). The soils are generally clayey and hydromorphic, which are annually renewed by flooding (Adeniyi 1993).

It has a semi-arid climate with prolonged dry season (Adams 1986; Adeniyi 1993; Yelwa 2008). Rainfall is highly seasonal and controlled by the irregular movement of the inter-tropical discontinuity (ITD). Diurnal concentration of rain shows occurrence mainly in the afternoon and early morning. In some years, rainfall is evenly dispersed throughout, and in some others, it may occur irregularly but in large amounts, affecting runoff characteristics. Prior to late 1960s and early 1970s, the mean annual rainfall varied from about 700 mm in the northern part to about 1100 mm in the southern part of the basin (Adeniyi 1993). Today, annual rainfall stands around 600 mm, and indeed, the basin is one of the few areas fingered for having more acute climate change impact in Nigeria (Odjugo 2010).

The area experiences relatively high temperatures throughout the year. Long-term daily maximum temperature is about 36 °C. During the harmattan season, daily minimum temperature falls below 17 °C. Between February and April which is the peak of heat, temperature reaches its highest at 44 °C (Ifabiyi and Eniolorunda 2012). Although temperature is generally sufficient to allow plant growth, insufficient rainfall and high evapotranspiration during the dry season limit farming activities in Sokoto State to the Rima floodplain (Adeniyi 1993), which partly explains why more than half of the population of the state is concentrated on or very near the floodplain.

The vegetation of the area is the Sudano-Sahel Savannah type consisting of open woodland with scattered trees such as *Acacia*, *Parkia clappertoniana*, *Porassus* etc. Generally, the vegetation is mainly of short shrubs and grasses, with grasses measuring below 1 m. Bush burning and uncontrolled grazing are carried out everywhere in the basin, thereby contributing immensely to the degradation of the marginal vegetation. The increasing consumption of the natural vegetation for various domestic purposes aggravates the environmental degradation of the basin (Adeniyi 1993).

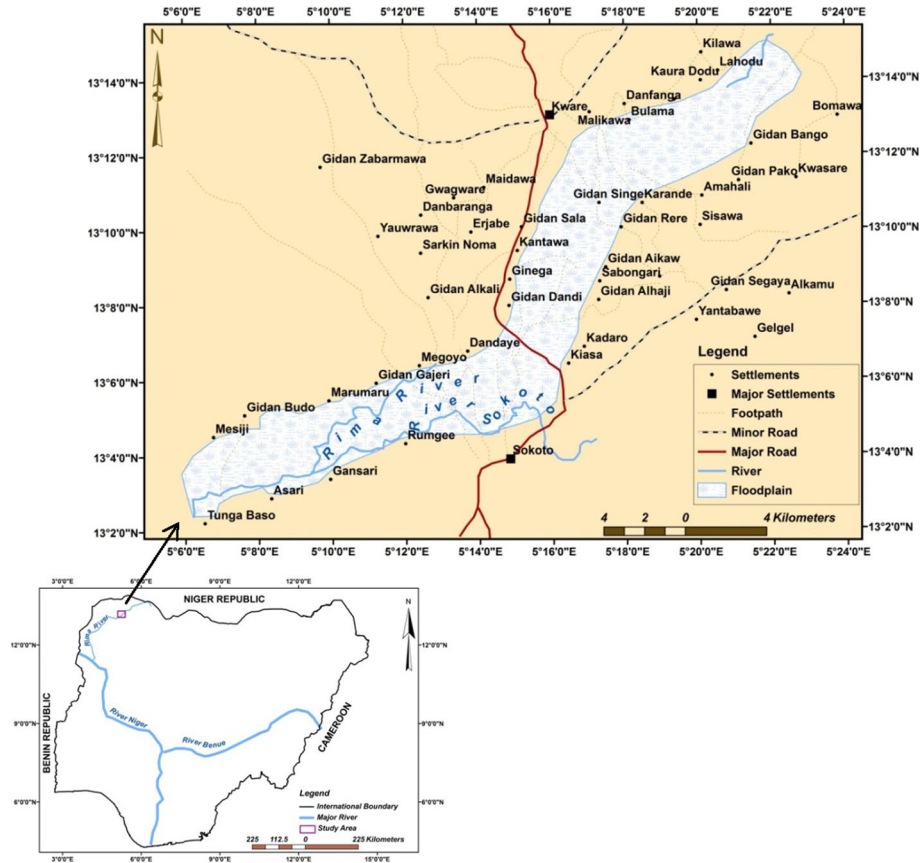


Fig. 1 The study area (upper part of Sokoto Rima River Basin)

The distribution of population within the Rima basin is uneven and variable in density, with high densities in the close-settled zone around Sokoto city. Availability of drinking water during the long dry season and high soil water retention which makes possible the extension of the growing season beyond the end of the rains explains why some 70 % of the population live within or near the river valleys (Adams 1986; Swindell 1986). Also significant is the historical fact that this Rima river basin became the core of the Sokoto caliphate in the nineteenth century which saw old settlements expanding and many new ones created, leading to the development of intensive cultivation in areas which formerly relied on bush-fallowing and herding (Swindell 1986). Settlement/population expansion and consequent intensification of cultivation engenders the production of food staples such as guinea corn, millet and rice together with commercial crops such as onions, cotton, henna and indigo which are produced to support not only the large rural population but also those who live in the towns. Agricultural intensification is also apparently a response to the economic opportunities of Sokoto City, the capital of the state (Swindell 1986). The floodplain is perennially cultivated with rice in the wet season and onions, tobacco and bananas in the dry season which require intensive inputs of labor. The superficial deposits of the floodplain soils are enriched with huge manure inputs from local herd dung kept in

the villages or from the direct droppings by the nomadic cattle that graze on the uncultivated fadama land areas, especially in the dry season.

Adeniyi (1993) stated that farm sizes are very small (estimated around 1 ha) as agriculture is mainly for subsistence. Land is under customary right of occupancy (CRO) title and may be transferred to other parties by sale or lease of the CRO. In general, farmers own the CROs to all the land they cultivate. Farms are fragmented into many plots, the effect of which, due to the growing population pressure, threatens agricultural productivity as farmlands are over-cultivated and soil fertility becomes reduced. Previously, the floodplain was cultivated during flood recession. But with the establishment of the Goronyo project in 1984, farming is now carried out all year round.

2.2 Data utilized

Near-anniversary Landsat 7 ETM+ of November 23, 1998, and Landsat 8 Operational Land Imager (OLI) of December 2, 2013, were selected for detailed LU/LC studies of the basin. The data correspond to path/row 191/051 in the active archive center of the United States Geological Survey (USGS), downloadable via glovis.usgs.gov. The data selected were cloud free and in Level 1T (precision and terrain corrected) format. A topographical map sheet of 1:100,000 covering the study area was obtained from the Federal Surveys Department Sokoto, from which settlements' locations and names and cultural features were extracted. Ground truth (GT) data for both image classification and classification accuracy assessment were selected from an unsupervised classification map derived from 2013 Landsat image using stratified random technique. As a rule of the thumb, $30 \times n$ (n = number of bands) were selected (Janssen and Gorte 2004).

2.3 Image pre-processing

2.3.1 Image geometric correction

Images acquired after the USGS opened the Landsat archive typically had sub-pixel geolocation accuracies and require no further geometric processing (Kennedy et al. 2010). However, for land use/land cover mapping, the 2013 Landsat image was geometrically corrected on the topographical map of the area within the ArcGIS 10.0 environment, taking ground control points (GCPs) at road intersections. The 1998 image was then referenced to that of 2013 with a root-mean-square (RMS) error of 0.245.

2.3.2 Image radiometric correction

Radiometric normalization is a critical procedure for multi-temporal remote sensing imagery classification and change detection. However, it is not always necessary when training data and the image to be classified are on the same relative scale (Chen and Rao 2008). Although the images of both dates were reported as cloud free, a simple haze removal by dark object subtraction was performed differently on each subset scene. For each band, the lowest value extracted from the histogram of the entire scene was used as the DN haze value (Eastman 2009). This method works on the assumption that haze effect is uniform across the whole scene (Eastman 2009).

2.4 LU/LC classification and change detection

An unsupervised classification was performed using ISODATA to produce ten classes from the reference image (2013). 406 GCPs were selected by stratified random sampling and were visited at an average of 10 GCPs per day in 42 visits performed between 23rd of October and 10th of December 2013. Based on the submission of Janssen and Gorte (2004), 180 GCPs required to classify 6 bands of each date were isolated for signatures extraction, while the remaining 226 were used for classification accuracy assessment. Image classification was performed using the maximum likelihood supervised method after Adeniyi (1993), Munyati (2000) and Eastman (2009).

Results of the classification for the two dates were compared to identify nature and pattern of LU/LC change of 1998–2013 period. To identify the main LU/LC changes that might have contributed to the net change in a particular LU/LC type, the area of each of the classes for both dates was estimated (in hectares) and compared in order to identify which of the various classes contributed negatively or positively to the net change in a specific LU/LC class.

2.5 Classification accuracy assessment

Out of the 406 GCPs visited, 180 were used for image classification, while the remaining 226 GCPs were tested against the 2013 LU/LC map for classification accuracy assessment. The error matrix was automatically generated within the Idrisi Taiga environment using the ground truth as the column data and 2013 LU/LC classes as row data. The overall KIA in this case is 0.8798 which when expressed as a whole number is 88 %. Also, the overall accuracy (OA) or proportion correctly classified which is a test of accuracy is expressed as the percentage of the diagonals (correctly classified pixels) in the entire sampled pixels. In this case, the OA is 89 % $((201 \times 100)/226)$, which is above the usual benchmark of 85 %.

3 Results

3.1 LU/LC classes

In the upstream of the Basin, land is highly fragmented at short distances such that two to three LU/LC types could be observed within a pixel. At Level I of the classification scheme of Anderson et al. (1976), there are four classes of LU/LC namely water, soil, agriculture and vegetation. At Level II, agriculture, vegetation and soil became diverse. Being mainly a floodplain where irrigation affords farmers all-the year round farming opportunity, activities such as crop harvesting, land clearing, land tilling, crop planting, irrigation, tree felling/cutting and grazing among others were observed in the course of the field work; bush burning was not common. This diversity of land-uses and the resultant land covers generated LU/LC complexity. Thus, and given the advantage of the medium resolution of the Landsat data, the LU/LC classification was carried out at Level III, with respect to land use practices and conditions of land cover. At first, 30 LU/LC classes were recognized. However, the pixel numbers of some of the classes did not meet up with the minimum requirement for signature extraction. Thus, classes were aggregated based on LU/LC similarity as recommended by Anderson et al. (1976). The 30 classes are: rice farmland, rice farmland with grazing, grazed open grassland, pepper cultivation, rice

farmland with shrubs, dry wetland, scrubland, wetland, millet with grass, rice/millet, maize harvested farmland, grassy fallow, open cultivation, dense grassy land, cleared land, cleared land/grazed, dry millet fallow, rice/millet harvested, onion cultivation, open sand/grazing corridor, open fallow millet, open fallow maize, grazing corridor, shrub land, burnt fallow, uncultivated grassland, sugarcane farm, wetland rice, forest and onion farmland.

The aggregation of the 30 classes yielded 13 classes which are: forest area (10.99 %), dense grassland (8.7 %), grassy fallow (8.54 %), grazed open grassland (3.58 %), open cultivation (14 %), open grain fallow farmland (1.57 %), pepper cultivation (3.86 %), rice farmland (9.73 %), shrub/scrubland (15.53 %), sugarcane farmland (5.99 %), dry bare land (2.41 %), sand deposit (2.7 %) and wetland/water (12.4 %). Among all, the Shrub/scrubland occupies 15 % has the highest coverage (15.53 %) of the area. The LU/LC maps of 1998 and 2013 are presented in Figs. 2 and 3 respectively. A close look at Figs. 2 and 3 gives an impression of similarity between both maps. It is evident that the patterns of LU/LC are different for both the upstream and downstream, differentiating the degrees of agricultural use of the floodplain.

It could also be observed from Figs. 2 and 3, and Table 1 that about 40 % of the floodplain is subjected to crop production (open cultivation, pepper farmland, rice farmland, sugarcane/orchard, part of wetland/water) mostly in the upstream and midstream, while about 11 % is forested. Some 22 % of the area is under fallow (dense grassland, grassy fallow, grazed open grassland, open grain fallow farmland) mostly in the downstream, while about 27 % is either degraded (shrub/scrubland, dry bar land, sand deposit) or non-cultivable (part of wetland) (Table 1). This distribution does not translate to non-disturbance of some classes that are not under cultivation.

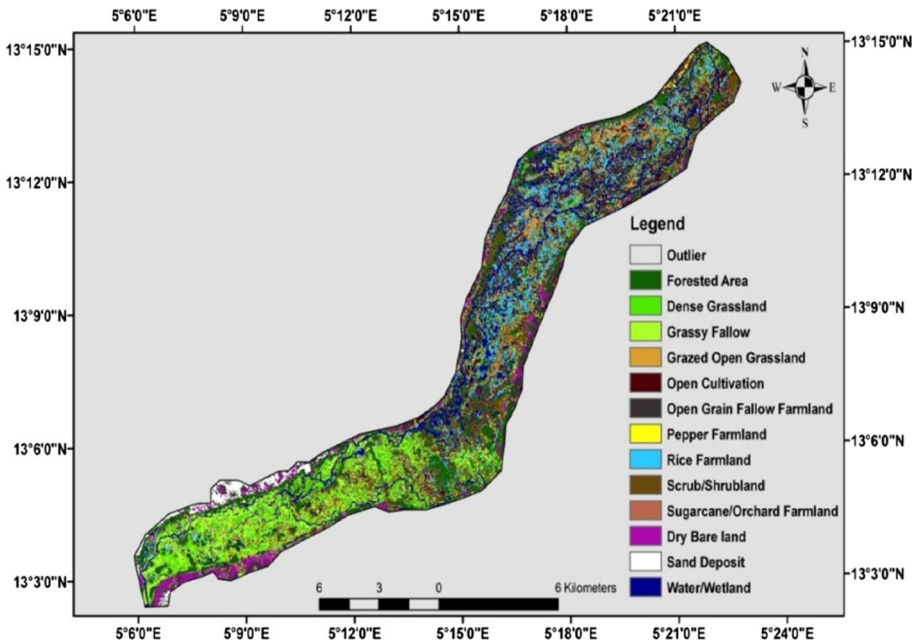


Fig. 2 Land use and land cover classes of 1998 over the study area

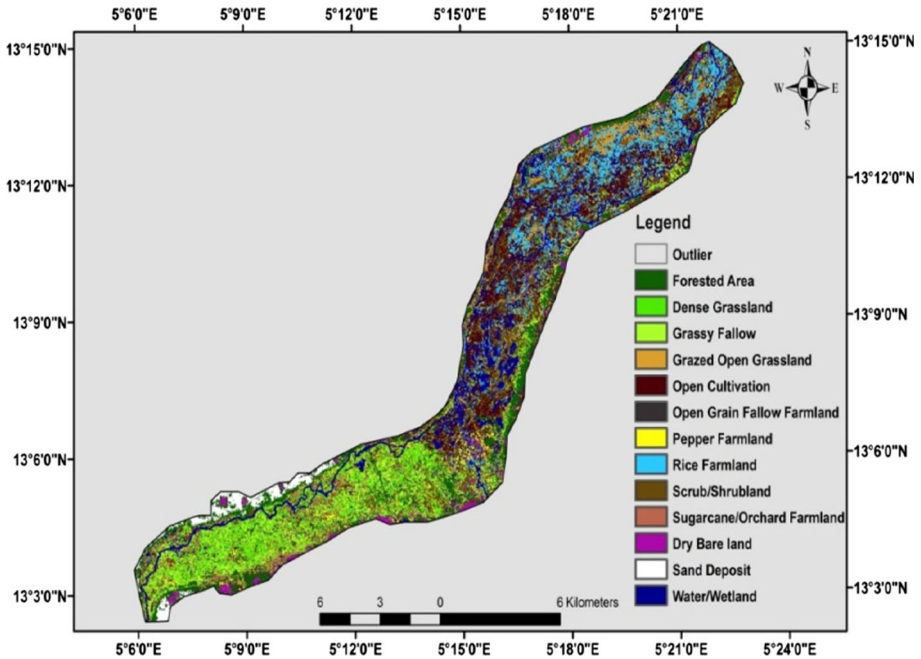


Fig. 3 Land use and land cover classes of 2013 over the study area

Table 1 Area estimates of the various LU/LC in Sokoto Rima Basin and pattern of their decrease or increase over 1998–2013

LU/LC	Area in 1998 (ha)	Area in 2013 (ha)	% in 1998	% in 2013	% Change	Pattern of change
Forest area	1771	1484	13.12	10.99	-16.20	↓
Dense grassland	1223	1174	9.06	8.70	-4.05	↓
Grassy fallow	1114	1153	8.25	8.54	3.47	↓
Grazed open grassland	537	483	3.98	3.58	-10.07	↑
Open cultivation	1475	1890	10.93	14.00	28.13	↑
Open grain fallow farmland	434	212	3.22	1.57	-51.12	↓
Pepper farmland	466	521	3.45	3.86	11.99	↑
Rice farmland	1489	1313	11.03	9.73	-11.84	↓
Scrub/shrubland	1931	2097	14.31	15.53	8.58	↑
Sugarcane/orchard farmland	360	809	2.67	5.99	124.86	↑
Dry bare land	731	325	5.41	2.41	-55.46	↓
Sand deposit	293	362	2.17	2.70	23.65	↑
Wetland/water	1676	1676	12.40	12.40	0.00	↔
Total	13,500	13,500	100	100		

↓ Decrease in land use/land cover; ↑ Increase in land use/land cover; ↔ No change in land use/land

3.2 Pathway of LU/LC change

Table 1 presents changes in LU/LC types between 1998 and 2013. Figures 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16, on the other hand, variously revealed the pathway of the LU/LC changes depicting the contributions of the change in the various land use/land cover to the observed change in a particular LU/LC type.

The LU/LC change statistics revealed that the forest class lost 287 ha (16.2 %) as a result of agricultural expansion (Fig. 4), while the dense grassland reduced by 4.07 % (50 ha) (Fig. 5). Much of this class was converted into sugarcane farmland in the latter year. The grassy fallow slightly increased in size by 39 ha (3.74 %) between the years (Fig. 6) due to both short-term fallowing and forest degradation, while the grazed open grassland lost 54 ha amounting to 10.07 % between both dates (Fig. 7). This suggests that the area was subjected more farming than grazing activities over the study period.

The open cultivation class expanded by 415 ha (28.13 %) between both dates, and major contributors were wetland/water, scrubland and forest (Fig. 8). Expansion of this class within the period was likely the consequence of increase in the demand for food crops. The open grain fallow farmland, on the other hand, lost 222 ha (51.12 %) largely due to long-term fallow and afforestation (Fig. 9). The pepper farmland expanded by 56 ha amounting to 11.99 % between 1998 and 2013. Major contributors to the increase were wetland/water, scrub/shrubland, rice farmland and forest.

Rice farmland class recorded a loss of 176 ha (11.84 %) between the years. About 122 ha of rice farmland turned scrubland, indicating long-term fallowing and abandonment of rice cultivation (Fig. 11). The scrubland class, on the other hand, expanded by 166 ha (8.58 %) over the study period, resulting mainly from long-term fallow of rice farmland and forest degradation (Fig. 12).

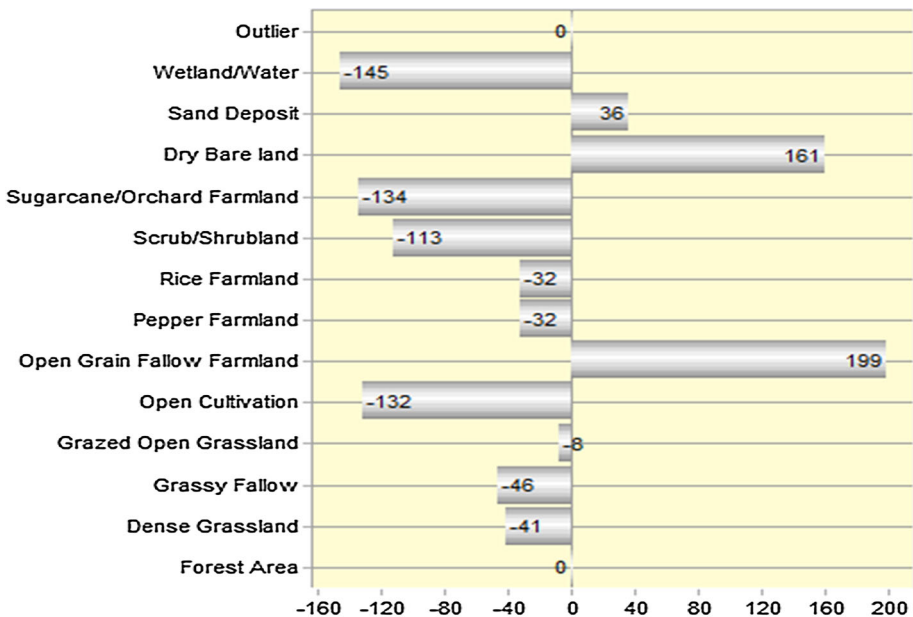


Fig. 4 Contributions to net change in forest (ha)

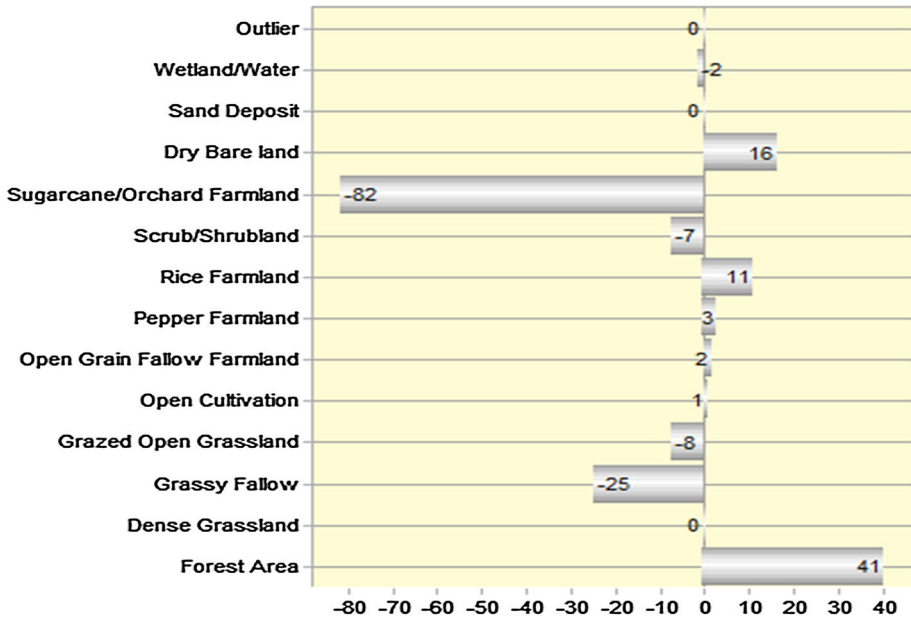


Fig. 5 Net change in dense grassland (ha)

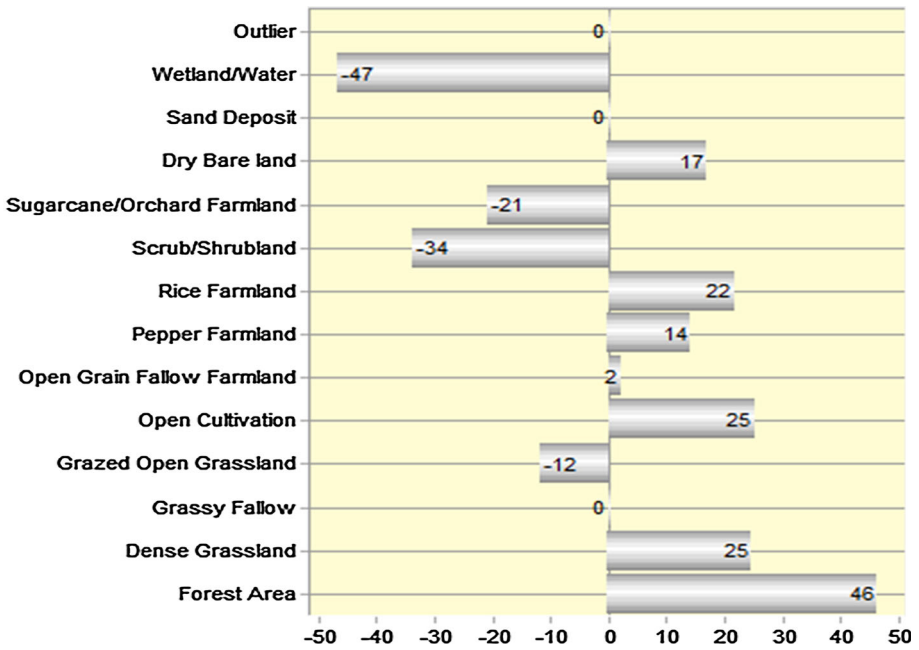


Fig. 6 Contributions to net change in grassy fallow (ha)

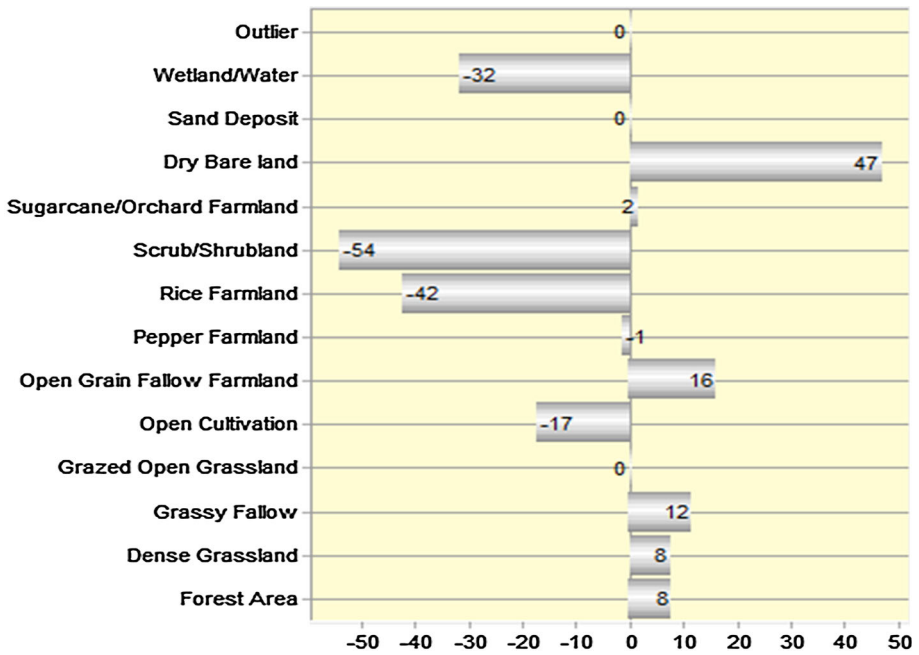


Fig. 7 Contributions to net change in grazed open grass (ha)

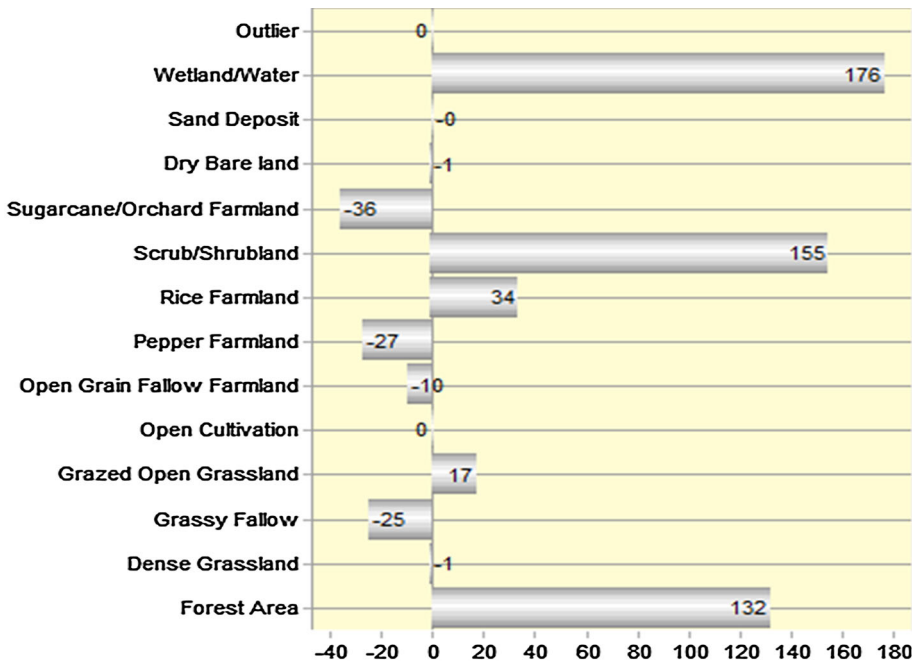


Fig. 8 Contributions to change in open cultivation (ha)

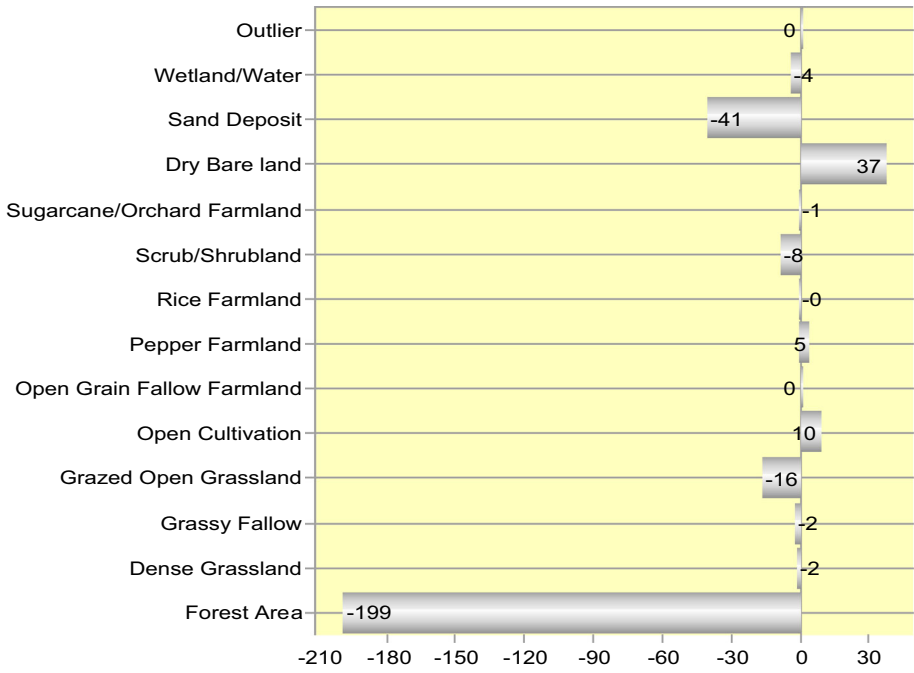


Fig. 9 Contributions to net change in open grain fallow farmland (ha)

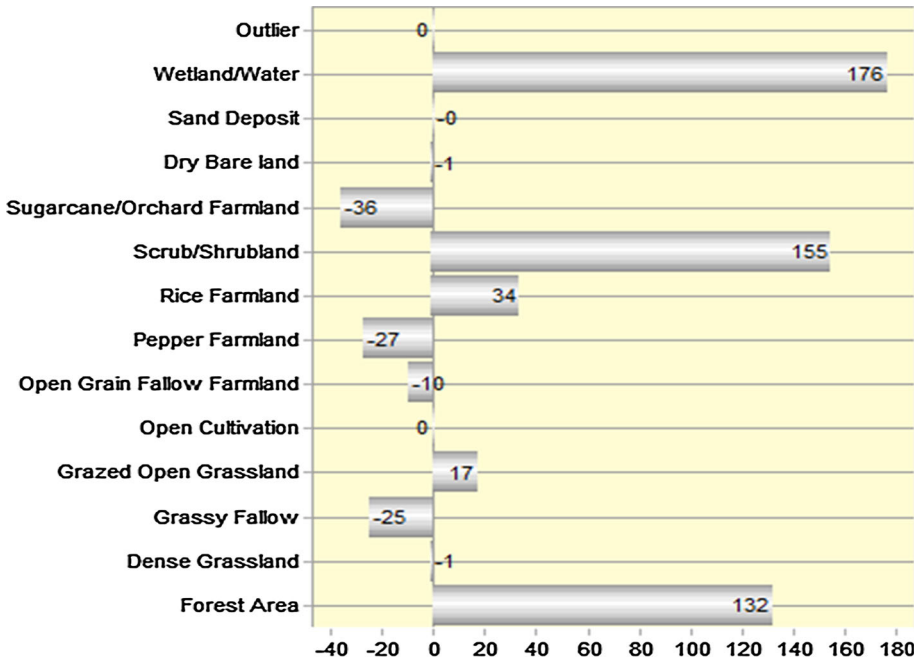


Fig. 10 Contributions to net change in pepper farmland (ha)

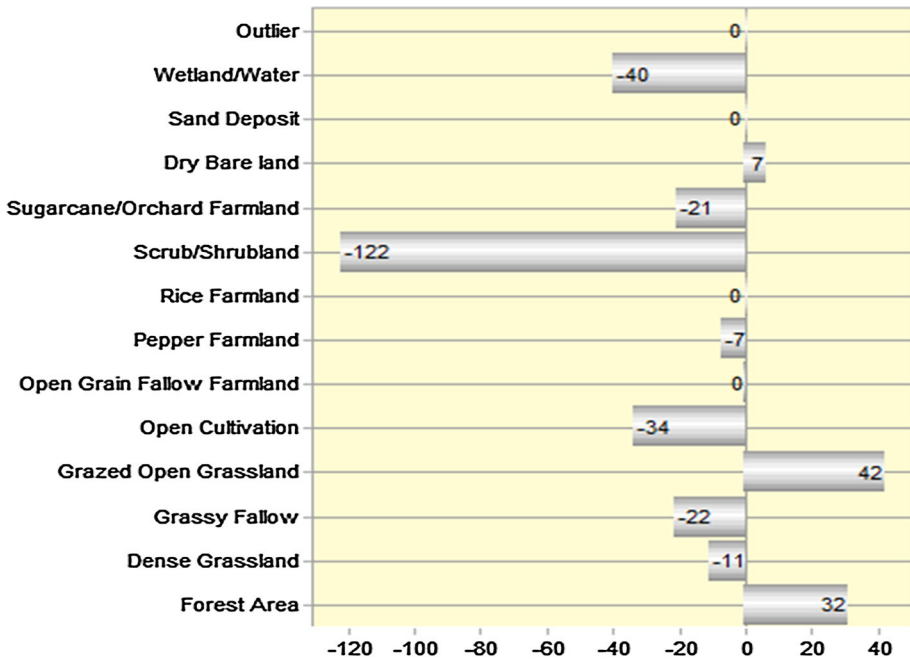


Fig. 11 Contributions to net change in rice farmland (ha)

Sugarcane farmland expanded by 449 ha (124.86 %). Being the class with the highest percentage change, it was the only class that benefitted from most classes, losing only 2 ha to grazed open grassland and gaining nothing from sand deposit (Fig. 13). Most of the contributors to the net expansion of the sugarcane farmland were forest (134 ha), dense grassland (82 ha), wetland/water (73 ha) and scrubland (57 ha). Expansion of this class was likely a response to an increase in the demand due to population increase. The dry bare land on the other hand lost 405 ha (55.46 %) between both dates largely due to long-term fallowing and afforestation. The sand deposit expanded by 69 ha (23.65 %) due to intensive use of land and unsustainable agricultural practices upslope, while wetland/water recorded no change (Table 1), although spatial variation in the class occurred between both dates where the class covered more area upstream than it did in the downstream (Fig. 16).

3.3 Population pressure and land use change

Records from the National Population Commission of Nigeria indicate that as at the first ever census conducted in Nigeria (in 1963), communities that constitute Sokoto state had 463,816 people of which 34 % (157,679) reside within the Sokoto Rima floodplain. The population density as at 1963 was 74.5 persons/Km². By 1976, the population figure of the state rose to 941,253 of which 43 % (404,738) reside within the floodplain. As at 1976 census, population pressure on the floodplain was 86.4 persons/Km². During the 1991 census, the population of the state increased to 2,397,000 with those in the floodplain estimated at 51 % (1,222,470), while the population density stood at 94.2 persons/Km². During the latest census exercise conducted in 2006, the population of the state stood at 3,702,676 of which 56 % (2,073,498) reside within the floodplain, while the population

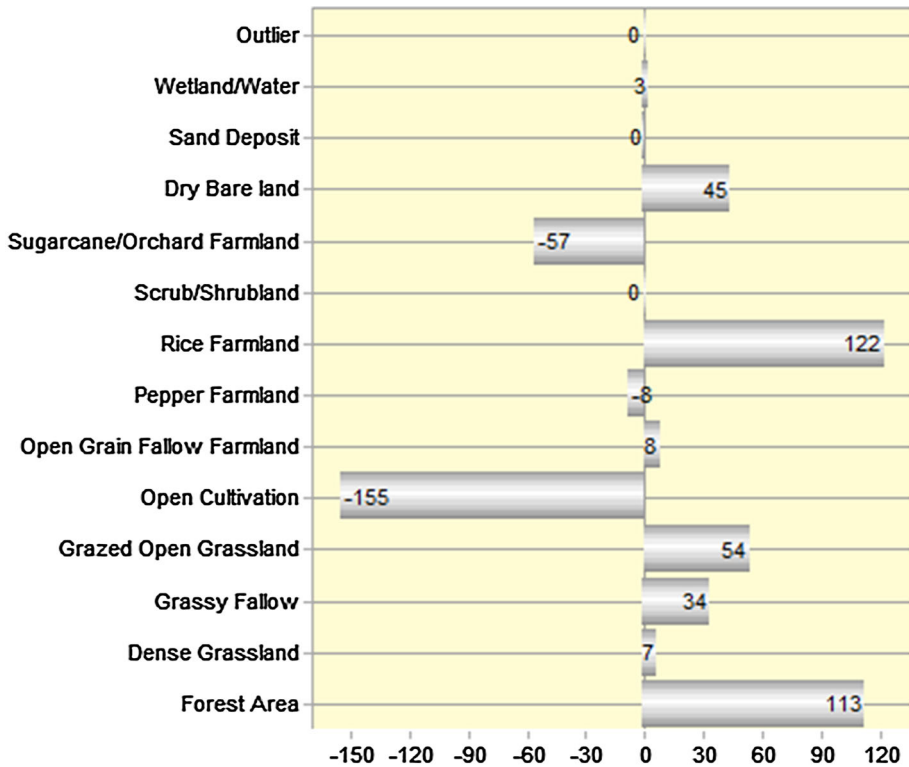


Fig. 12 Contributions to net change in scrubland (ha)

pressure of the floodplain was estimated at 109.6 persons/Km² (Abdullahi, et al. 2014). These hence indicate that over 1963–2006, period, the population (and density) of the Rima Basin changed from 157,679 (74.5 persons/Km²) in 1963–404,738 (86.4 persons/Km²) and then to 1,222,470 (94.2 persons/Km²) and to 2,073,498 (109.6 persons/Km²). These show that both the total population and density of the Basin have both progressively increased over the 1963–2006 period. The implication of these is that more lands will be demanded for cultivation and grazing which will no doubt result into loss of productive lands like fallow lands, forest and grass cover. Land use change statistics obtained over the 1998–2013 period (Table 1) indicate that while vegetated land-uses (forest, dense grassland, grassy fallow, grazed open grassland, open grain fallow land) decreased in areal extent by between about 4–16 %, cultivated land-uses (open cultivation, pepper farmland, rice farmland, orchard and sugarcane farmland) have increased by between about 11 and 125 %. Over the same period, less-productive land-uses (Scrubland/shrubland) increased by about 9 %. Thus population pressure has contributed greatly in influencing LU/LC change in the area.

In addition to population pressure, climate change impacts have been identified as other important determinants of land use change in the basin. Ezemonye and Emeribe (2015) have investigated the response of rainfall and temperature to climatic change in Sokoto Rima Basin, using data for the period 1943–2012. They found out that there is evidence of decreasing trend in the time series of annual rainfall, while evidence of rising trend was detected in the time series of temperature. There was particularly an evidence of statistical

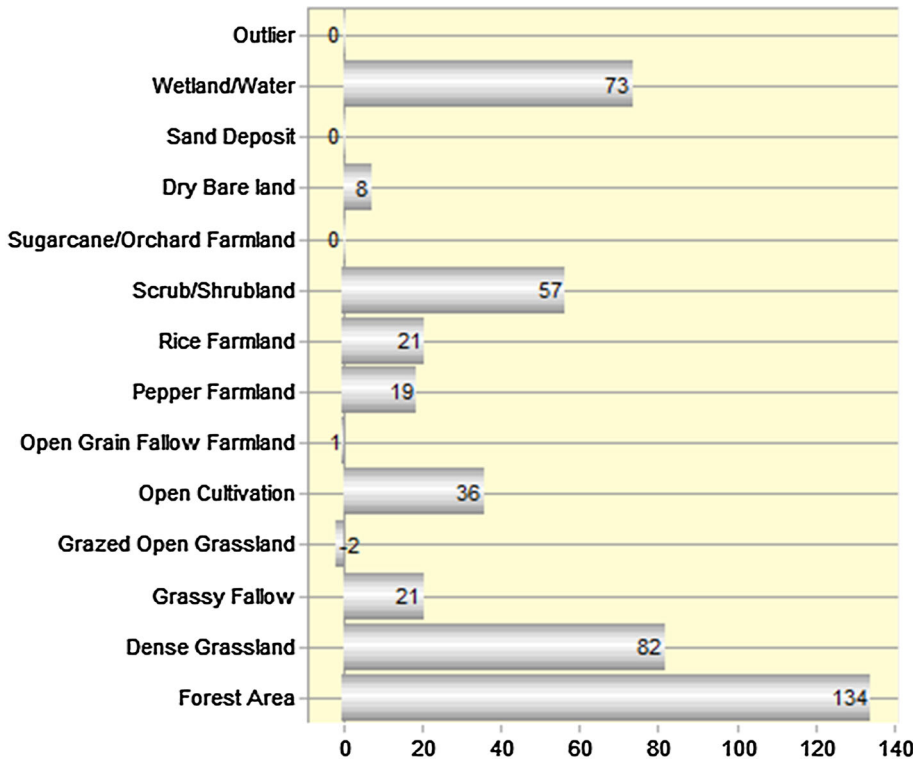


Fig. 13 Contributions to net change in sugarcane farmland (ha)

difference between two climatic periods; 1943–1977 and 1978–2012, with change points for rainfall and temperature found to be 1970 and 1981, respectively. Average percentages of change in annual rainfall and temperature which is the magnitude of deviation from annual rainfall and temperature of the first climatic period during the second climatic period were determined as about 5 for rainfall and 0.9 % for temperature. In addition, the study showed that annual temperature change in the basin was higher than the observed 0.74 ± 0.18 °C increase in average global temperature of the Earth during the past 100 years. Such climatic changes are also expected to have contributed toward reduction in surface and ground water availability which could also aggravate declines in amount of vegetation cover and increase in dry bare soil surfaces.

3.4 Spatial dimension of land use change

Comparison of Figs. 2 and 3 reveal that the changes in land use/covers in the study area are more pronounced in the upper and least in the lower segments of the study area. This is partly expected because increase in temperature and declines in rainfall amount and length of rainy season have been shown by some previous investigations on the Rima Basin to be higher in the upper reaches/segments of the basin (to the north of Figs. 2, 3) (Ati et al. 2007; Tarhule and Woo 1998; Odjugo 2010). Data obtained in this study revealed particularly that declines in forest cover and dense grassland were highest in the upper and

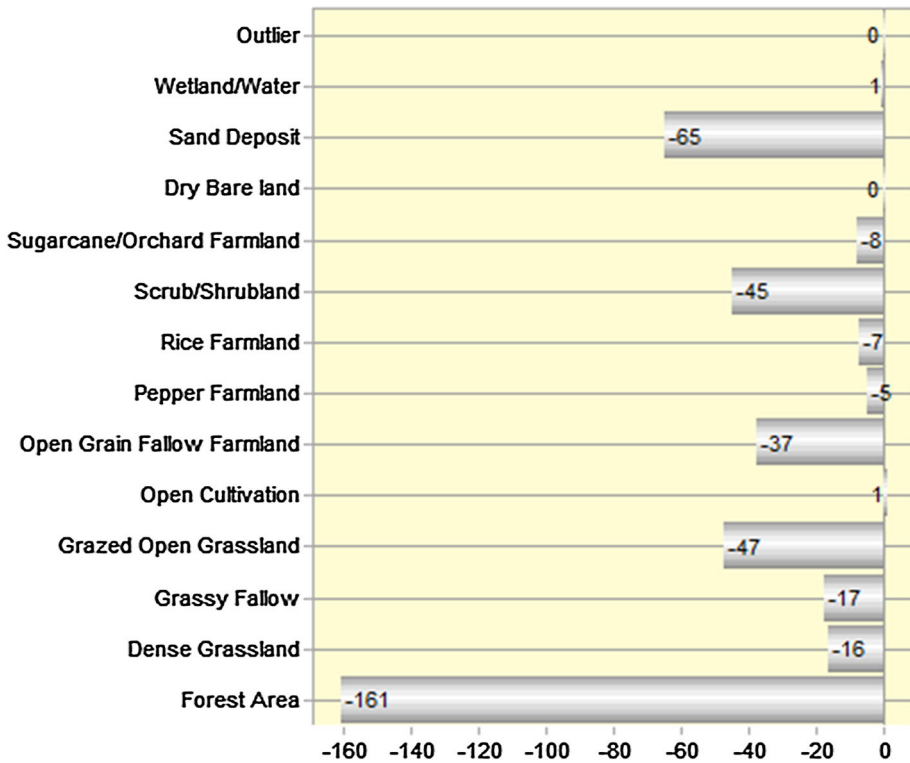


Fig. 14 Contributions to net change in dry open land (ha)

least in the lower segments of the basin. With the climate becoming more arid in the northern than central and southern segments of the Rima Basin, soil moisture and surface runoff are expected to be lower leading to loss of pasture and capacity to support dry season crop production. While this causes reduction in vegetation cover and crop production capacities, it will particularly translate into more land use pressure (especially grazing and dry season crop cultivation) on the central and southern segments of the basin. In addition, there are comparatively more and bigger human settlements in the upper than either the central or northern segments of the Rima basin, and since human population pressure is a major determinant of land use change in the basin, it is expected that this scenario would be contributing toward higher land use change in the upper segments.

4 Discussion

4.1 LU/LC classification

The proportion correctly classified (PCC) value of 89 % obtained in this study as a measure of classification accuracy shows the reliability of the digital classification conducted in this study. Diallo et al. (2009) affirms that a PCC of 76 % is greater than chance. Although there are no universally defined accuracy standards for thematic mapping from

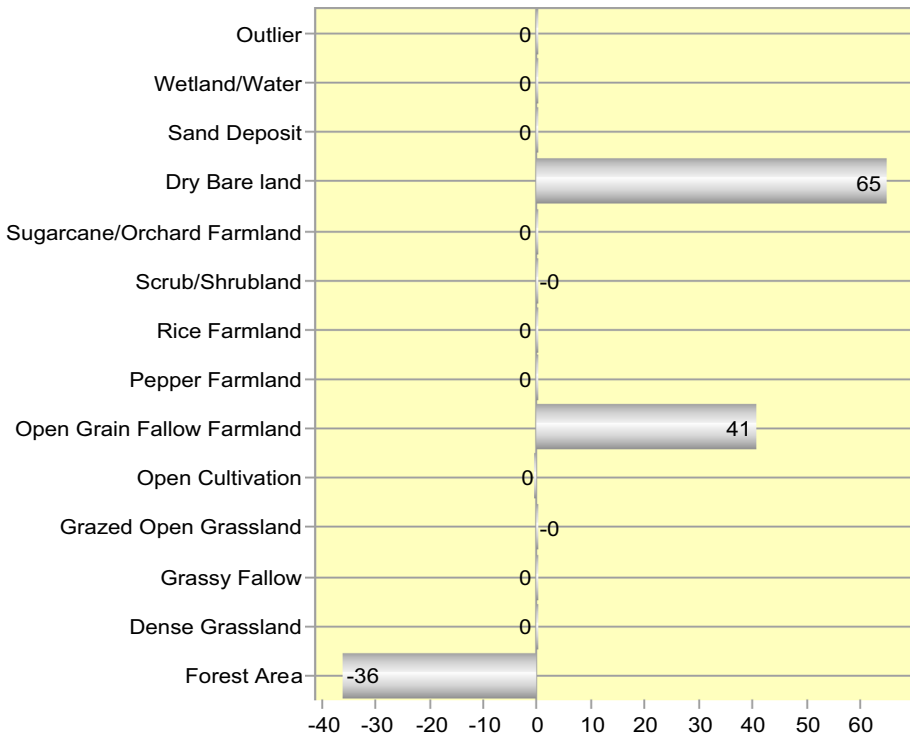


Fig. 15 Contributions to net change in water body (ha)

remote sensing (Foody 2008), the PCC yielded a close result which agrees favorably with those obtained by Munyati (2000), Chen and Rao (2008), Gutierrez et al. (2011), Hubert et al. (2012), among many others. The value in this classification exercise is above the 85 % globally referenced benchmark for testing image classification accuracy. Therefore, the classification carried out in this study can reasonably be considered as representative of the LU/LC of the study area.

The overall classes obtained in the classification at Level III of Anderson et al. (1976) classification scheme are forest, dense grassland, grassy fallow, grazed open grassland, open cultivation, open grain fallow farmland, pepper farmland, rice farmland, scrub/shrubland, sugarcane/orchard farmland, dry bare land, sand deposit, and water/wetland. These classes were obtained after the aggregation of 31 smaller classes. Most of these aggregated classes were obtained at the same level of classification by Adeniyi (1993) with Landsat Multispectral Scanner (MSS) data covering the area. Munyati (2000) identified similar LU/LCs in the wetland on the Kafue Flats, Zambia. Mwita (2013) also obtained similar classes for two floodplains in both Kenya and Tanzania using Landsat data. In a similar environment in South Ethiopia, Worku et al. (2014) observed related LU/LC classes using Landsat data.

Based on the ground truth and LU/LC classes obtained, the study area can mainly be described as an agricultural floodplain (Iliya and Baba 2013). Based on the same facts, it is highly fragmented, making the LU/LC pattern a complexity. Adeniyi (1993) made this observation about the floodplain as well where he submitted that farmlands are excessively

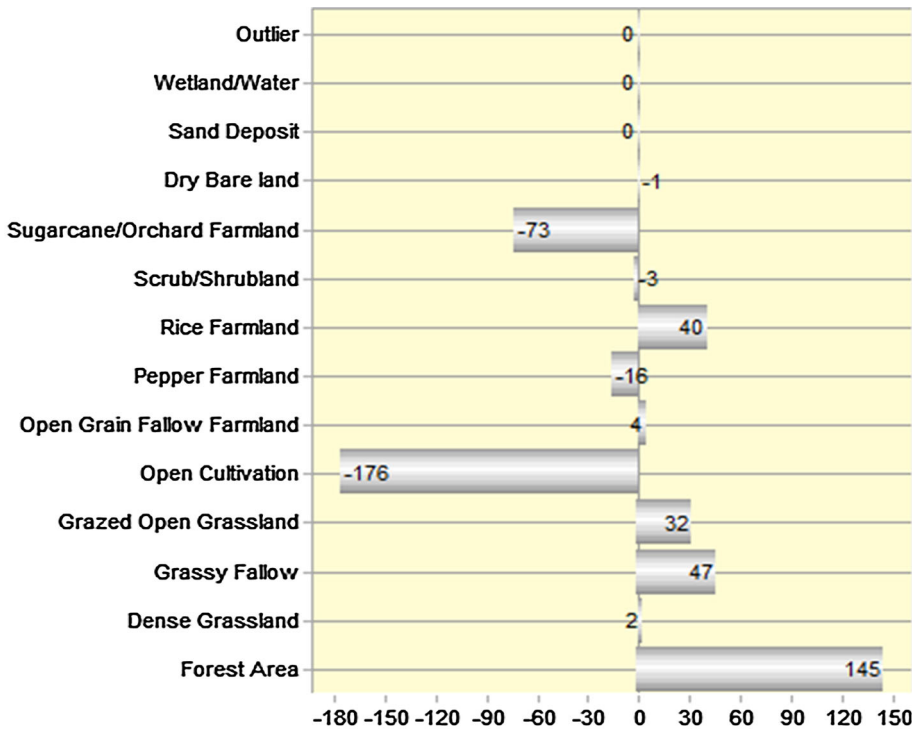


Fig. 16 Contributions to net change in wetland/water (ha)

fragmented. Swindell (1986) earlier observed that the floodplain farmlands are extremely small, ranging from 0.05 to 1.5 ha. Angel et al. (2012) added that land fragmentation is a response to population increase. More land fragmentation and the attendant intensification are still expected with rising demand for space for cultivation due to increase in population around the floodplain. These have implications for the soil and ground water quality of the area, especially as agricultural intensification typically goes along with widespread use of chemicals which are sources of soil and water pollution (Nash et al. 2015).

LU/LC classification conducted also indicates that about 40 % of the area is under cultivation, while 22 % is fallowed. 27 % is either degraded or non-cultivable, while 11 % is forested. This land use distribution suggests low crop production due to underutilization of a supposedly resourceful floodplain in the face of available space, technology and burgeoning population. This has implication for human employment and food security. Expansion and dominance of shrub/scrubland class as a consequence of forest degradation and land mismanagement also has effect on the biodiversity of the area with consequent impact on soil quality (Mwavu and Witkowski 2008).

Field visits and the LU/LC maps produced have prided an indication that the intensity of activities appears higher in the upstream and midstream areas than in the downstream such that the downstream appears more fallowed than cultivated. A plausible explanation is that there is abundance of wetland/water in the upstream and midstream than in the downstream; thus, the floodplain is more tilled in the upper and middle parts. This is confirmatory of Swindell's (1986) submission that cultivation around Sokoto and below toward

Birnin Kebbi is limited due to the erratic nature of flooding in the wet season and shifting of river channels. The implication is that the soil in the upper part will expectedly be more impacted than that in the lower part. It also suggests underutilization of the agricultural potential of the floodplain in the face of burgeoning population.

Since most agricultural activities in the dry season are concentrated at the upstream and midstream where surface water is more abundant, although irrigation is practiced everywhere in the floodplain, it is plausible to submit that surface water availability is one of the potent factors that determine agricultural activity location (crop type and intensity of cultivation) in the floodplain.

4.2 LU/LC change

Studies (Adams 1986; Swindell 1986; Adeniyi 1993; Mohammed 2002; Ojo et al. 2009, Iliya and Baba 2013) have shown that the fundamental basis of LU/LC change in the study area is agriculture. The Boserupian theory posits that population pressure is the basis for agricultural expansion and intensification that when the population increases, farmers will begin to cultivate unused land (Keita and Zhang 2010). As population keeps increasing, a threshold of land saturation where expansion is substituted by intensification is reached. This theory is applicable in the Rima River floodplain where agricultural intensification is practiced as a result of land saturation due to population pressure caused by natural increase as well as in-migration (Swindell 1986). Additionally, Von Thunen's theory states that agricultural land-uses are arranged in a concentric pattern around a central market city, with intensive agriculture/dairy farming found closest to the city. Concentricity is the outcome of the competition for accessibility (Verburg et al. 2004). Although technological developments have overtaken most of the assumptions, the first ring of the concentric zones where intensive agriculture takes place coincides with the adjoining part of the floodplain to Sokoto North which has the highest demand for the vegetables which form the major output of the floodplain.

Campbell et al. (2005) recognized these theories as the starting point for understanding LU/LC change factors and processes especially at local and regional scales, although no single theory suffices to analyse aspects of LU/LC change, as the factors and processes are more complex than imagined; therefore, conceptualizing LU/LC change requires a synthesis of different disciplinary theories (Verburg et al. 2004).

The cause-cover concept of Turner II et al. (1990) agrees that an association exists between LU/LC change and population growth. Turner II et al. (1990) explained that population pressure, state politics, market incentives, climate variations, and access to land and water resources are the driving forces of LU/LC change. They further posited that land use changes resulting from these driving forces will cause cumulative transformation in forms of modification (e.g., changes in fallow cycles, levels of input, rotation systems, agricultural land intensification), conversion (e.g., deforestation for cultivation) and maintenance of land cover (e.g., the upkeep and repair of soil terraces, of improved pasture, or of irrigation systems). These forms of transformation have impacts on the immediate physical system such as vegetation, soil, hydrology, etc. at the local scale (Lambin et al. 2000), but become globally significant by widespread cumulative occurrence (e.g., climate change) which also impact on the driving forces (Turner II et al. 1990). Stephenne and Lambin (2001) emphasized that competition exists among different LU/LC types within the space as a result of the interactions of the factors, suggesting agricultural land saturation.

Theories of LU/LC abound in the literature, and no single theory suffices to analyse aspects of LU/LC change, as the factors and processes are more complex than imagined (Campbell et al. 2005). Thus, conceptualizing LU/LC requires a synthesis of different disciplinary theories (Verburg et al. 2004). The Boserupian theory posits that population pressure is the basis for agricultural expansion and intensification that when the population increases, farmers will begin to cultivate unused land (Keita and Zhang 2010). As population keeps increasing, a threshold of land saturation where expansion is substituted by intensification is reached. The cause-cover concept of Turner II et al. (1990) agrees that an association exists between LU/LC and population growth. Turner II et al. (1990) further explain that population pressure, state politics, market incentives, climate variations, and access to land and water resources are the driving forces of LU/LC change. They further posited that land use changes resulting from these driving forces will cause cumulative transformation in forms of modification, conversion and maintenance of land cover. These forms of transformation have impacts on the immediate physical system such as vegetation, soil and hydrology at the local scale (Lambin et al. 2000), but become globally significant by widespread cumulative occurrence (e.g., climate change) which also impact on the driving forces (Turner II et al. 1990). Stephenne and Lambin (2001) emphasized that competition exists among different LU/LC types within the space as a result of the interactions of the factors, suggesting agricultural land saturation.

The Boserupian theory and the cause-cover concept provide explanations for LU/LC in the floodplain where agricultural intensification is practiced as a result of land saturation due to population pressure caused by natural increase as well as in-migration (Adams 1986; Swindell 1986; Adeniyi 1993; Mohammed 2002; Ojo et al. 2009, Iliya and Baba 2013). Agricultural intensification is reinforced by availability of nutrient-rich and naturally fertilized soil resulting from flooding events, existence of two dams (Goronyo and Lugu Dams) upstream, and availability and proximity of market (Swindell 1986; Verhoeven and Setter 2010; Iliya and Baba 2013). All these factors favor dry season farming and evolution of different agricultural activities and complex LU/LC types within the floodplain.

The overall change analysis shows that there were changes across the LU/LC classes in the floodplain between 1998 and 2013. Notable among these change events are: loss and conversion of forest cover, expansion of scrubland and pervasiveness of grazing, expansion of cultivation and change in crop patterns, shift in water/wetland areas and overall increase in agricultural intensity upstream where the floodplain is wetter, and fallowing of the downstream. Such changes expectedly have impacts on the biodiversity and soil quality of the study area including food security of the people.

Elsewhere, and particularly in the dry areas of developing countries, impacts of LU/LC change are adverse on soil quality (Yukseket al. 2009; Nkonya et al. 2011; Flores and Tracy 2012; Ghosh 2012; Bravo-Espinosa et al. 2012). Globally, vegetation alteration in forms of deforestation, forest conversion into scrubland and grassland is a major factor of soil degradation (Bridges and Oldeman 1999; Cerli et al. 2009; Covaleda et al. 2011). While scrubland is a resultant feature of degraded forest and long fallow, it constitutes a favorable site for fuel wood cutting and grazing in the study area. Such areas look soil-eroded, and patches of bare surfaces are apparent. Grazed open grassland, although reduced in area but pervasive, high stocking rate especially in the upstream, can increase the soil BD, decrease pH, organic C, N and P. (Pierre et al. 1999; Medina-Roldan et al. 2012; Flores and Tracy 2012). Grazing is also known to increase the concentration of heavy metals elsewhere (Mashi et al. 2004). Cultivation expansion and change in cropping patterns are evidence of declines in shifting cultivation, with soil degradation expected to

be more severe in areas no longer under shifting cultivation (Abu-Hamdeh 2000; Ly et al. 2012). The intensification of farming systems with annual crops lead to decline in soil organic matter pools (Ly et al. 2012). Mashi and Al-Hassan (2007) observed that irrigation could cause high concentrations of heavy metals in the sub-soil. FAO (1969), Noma and Gabasawa (2005) and Yakubu et al. (2006) observed dangerous concentration of salts in the irrigation schemes, while Abdullahi et al. (2010) reported fertility disturbance in parts of the study area. Similarly, Adelana et al. (2003) also stated that irrigation and applications of agro-chemicals have impacted on the ground and surface water of the area. Areas of agricultural intensity in the Rima floodplain are mainly areas in the upstream and the midstream. Thus, land degradation problems resulting from intensive cultivation of the floodplain are expected to be more pronounced in the upper and middle segments of the Rima basin.

A number of research workers have established that climate change has also been impacting negatively on soil, water and vegetation resources of the floodplain (Adeniyi 1993; Ekpoh and Ekpenyong 2011; Abdulrahim and Eniolorunda 2012; Umar 2013; Ezemonye and Emeribe 2015). The basin has in fact been described as one of the few areas that have suffered more acute climate change impact in Nigeria (Odjugo 2010). Low annual rainfall, late arrival and early cessation of the wet season, sporadic drought and extended dry season with high temperature, all occasioned by climate change, have been described as important features that characterize the study area. The various studies have provided evidence of decreasing trend in the time series of annual rainfall, with rising trend in temperature. Ezemonye and Emeribe (2015) obtained evidence of statistical difference between two climatic periods in the basin 1943–1977 and 1978–2012. They noted that late arrival and early cessation of wet season have resulted in constricted rainfall season and consequent abnormal flood occurrences. This creates isolated ponds and wetlands, braided channels and shifts in river channels thereby creating shifts in the use of land from 1 year to another. The lengthening of the dry season with attendant temperature extreme which causes drought affects the hydrology of the floodplain and results in crop failure. Thus, farmer's cropping calendar and land use choices are affected, and these partly account for the crowdedness of activities around areas with favorable soil and water conditions for farming, grazing and even settlement development. The findings of the study by Ekpoh and Ekpenyong (2011) have also shown that variations in the weather and climate of the region have significantly impacted on water yields in surface reservoirs, with over 80 % of the yearly variations in water yield in the Sokoto Rima Basin being explained by variations in the weather and climate. As water is very critical to human use of the land in the area, this trend is no doubt expected to be influencing land use and cover conditions.

5 Conclusion

Application of Landsat data has allowed for LU/LC inventory and understanding of LU/LC dynamics. Results from this study indicate that although the floodplain of the Sokoto Rima Basin is agricultural, it is not properly managed. Change events as observed can potentially impact on the soil, hydrology and biodiversity including crop productivity. Thus livelihood and food security could become jeopardized. Therefore, for optimum utilization of the floodplain toward sustainable development, government should aid the farmers in financing and managing the floodplain, while extension workers should teach farmers agricultural best practices. In future, higher resolution satellite data could be used to

achieve a finer level of LU/LC classification in such a highly fragmented floodplain to enable better understanding of the floodplain.

Acknowledgments The authors are grateful to the United State Geological Survey (USGS) Department for providing the Landsat data used for this study.

References

- Abdullahi, S. A., Muhammad, M. M., Adeogun, B. K., & Mohammed, I. U. (2014). Assessment of water availability in the Sokoto Rima River Basin. *Resources and Environment*, 4(5), 220–233.
- Abdullahi, A. A., Usman, Y. D., Audu, M., Danmowa, N. M., & Shuaibu, H. (2010). fertility status of floodplain soils in Gatsare Village, Wamakko Local Government, Sokoto State, as affected by cement dust. *Nigerian Journal of Basic and Applied Science*, 18(1), 58–64.
- Abdulrahim, M. A., & Eniolorunda, N. B. (2012). Manifestation of climate change: 2010 Flood disaster at Kwakwalawa, Dundaye District of Wammako Local Government Area, Sokoto State of Nigeria. *Nigeria Geographical Journal*, 8(1), 132–144.
- Abu-Hamdeh, N. H. (2000). Effect of tillage treatments on soil thermal conductivity for some Jodanian clay-loam and loam soils. *Soil and Tillage Research*, 56, 145–151.
- Adams, W. M. (1986). Traditional agriculture and water use in the Sokoto valley, Nigeria. *The Geographical Journal*, 152(1), 30–43.
- Adelana, S. M. A., Olasehinde, P. I., & Vrbka, P. (2003). Isotope and geochemical characterization of surface and subsurface waters in the Semi-Arid Sokoto basin, Nigeria. *African Journal of Science and Technology (AJST) Science and Engineering Series*, 4(2), 80–89.
- Adeniyi, P. (1993). Integration of remote sensing and GIS for agricultural resource management in Nigeria. *EARSel Advances in Remote Sensing*, 2(3-XI), 6–21.
- Anderson, J. R., Hardy, E. T., Roach, J. T., & Witmer, R. E. (1976). A land use and land cover classification system for use with remote sensor data. *U.S. Geology Survey prof Paper 964*. U.S. Government Printing Office, Washington, DC.
- Angel, S., Parent, J., & Civco, D. L. (2012). The fragmentation of urban landscapes: Global evidence of a key attribute of the spatial structure of cities, 1990–2000. *Environment and Urbanization*, 24, 249–283.
- Ati, F. O., Edwin, O., & Joseph, O. A. (2007). Are we experiencing drier conditions in the Sudano-Sahelian Zone of Nigeria? *Journal of Applied Sciences Research*, 3(12), 1746–1751.
- Bravo-Espinosa, M., Mendoza, M. E., Carlónallende, T., Medina, L., Sáenz-Reyes, J. T., & Páez, R. (2012). *Effects of converting forest to avocado orchards on topsoil properties in the trans-Mexican volcanic system*. Mexico: Land Degradation & Development. doi:10.1002/ldr.2163.
- Bridges, E. M., & Oldeman, L. R. (1999). Global assessment of human-induced soil degradation. *Arid Land Research and Management*, 13(4), 319–325.
- Campbell, D. J., Lusch, D. P., Smucker, T. A., & Wangui, E. E. (2005). Multiple methods in the study of driving forces of land use and land cover change: A case study of SE Kajiado District, Kenya. *Human Ecology*, 33, 763–794.
- Cerli, C., Celi, L., Bosio, P., Motta, R., & Grassi, G. (2009). Effect of land use change on soil properties and carbon accumulation in the Ticino Park (North Italy). *Studi trentini di scienze naturali*, 85, 83–92.
- Chen, S., & Rao, P. (2008). Land degradation monitoring using multi-temporal Landsat TM/ETM data in a zone between grassland and cropland of northeast China. *International Journal of Remote Sensing*, 29(7), 2055–2073.
- Covaleada, S., Gallardo, J. F., Garcia-Oliva, F., Kirchmann, H., Prat, C., Bravo, M., & Etchevers, J. D. (2011). Land-use effects on the distribution of soil organic carbon within particle-size fractions of volcanic soils in the Transmexican Volcanic Belt (Mexico). *Soil Use and Management*, 27, 186–194.
- Diallo, Y., Hu, G., & Wen, X. (2009). Applications of remote sensing in land use/land cover change detection in Puer and Simao countries, Yunnan Province. *Journal of American Science*, 5(4), 157–166.
- Eastman, J. R. (2009). *IDRISI Taiga guide to GIS and image processing*. Clark Labs for Cartographic Technology and Geographic Analysis, Clark University, Worcester, MA 01610, USA.
- Ekpoh, I. J., & Ekpenyong, N. (2011). The effects of recent climatic variations on water yield in the Sokoto Region of Northern Nigeria. *International Journal of Business and Social Science*, 2(7), 251–256.
- Ezemonye, M. N., & Emeribe, C. N. (2015). Spatial and temporal patterns of climatic change in the Sokoto-Rima River Basin, Sudano-Sahel region, Nigeria. *European Scientific Journal*, 11(26), 392–403.

- FAO. (1969). *Soil and water resources survey of the Sokoto Valley, Nigeria*. Final Report (Vol. 5), FAI/SF, Rome.
- Flores, J. P., & Tracy, B. (2012). Impact of winter hay feeding on pasture soils and plants. *Agriculture, Ecosystems & Environment*, *149*, 30–36.
- Food and Agriculture Organization (FAO)/UNEP. (1997). *Negotiating a sustainable future for land*. Rome: FAO/AGLS, 61 pp.
- Foody, G. M. (2008). Harshness in image classification accuracy assessment. *International Journal of Remote Sensing*, *29*(11), 3137–3158.
- Ghosh, D. (2012). Effects of landuse change on soil properties in Haryana area. *Journal of Indian Remote Sensing Society*, *36*, 121–132.
- Gutiérrez, J. A., Seijmonsbergen, A., & Duivenvoorden, J. (2011). Optimizing land cover change detection using combined pixel-based and object-based image classification in a mountainous area in Mexico. *Anais XV Simpósio Brasileiro de Sensoriamento Remoto - SBSR*, Curitiba, PR, Brasil, 30 de abril a 05 de maio de 2011, INPE p. 6556.
- Hubert, S., Schwarzer, S., & Jaquet, J. (2012). Spatial degradation of classified satellite images. *The Open Remote Sensing Journal*, *5*, 64–72.
- Ifabiyi, I. P., & Eniolorunda, N. B. (2012). Watershed characteristics and their implications for hydrologic response in the Upper Sokoto Basin, Nigeria. *Journal of Geography and Geology*, *4*(2), 147–155.
- Iliya, M. A., & Baba T. A. M. (2013). Sokoto State: Overview. In M. A. Iliya, & A. G. Fada (Eds.) *The impact of climate change on Sokoto State, Nigeria: Evidence and challenges* (1st edn). Sokoto: UNDP/Sokoto State Government.
- Janssen, L. L. F., & Gorte, B. G. H. (2004). Digital image classification. In N. Kerle, L. L. F. Janssen, & G. C. Huurneman (Eds.) *Principles of remote sensing: An introductory textbook*. The International Institute for Geo-Information Science and Earth Observation (ITC), Hengelosestraat 99, P.O. Box 6, 7500 AA Enschede, The Netherlands.
- Keita, K., & Zhang, D. (2010). *Conflict and conflict resolution in the Sahel*. Strategic Studies Institute Monograph, University of Leiden, p 46.
- Kennedy, A. D., Dong, X., Xi, B., Minnis, P., Del Genio, A. D., Wolf, A. B., & Khaiyer, M. M. (2010). Evaluation of the NASA GISS single column model simulated clouds using combined surface and satellite observations. *Journal of Climate*, *23*, 5175–5192.
- Lambin, E. F., Helmut, J. G., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, *28*, 205–241.
- Lambin, E. F., Rounsevell, M., & Geist, H. (2000). Are current agricultural land use models able to predict changes in land use intensity? *Agriculture, Ecosystems & Environment*, *165*, 1–11.
- Ly, P., Pillot, D., Lamballe, P., & Neergaard, A. (2012). Evaluation of bamboo as an alternative cropping strategy in the northern central upland of Vietnam: Above-ground carbon fixing capacity, accumulation of soil organic carbon, and socio-economic aspects. *Agriculture, Ecosystems & Environment*, *149*, 80–90.
- Mashi, S. A., & Al-Hassan, M. M. (2007). Effects of waste water discharge on heavy metals pollution in Floodplain soils in Kano city, Nigeria. *Biomedical and Environmental Sciences*, *20*, 70–77.
- Mashi, S. A., Yaro, S. A., & Haiba, A. S. (2004). Correlation of heavy metals in the soils of Shika area of Kaduna State, Nigeria. *Biomedical and Environment Sciences*, *17*, 426–431.
- Mather, P. M. (1999). *Computer processing of remotely sensed images—An introduction*. Toronto: Wiley.
- Medina-Roldan, E., Paz-Ferrero, J., & Bardgett, R. D. (2012). Grazing exclusion affects soil and plant communities, but has no impact on soil carbon storage in an upland grassland. *Agriculture, Ecosystems & Environment*, *149*, 118–123.
- Meyer, W. B., & Turner, B. L, I. I. (Eds.). (1994). *Changes in land use and land cover: A global perspective*. Cambridge: Cambridge University Press.
- Mohammed, K. Y. (2002). Development and challenges of Bakolori Irrigation Project in Sokoto State, Nigeria. *Nordic Journal of African Studies*, *11*(3), 411–430.
- Munyati, C. (2000). Wetland change detection on the Kafue Flats, Zambia, by classification of a multi-temporal remote sensing image dataset. *International Journal of Remote Sensing*, *21*(9), 1787–1806.
- Mwavu, E. N., & Witkowski, E. T. F. (2008). Land-use and cover changes (1988–2002) around Budongo Forest Reserve, NW Uganda: Implications for forest and woodland sustainability. *Land Degradation and Development*, *19*, 606–622.
- Mwita, E. J. (2013). Land cover and land use dynamics of semi-arid wetlands: A case of Rumuruti (Kenya) and Malinda (Tanzania). *Journal of Geophysics & Remote Sensing*, *51*, 001. doi:10.4172/2169-0049.51-001.

- Nash, D. M., Watkins, M., Heaven, M. W., Hannah, M., Robertson, F., & McDowell, R. (2015). Effects of cultivation on soil and soil water under different fertiliser regimes. *Soil and Tillage Research*, *145*, 37–46.
- Nkonya, E., Winslow, M., Reed, M. S., Mortimore, M., & Mirzabaev, A. (2011). Monitoring and assessing the influence of social, economic and policy factors on sustainable land management in dry-lands. *Land Degradation and Development*, *22*, 240–247.
- Noma, S. S., & Gabasawa, A. I. (2005). Assessment of the quality of water and irrigated soils of Sokoto-Rima floodplains. *Bulletin of SAN*, *26*(2005), 63–69.
- Odjugo, P. A. O. (2010). General overview of climate change impacts in Nigeria. *Journal of Human Ecology*, *29*(1), 47–55.
- Ojo, M. A., Mohammed, U. S., Adeniji, B., & Ojo, A. O. (2009). Profitability and technical efficiency in irrigated onion production under middle Rima Valley irrigation project in Goronyo, Sokoto State Nigeria. *Continental Journal of Agriculture*, *3*, 7–14.
- Pierre, H., Bielders, C. L., Valentin, C., Bationo, A., & Fernandez-Rivera, S. (1999). Effects of livestock grazing on physical and chemical properties of sandy soils in Sahelian rangelands. *Journal of Arid Environments*, *41*, 231–245.
- Shao, J., Ni, J., Wei, C., & Xie, D. (2005). Landuse change and its corresponding ecological responses: A review. *Journal of Geographical Sciences*, *15*(3), 305–328.
- Stephenne, N., & Lambin, E. L. (2001). A dynamic simulation model of land-use changes in the Sudano-Sahelian countries of Africa. *Agriculture, Ecosystems & Environment*, *85*, 145–161.
- Swindell, K. (1986). Population and agriculture in the Sokoto Rima Basin of North-West Nigeria: A study of political intervention, adaptation and change, 1800–1980. *Cahiers d'études Africaines*, *26*(101–102), 75–111.
- Tarhule, A., & Woo, M. (1998). Changes in rainfall characteristics in Northern Nigeria. *International Journal of Climatology*, *18*, 1261–1271.
- Turner II, B. L. (1995). *Global land-use change: A perspective from the Columbian encounter*. Madrid: Consejo Superior de Investigaciones Científicas.
- Turner II, B. L., Kasperson, R. E., Meyer, W. B., Dow, K., Golding, D., Kasperson, J. X., Mitchell, R. C., & Ratick, S. J. (1990). Two types of global environmental change: Definitional and spatial-scale issues in their human dimensions. *Global Environmental Change: Human and Policy Dimensions*, *1*(1), 14–22.
- Turner, B. L., Skole, D., Sanderson, S., Fischer, G., Fresco, L., & Leemans, R. (1995). LU/LC Science/ Research Plan. The International Geosphere–Biosphere Programme: A study of global change (IGBP) of the International Council of Scientific Unions (ICSU) and the Human Dimensions of Global Environmental Change Programme (HDP) of the International Social Science Council (ISSC), Stockholm and Geneva.
- Umar, U. (2013). An assessment of the changing climate in Northern Nigeria using Cokriging. *American Journal of Applied Mathematics and Statistics*, *1*(5), 90–98.
- Verburg, P. H., Van Eck, J. R. R., Nijs, T. C. M., Dijst, M. J., & Schot, P. (2004). Determinants of land use change patterns in the wetlands environment and planning. *Planning and Design*, *31*, 125–150.
- Verhoeven, J. T. A., & Setter, T. L. (2010). Agricultural use of wetlands: Opportunities and limitations. *Annals of Botany*, *105*(1), 155–163.
- Worku, G., Bantider, A., & Temsgen, H. (2014). Effects of land use/land cover change on some soil properties in Ameleke Micro Watershed, Gedco and Barena Zones, South Ethiopia. *Journal of Environment and Earth Science*, *4*(11), 13–24.
- Yahaya, M. K. (2002). Development challenges of Bakolori irrigation project in Sokoto State, Nigeria. *Nordic Journal of African Studies*, *11*(3), 411–430.
- Yakubu, M., Bello, S., Noma, S. S., & Danmowa, N. M. (2006). Quality of irrigation water and soil characteristics of floodplain lands in Sokoto metropolis. In *Proceeding, 30th annual conference of soil science society of Nigeria*, 5th–9th December, 2006, University of Agriculture, Makurdi, Nigeria.
- Yelwa, S. A. (2008). *Broadscale vegetation change assessment across Nigeria from coarse spatial and high temporal resolution AVHRR data*. Gottingen: Cuvillier Verlag.
- Yukse, T., Gol, C., Yuksek, F., & Yuksel, E. E. (2009). The effects of land use changes on soil properties: The conversion of alder coppice to tea plantations in the Humid Northern Blacksea Region. *African Journal of Agricultural Research*, *4*(7), 665–674.