

Complex multispatio-periodic land use and land cover change processes, and woody resources management in a forest-Savanna Ecotone, Ghana

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ABSTRACT

Vegetation change discourse in tropical Africa is characterized by assumptions of generalised deforestation and degradation. Premised on the concept of the heterogeneity of the tropical African landscape, we make a multispatio-periodic analysis of land use and land cover change (LULCC), and examine its ramifications for woody resources of a forest-Savanna transition, that is characterized by assumed deforestation change discourse. Landsat data for 1985, 2000 and 2016, classified into seven (7) LULC categories were analyzed for change for 1985–2016, 1985–2000 and 2000–2016: for the whole study area, and six (6) smaller localities. In 1985–2016, all woody vegetation categories of the study area experienced reduction: ranging between 60.00% and 23.61%. Reduction in woodland was higher in 1985–2000. Dense woodland cover reduced in, practically, all localities in 1985–2000. The LULCC mechanism was a complex transfer among LULC types, resulting in different emergent LULC types. Hence, change process was not a simple linear deforestation and degradation. Dense woodland that existed at the end of each period was, predominately, regenerated from pre-existing fallow, rather than remnants of ‘virgin’ or pre-existing dense woodland. When pre-existing woody cover was higher, greater amount of woody vegetation regenerates by transformation in a shorter period, whereas limited woody regeneration of woody vegetation on pre-existing fallows dominates when there is limited pre-existing woodland, through a long processes of conversion and transformation. Therefore, maintaining higher woody vegetation cover will promote quicker and substantial regeneration of woody vegetation, and availability of woody resources for sustainable wood-based livelihoods, such as charcoal production.

Introduction

The strong and multiple links between vegetation conditions, and the levels of the provision of ecosystem services (Li et al., 2014; Polasky et al., 2011; Figuepron et al., 2013; Munch et al., 2017), makes it imperative to analyze and understand the dynamics of the trajectory of the spatio-periodic status and processes of LULCC. Inadequate knowledge of LULCC dynamics challenges the identification and management of the distinct set of agents and processes that define their unique periodic and local specific dynamics (Elmqvist et al., 2013; Verburg et al., 2015). In tropical Africa, especially, the nature of the heterogeneity of LULCC of the landscape has attracted long debates and research attention (Fairhead and Leach, 1996a; Lambin et al., 2003; Guyer et al., 2007). Yet, environmental change orthodoxies of simple and linear characterizations have tended to dominate LULCC discourses, which undermine objective construction of realities, and inform effective policy formulation. Though, single spatio-periodic LULCC analysis has

provided generalized information on LULCC dynamics, multiple spatio-periodic LULCC analysis that reveals patterns of trends and heterogeneity of processes and emergent states that reflect contextual local specificity and periodicity of agents of change has not been adequately employed. This approach has been leveraged in this study to yield evidence for informed theoretical discourse, policy formulation and effective LULCC management of woody resources.

The conventional categorization of forest and woodland formations as “primary”, “secondary”, “virgin” and “pristine” (Baseler, 1932; Jones, 1945; Brown and Lugo, 1990), has stimulated debates that question whether there are forest landscapes which have not been subjected to human influences (Corlett 1994; Rouvinen and Kouki, 2008). Adherence to this classification scheme may have advocated the discourse of generalized progressive forest degradation and deforestation. For instance, Fairhead and Leach (2000), cite a British Empire Forestry Conference report on deforestation of ‘Primeval Forest’ in Sierra Leone in 1924. The persistence of the tropical ‘deforestation’

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discourse has perpetuated “myths” which portray over-simplifications of LULCC patterns. In the global environmental change context, forest resource changes in tropical Africa have been dominated by simple and linear process of deforestation (FAO, 2001, Congalton and Green, 2009; Curtis et al., 2018 Aleman et al., 2018).

The book “The lie of the land” edited by Leach and Mearns (1996) constitutes a landmark study challenging long-held perceptions of environmental change, the causal factors driving such change, and ultimately, environmental policy. Environmental orthodoxies generalize environmental degradation, that are often accepted as fact, but have been shown by research to be inaccurate (Temudo and Santos, 2017). Bassett and Boutrais (2000) and Mitchard et al. (2011) have also reported of evidence of gains of forest at the expense of savanna in regions of Cameroon. Therefore, the issue of the spatio-temporal heterogeneity of the tropical African landscape respecting LULCC remains contested.

The one-sided characterization of vegetation change de-emphasizes the potential of natural regeneration of woody vegetation (Mitchard and Flintrop, 2013). In the 2005–2010 global forest resource assessment report, only 0.45% forest gain was reported: this was attributed to forest plantations rather than natural regeneration (FAO, 2010). In many instances of reported change of woodland and forest vegetation, transfers between LULC types are not highlighted (Mitchard and Flintrop, 2013). Multi-periodic differential patterns of LULCC that provide the basis and opportunities for explanatory analysis that identifies and quantifies the periodic mix of drivers of change are lacking. Largely, land cover status of particular dates, and change in cover of same cover types between different dates are analyzed. Land use and land cover change transfers among different cover categories are not analyzed. In many studies, only a single-sampling strategy is adopted: this reduces the consistency or robustness of conclusions through inductive logic (Atsri et al., 2018; Othow et al., 2017).

This paper concerns the south-western part of the forest-savanna zone in Ghana which according to the dominant narrative has been subjected to general and linear processes of deforestation and degradation (Oppong-Anane, 2001; Wardell and Lund, 2006). This area, which is referred to as a tension zone (Hopkins, 1981; Taylor, 1960), consists of mosaics of dry semi-deciduous forest, woodland and guinea savanna (Amanor and Pabi, 2007). Foresters in the 1920s and 1930s assumed that the zone was derived from a denser and taller forest vegetation type that had earlier covered the zone, but which had been replaced by a more open vegetation type with grasses due to farming (Fairhead and Leach, 1998; Taylor, 1952). The Ghana REDD+ Strategy states that the forest eco-zone, which covers vast swathes of Ghana’s landmass (over 60%) is fast losing its preponderance of forests and highly valuable savanna woodland species (Forestry Commission, Ghana FC, 2015). However, Amanor and Pabi (2007) who made a single period analyses of LULCC between 1984 and 2001 at various locations in the zone did not confirm a uniform and unidirectional downward trend of degradation. Swaine et al. (1976), have emphasized the role of localized, traditional farming practices that encourage and promote the regeneration of woody species. Thus, the question of the multiperiodic and spatial specific vegetation change dynamics within the zone remains unresolved.

This study makes a multiperiodic analysis of LULCC at different extent and localities and provides evidence for improved construction of LULCC dynamics, and contributes to resolving the prevailing contradictory claims in respect of the nature, quantum and direction of LULCC patterns. It advances the knowledge frontiers of the broader concept spatio-temporal heterogeneity of LULC dynamics of the tropical Africa, by elevating the discourse with data of high evidential value (Guyer et al., 2007; Lambin and Geist, 2006). Specifically, the paper examines land use and land cover changes in the northern forest-savanna zone of Ghana in a long-term perspective (1985–2016; 30 years) through analysis of Landsat data for 1985, 2000 and 2016. We analyzed the status and processes of LULCC patterns for two periods: 1985–2000 and 2000–2016 at broad scale (study area extent) and local scale (selected site) levels.

The analysis unpacks and reveals the real and potential implications of the patterns of LULCC for wood resources, and associated livelihoods in the area.

Methodology

Study area

The study area is located in the forest-savanna transitional zone of Ghana between 110°W and 210°W and between 845°N and 703°N (Fig. 1). The study site covers the administrative districts Kintampo North and Kintampo South. The topography is generally gentle rolling, with elevations between 60 and 150 m above sea level. The rivers in the study area are all contributors to the Volta river. Annual rainfall ranges from 1400 mm to 1800 mm per annum, with major rains between May and July and minor rains in September and October. In some years the two rainy seasons are indistinguishable. Mean temperatures range between 26.5 °C and 27.2 °C.

The key livelihood activities in the area are agriculture, livestock rearing and charcoal production (Brobbe et al., 2019). The main crop cultivated in the area is yam. Other important crops are cassava, cowpea, maize, groundnut and beans (Brobbe et al., 2019). Most crop farming is shifting cultivation where a succession of crops is cultivated for two or three years after which the land is left fallow for a number of years to regain its fertility. In more moist localities, plantain is cultivated together with other crops in a mixed cropping system. In recent years, perennial tree crops such as cashew and mango, and tree plantations for timber (teak), have become popular, and are becoming key sources of income (Evans et al., 2015). Many households are also involved in charcoal production, and incomes from charcoal sales are the second most important source of income after crops (Brobbe et al., 2019). The study area is one of the hotspots of charcoal production in Ghana (Nketiah and Asante, 2019). Cattle-rearing is gaining importance in the area leading to conflicts between farmers and herders over crop damage (Brobbe et al., 2019).

Methods

The study examines the spatial and temporal heterogeneity of land use and land cover (LULC) change. We adopted a research design driven by inductive logic in line with Parker et al. (2002), which established patterns of LULC dynamics from multi-site samples at three points in time: 1985, 2000 and 2016. The examination of multiple sites allows an analysis that reflects local dynamics and different patterns of LULC change that may be overshadowed in an analysis of a single site and a generalized LULC change pattern. The inductive reasoning was adopted in order to refrain from taking sides *a priori* on the various positions and opposing claims on the nature of LULC change, and to simply establish the LULC matrix from empirical observations. We assumed that we would see different LULC dynamics in different localities and periods of time. The study adopted a two-scalar analysis, based on spatial extent (Saura and Millan, 2001): broad scale (whole study area) and local scale (six (6) localities within the study area, cf. Fig. 1 and Table 3).

Landsat data of 1985, 2000 and 2016 was used for the change analysis (Table 1). The 15-year interval between images was considered adequate to capture general patterns of all LULC changes. This was conducted for a period of 30 years. The selection of the imagery was based on the need for quality images. Images from the late dry season (inception of raining) were used to avoid cloudiness, but allow for the detection of cleared and recently cultivated lands. Landsat images were freely downloaded from the United States Geological Survey (USGS) portal: <http://glovis.usgs.gov/>.

The images were radio atmospheric corrected using Fast Line-of-sight Atmospheric Analysis of Spectral Hypercube (FLAASH) (Feldel et al., 2003). The ENVI 5.3 automated modules and IDRISI Terrset were used for all processes and analysis. The 2016 images were used as

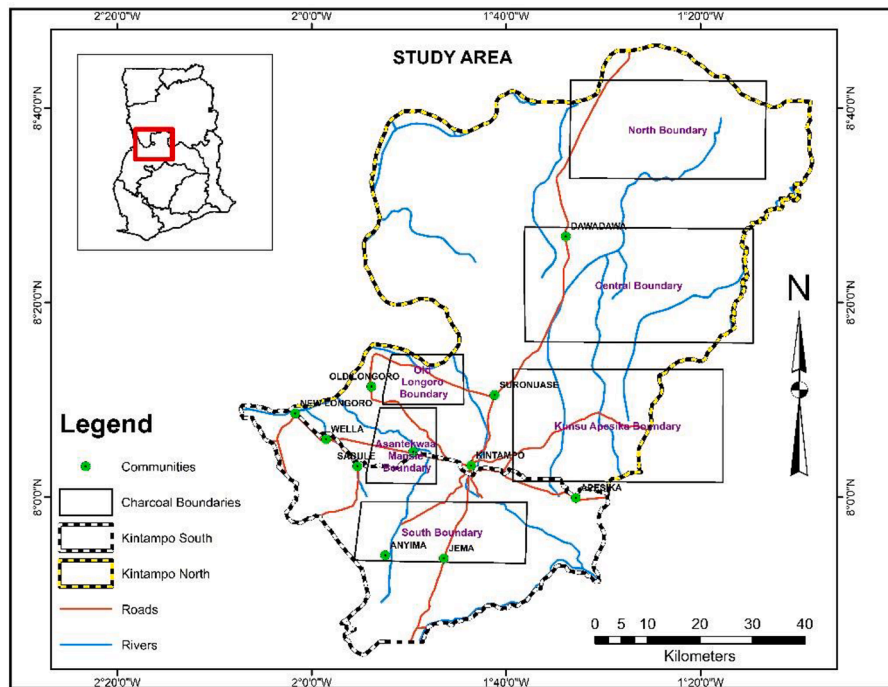


Fig. 1. The study area and local sites.

Table 1
Satellite data.

Data	Satellite	Acquisition date	Bands used	Spatial resolution
Landsat TM	Landsat	20–12–1985	1,2,3,4,5,7	30 m
Landsat TM	Landsat 7	30–03–2000	1,2,3,4,5,7	30 m
Landsat OLI	Landsat 8	06–02–2016	2,3,4,5, 6, 7	30 m

reference for the interpretation because ground truth samples were available for verification. Image interpretation began with an unsupervised classification procedure using Self-Organizing Data Analysis Technique (ISODATA) (Tou and Gonzalez, 1974). The output was used for the initial exploration of possible LULC classes. The LULC classification system was characterized floristically using *in situ* information obtained from ground truthing. The sampling involved the use of forty quadrats of 20 × 20 m, in all the LULC types. Trees and shrubs were manually counted, whereas height and canopy cover were estimated using manual methods, drone images and recent (including January 2016) high resolution Google Earth images. A GPS was used to locate quadrats in the LULC classes and plotted onto Google Earth images for verification purposes.

A hybrid (functional and structural) land use and land cover classification scheme was developed for the supervised classification. The scheme prioritized the need to generate information on the status and the dynamics of change among LULC classes through modification (quantitative/continuous), conversion(discontinuous/qualitative) and persistence processes. The scheme was structured with woody vegetation formations, fallows, crop lands and barelands/built-up, and had seven classes (Table 2 and Fig. 2).

The Maximum Likelihood Classifier Algorithm was used for the supervised classification. Maximum likelihood classifier returns the most likely outcome among candidates chosen, and has a well-developed theoretical foundation. It is used for normally distributed data, is statistically desirable and accommodates co-varying data: a common occurrence with satellite data. Finally, it has been proven to perform well over a range of cover types, conditions, and data of many satellite systems, including Landsat (Lillesand and Kiefer, 1987; Richards, 1986).

Table 2
LULC classification scheme used in the study.

LULC class	Description
Dense woodland (Dw)	Mature woodland vegetation. Tree heights range between 15 and 24 m. Canopy cover > 75%. Practically no agricultural use, but charcoal production and timber exploitation may be present. It includes some mature teak plantations (Fig. 2).
Open woodland (Ow)	Mature woodland vegetation. Tree heights are similar to Dw (15–24 m), but vegetation is less dense. Canopy cover is between 55% and 75%, with undergrowth of a mixture of bush. Farming of yam and cassava. Charcoal production and timber exploitation. It includes some mature teak plantations (less dense than Dw) (Fig. 2).
Long Fallow/Tree plantation (LFTp)	Mature (long) fallows and tree plantations, especially, teak. The tree heights are between 8 and 14 m. Canopy cover between 60 and 80%. No agricultural use. Charcoal production and timber exploitation may take place.
Medium fallow/Shrubs (MfSh)	This class consists of fallow lands with shrubs and tree plantations, especially of teak and cashew. Tree heights range between 4 and 7 m and canopy cover between 40 and 60%. There may be isolated, bigger trees dispersed. There may be crop production (yam, cassava, maize). Charcoal production on large commercial scale is rare. Women and children may engage in charcoal production or extract young trees and shrubs as fuel wood for domestic use.
Short fallow/Annual crops (SfAc)	This class includes bush land and farm land with matured crops. Height is 1,2 m. There may be isolated, larger trees and shrubs. Medium height grasses are present. The main crops are maize and cassava, and in some cases yam.
Young crops/Short grass (YcSg)	Recently cultivated crops and short grasses. Height of 1 m or less. Much of the soil is exposed. Short grasses also occur on lands with very thin soils (rock and gravel). The main crops are maize and cassava, and in some cases yam.
Built-up/Bareland (BuBl)	Buildings and other infrastructure, rocks surfaces and land that has been cleared for farming.



A. Dense woodland. These are regenerated on fallows and Farmlands. They are not remnants of virgin forest.



B. Open Woodland (Ow). This may recover to dense forest if undisturbed, or converted to any less woody cover types through slow extractive processes such as charcoal production and yam cultivation.



C. Medium and shrubs with yam cultivation. Some trees are killed and extracted for charcoal production, whereas others are left for staking yams. Future trajectory of cover development will be largely, determine by dominant land uses.



D. Permanent annual cropped land. Continuous cropping of the same land suppresses regeneration of woody vegetation.

Fig. 2. Land used and land cover types of the study area.

Classification accuracy test reference samples were selected by stratified random technique using IDRISI Terrset software. Ground truth data were geo-referenced in all LULC types, and complemented those generated by IDRISI. The pixels used to train the Maximum Likelihood algorithm were not used as test samples to ensure that the reference information was independent and unbiased. In line with (Congalton and Green, 2009), 60 test samples per category were considered a reasonable compromise, making a grand total of 420 samples. This is to compensate for the high within-LULC variability. The points were converted into vector shapes, and co-registered with the image (map) samples. Classification accuracy was calculated using the confusion matrix and the Kappa statistics (Afify, 2011).

We applied post-classification LULC change analysis in this study. It enables the determination of vector change of land-use/cover. The transfer of land categories during the research period, in the form of from-to transformation, conversion and persistence matrixes and images is a valuable advantage. However, it has the drawback of transferring errors from the separately classified images to the final change image. Therefore, as mentioned earlier, we conducted a comprehensive ground truthing for the verification and validation processes to ensure a high level of classification accuracy.

For the fine scale (local) analysis, we identified six sites within the

study area (Table 3 and Fig. 1). They were selected with the aim of sampling variations in rainfall, vegetation type and socioeconomic conditions within the study site. Some of the site marginally expands beyond the study site (cf. Fig. 1).

Results

Status and change in land use classes: broad and fine scale

The overall classification accuracies of 85.8%, 87.3% and 89.8% were reported for the 1985, 2000 and 2016 image classifications, respectively, whereas the Kappa statistics were: 84.73%, 85.26% and 86.40%, respectively. The LULC changes are reported for the whole study area, different localities and periods. The change processes of LULC transfers are presented in cross-tabulations, and a synthesis provided. The distribution of LULC classes for the entire study area and the localities in 1985, 2000 and 2016 are shown in Tables 4–6. Figs. 3 and 4. depict the vector change of LULC categories in different periods for the entire study area and the selected localities. For the whole study area, woodland categories: Dw, Ow and LfTp, in combination made up 63.60% of the total area in 1985. In 2000 and 2016, the total woodlands reduced to 44.00% and 40.30%, respectively. All the woodland types

Table 3
Overview of the sites used in the fine scale analysis.

Name of site	Size (ha)	Boundary	Description
Asantekwa-Mansie (AM)	17,350	8°08'45"N, 8°01'12"N, 1°48'08"W, 1°54'50"W	This area surrounds the important villages of Asantekwa and Mansie. It is a typical transitional zone landscape with some remnants of dry semi-deciduous woodlands on river banks. The area has been intensely cultivated as a result of easy access. It has a long history of charcoal production.
Apesika-Kunsu (AK)	84,722	8°15'08"N 8°01'44"N 1°17'38"W 1°30'17"W	This is located in the SE part of the study area. The vegetation is woodland with some distinct dry-semi-deciduous forest trees. The area is intensively farmed. Charcoal production appears to be on a relatively lower intensity at the southwestern section, especially in areas with a more pronounced semi-deciduous vegetation.
Central (CN)	939,589	8°26'51"N 8°16'08"N 1°14'49"W 1°38'06"W	The vegetation in this area is more Savannah like than the Apesika-Kunsu to the south. Vast areas have been converted into areas of permanent farming with intensive food crop production, especially areas close to the Kintampo-Tamale highway.
Northern (NO)	68,855	8°42'29"N 8°32'29"N 1°34'10"W 1°13'10"W	This is the most northern area and features a Savannah vegetation type. The vegetation close to the Black Volta is of a Shrub Savannah type, with short shrubs and grass. The soil is thin and gravelly in many localities.
Southern (SO)	36,194	7°59'30"N 7°52'11"N 1°38'34"W 1°56'02"W	This is the southernmost area with a woodland and dry semi-deciduous transitional vegetation, some of which are gallery in nature. This area hosts a number of protected forest reserves, many of which have been converted into tree plantations of teak. Farming is intensive, charcoal production is not.
Old Longoro (OL)	13,749	8°14'00"N 8°08'59"N 1°44'44"W 1°52'51"W	This location is less accessible than the other sites. On a long stretch it is bounded by the Volta river, and just below the newly constructed Bui dam. Many locations are waterlogged or rocky. The vegetation is largely woodland, with opened shrub Savannah. It is less intensively cultivated than many of the other sites. Hitherto, charcoal burning was less intense, but currently the area is becoming an important charcoal production area. The area is infested with black flies.

Table 4
Distribution of LULC categories (percent) across full study area and sub-locations in 1985.

LULC	Full Area	AM	AK	CN	NO	SO	OL
Dw	15.4	21.94	34.62	10.58	11.42	31.38	10.68
Ow	25.8	34.12	32.72	28.48	18.23	24.10	26.74
LfTp	22.4	22.03	17.54	34.42	27.15	19.58	33.59
MfSh	13.3	8.80	6.45	13.12	15.02	9.72	12.99
SfAc	9.5	5.89	4.18	6.64	10.04	6.47	7.60
YcSg	6.9	4.56	3.12	3.65	7.93	5.52	4.53
BuBl	6.5	2.66	1.38	3.11	10.20	3.22	3.88
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 5
Distribution of LULC categories (percent) across full study area and sub-locations in 2000.

LULC	Full area	AM	AK	CN	NO	SO	OL
Dw	7.9	4.59	32.97	0.84	2.25	22.55	1.40
Ow	16.2	34.00	42.13	14.90	14.11	46.27	9.07
LfTp	19.9	24.09	13.41	20.11	14.61	17.74	14.86
MfSh	16.1	18.56	5.03	17.52	23.63	7.64	22.46
SfAc	13.7	11.66	3.42	16.68	19.90	3.56	20.24
YcSg	17.5	6.46	2.38	21.99	19.39	1.65	22.64
BuBl	8.6	0.63	0.66	7.95	6.11	0.59	9.33
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 6
Distribution of LULC categories (percent) across full study area and sub-locations in 2016.

.LULC	Full area	AM	AK	CN	NO	SO	OL
Dw	6.2	6.64	14.80	7.32	2.37	9.95	8.46
Ow	17.0	26.12	40.26	18.53	4.58	39.88	15.16
LfTp	17.1	22.58	13.50	24.10	16.10	10.23	31.27
MfSh	18.5	24.24	18.37	17.08	18.17	24.66	23.84
SfAc	14.9	13.10	7.34	13.50	20.39	10.46	13.66
YcSg	16.4	5.86	3.91	12.05	21.18	3.50	5.90
BuBl	9.8	1.46	1.82	7.42	17.22	1.32	1.71
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

declined, but this was highest for Dw and Ow, especially, for 1985–2000. The coverage of MfSh, SfAc and YcSg increased between 1985 and 2000, with YcSg increasing by 151.1%. From 2000 to 2016, MfSh and SfAc the increase in coverage declined.

There was a decline in woodlands for the localities, with specificity in patterns across the localities and periods (Fig. 5). Woodland dropped significantly for the 1985–2016 period in all locations. There was a sharp decline in Dw from 1985 to 2016, with different patterns across the locations. Generally, a drastic decline occurred between 1985 and 2000 than 2000–2016. For MfSh, SfAc and YcSg, the general trend was a consistent increase in coverage, with two main patterns: AM, CN, OL and NO experienced a high increase in cultivated landscapes from 1985 to 2000, and a decline between 2000 and 2016. The SO and AK experienced relatively minor changes between 1985 and 2000, and major increases between 2000 and 2016.

Change processes and LULC transfers

The change transfers or processes among the LULC types were classified into three: (1) Transformation, a change from one cover type to a modified form of the original LULC; (2). Conversion is a change from one LULC category to an entirely new or different cover type, and (3). Persistence is where a LULC type found at the beginning of a period at a locality is the same type found at the end of the period. Different patterns of persistence, transformation and conversion occurred at different localities, and within periods.

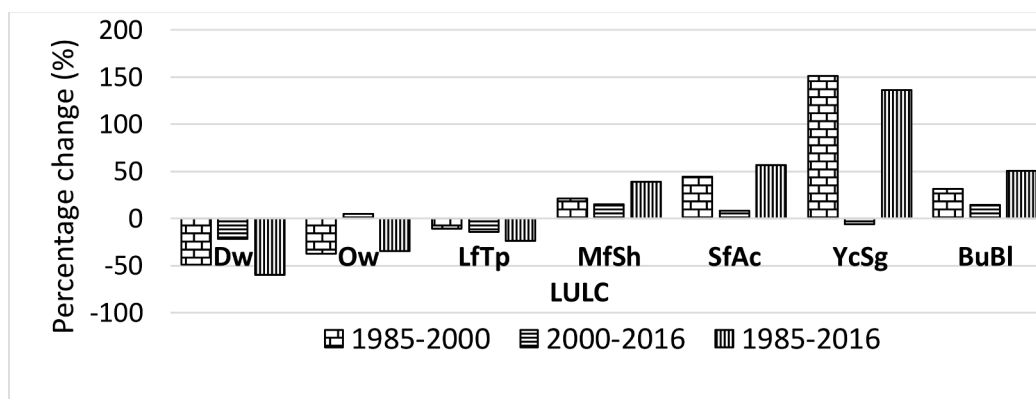


Fig. 3. Percentage vector change of LULC categories in different time periods, 1985–2000 and 2000–2016 for the Full study area.

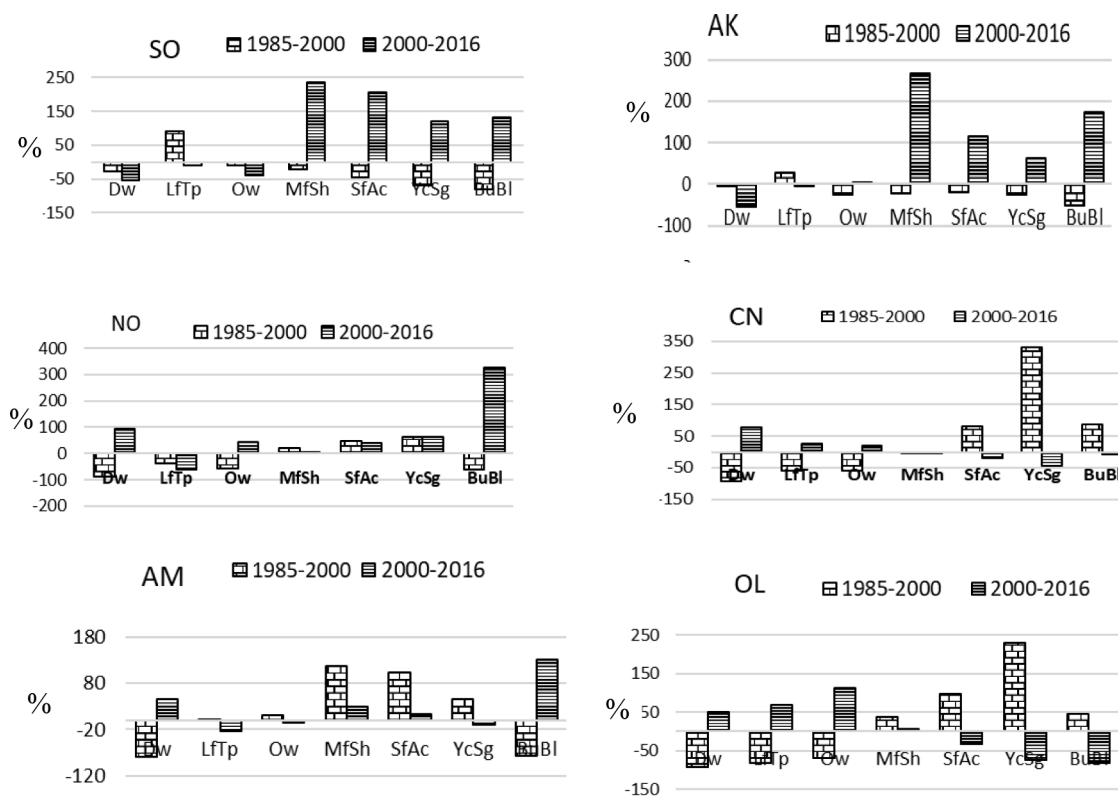


Fig. 4. Percentage vector change of LULC categories in different time periods, 1985–2000 and 2000–2016, at the local sites.

For the whole study area (Table 7), persistence of woody vegetation was higher in 1985–2000, than 2000–2016. Conversely, persistence of the SfAc and YcSg was higher for 2000–2016, than the earlier period (1985–2000). High proportion of the Ow and the LfTp were directly converted of SfAc and YcSg than the Dw. This was lower in the 1985–2000 period and higher in 2000–2016, resulting in expansion of farms into woodlands in recent years. Between 2000 and 2016 period, the woody vegetation experienced higher conversion to farmlands and fallows. However, the fallows and cropped areas simultaneously experienced both regeneration to woody vegetation and conversions to new farms and fallows than 1985–2000. Extensive farmed and short fallow lands persisted in 2000–2016 period. In both 1985–2000 and 2000–2016, more Ow and the LfTp were converted to fallows and farms than the Dw. Between 2000 and 2016, greater proportions of fallows and farms were transformed into similar cover types than in 1985–2000 (Table 7).

Local change processes and LULC transfers

Persistence (Unchanged)

Persistence made contributions to different LULC categories in all the localities for the two periods (Table 8). Generally, the woody vegetation types experienced the highest proportional persistent coverage than the young fallows and cropped lands for the two periods. In 1985–2000, persistent woody vegetation coverage was higher than the 2000–2016 period for many localities. Old Longoro experienced a converse pattern of persistence (Table 4). The following were records for two localities: AK: 1985–2000 (35.90%), 2000–2016 (26.00%) and SO: 1985–2000 (37.00%), 2000–2016 (23.40%). Conversely, from 2000 to 2016, high coverage of farms and cultivated lands persisted than in 1985–2000.

Largely, there was an inverse relation between the level of persistence of the woodier LULC (Dw, LfTp and Ow) on the one hand, and the SfAc and YcSg, on the other (Table 8). That is, when a large coverage of woodland existed, lower coverage of young fallows and farmed areas

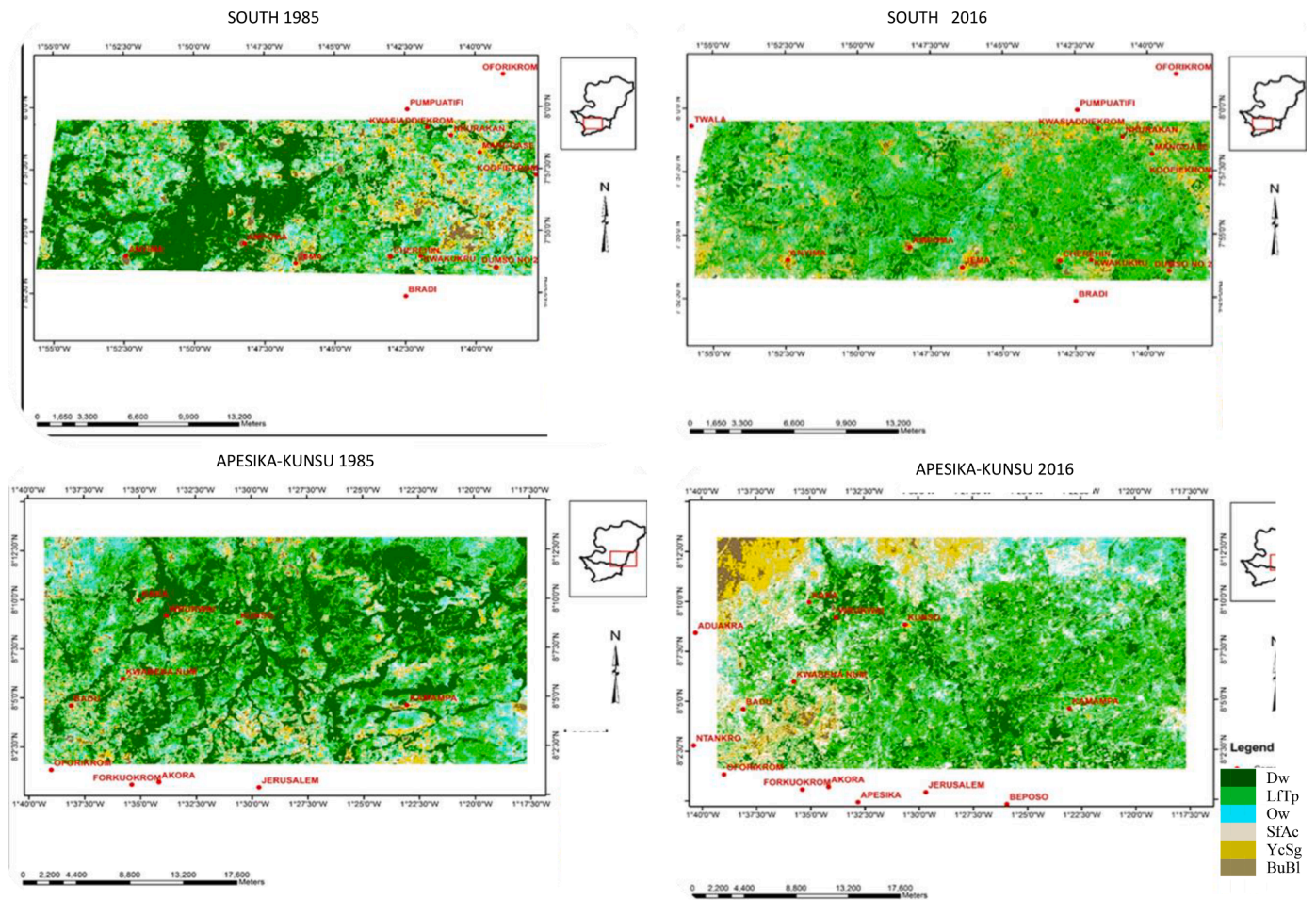


Fig. 5. Illustrations of LULC, indicating different coverages in South and Apesika-Kunsu in 1985 and 2016.

Table 7
Broad LULC change processes for the two periods.

		2000							2016										
1985	LULC	Dw	LfTp	Ow	MfSh	SfAc	YcSg	BuBl	Total	2000	LULC	Dw	LfTp	Ow	MfSh	SfAc	YcSg	BuBl	Total
		Dw	3.70	1.93	1.14	0.42	0.27	0.22	0.13		7.81		Dw	1.57	1.76	0.86	0.57	0.49	0.57
	LfTp	5.00	6.78	4.72	1.78	1.11	0.94	0.56	20.90		LfTp	3.92	6.49	2.79	1.57	1.25	1.36	0.38	17.76
	Ow	2.36	4.42	4.62	1.81	1.19	0.95	0.76	16.11		Ow	0.55	3.06	3.05	2.73	2.47	3.44	1.36	16.65
	MfSh	1.64	3.37	4.78	2.25	1.47	1.10	0.95	15.56		MfSh	1.19	5.05	3.62	2.90	2.12	2.60	1.06	18.54
	SfAc	1.10	2.59	4.04	1.89	1.41	1.04	1.01	13.09		SfAc	0.33	2.73	2.79	2.95	2.17	2.51	1.09	14.58
	YcSg	1.19	2.77	5.47	2.91	2.31	1.61	1.93	18.20		YcSg	0.11	1.37	2.14	3.20	2.84	4.71	2.36	16.73
	BuBl	0.42	0.89	2.13	1.37	1.22	0.86	1.47	8.35		BuBl	0.08	0.34	0.84	1.70	1.74	3.05	2.04	9.78
	Total	15.40	22.77	26.90	12.43	8.97	6.72	6.82	100.00		Total	7.74	20.81	16.08	15.62	13.08	18.23	8.42	100.00
1985-2000										2000-2016									

persisted and vice-versa. For instance, in 1985–2000, when the combined coverage of persistent woody vegetation in SO was 15.85%, the combined coverage of SfAc and YcSg was 1.22%. In contrast, in 2000–2016, when the persistent woody LULC decreased to 10.03%, the persistent coverage of farmed and fallow lands increased to 2.64%. With the exception of the NO, all the sites displayed this pattern (Table 8, refer to Table 7).

Regeneration processes: spatial and periodic

The Dw, Ow and LfTp formations experienced transformation amongst themselves during the two periods (Tables 7 and 8), resulting in regeneration to different extent for localities and periods. Transformation dominated the woody landscape when the highest pre-existing coverage of woodland existed. It was the key process that

generated woody vegetation types, especially, in 1985–2000, when woody vegetation coverage was higher in 1985. To illustrate, for 1985–2000 period, SO was (22.10%), AK (22.46%) and Apesika (17.75%), whereas the 2000–2016 were: SO (17.17%), AM (18.00%) and AK (15.23%). Generally, transformation from LfTp made the highest contributions to Dw and Ow vegetation for all the two periods in all the localities.

Conversion processes from SfAc and YcSg to woody formations (Dw, LfTp and Ow) resulted in regeneration (Table 8). The proportion of SfAc and YcSg that converted to woodland was higher in 2000–2016 than 1985–2000. Thus, where existing woody vegetation is low, high amounts of woody recovery occurs on previous abandoned farmed and fallow lands, rather than on pre-existing woodlands. This was,

Table 8
Local LULC change.

AM 2000									AM 2016										
LULC	Dw	LfTp	Ow	MfSh	SfAc	YcSg	BuBl	Total	LULC	Dw	LfTp	Ow	MfSh	SfAc	YcSg	BuBl	Total		
AM 1985	Dw	2.03	0.40	0.20	0.21	0.21	0.17	0.04	3.27	AM 2000	Dw	1.17	1.37	0.87	0.67	0.56	0.47	0.33	5.43
	LfTp	7.21	5.68	3.48	3.19	3.01	2.67	1.39	26.63		LfTp	6.75	4.97	3.80	2.75	1.90	1.27	0.64	22.08
	Ow	2.70	3.76	3.74	3.37	3.22	3.69	2.75	23.23		Ow	1.74	2.55	3.42	4.14	3.93	3.37	2.02	21.15
	MfSh	1.43	2.48	3.22	3.18	3.44	3.61	3.75	21.11		MfSh	2.76	3.38	3.45	3.55	3.70	3.79	3.47	24.09
	SfAc	0.63	1.35	2.22	2.35	2.55	2.57	3.28	14.95		SfAc	1.24	1.41	1.86	1.98	2.53	3.05	4.04	16.11
	YcSg	0.27	0.58	1.34	1.75	1.64	1.41	2.42	9.40		YcSg	0.52	0.49	0.71	0.97	1.35	1.88	2.57	8.48
	BuBl	0.01	0.03	0.10	0.24	0.21	0.16	0.66	1.41		BuBl	0.10	0.12	0.19	0.23	0.33	0.45	1.22	2.64
	Total	14.29	14.29	14.29	14.29	14.29	14.29	14.29	100.00		Total	14.29	14.29	14.28	14.29	14.29	14.29	14.29	100.00
	CE 2000										CE 2016								
LULC	Dw	LfTp	Ow	MfSh	SfAc	YcSg	BuBl	Total	LULC	Dw	LfTp	Ow	MfSh	SfAc	YcSg	BuBl	Total		
CE 1985	Dw	0.35	0.18	0.10	0.06	0.04	0.02	0.04	0.78	CE 2000	Dw	1.32	1.34	1.22	1.09	1.00	0.84	0.60	7.41
	LfTp	3.15	2.58	2.00	1.50	1.40	1.98	2.23	14.83		LfTp	4.54	3.65	3.15	2.59	2.39	2.03	1.73	20.06
	Ow	3.00	2.84	2.70	2.47	2.13	2.55	3.24	18.93		Ow	1.92	3.13	3.24	3.07	3.37	3.82	4.61	23.17
	MfSh	2.21	2.32	2.50	2.63	2.25	2.17	2.24	16.33		MfSh	3.37	2.62	2.70	2.63	2.29	2.06	2.29	17.96
	SfAc	1.85	2.12	2.41	2.67	2.52	2.20	2.06	15.82		SfAc	2.06	1.99	1.97	2.22	2.07	1.69	1.43	13.43
	YcSg	2.21	2.28	3.11	3.93	4.18	3.82	3.29	22.81		YcSg	0.99	1.21	1.41	1.80	1.93	2.10	1.88	11.31
	BuBl	0.52	0.59	1.02	1.72	2.44	2.23	1.97	10.50		BuBl	0.07	0.34	0.60	0.91	1.23	1.75	1.76	6.66
	Total	13.29	12.92	13.84	14.98	14.95	14.97	15.05	100.00		Total	14.29	14.29	14.29	14.29	14.29	14.29	14.29	100.00
	NO 2000										NO 2016								
LULC	Dw	LfTp	Ow	MfSh	SfAc	YcSg	BuBl	Total	LULC	Dw	LfTp	Ow	MfSh	SfAc	YcSg	BuBl	Total		
NO 1985	Dw	0.68	0.37	0.19	0.13	0.10	0.09	0.10	1.65	NO 2000	Dw	1.00	0.49	0.36	0.28	0.23	0.26	0.14	2.76
	LfTp	3.93	2.87	2.18	1.64	1.21	1.32	1.72	14.87		LfTp	2.46	1.20	0.67	0.60	0.42	0.47	0.46	6.28
	Ow	2.49	2.48	2.35	2.14	1.83	1.47	1.89	14.64		Ow	5.07	4.52	3.02	2.14	1.47	1.51	1.86	19.58
	MfSh	3.49	3.76	3.73	3.73	3.58	3.33	2.51	24.13		MfSh	2.80	3.87	3.80	2.73	1.93	1.60	1.60	18.34
	SfAc	1.72	2.64	3.07	3.21	3.34	3.62	2.67	20.27		SfAc	1.31	2.88	3.60	3.08	2.79	2.43	1.80	17.88
	YcSg	1.02	1.84	2.66	2.91	3.11	3.39	3.40	18.33		YcSg	0.50	1.19	2.30	3.19	3.70	4.13	4.65	19.67
	BuBl	0.66	0.52	0.63	0.73	0.91	0.98	1.67	6.11		BuBl	1.15	0.14	0.54	2.25	3.74	3.89	3.78	15.50
	Total	13.99	14.48	14.80	14.49	14.08	14.20	13.96	100.00		Total	14.29	14.29	14.29	14.29	14.29	14.29	14.29	100.00
	SO 2000										SO 2016								
LULC	Dw	LfTp	Ow	MfSh	SfAc	YcSg	BuBl	Total	LULC	Dw	LfTp	Ow	MfSh	SfAc	YcSg	BuBl	Total		
SO 1985	Dw	5.61	2.86	2.04	1.66	1.50	1.44	1.03	16.15	SO 2000	Dw	2.27	1.33	1.03	1.04	0.88	0.92	0.06	7.53
	LfTp	5.66	7.35	7.31	6.96	6.67	6.29	5.49	45.72		LfTp	7.59	6.04	4.62	3.77	2.85	1.70	0.14	26.71
	Ow	1.75	2.48	2.92	3.20	3.39	3.46	2.91	20.12		Ow	1.02	1.59	1.72	1.65	1.31	1.00	0.22	8.51
	MfSh	0.74	1.01	1.22	1.43	1.57	1.65	1.43	9.04		MfSh	2.48	3.64	4.20	4.11	4.04	3.14	0.56	22.16
	SfAc	0.35	0.41	0.54	0.70	0.77	0.88	0.90	4.54		SfAc	0.68	1.27	1.92	2.55	3.28	3.50	1.23	14.43
	YcSg	0.16	0.16	0.22	0.30	0.33	0.46	0.92	2.53		YcSg	0.19	0.33	0.61	0.86	1.36	2.74	5.36	11.45
	BuBl	0.01	0.02	0.04	0.05	0.06	0.11	1.62	1.91		BuBl	0.06	0.09	0.18	0.30	0.58	1.28	6.72	9.21
	Total	14.29	14.29	14.28	14.29	14.29	14.29	14.29	100.00		Total	14.29	14.29	14.29	14.29	14.29	14.29	14.29	100.00
	OL 2000										OL 2016								
LULC	Dw	LfTp	Ow	MfSh	SfAc	YcSg	BuBl	Total	LULC	Dw	LfTp	Ow	MfSh	SfAc	YcSg	BuBl	Total		
OL 1985	Dw	1.23	0.06	0.02	0.02	0.01	0.00	0.00	1.35	OL 2000	Dw	10.88	1.94	0.73	0.65	0.81	1.12	2.22	18.36
	LfTp	1.53	1.10	0.98	0.79	0.71	0.61	0.30	6.01		LfTp	1.95	2.95	2.06	1.85	2.13	2.02	2.81	15.78
	Ow	1.66	1.72	2.12	2.34	2.64	2.64	1.40	14.52		Ow	0.66	3.85	4.34	4.23	4.46	4.90	5.41	27.84
	MfSh	2.65	2.71	3.14	4.34	5.18	5.21	4.19	27.42		MfSh	0.64	3.91	4.26	4.01	3.30	2.96	1.84	20.92
	SfAc	1.95	2.62	2.84	3.09	3.51	3.92	4.18	22.11		SfAc	0.13	1.29	2.05	2.31	2.33	1.99	0.95	11.05
	YcSg	1.53	2.73	2.91	3.53	3.36	2.97	4.44	21.46		YcSg	0.03	0.30	0.72	1.02	1.03	0.92	0.62	4.64
	BuBl	0.32	0.96	1.54	1.04	0.70	0.68	1.92	7.14		BuBl	0.00	0.05	0.12	0.22	0.23	0.37	0.43	1.42
	Total	10.87	11.89	13.54	15.14	16.11	16.02	16.43	100.00		Total	14.29	14.29	14.29	14.29	14.29	14.28	14.29	100.00

especially, true of regeneration of woody vegetation on MfCp: it was a key landscape where woody regeneration prevailed in a situation where landscapes were dominated by immature fallows and farms.

Deforestation & degradation processes

Both transformation and conversion for the two periods led to deforestation (total conversion of woody vegetation into young fallows and farms) and degradation (modification from Dw and LfTp into lower tree density formation (Ow)) (Table 8). For many localities, degradation of Dw was higher in 2000–2016 than 1985–2000. However, the percentage coverage was usually low. Conversion process occurred during both 1985–2000 and 2000–2016 in all localities. The conversion from woody vegetation to farms and fallows: namely, Dw, LfTp and Ow to SfAc and YcSg was generally higher in 1985–2000 than 2000–2016, particularly, for the SO, AK and AM (Table 8). For instance, in 1985–2000, a total of 8233.00 ha of Dw, LfTp and Ow were converted to SfAc and YcSg, whereas 3133.00 ha occurred in 2000–2016 in SO. The

following conversions in these localities exemplify this common pattern: AK (1985–2000), 20,581.00 ha, AK (2000–2016), 11,440.13 ha and CE (1985–2000) 76,227.00 ha, CE(2000–2016), 126,393.50 ha. Between 2000–2016, where reduced amounts of woody landscapes existed, MfSh was the major LULC converted to farms than woody vegetation (Table 8).

Synthesis: spatio-periodic state and process framing of LULCC

The change and transfer processes among LULC types could be synthesized, and conceptually framed as shown in Fig. 6. Spatio-periodic deforestation, degradation and recovery processes on the landscapes can be gradual or abrupt; long or short; single or multi-stage; progressively linear and feedback sequence of determines persistence, conversion and transformation mechanisms. Antecedent landscape LULC state determined the configuration and number of stages, intensities,

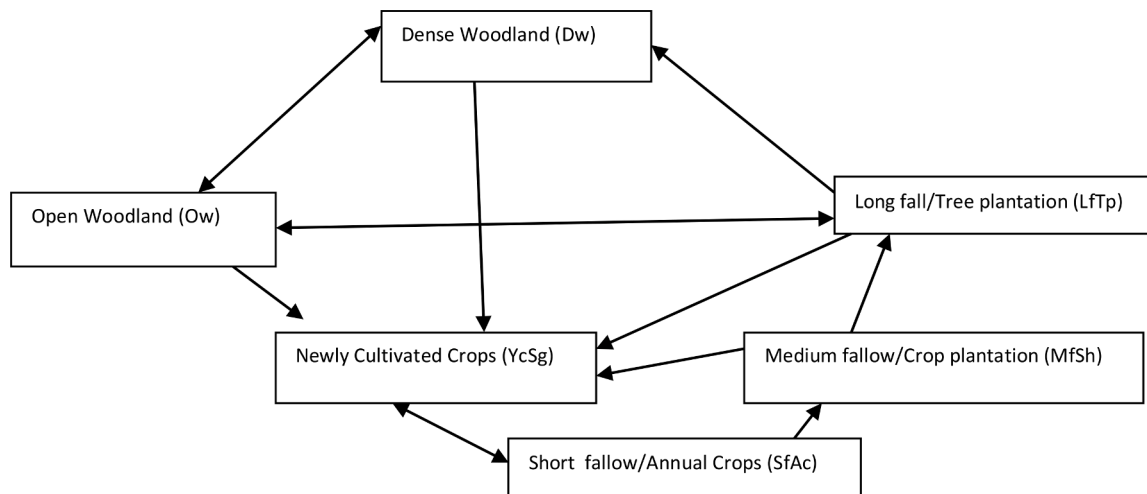


Fig. 6. Conceptual framing of LULCC processes that generated all LULC types. The length of processes, number of stages and feedbacks are involved in generating different LULC types (Pabi, 2021).

direction and dominance of the change processes. Woody vegetation regeneration is rapid when a landscape is dominated by pre-existing woody formations, with minor coverage of young fallows and farms, at the beginning of a period; and lowest when the landscape is initially dominated by short fallows and farmlands. When woody LULC types dominated, transformation and persistence among them resulted in rapid restoration of woody formations within a shorter period. Conversely, landscape dominated by fallows and farms, experienced high levels of persistence and transformation processes on these landscapes, resulting in suppression of regeneration and low level of conversion or restoration to woody vegetation on these landscapes. Thus, regeneration from SfAc and YcSg to Dw would be slow, long and highly multi-stage and multiple processes than that which occurred on LfTp. This will involve the processes of conversions, transformation and persistence. However, on LfTp landscape, change to Dw is a short and one-stage process of transformation.

Discussion

The simultaneous application of multi-scalar, periodic and multi-site analyses have unearthed insights into LULCC dynamics that contribute to the resolution of the nature of vegetation change debate. It expands the perspectives of the periodic and spatial dimensions of LULCC heterogeneity discourse of the tropical African landscape (Guyer et al., 2007; Amanor and Pabi, 2007; Lambin and Geist, 2006). The research methodology and findings provide a framework and basis for designing an explanatory research to explain underlying unique processes of change at distinct localities and periods. This should be based on an assumption of spatio-temporal heterogeneity of LULCC of the landscape. The choice of classification scheme allowed the identification of natural sequential change of LULC categories along a continuum, and the construction of LULCC process in the area (Defries et al., 2002). There were few practical methodological challenges, though, but these were satisfactorily addressed. The barelands and the built-up areas were practically impossible to separate since many villages were constructed with houses of mud bricks and grass roofing materials. These categories were merged. This was of limited coverage, and scarcely highlighted in the results and the interpretation sections for drawing conclusions in the study.

Change within LULC types

The forest-Savanna transitional landscape of the Kintampo area has been dominated by different configuration and coverage of LULC types

at different locations and times. These states of LULC types have evolved through a complex non-linear process of LULCC, which are periodic and spatially unique. Land use and land cover change was a common phenomenon, but with variations in nature and quantum across periods, extent and location. Similar cover change has been reported in Amazon forest (Dias et al., 2016). In West Africa, the extent of arable fields and fallows was reportedly increased from 580 km² in 1972 to 2870 km² in 2001 (Wittig et al., 2007), an observation which agrees with findings of this study. Though, a similar observation were made in earlier studies, they were based on single period analyses (Nolte et al., 2013; Pabi, 2007; Soares-Filho et al., 2014). Studies designed to capture multi-periodic LULC dynamics are rare, especially in the West African Sub-region. A West African report by FAO (2010), indicated that a forest reduction at an earlier period, 1990–2000, was higher than that of the later period (2000–2010), which is similar to that found in this study. In this study, the rate of woody vegetation loss was higher in the earlier period (1985–2000), than the later (2000–2016). The reason is that in the later period, woodland available for exploitation was highly reduced.

The specificity of within periodic LULCC patterns indicates that making generalized conclusions based on a single periodic analysis will be misleading, since it masks the unique temporality of LULCC patterns. Policy interventions informed by such assumed temporal homogeneity of change in LULC and forecast would be flawed. It would ignore the time-dependence of contextual realities of LULCC dynamics, and the configuration of associated unique drivers of change. Therefore, analysis of socio-ecological drivers and events within the context of environmental change (Stephenson et al., 2010), must be based on multiple and shorter periodic frames to unearth contextual patterns.

Differences in the status and process patterns of LULCC that emerged at different periods, extents and locations confirm the complex nature of LULC change dynamics and the underlying processes at nested scales (Defries et al., 2010; Vayreda et al., 2012; Bryan et al., 2013). Through a qualitative study, the landscape of the Kintampo area has been observed to be subjected to multiple land uses of farming and charcoal production (Amanor and Pabi, 2007). This may have to be verified by quantitative studies. Other studies have found differences in based on nested spatio-temporal scales of socio-ecological landscapes (Allen et al., 2014; Huntingford et al., 2013).

Persistence, transformation and conversion processes

The transfer among LULC types by persistence, transformation and conversion shaped emergent patterns of different LULC types at different localities and periods. Certainly, the mechanism of the LULCC is a

complex pattern of multi-dimensional, non-linear and feedback processes, rather than simple and linear phenomenon. The observed change processes of conversion, transformation and persistence that occurred in different combinations and relative quantum at different localities and periods have been observed by *Ojima and Moran (2004)*. Studies have reported of the conversions of woody vegetation to farms (*Gasparri, et al., 2008; Oueslati and Bellon, 2015*), and recovery of woody vegetation on farmed and fallow lands. In many studies, however, findings are dominated by the conversion of forest and woodland to farms and fallows (*Curtis et al., 2018; Aleman et al., 2018; FAO, 2010*).

The low proportions of LULC types that persisted indicate that the large proportions of all LULC types that existed at the end of each period were not remnant of what existed at the beginning of the periods (*Tables 7 and 8*): they were products of transformation and conversion processes that occurred in different cover types, including fallows and cropped lands, over the periods. This contradicts the dominant narrative that dense woody vegetation that exists on landscapes of different times and localities are remnants of so-called “primary”, “virgin” and “pristine” forest, preserved over several decades or centuries (*Baseler 1932; Jones, 1945; Brown and Lugo, 1990*). *Fairhead and Leach (1996)*, also made a contradictory observation to this claim, though without proving with quantitative data. Further analysis of extended time interval should be conducted to fully resolve the debate of whether there are forest landscapes which have not been subjected to human influences (*Corlett, 1994; Rouvinen and Kouki, 2008*). Without conclusive resolution, the dominant narrative of a linear process of deforestation and degradation could discourage management regimes based on natural regeneration in favor of plantations of exotic and single-species tree plantation.

This study shows that woody vegetation regeneration mostly occurs on landscapes dominated by pre-existing woody vegetation formations, through transformation. Again, farming also takes place, largely, on pre-existing woody landscape through conversion, where woodland is in abundance. As woody vegetation cover decreases, recently abandoned farmed areas and young fallow fields become sites of both recovery of woody vegetation and farming activities. The short-period LULCC cycle involving young fallow, medium fallows and farmlands suppresses the recovery of woodland. Thus, whereas high coverage of woody vegetation facilitates a rapid restoration of woody vegetation, a landscape dominated by farms and young fallows sustains a positive feedback process that maintains fallow-farms formation.

From the conceptualized framing of woody vegetation regeneration (*Fig. 6*), the process of regeneration on recently abandoned lands with no or limited woody coverage will involve multiple stages of conversion, transformation and persistent processes. This will take a longer period, than would have occurred on woody landscapes. If land uses destructive of vegetation occur on short fallows and recently abandoned farmed areas, a positive feedback loop process will suppress woody vegetation regeneration. This will mean shortage of wood-based resources, with negative implications for associated livelihoods such as charcoal production. Consequently, management of the landscape must ensure that adequate woody vegetation is maintained on the landscape to facilitate woody vegetation recovery.

Conclusion and implications for woody resources

The study made a multispatio-periodic analysis of LULCC patterns and processes, to provide evidence for settling the debate on the nature of the evolutionary patterns of LULCC. The outcome advances the broader concept of the spatio-temporal heterogeneity of the African landscape. The evidence indicates periodic and spatial differentiations in LULCC. Land use and land cover change process was characteristically non-linear: there were multiple feedback processes at different extent, periods and locations, whose outcomes are unpredictable. Different configuration of multiple mechanisms of transformation and conversion among LULC types resulted in emergent land LULC patterns at different localities and periods. These must premise the design of explanatory

study that investigates the underlying socio-ecological agents and processes that shape the unique patterns of LULCC in space and different periods.

Changes in vegetation patterns for different periods varied. Hence, policy and academic discourse should not generalize the periodic patterns of LULCC, since it has the potential to obscure the temporality of events and processes that drive LULC change. Locally, different mix of LULCC processes contributes to the emergence of different LULC status. Hence, a spatially generalized LULCC discourse is not supported by evidence. The configuration and relative importance of the processes of persistence, transformation and conversion determined the emergent LULC patterns: persistence made a limited contribution to existing woody vegetation, whereas transformation contributed the highest proportion. Thus, dense woody vegetation in the area were not remnants of long preserved ‘virgin’ woodland, but a products regeneration processes pre-existing degraded woodland and fallows, within the period investigated. Further studies of a much longer and many periodicity must be conducted to conclusively answer the question of whether dense vegetation cover have never been influenced by humans.

Although all the LULC types have regenerative potential, the rate of restoration of woody vegetation is positively related to the amount of pre-existing woodiness, all things being equal. Thus, pre-existing woody formations promotes rapid woody vegetation restoration, whereas recovery process on fallow-dominated lands is slow, long and multi-stage. Hence, short fallow lands are progressively becoming dominant, with reduction in woodland coverage, as farming dominates the landscape, with resultant suppression of woody vegetation regeneration. To ensure that woody vegetation is restored and maintained, land-use management practices should maintain woody vegetation on the landscape, in order to facilitate the process of regeneration of woody vegetation. This will ensure availability of woody resources and carbon sink capacity, restoration of soil fertility, and maintain ecosystem functions, services and health.

Declaration of Competing Interest

The authors, hereby, unreservedly declare no conflict of interest in the study and manuscript writing.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.tfp.2021.100144](https://doi.org/10.1016/j.tfp.2021.100144).

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