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Implications of some major human-induced activities on forest cover using extended change matrix quantity and intensity analysis based on historical Landsat data from the Kloto District, Togo

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A R T I C L E I N F O

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A B S T R A C T

This study analyses forest reference level in terms of loss, gain and transitions among forest, cocoa agroforestry, cassava, maize, settlement and others in the Kloto district (Togo) for REDD+ and sustainable forest and agriculture. The pixel-based classification was adopted and combined with the extended change matrix quantity and intensity analysis using 32-year (1985–2017) Landsat data and land use information from land owners and farmers. Results indicate an active forest loss (19.5%) with dormant gain (0.8%). Forest is involved in most transitions as the most targeted category with the largest transition being a forest to cocoa agroforestry while the avoiding transition was from forest, cocoa agroforestry, maize, cassava and settlement to unclassified classes (e.g. road, water body) and vice versa. Other targeting categories were from forest to settlement, cassava and maize Thus, both cash and food crops are major contributors of forest loss. The study concludes that cropland land degradation is the main reason that explains the significant conversion of forest lands to stable agricultural lands. Therefore, review of the existing cropping and farming systems by promoting agroecology systems (e.g. agroforestry, rotational cropping, mixing cropping with pulses) to sustain and restore soil degradation while mitigating climate change, forest degradation and provide food security for the rural communities is recommended. Economic measures such as: trade-off compensations for agroecology practices and afforestation and reforestation through farmer's association initiatives could be encouraged to limit forest extensions.

1. Introduction

The deliberate conversion of tropical forests to agricultural lands, intensive deforestation, and forest degradation and inappropriate land management practices are the major impediment to forests and soil carbon sequestration potential (Denman et al., 2007; Lal, 2008a,b; Stockmann et al., 2013; Koglo et al., 2016, 2017) in changing climate. According to Valentine et al. (2000), forests have a remarkable ability to store carbon in both plants and soils and they are valuable natural break and sinkers of atmospheric carbon dioxide. The largest source of GHG emissions in most tropical countries is from deforestation and forest degradation. Fearnside and Laurance (2003) and Houghton (2005) investigation on tropical deforestation revealed that 1–2 billion tonnes (roughly 15–25% annual global greenhouse) of carbon are being lost per year since 1990's. Lasco (2002) also posited that land use change and forest conversion are a significant source of CO_2 contributing to around 1.7 ± 0.6 Pg C per year (e.g., Parks and Hardie, 1995; Plantinga and Birdsey, 1995; Callaway and Mccarl, 1996; Stavins, 1999; Kanime et al., 2013). Besides, land use change (e.g. forest to agricultural and non-agricultural lands) is one of the primary drivers of climate change and global warming (e.g., changes in albedo and radiative forces) with serious environmental and socioeconomic concerns. Following this background, in Togo, close analysis of available statistics on greenhouse gas emissions revealed significant released

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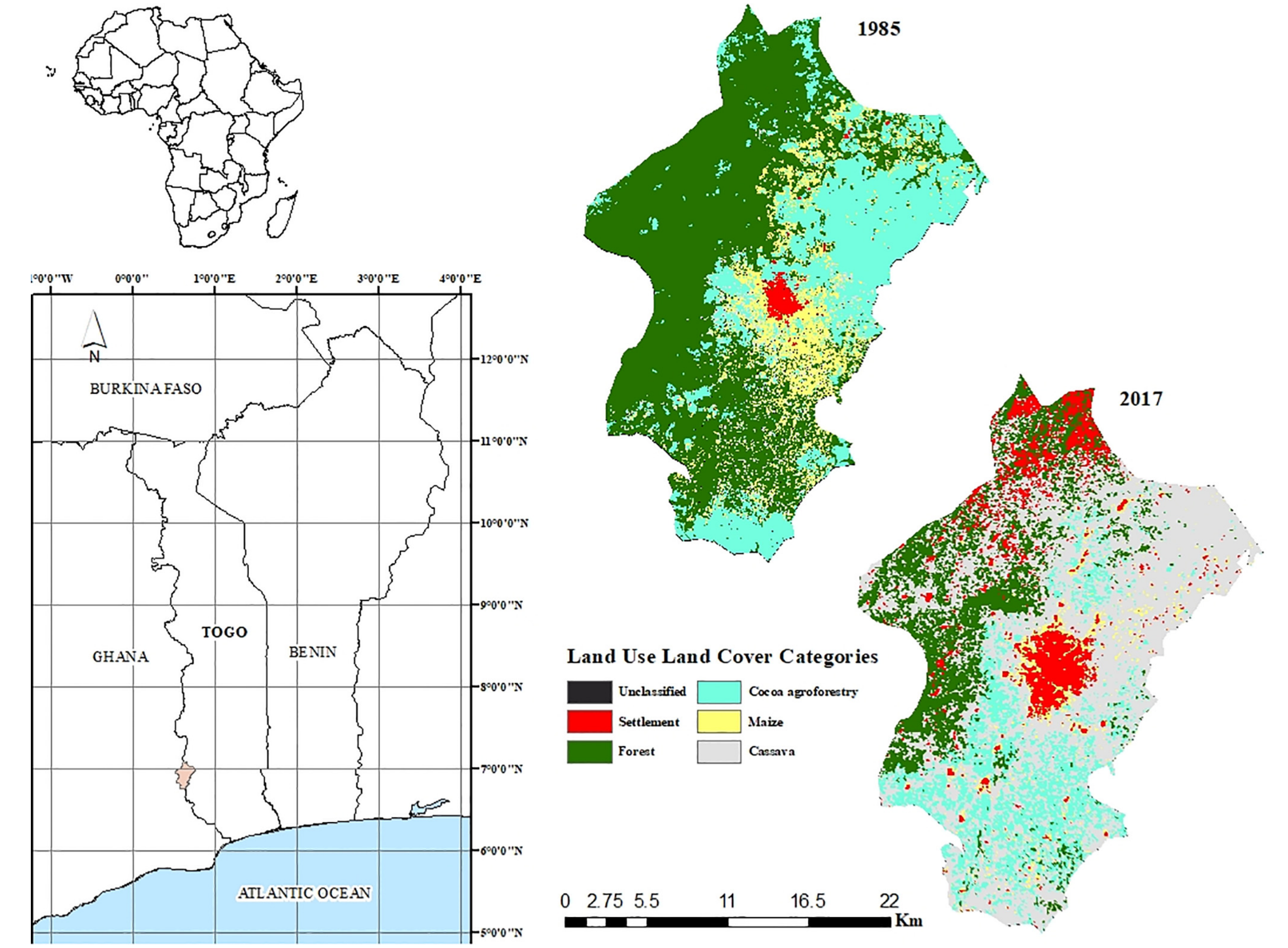


Fig. 1. Land use land cover map of the study area.

from land use change (forest to agriculture) compared to energy, industry, and waste management sector (MERF, 2001). This crucial step is paramount for the implementation of precautionary measures to mitigate the emissions resulting from forest conversion to agriculture lands. Thus, it urges to answer following questions related to the changes, viz: when? (period and identification of the changes via remote sensing and GIS technology), how much? (referring to the significance of the changes), where? (locations) moreover, what to do? (what necessary and sustainable decision or measure to make). Knowing the initial time (time 1) and the transition time (time 2), change detection (pixel, area or percent of the map) analysis or transition matrix analysis can be performed to account for the net changes for each land use type from time1 to time 2. However, this method fails to account for the likelihood gains and losses of a category from one location to the other. Moreover, it does not inform on the intensity of the changes (targeted/avoided and active/dormant categories) as well as the swap change (the difference between the total change and net change or spatial relocation), swap distance and persistent land use category (Pontius et al., 2004). Thus extended cross-tabulation matrix analysis combined with the intensity of gains and losses and transition intensity accounts for allocation changes based on land cover change signals. It is against this background that, scientific communities and policy makers have given credit to driven forces of deforestation and forest degradations projects and researchers to limit forest depletion and degradation. The role of forests in a changing climate is of utmost importance to meet the requirements of sustainable development goals. Diminishing emission from deforestation and forest abasement; protection of timberland carbon stocks; sustainable management of forests and improvement of forest carbon stocks (REDD+) have turned into the major theme of environmental change discussion. For instance, the 2030 Agenda for Sustainable Development and the Development Goals and the United Nations Strategic Plan for Forest (UNSPF) 2017 – 3030 made and bold an ambitious commitment to halting deforestation in 2020 by reversing the loss of forest cover and increasing forest area by 3% (www.cpfweb.org). REDD+ does not only rolls back climate change but also proffers additional co-benefit in response to food security, conservation of nature and improvement of socio-economic livelihoods of rural and poorest communities that are likely to experience the adverse effects of climate changes. Accordingly, the main question to ask is how much forest changes and at which rates? and what are the impacts of anthropogenic activities on forests carbon loss or gain in Kloto district (Togo)? Several studies have been carried out on land use, land cover changes from one period to another (e.g., Han et al., 2009;Munsi et al., 2010; Badjana et al., 2014; Folega et al., 2014; Sambou et al., 2015; Diwediga et al., 2017), intensity analysis and its implications on carbon cycle (e.g., Pontius et al., 2004; Manandhar et al., 2010; Aldwaik and Pontius, 2012; Runfola and Pontius, 2013; Villamor et al.,2014). However, little is known about the differentiation of food and cash crops extent (e.g. maize, cassava and cocoa agro-forestry) and the extent of urbanization (population growth). Moreover, these studies fail to integrate historical land occupation information and the extended quantity and intensity analysis. It is, therefore, a prerequisite to investigating long-term transitional dynamics of annual and perennial farming system expansions and population growth on the gain and loss of native forest extent at a local and national level in developing countries, notably Togo to facilitate forest reference levels (FRL) and forest emission reference level (FREL) assessment. It is a way to formulate solid arguments for the REDD+ establishment and accurate measuring, reporting, and verification of REDD+ to United Nations organs and Climate change, donors. From the foregoing introduction, this paper aims to assess 32 years transitional and intensity changes on the native forest extent due to maize, cassava, cocoa agroforestry cropping, and urbanization extent for establishing a logical framework model for sustainable forest management while increasing crop productivity and establishing recommended landscape programmes. Simply put its presents: (i) the quantity of changes in terms of gross gains, losses, persistence, net and swap changes; (ii) the intensity of gains and losses and (iii) the intensity of transition from forest to other land use type (maize, cassava, cocoa agro-forestry farming and settlements).

2. Study area

The study was conducted in Kloto district, Togo and covers an approximate land area of 528.23 km^2. It encompasses 13 sub-districts located in the northwest of the capital, Lomé (Fig. 1). Kloto is located between 0.50° and 0.77° East and 6.75° and 7.0° North. The district covers a total area of 528.23 km^2. The major economic activity is farming of food crops (e.g. maize, cassava) and cash crop (cocoa and coffee agroforestry). The average production of maize and cassava from 1990 to 2016 revealed an annual production of 10,928 and 19,498 tonnes for maize and cassava over an area of 8291 and 3080 ha, respectively. From 2014 to 2016 cocoa agroforestry of 2762 ha produced 1041 tonnes annually (DSID, 2017: analyzed statistic data).

3. Data collection and analysis

Two Landsat data (5 and OLI) of March 1985 and April 2017 were downloaded from the USGS with cloud cover less than 10% using path (193) and row (055). We assumed same phonological conditions because of the bimodal climate season. Acquired images were pre-processed for atmospheric (cloud and noise removal) and radiometric (brightness) corrections as well as layer stacking and sub-setting in ArcGIS. Thereafter, thematic analysis was performed in ENVI software based on six (06) Land Use, Land Cover types (Fig. 1), viz: forest, cocoa agroforestry, maize, cassava farms, settlements and unclassified.

A field campaign was organized from May to October 2017 for historical land occupational information via an interview with landowners and farmers and 40 random points of each land use type were collected to train and validate the classification. Image calibration of the two years was done using ground through and archive land occupational geo-referenced points (40 in total) of each land use type of the subsequent years of available statistics (DSID, 2017: Agriculture Census statistic data) with the assistance of google earth historical data records, and classification was performed using a Maximum Likelihood Classifier. And the post-classification technique was initiated to derive the extended cross-tabulation matrix for land use change and intensity analysis. Images were classified with 100% accuracy with Kappa coefficient equal to 1 (Appendices A and B).

3.1. Quantity of land use change

Change analysis of the thematic classes from time 1 (1985) to time 2 (2017) (Fig. 1) as percent of map was assessed in terms of persistence (diagonal entries), total loss (total row of category i minus percentage map of the same category of final year), total gain (total column of category j minus category j of the initial year). The extended change matrix was also used to derive the total, net and swap changes of each land use category. The total change (TC) of a category is the sum of its gross gain and loss. At the main time, the net change (NC) of a category is the difference between its gross gain and loss while the swap change (SC) of a category is the difference of a total change and net change for the category.

3.2. Intensity analysis

The gain and loss intensity (GI, LI) were duly derived from the change matrix knowing that the uniform intensity (UI) of the transition is the total gain or loss of the four thematic classes. The gain and loss intensity help to identify dormant (GI or LI less than UI) or active (GI or LI greater than UI) categories. The LI and GI of a category were calculated by dividing the loss of a category in 1985 and a gain of a category in 2017 with the size of the categories in 1985 and 2017, respectively. Similarly, the loss and gain transition intensity of forest, cocoa agroforestry, maize and cassava farms were calculated from the extended matrix. In this case, the transition intensity (TI) denotes targeted (TI greater than UI) or avoided (TI smaller than UI) categories when a particular category change into another category. Thus, the loss transition intensity (LTI) from forest to cocoa agroforestry, for instance, was obtained by dividing the loss of forest to cocoa agroforestry in 1985 with the gain of cocoa agro-forestry in 2017. Therefore, the LTI is compared to the hypothesized Uniform Loss/Gain Intensity (ULI/UGI) of forest loss to cocoa agroforestry, maize, and cassava. The ULI/UGI is the union of forest loss to cocoa agroforestry, maize and cassava divided by the sum of cocoa agroforestry, maize and cassava and vice versa. Moreover, the gain transition intensity (GTI) of forest from cocoa agroforestry farms, for example, is computed by dividing the size of cocoa agroforestry in 1985 with the gain of forest from grassland.

4. Results and discussion

4.1. Quantity of land use transition

Results (Table 1 and 2) revealed significant persistence (49.50%) of

Table 1
Change matrix from 1985 to 2017 in the percentage of the map.

		2017							
		Unclassified	Settlement	Cassava	Maize	Cocoa agroforestry	Forest	Total 1985	Loss
1985	Unclassified	49.49	0.00	0.02	0.00	0.01	0.00	49.53	0.04
	Settlement	0.00	0.54	0.01	0.02	0.00	0.00	0.57	0.03
	Cassava	0.00	0.05	0.70	0.08	0.43	0.05	1.32	0.62
	Maize	0.00	0.71	3.14	0.51	1.04	0.17	5.58	5.06
	Cocoa agroforestry	0.00	1.29	10.51	0.75	1.56	0.52	14.63	13.07
	Forest	0.00	2.21	12.12	0.65	4.49	8.90	28.37	19.47
	Total 2017	49.50	4.80	26.49	2.03	7.54	9.65	1.00	38.291
	Gain	0.00	4.26	25.79	1.51	5.97	0.75	38.29	

Table 2
Gain, loss, persistence, total change, net change and swap change per category.

	Gain	Loss	Persistence	Total change	Net change	Swap change
Unclassified	0.00	0.04	49.49	0.04	−0.04	0.00
Settlement	4.26	0.03	0.54	4.29	4.23	0.06
Cassava	25.79	0.62	0.70	26.41	25.18	1.23
Maize	1.51	5.06	0.51	6.57	−3.55	3.02
Cocoa agroforestry	5.97	13.07	1.56	19.05	−7.10	11.95
Forest	0.75	19.47	8.90	20.22	−18.72	1.50
Total	38.29	38.29	61.71			

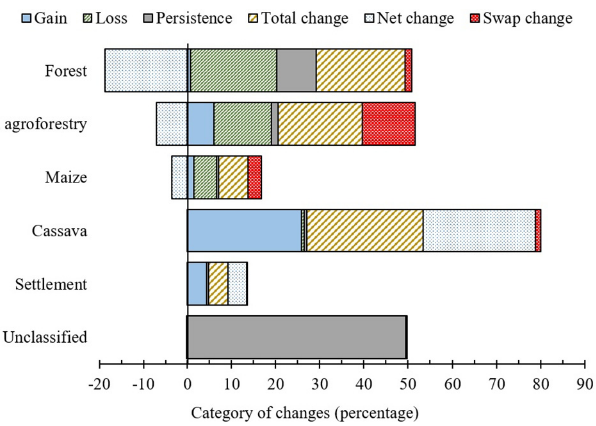


Fig. 2. Quantity of land use transition.

unclassified pixels (e.g. road, water bodies) with the marginal loss (0.04) and gain (0.00), respectively. The transition of other classes (settlement, Cassava, Maize, Cocoa Agroforestry, and forest) to such pixels is quite negligible (0%) over 32 years (1985–2017) land use and land cover transition analysis.

In the meantime, Table 2 shows a total gain/loss of 38.29% with 61.71% persistence. Very dynamic categories were distinguished in terms of total changes (Fig. 2) namely cassava (26.41%), forest (20.22%) and cocoa agroforestry (19.05%); dynamic classes encompassing maize (6.57%) and settlement (4.29%) and unclassified pixels as a stable class (0.04%) in terms of loss-gain and vice versa over 32 years period. The net change (Fig. 2) reveals high forest land reduction (18.72%) follow by cocoa agroforestry (7.10%), maize (3.55%) and others (0.04%) to the detriment of cassava and settlement which are gaining 25.18 and 4.23%, respectively. The spatial relocation regarding loss or gain pixels shows a maximum distance change of 11.95 km for coca agroforestry and 1.50 km of forest lands. Cassava lands gain from others land use categories at a minimum distance of 1.23 km less than maize (3.02 km) and settlement (0.06 km). In sum, the quantitative analysis indicates that there are a change from forest to agricultural (cassava, maize, cocoa agro-forestry) and non-agricultural (settlement and unclassified) land use systems. However, it did not give the information about the speed of the change as well as the intensity at which the changes are occurring. In that line, intensity analysis was performed to determine dormant and active categories (Fig. 3) of the transition as well as the targeted and avoided categories (Fig. 4) of the 32 years transition analysis.Fig. 1.

4.2. Intensity analysis

Results (Fig. 3) depict the loss and gain intensity per category in percentage of map. Some categories, namely: unclassified and settlement is losing slowly while, cassava, maize, cocoa agroforestry, and forest are losing faster. Simply put, unclassified and settlement is dormant regarding area expansion, while, the remaining categories

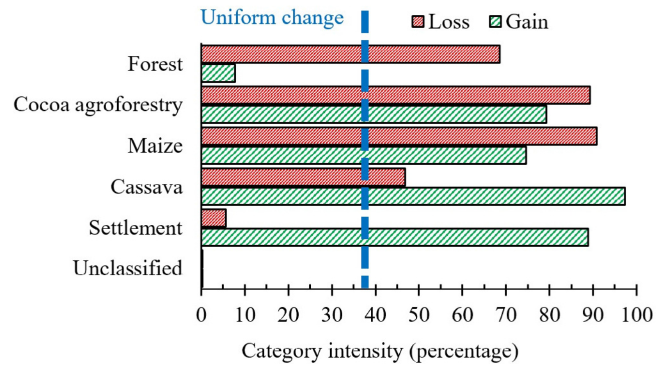


Fig. 3. Gain and Loss intensity per category in percentage.

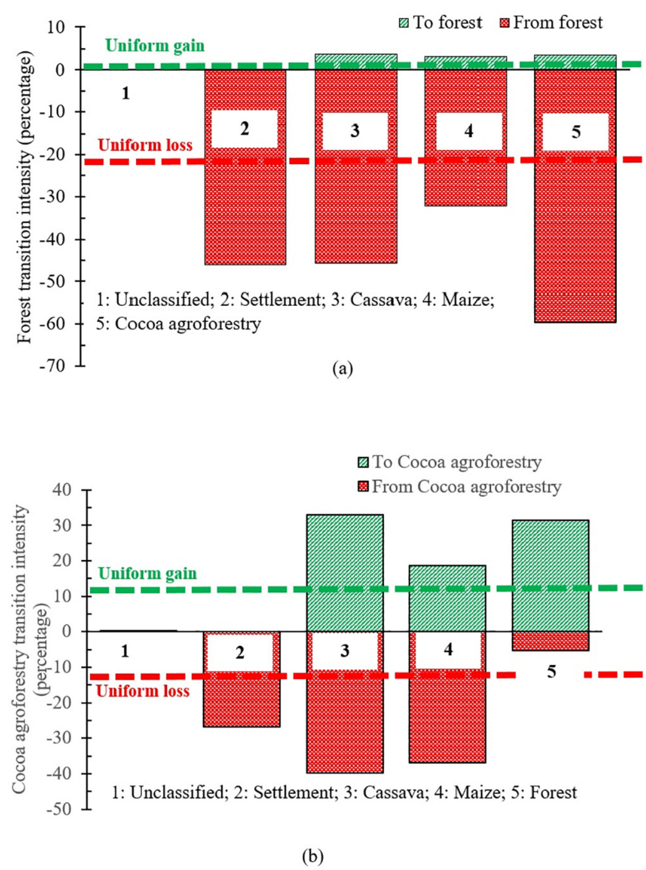
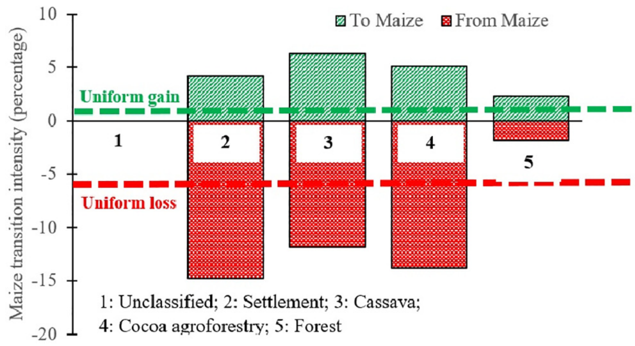
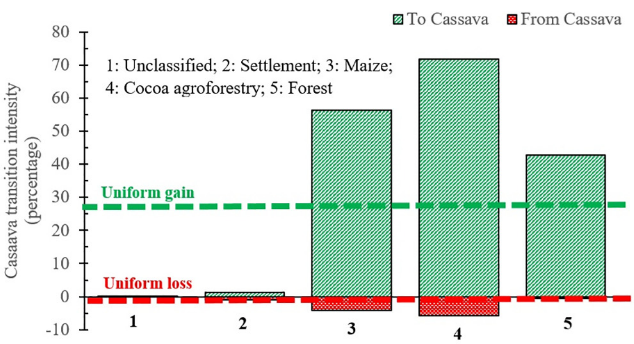


Fig. 4. Land use land cover intensity of transitions expressed as (a) Forest, (b) Cocoa agroforestry, (c) Maize, (d) Cassava and (e) Settlement.

reduced significantly. In the meantime, some gain more sites compared to others (Fig. 3). This is the case of forest which gains less than its losses. Forest gain is dormant (7.76 < 38.29) while the conversion of forest to other land use, land cover types (e.g. settlement, cassava, cocoa agroforestry and maize) is active. This expansion of cultivated and non-cultivated areas is intense for cassava farms (97.36) followed by settlement (88.80), cocoa agroforestry (79.28) and maize (74.63) farming systems. For the targeted and avoided categories of loss and gain transitions, Fig. 4 (a–e) were used. The loss analysis (Fig. 4a) revealed that deforestation and forest degradation is mainly targeted by cocoa agroforestry farms (59.60%) followed by housing expansion (46.08%), cassava (45.73%) and maize (32.26%) farms in 2017. In the meantime, the cocoa agroforestry loss (Fig. 4b) is targeted by cassava (39.69%) and maize (36.96%) farming. In contrast, maize lost (Fig. 4c) 14.75, 13.79 and 11.86% to the detriment of the settlement, cocoa



(c)



(d)

(e)

Fig. 4. (*continued*)

agroforestry, and cassava farm. The transition intensity of cassava, settlement, and unclassified categories (Fig. 4d), Fig. 4 depicts the high proportion of cassava loss to cocoa agroforestry (5.75%) followed by maize (4.10%) which also targeted settlement and others land use cover categories at 1.19 and 0.10%, respectively. Transition to and from settlement is reciprocal with maize farming (Fig. 4e), whereby, settlement losses and gains simultaneously from maize. Furthermore, the marginal gain of the forest came from cassava, cocoa agroforestry, and maize at 3.69, 3.56 and 3.13%, respectively while cocoa agroforestry took 32.89 and 31.37% from cassava and forest rather than maize (18.64%). In the meantime, cassava targeted cocoa agroforestry farms (71.84%) compared to maize (56.33%) and forest (42.70%). Results also revealed that settlement expansion is 12.70, 8.81 and 7.80% due to maize and cocoa agroforestry farms and forest lands reduction respectively whereas, unclassified gain did not target any land use classes. From the analysis, it is quite an evident that deforestation and forest degradation transition intensity analysis in Kloto district is both agricultural (cocoa, agroforestry, cassava, and maize) and non-agricultural (settlement expansion) issues. The results present the role of agriculture and population growth on forest extinction. These results are consistent with similar studies in Indonesia (Villamor et al., 2014; Gao et al., 2016); Ghana (Aloô and Pontius, 2008) and in China (Huang et al., 2012; Zhou et al., 2014) where, transition analysis revealed a systematic transition from either forest to croplands and from croplands to build-up. However, they failed to account for the part of individual systems for forest reference and emission level determination as a benchmark for REDD+ projects. Kloto district is a forest zone with the dominance of indigenous trees and cocoa agroforestry systems. These results could be explained by population growth, the market price of cash and food crops and farming and cropping systems in use. The perception of farmers and landowners bring to the conclusion that, population growth from 1985 to 2017 had implied a tremendous increase in food demand and expansion of residences. Recent population census (MPDAT, 2010) depicted a significant increase of rural population at national level to the rate of 25.2% (1981) for 37.7% (2010). The population density of Kloto in 1981 was between 50 and 100 inhabitant/km^2 (Anipah et al., 1989) against 263 inhabitants/km^2 in 2010 for a total population of 139,043 inhabitants (MPDAT, 2010). Moreover, economic incentives to cocoa and cassava prices in the market had promoted the conversion of many maize farms to cassava and cocoa agroforestry farms. Interview from farmers revealed that most of the farmers are adopting cocoa agroforestry farming systems (e.g. cocoa and coffee; cocoa, coffee, and cassava or cocoa, cassava and plantain) to increase and diversify their level of income. For others, the price of these cash and food crops are more stable at national and international markets compared to maize price. In addition to cocoa-cassava agroforestry systems, farmers also practice mono-cropping cassava systems with either indigenous or improved varieties while maize cultivation is mainly mono-crop. In some areas, maize is cultivated in association with cassava or as sequential cropping systems. The intensity of mono-cropping and the decline of soil fertility oblige farmers to clear more forests to the detriment of cocoa agroforestry, cassava and maize farms as revealed by the 32 years land use transition analysis (Koglo et al., 2018). These analyses are similar to recent studies conducted in northern Togo by Diwediga et al. (2017). An evaluation of multifunctional landscapes progression in the mountainous basin of the Mo River (Togo, West Africa) from 1972 to 2014 uncovered an imperative anthropogenic land change prompting land degradation. This also explained part of the results of this study whereby, conventional agriculture intensifications and population growth are targeting native forest stability. The systematic land use transition was from forest to cocoa agroforestry followed by settlement expansion, cassava and maize farming with the total dormancy of forest gain and very active non-forest land cover types.

5. Conclusions

Land use transition analysis at sub certain level using extended matrix analysis, remote sensing and land occupational data information is scarce in developing countries for accurate REDD+ implementation, accountability and establishment of cost-effective sustainable land and forest sustainable management policies. This study uses this technique with pertinent results. Conclusions drawn revealed an intensive loss (19.47%) of forest in the past 32 years (1985–2017) to the detriment of cocoa agroforestry, maize, cassava farming and settlement expansion. In contrast, forest gain (0.75%) slowly while, settlement, cocoa agroforestry, cassava, and maize are gaining faster. The systematic transition was from forest to cocoa agroforestry followed by cassava, settlement, and maize. These results are more explicit in formulating sustainable policies for each land use land cover type in forest management while promoting sustainable agriculture in forested zones (Kloto, Togo). This confirms the robustness of the land use transition analysis when combining satellite data with strong post classification analysis and historical land use information from landowners and/or farmers. In other words, it gives the exact effect of each land use type (e.g. food, cash crop or residential) on forest stability, loss or gain. This study recommends demographic policies (e.g. family planning; incentive measures for small households), capacity building of land owners and farmers (e.g. sustainable forest management). As both cash and food crops are major impediments to forest loss, it urges to review the existing cropping and farming systems in the area by promoting agro-ecology systems (e.g. agroforestry, rotational cropping, mixing cropping with pulses) as natural fertilizers to regain and restore soil fertility while mitigating climate change, forest decline and providing more foods for the rural communities.

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Appendix A. Analysis report land use land cover map 1985.

Overall Accuracy = (1162188/1162188) 100%
Kappa Coefficient = 1

Table a. Confusion matrix

Class	Unclassified	Settlement	Cassava	Maize	Cocoa agroforestry	Forest	Total
Unclassified	100	0	0	0	0	0	100
Settlement	0	100	0	0	0	0	100
Cassava	0	0	100	0	0	0	100
Maize	0	0	0	100	0	0	100
Cocoa agroforestry	0	0	0	0	100	0	100
Forest	0	0	0	0	0	100	100
Total	100	100	100	100	100	100	

Table b. Omission and Commission error

Class	Producer accuracy (%)	User accuracy (%)	Producer accuracy (Pixels)	User accuracy (Pixels)
Unclassified	100	100	575228/575228	575228/575228
Settlement	100	100	9216/9216	9216/9216
Cassava	100	100	83425/83425	83425/83425
Maize	100	100	93908/93908	93908/93908
Cocoa agroforestry	100	100	148596/148596	148596/148596
Forest	100	100	251815/251815	251815/251815

Appendix B. Analysis report land use land cover map 2017.

Overall Accuracy = (1162188/1162188) 100%.
Kappa Coefficient = 1

Table a. Confusion matrix

Class	Unclassified	Settlement	Cassava	Maize	Cocoa agroforestry	Forest	Total
Unclassified	100	0	0	0	0	0	100
Settlement	0	100	0	0	0	0	100
Cassava	0	0	100	0	0	0	100
Maize	0	0	0	100	0	0	100
Cocoa agroforestry	0	0	0	0	100	0	100
Forest	0	0	0	0	0	100	100
Total	100	100	100	100	100	100	

Table b. Omission and Commission error

Class	Producer accuracy (%)	User accuracy (%)	Producer accuracy (Pixels)	User accuracy (Pixels)
Unclassified	100	100	627/627	627/627

(*continued on next page*)

Table b. Omission and Commission error (*continued*)

Class	Producer accuracy (%)	User accuracy (%)	Producer accuracy (Pixels)	User accuracy (Pixels)
Settlement	100	100	658000/658000	658000/658000
Cassava	100	100	206470/206470	206470/206470
Maize	100	100	49902/49902	49902/49902
Cocoa agroforestry	100	100	101300/101300	101300/101300
Forest	100	100	145889/145889	145889/145889

Appendix C. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2018.09.042.

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