Applied Geography 99 (2018) 109–119

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Assessing land-use typologies and change intensities in a structurally complex Ghanaian cocoa landscape

Daniel Tutu Benefoh[a,*], Grace B. Villamor[a], Meine van Noordwijk[b,e], Christian Borgemeister[a], Winston A. Asante[c], Kwabena O. Asubonteng[d]

[a] Center for Development Research, University of Bonn, Bonn, Germany
[b] World Agroforestry Centre, Southeast Asia Regional Office, JL. CIFOR, Situ Gede, Bogor, Indonesia
[c] Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science & Technology, Kumasi, Ghana
[d] Department of Geography, Planning and International Development Studies, University of Amsterdam, Netherlands
[e] Plant Production Systems, Wageningen University, Wageningen, Netherlands

ARTICLE INFO

Keywords:
Image-fusion
Intensity analysis
Land-use transitions
Deforestation
Cocoa

ABSTRACT

Cocoa plantation is a major land-use system that influences the functional structure of the forest landscape in Ghana. As a key driver of forest landscape dynamics, there is no adequate existing information on the nature, extent and magnitude of land-use change associated with cocoa expansion into forests. Therefore, we have studied the land-use transitions and intensities by using image-fusion on vegetation indices (VI) and a digital elevation model (DEM) to detect and distinguish cocoa plantation from the forest and other vegetation types. This was followed by intensity analysis based on historical land-use changes. With the VI-DEM image, we mapped out different cocoa plantations from the forest and other vegetations with a higher degree of success. The land-use categories were clustered into five main types (closed forest, open-forest, cocoa, lands-in-transition and settlement) to evaluate the transition and intensities from 1986 to 2015. The results showed two main transition patterns, namely 1) the conversion of forest to settlement and cocoa plantation; 2) the conversion of closed forests to open forest, due to logging and conversion of cocoa plantation to lands-in-transition (LIT). The intensity analysis further revealed that expansion in cocoa plantation instead targets least resisted open-forest and LIT areas with an isolated localised fragment of the fringes of forest reserves. Generally, the study revealed that the VI-DEM image-fusion technique is effective for detecting and isolating cocoa plantations, forest and other land-uses with high accuracy. Estimation of cocoa-led deforestation improved after isolating cocoa plantations. Cocoa expansions target more often open-forest and lands-in-transition than closed-forest. When cocoa expansion occurs in closed-forest, it is episodic, localised and coincides with the early stage of the boom-bust pattern.

1. Introduction

The West Africa Guinean rainforest is a designated global biodiversity hotspot (Myers, Mittermeier, Mittermeier, Fonseca, & Jennifer Kent, 2000). The region has a vibrant extractive industry and a production-hub of primary agricultural commodities. As a result of pressures from incompatible land-uses the forest estates in West Africa are highly fragmented and most severely threatened in the world (USGS, 2017). Cocoa plantations are dominant land-use system and modifier of most parts of the West African forest landscape (Gockowski & Sonwa, 2011) particularly in Ghana, Nigeria, Cameroon and Cote d'Ivoire (Wessel & Quist-Wessel, 2015). The Ghanaian cocoa industry generates $2 billion (COCOBOD, 2017) as 30% of the country's total export revenues (Ashitey, 2012, p. 7) and make-up 8% of gross domestic product (GDP). Cocoa farming is the mainstay of nearly 800,000 smallholder households (COCOBOD, 2017). Despite the fact that the positive contributions to the socio-economic advancement of Ghana, expansion of cocoa plantations is a primary driver of deforestation (FC, 2016).

The establishment and decommission of cocoa plantations follow a “boom-bust” pattern (Ruf et al. 1998) and can instigate deforestation due to its expansive nature (Asare, Afari-Sefa, Osei-Owusu, & Pabi, 2014a, b; FC, 2015; Tondoh et al., 2015; Koranteng, Zawila-Niedzwiecki, & Adu-Poku, 2016). Forest canopy provides the suitable growing microclimate for cocoa plantations. Cocoa is established by removing forest understorey and thinning the forest canopy to allow the seedlings can grow into productive trees by utilising the forest rent and

* Corresponding author.
E-mail address: dbenefor2000@gmail.com (D. Tutu Benefoh).

https://doi.org/10.1016/j.apgeog.2018.07.027
Received 29 July 2017; Received in revised form 7 October 2017; Accepted 31 July 2018

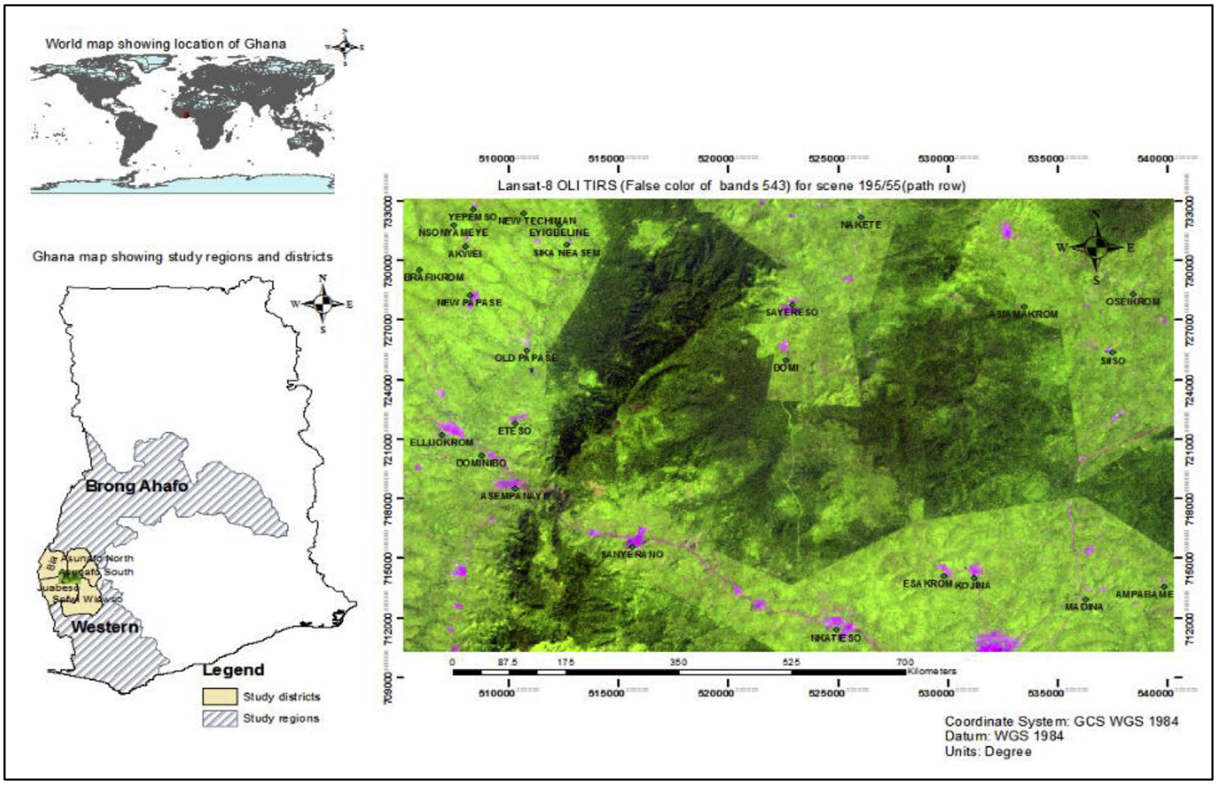

Fig. 1. Map showing the study area in relation to the administrative regions.

Table 1
Vegetation indices and the formulae used to derive from the Landsat-8 image.

Vegetation Indices	Formulae	Sources
NDVI	(NIR – R)/(NIR + R)	Girolimetto and Venturini (2013)
TC-G	(-0.2941*B) + (-0.243*G) + (-0.5424*R) + (0.7276*NIR) + (0.0713*SWIR1) + (0.1608*SWIR2))	Kauth and Thomas (1976)
TC-B	(0.3029*B) + (0.2786*G) + (0.4733*R) + (0.5599*NIR) + (0.508*SWIR1) + (0.1872*SWIR2)	Baig, Zhang, Tong Shuai, and Tong (2014)
TC-W	(0.1511*B) + (0.1973*G) + (-0.3283*R) + (0.3407*NIR) + (-0.7117*SWIR1) + (-0.4559*SWIR2)	
LSWI	(NIR – SWIR1)/(NIR + SWIR1)	Chandrasekar and Roy (2010)

Red = Red; B = Blue band; G = Green band; NIR = Near infrared band; SWIR = Shortwave infrared.

the shade provided by the remaining trees (Anglaaere, Cobbina, Sinclair, & McDonald, 2011; Asare et al., 2014a,b). New cocoa plantations usually have high yields because of fertile soils, low labour and low input cost (Wessel & Quist-Wessel, 2015) but as the plantation ages, yields and incomes decline, so farmers find the traditional practice unprofitable and begin to evaluate other options. As a result, most farmers abandon their existing farms to establish new cocoa plantations preferably in the forest frontier to initiate another cycle of forest clearing. Where fertile lands are scarce, and expansion is no more a viable choice, the strategy is to rehabilitate or replant the cocoa plantation or explore various intensification options boost yields (Tscharntke et al., 2011). The notion that cocoa expansion is a leading driver of deforestation has gained full acceptance among policymakers and the cocoa industry (FC, 2016). The cocoa industry actors are pressing for the adoption of "zero-deforestation cocoa supply chains" as a way to tackle deforestation and promote sustainable chocolate (Camargo & Nhantumbo, 2016). In the cocoa industry, the zero-deforestation concept is at its nascent stages, and its design and practice rigour will depend on the availability of reliable deforestation data.

Empirical evidence on cocoa-driven deforestation is hard to come by from most recent literature. Over the years, satellite-based remote sensing technology has successfully been applied in the detection and tracking of deforestation in the tropics (Kilawe, Mertz, Silayo, Birch-Thomsen, & Maliondo, 2018; Portillo-Quintero & Smith, 2018). However, most of the studies (Asare et al., 2014a,b; Koranteng et al., 2016) make generic references to cocoa expansion as an agent of deforestation without empirical basis to back the extent and rate of deforestation. Two reasons may account for the lack of empirical evidence of cocoa-induced deforestation. Firstly, the difficulty in using remote sensing to delineate cocoa trees (especially cocoa agroforest) from natural forest due to their spectral similarities. Secondly, the challenge in accessing quality (cloud-free) imageries for a given period.

This study, therefore, examines ways of spatially segregating the cocoa plantations and other land-uses to evaluate the implications of cocoa-induced deforestation. The specific objectives are: (a) to identify and map-out dominant land-use types; (b) examine the trends in land-use changes for the period of 1986-2015, and (c) undertake intensity analysis of land-use transitions for the same period.

2. Methodology

2.1. Study area

The research was conducted in the Brong Ahafo and Western Regions of Ghana in an area which lies in coordinates 6.631822°–2.952925° and 6.425712°–2.634741° covering 80,506.80ha (Fig. 1). The study area converges at five neighbouring districts by Bia, Juabeso and Sefwi Wiawso (Western Region) to the westerly border and