Land Use Policy 64 (2017) 95–100

Contents lists available at ScienceDirect

Land Use Policy

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

Implications of land use transitions on soil nitrogen in dynamic landscapes in Tanzania

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ARTICLE INFO

Article history:
Received 1 June 2016
Received in revised form 15 February 2017
Accepted 16 February 2017
Available online 1 March 2017

Keywords:
Land use
Dynamics
Soil
Nitrogen
Remote sensing
Impact

ABSTRACT

Land use transitions are rated among the leading sources of greenhouse gas emissions in the tropics. They significantly challenge the functioning of ecosystems and affect multi-temporal stability of greenhouse gases such as N_2O and soil properties. Studies on dynamics in nitrogen balances are essential in understanding greenhouse gas emissions such as N_2O and to manage their impacts on productivity. In this study, multi-temporal Landsat images (1975, 1995 and 2012) were classified to determine land use transitions and potential drivers. The classified images were categorized into degraded and non-degraded lands and eighty sampling plots generated within the entire study area. Soil samples were then collected at 0–15, 15–30 and 30–60 cm depths on each plot and soil nitrogen determined. A regression analysis was developed to determine the influence of forest and grassland degradation on soil nitrogen. Results indicated a significant change in major land use and land cover types. Specifically, there was a decrease in areas covered by forests, woodland and grassland, however, area covered by less dense forest increased. Results also indicated variability in mean nitrogen content between degraded and non-degraded areas and depths. Furthermore, levels of degradation influence nitrogen content up to a soil depth of 30 cm. The present study is relevant in the detailed assessment of the extent of damage and threats posed to biodiversity hotspots in sub-Saharan Africa. These results are transferable to other parts of the world characterized by dynamic ecological transformation.

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1. Introduction

Terrestrial forest ecosystems occupy more than a fifth of Africa's land area (UNEP, 2008). The continent, which saw a net loss of approximately 4.1 million hectares of forests per year in the 1990s, reported a further average net loss of about 3.4 million hectares per year between 2000 and 2010 (FAO, 2010). These losses are mainly attributed to population growth and associated demand for ecological resources (Henzen, 2008). The ever increasing human pressure on land has led to an increase in the urgency to assess effects of land use on soil (Islam and Weil, 2000). Land use transitions, which refer to spatio-temporal land use morphology of a region due anthropogenic impacts, affect ecosystem support services and conservation efforts (Long et al., 2014; Polasky et al., 2011). According to Maitima et al. (2009), alteration of natural landscapes due to land use transformations influence ecosystem functioning, vegetation structure and biodiversity while Gude et al. (2007) note that land use transformations affect ecological parameters like species composition and densities. The modification of landscapes into other land uses interferes with environmental quality (Don et al., 2011); changes the climatic and hydrological systems and bio-geochemical cycles (Reyers et al., 2009; Ward and Robinson, 1990). Furthermore, landscape modification affects the quality, size and ecological functioning of ecosystems, leading to changes in the composition of structural habitat entities, spatial characteristics and habitat organization (Wilson et al., 2004). These pose serious threats to the ecosystems ecological integrity (Foley et al., 2005). As aforementioned, increased rural settlements, commonly accompanied by creation of new farmlands for instance leads to habitat loss

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http://dx.doi.org/10.1016/j.landusepol.2017.02.023
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and consequent inability to support species diversity due to insufficient vegetation cover and fragmented landscape (Wilson et al., 2004).

Essential knowledge on land use transitions and impacts is necessary for conservation monitoring, planning and management (Burgess, 2000). Understanding land use and land cover transformations and associated impacts is therefore necessary for sustainable long term ecological management plans (Polasky et al., 2011). However, there are limited observational and/or experimental studies on ecosystem exposure to anthropogenic activities (Reid et al., 2004). In East Africa, information on the implication of land use and land cover transformations on vegetation and other environmental parameters remain limited (Maitima et al., 2009).

Land use transformation is ranked among the leading sources of greenhouse gas emissions in tropical countries and is known to affect the stability of greenhouse gases such as CH_4 and N_2O (Marland et al., 2004). Generally, such transformations alter microclimate and soil quality (Post and Kwon, 2000; Winowiecki et al., 2016a,b). Soils are known to be dynamic in space and time (Quinton et al., 2010). It is projected that soil is degraded approximately 10–40 times more than the rate of rehabilitating the quality of ecosystems (Pimentel, 2006). Within the tropics, conversion of forests into other land uses often translates into changes in the soil's bulk density (Don et al., 2011). Furthermore, exposure of forest ecosystems through changing land uses decreases the total productivity by depleting soil nutrients and decreasing soil depths, essential for ecological sustainability (Pimentel, 2006; Winowiecki et al., 2016a,b). There are gaps in our knowledge and understanding of the impacts of land use changes on soil nutrients and vegetation linkages (Ojoyi et al., 2015a,b; Mcgrath et al., 2001). Therefore, studies on land use transitions and impacts are significant steps in addressing socio-ecological and climate change challenges (Liu et al., 2003). A better understanding of factors regulating spatial and temporal variability in soil balances is needed in the long term ecosystem protection and management (Lal, 2003). Furthermore, the impacts of soil loss on greenhouse gases remain largely unexplored, information necessary for monitoring the global carbon budget (Lal, 2003).

Globally, soil nitrogen is approximated at 133–140 Pg in the upper layer found within the 100 centimeter's depth; therefore, any possible changes in temperature can influence soil nitrogen concentration (Batjes, 1996). Previous research indicated the need to assess differences in nitrogen levels, due to soil type's variability, dynamics in topography, changes in land use and land cover (Marland et al., 2004). In recognition of the above, the objective of this paper was to identify impacts of land use transitions on soil nitrogen. Specifically, the paper investigates: (1) land use transitions and potential driving forces; (2) effects of land use transitions on soil nitrogen; and (3) land use transition effects on soil nitrogen at different soil depths. It is anticipated that the methodology used and research findings will have a wider applicability in the management of changing landscapes in Tanzania and other parts of sub-Saharan Africa.

2. Methods

2.1. Morogoro region

The study was conducted in Morogoro region in Tanzania. Morogoro region, lies between 5°58′ and 10°00′ South and 35°25′ and 38°30′ East (Fig. 1). A section of Morogoro region dominated by forest, grassland and woodland vegetation types was selected. Natural forests such as Uluguru forest, hosts approximately 135 plant species (Burgess, 2000). However, 80 km^2 of forest was lost between 1955 and 2000; increasing the extinction risk of rare species such as the Uluguru Bush Shrike (Birdlife International, 2000). Miombo woodlands cover approximately 90% of the total forested terrestrial ecosystem in Tanzania. The region faces a series of undesirable shocks mainly from effects of climate change (Paavola, 2008). More than 80% of the population in Morogoro region is dominated by smallholder farmers who earn their living from agriculture. The agricultural sector is the main growth domestic product contributor to the country (UNFPA, 2011), providing about 80% of employment opportunities.

2.2. Satellite image processing

A series of satellite images with less than 15% cloud cover were used for the study. Landsat Multispectral Scanner (20/08/1975), Landsat Thematic Mapper (30/09/1995) and Landsat Enhanced Thematic Mapper Plus SLC-off (20/07/2012) from the Global Landcover Facility (http://glcf.umd.edu/data/landsat/) were selected. All images were orthorectified using ground validation points, digital elevation model, and aerial photos as a reference. Landsat images were resampled to their initial pixel resolution (30 m) using bilinear resampling to ensure consistency of the resolution with all image scenes. First order polynomial transformation was applied in image registration to correct for any shifts and root mean square errors of less than a pixel were obtained indicating an accurate orthorectification of all Landsat images. The contamination by spatially varying, semi-transparent cloud and aerosol layers is a common problem that affects a significant portion of Landsat scenes. Reduction of haze is therefore an indispensable pre-processing step when used images are acquired under such conditions. In this study, this was done using the atmospheric and topographic correction (ATCOR) module of ERDAS Imagine 2013 software. This procedure simulates atmospheric interactions between the sun surface and sensor pathways. The software masks haze and water vapor and enhances pixel visibility. Digital number values were converted to surface reflectance values as recommended by Chander et al. (2009) using the metadata provided with Landsat images (Richter and Schlaepfer, 2011; Richter and Schläpfer, 2004).

2.3. Image classification

The parametric supervised classification using the maximum likelihood classifier was adopted for the study (Xi, 2007; Liu et al., 2003). This approach is based on the Bayes theorem that utilizes a discriminant function which assigns pixel values to the category with the highest likelihood (Dean and Smith, 2003; Aldrich, 1997). Spectral signatures were created and applied in categorising similar pixels in the entire image using eight polygons representing training data sets for each vegetation class. A color composite consisting of bands 3, 4 and 5 facilitated visual interpretation process while the Gaussian distribution function was applied in the stretching process. The image was then classified into the study area's dominant vegetation types; woodland, grassland, dense forest and less dense forest (Table 1).

A total of 82 field ground data points (20–21 from each class) were collected, following a stratified random sampling method, to validate the classified 2012 image. The data points were randomly generated using the Hawth's analysis tool extension (Beyer, 2007) in ArcMap software and input into a sub-meter handheld geographical position system (GPS). A confusion matrix was then created to compare ground truth data with the maximum likelihood prediction and to determine the overall accuracy (OA), producer's accuracy (PA) and user's accuracies (UA) (Stehman, 1997). The OA represents the percentage (%) between correctly classified classes and the total number of test ground truth samples, whereas the PA is the probability of a specific class being correctly classified (Adam

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