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Integrated analysis of land use changes and their impacts on agrarian livelihoods in the western highlands of Kenya

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ABSTRACT

Land degradation is affecting rural livelihoods across sub-Saharan Africa. Promoting sustainable land management requires a thorough understanding of land use change drivers, processes and effects. However, in most African countries reliable data for such investigations are missing. We therefore test an integrated approach to analyse land use dynamics, combining remote sensing images, an in-depth quantitative survey, stakeholder interviews and local statistics. We analyse land dynamics and agricultural production over a 25-year period in Vihiga District, Western Kenya. Specifically, we examine how land use has changed in this period, the main drivers for land use change, and the main effects of these changes on agricultural production. Vihiga District is one of the most densely populated rural areas in Africa. We find that the district has undergone rapid land use change in the past 25 years. In particular, there has been a major conversion of forest and bare land to agricultural land use. Often, it is stated that increasing population pressure triggers agricultural intensification; however, we find little evidence of such a process in Vihiga District. Productivity of tea and, to a lesser extent, vegetables increased but the yields of maize and beans, the most common crops, fluctuated around a ton per hectare. Overall, per *capita* food crop production dropped by 28% during the past two decades. Our study shows that high and increasing population pressures do not necessarily lead to agricultural intensification, and that there is a need to consider more explicitly off-farm income in development and land management policies and projects.

1. Introduction

Land degradation is a function of complex and dynamic interactions between human and natural systems, and is of particular concern in sub-Saharan Africa (SSA) because of a still increasing population and the important role of agriculture in SSA economies (Morton et al., 2006; Pacheco, 2006). Intensification of agriculture in combination with investment in sustainable land management (SLM) has the potential to reverse land degradation and improve agricultural productivity (Hurni, 2000). Previous studies indicate that increasing population density can be expected to lead to intensification of land use (e.g. Pender, 1998; Roose, 1996). A high population density, it is argued, induces innovation and investment to enhance land productivity and increase agricultural returns (Boserup, 1965; Mortimore et al., 2005; Ruttan and Thirtle, 1989; Tiffen et al., 1994). However, there is lack of empirical evidence that such intensification actually occur in many SSA countries (Tiffen et al., 1994).

Various quantitative analytical approaches have been applied in the analysis of land-use and land-cover (LUC) changes (Paré et al., 2008; Veldkamp and Lambin, 2001; Verburg et al., 2008; Wyman and Stein, 2010). Analysing LUC changes generally requires an integrated approach that considers multiple disciplines, data sources and methodological constructs. One of the greatest constraints to determining LUC change and its impacts is that reliable data are missing in most African countries (Hietel et al., 2007; Kline, 2003; Rembold et al., 2000). Although detailed information may be available locally at field and farm level, these local data do not generally provide sufficient information for understanding LUC changes over time and over larger areas. Also the application of remote sensing technique alone has limitations and is sometimes difficult given the heterogeneous mosaic of the landscape character in African farming zones (Jellema et al., 2009; Pontius and Lippitt, 2004).

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The objective of this study is to analyse land use change, drivers of land use changes and effects of land dynamics on agricultural production, in the western highlands of Kenya. We test a trans-disciplinary approach integrating remote sensing imagery, local statistics on climatic, demographic and agricultural variables and an in-depth household survey to examine LUC changes and their implications at the district level. Our approach involves the use of five different data sets, and cross-referencing and counter-checking results across these data sets. We generate LUC maps for 1984, 1988, 2000 and 2009 from remote sensing imagery. These data were supplemented with primary data from a quantitative survey and stakeholder interviews, and secondary statistics from various sources. We analyse changes in demography, climate and agricultural productivity to determine how people's livelihoods have been affected by the dynamics in environmental conditions.

2. Materials and methods

2.1. Description of the study area

The study focuses on the Vihiga District (the current Vihiga County) covering 563 km^2 in Western Province of Kenya (Fig. 1). The district lies between longitudes 34°30 to 35°0 East and latitudes 0°0 to 0°5 North. Vihiga District experiences an Equatorial climate with rainfall ranging between 1800 and 2000 mm per year. Rainfall distribution is bimodal with a distinct long rainy season (March – June) and a short rainy season (September – November). The district is characterised by gently rolling hills and valleys, sloping from west to east. Altitude ranges from 1300 to 2100 m above sea level, and rugged granitic hills dominate the southern part of the district. Deep and well drained Acrisols cover 95% of the district (Government of Kenya, 2004; Jaetzold et al., 2007).

Agriculture is the most important land use in the district, followed by forest cover, bare land and built-up areas. About 75% of the land area of Vihiga District is arable with an average farm size of 0.65 ha per household (Government of Kenya, 2010). The main farming systems in the district reflect the two major agro-ecological zones namely Upper Midland (UM), a high potential tea-coffee zone and Lower Midland (LM), a maize-bean-sugar cane zone (Jaetzold et al., 2007). The major food crops grown include maize, beans, bananas, potatoes and sorghums. Tea, coffee and sugar cane constitute the main cash crops. Most of the cattle are local zebus with some improved dairy cows (Government of Kenya, 2010).

The main forest block found in the north-eastern tip of the district is part of the larger Kakamega tropical forest. The forest is part of the last remaining rainforest in Kenya and is an important provider of wood and non-timber forest products. It also contains significant biodiversity (indigenous flora and a variety of fauna species) and is important for cultural activities of the neighbouring communities (Government of Kenya, 2004).

Vihiga District is one of the most densely populated and poorest parts of Kenya. The overall population density of the district is 1045 people/km^2. Even though literacy level is over 95%, poverty incidence (*per capita* daily income of less than a dollar) is estimated at 62% of the population (Government of Kenya, 2005a,b; KNBS, 2010).

2.2. Remote sensing analysis

Land cover changes in Vihiga District for the past 25 years were determined based on a classification of four remote sensing images. We used geo-referenced Landsat satellite images with 30 m resolution, acquired from Regional Centre for Mapping Resources for Development (RCMRD), Nairobi supplemented with online downloads from the Landsat archive in Geotiff format. Data were re-projected to the Universal Trans Mercator Projection, zone 36, using the WGS-84 spheroid. The metadata of the used images are described in Table 1. Only unclouded scenes were selected. The image preparation and processing was done in Erdas Imagine 9.3 and ArcGIS 9.3.1 to prepare the LUC maps.

The satellite images were classified into LUC maps using the Maximum likelihood classification algorithm (Lillesand et al., 2008). Training areas were defined for each time separately and each land-use/cover was classified and visually inspected iteratively to control for map quality. The number of training fields is variable for each time (39 for 2009, 24 for 2000, 27 for 1988 and 44 for 1984). The LUC types classified include agriculture, forest, bare, tea and built-up areas. We defined 'Agricultural land' as arable land used for the cultivation of cereals, legumes, fodders and horticultural crops. 'Tea' consisted of areas used for the cultivation of tea, which is the only perennial crop grown on a significant area in the district. Areas with a closed forest canopy cover were classified as 'Forest'. 'Bare areas' included open spaces such as land covered with perennial grasses, in particular along the river courses, rocky hillsides, roadsides and playgrounds. Finally, the class 'Built-up' consists of urban centres, rural markets, schools, roads, hospitals, offices and factory buildings.

We calculated several specific LUC measures such as area under each class and its proportion of total land area. We also estimated long-term changes between LUC classes using a transition matrix. Since ground truth observations were only available for the recent image, an independent validation of the classification result could not be done for the past periods, but we crosschecked calculated area under agriculture with available district statistics. For the 2009 classification result, we assessed the classification accuracy based on 336 randomly selected land cover locations, using fine resolution aerial photographs of 17 December 2010, available in Google Earth, as surrogate for ground observations. Aerial photographs were not available for the earlier years. We compared how well the 2009 image classification matched with the actual ground data by calculating percentage correct as a measure of classification accuracy (Foody, 2002).

2.3. Analysis of factors driving land-use and land-cover changes

Selected socio-economic and environmental factors responsible for the detected LUC changes were analysed based on secondary statistics and local survey data collected using participatory approaches (e.g. Bakker and van Doorn, 2009; Castella et al., 2007). We started the selection of key drivers of LUC change based on the broad classification of drivers developed by Geist and Lambin (2002), which includes demographic, technological, economic, institutional, cultural and biophysical drivers. Based on open interviews with 10 key informants we selected the main drivers in each category for detailed analysis in our study. The informants included four local resource persons, two each for local administrators, agricultural extension staff and NGO workers and they were interviewed using a checklist. The checklist contained open-ended questions on perceived changes in the landscape, effect on agricultural and forest systems, and key driving factors. They identified drivers in each category as population growth, technological practices, market changes for food products and climatic variability. In addition, the key informants provided information on perceived changes in area and quality of arable land, forest cover and community land. They also indicated resultant changes in the farming system and the impacts on agricultural production.

We gathered data on agricultural production and technological changes in the district with a detailed household survey. Vihiga District has five sub-districts, which we stratified into two strata according to agro-ecological zones and main farming types. We