Zbl. Geol. Paläont. Teil I, Jg. 2016, Heft 1, 23–40
Stuttgart, Juni 2016

Land use change dynamics in the Mt. Kenya region – a remotely sensed analysis using RapidEye satellite images

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With 4 figures

Zusammenfassung: Vor dem Hintergrund von Landnutzungsveränderungen im subsaharischen Afrika und insbesondere dem Problem zunehmenden Waldverlustes durch Landwirtschaft ist es das Ziel dieser Studie, aktuelle Landnutzungsentwicklungen am Beispiel von östlichen Teilen der Mt. Kenia Region zu analysieren und zu klassifizieren. Zu diesem Zweck wurde ein Fernerkundungsansatz mit hochauflösenden RapidEye Satellitenbildern aus den Jahren 2010 und 2015 durchgeführt. Die wesentlichen Forschungsziele konzentrierten sich auf (1) eine Überprüfung der methodischen Durchführbarkeit von Landnutzungsklassifizierungen in der von kleinbäuerlichen Landwirtschaft geprägten Region; (2) die Erfassung der Landoberflächen- und Landnutzungsstrukturen und deren Veränderung zwischen 2010 und 2015; (3) eine Bewertung, in wie fern Entwaldung durch die Anlage der Nyayo Tee Zonen reduziert werden kann. Die Ergebnisse zeigten, dass eine Klassifizierung grundsätzlich möglich ist. Schwierigkeiten bei der Unterscheidung von Landnutzungstypen traten aufgrund von heterogenen Eigenschaften der Landoberfläche und der räumlichen und spektralen Überschneidung verschiedener Flächentypen auf (z.B. Landwirtschaft und lichter Wald). Das ermittelte Landnutzungsmuster lässt sich als eine konzentrische Anordnung verschiedener Oberflächentypen (wie Wald, Teefelder, weitere landwirtschaftlich genutzte Flächen, Buschland und kahler Boden bzw. Brachland) um den Mt. Kenia beschreiben. Der multitemporale Vergleich zeigt ein Wachstum der landwirtschaftlich genutzten Flächen. Während kleinere zusammenhängende Waldflächen von einer massiven Abholzung gekennzeichnet waren, blieben die Wälder des Mt. Kenia National Parks weitgehend unangetastet. Diese Entwicklung hängt offensichtlich mit der Einrichtung der Nyayo Tee Zonen zusammen, die die Waldflächen vor einem anthropogenen Eindringen schützen.

Abstract: In the context of land use changes in sub-Saharan Africa and especially deforestation due to agricultural intensification, this study aimed to characterize recent land use developments in eastern parts of the Mt. Kenya region. A remote sensing approach with high resolution RapidEye satellite images from 2010 and 2015 was conducted. The main research goals were to (1) clarify in how far RapidEye data can contribute to a land use change analysis in the small-scale farming-driven Mt. Kenya region; (2) detect general land use and land cover structures and changes between 2010 and 2015; (3) examine how far forest encroachment can be reduced with the arrangement of Nyayo Tea Zones. The results showed that it is possible to detect main land cover classes. Different limitations of the classification occurred due to heterogeneous characteristics of the land cover and the spatial and spectral mixture of different areas (e.g. agriculture and scrublands). The land use pattern can be described as a concentric arrangement of different types of land use around Mt. Kenya, including forest areas, tea plantations, other agricultural areas, scrubland and fallow and barren ground. Land use change detection between 2010 and 2015 showed a general increase in croplands. While single forest clusters are characterized by a massive decrease, forests in Mt. Kenya National Park are widely untouched by human activities. This can be linked to the creation of Nyayo Tea Zones, which passes into the protection of the natural forest areas.

DOI: 10.1127/zgpl/2016/0023-0040 $ 4.50

Schlüsselwörter: Afrika, Landnutzungswandel, Mt. Kenia Region, Landwirtschaft, Entwaldung, Fernerkundung, RapidEye

Keywords: Africa, land use change, Mt. Kenya region, agriculture, deforestation, remote sensing, RapidEye

1. Introduction

The Mt. Kenya region in central Kenya is one of the most important areas for agricultural production in eastern Africa (Dannenberg & Nduru 2012). The economic importance of the agricultural sector highly relates to its integration into coordinated global supply chains. Especially in the 1990s, the trade in fresh fruit and vegetables (FFV) between the Mt. Kenya region and the EU rapidly emerged, thus leading to high export driven revenues in the region (Mithöfer et al. 2008, Dolan & Humphrey 2004). The horticultural sector in particular is often referred to as a general success story due to its possible high margins for the farmers and international demand for the produce. In addition, other crops, such as tea or cut flowers, play an important socioeconomic role for agriculture of the Mt. Kenya region (Gesimba et al. 2005). Mwangi (2008) and Were et al. (2013) expect that the agricultural market in the region will grow. They assume that agricultural areas will increase in the future. Further studies support this expectation due to supermarketisation (Lenné et al. 2005, Neven & Reardon 2004) and a rising population in the region (Lambin et al. 2001, Imbernon 1999, Jätzold et al. 2006). In contrast, other investigations question the expansion of croplands (Mwaniki & Möller 2015). Although there are governmental efforts to reduce deforestation, e.g. by creating tea plantations on the boundary of national parks (Nyayo Tea Zones), a general forest decline is expected due to an increase in agriculture (Were et al. 2013, Mundia & Aniya 2006). Deforestation in sub-Saharan Africa is discussed as a very characteristic change in land use studies (Lambin et al. 2003). However, recent evidence on the extensive development of agricultural areas and forests in the Mt. Kenya region is rare. Thus, it is widely unknown how far land use has effectively changed in the recent past.

This study tries to identify and analyse current short-term changes of the regional land use pattern in the Mt. Kenya region. Detected different physical shifts in land cover can often be linked to ongoing dynamics of agricultural demands and population pressure. A remote sensing approach is presented to get a better understanding of changing land use structures. Due to the intensively practiced agriculture in the east of Mt. Kenya, information on land cover and land use change based on high spatial resolution and multi-temporal data was derived from RapidEye satellite images. The study monitors and analyses the dynamics and heterogeneities of general land use and its changes in the past five years (2010–2015). A comparable analysis with data of a high spatial resolution (5 m) does not exist for the Mt. Kenya region. The data which is investigated in literature is mostly outdated and may not fit the highly dynamic and recent processes found in the research area (e.g. Imbernon 1999, Mwaniki & Möller 2015). The data set applied here is complemented by qualitative interviews which include expert surveys of local stakeholders.

The given approach gains insights not only into recent content-related structures, but rather in methodical issues of land use approaches. These issues are investigated by implementing a supervised classification of the given satellite imagery. There will be three main foci: (1) The first aim is to clarify how RapidEye data can contribute to land use change analysis in the small-scale farming areas of the Mt. Kenya region. The study investigates which types of land cover can be distinguished and which cannot be clearly identified. (2) The change detection and structures between 2010 and 2015 are presented and compared in order to observe changes. (3) In the context of the Nyayo Tea Zones the investigation of land use change examines how far forest encroachment can be reduced by the setting up of "tea boundaries".

2. State of the art

The dynamics of land use change in sub-Saharan Africa and their impact on nature and society are a major topic of current scientific and societal discussions (Lambin & Meyfroidt 2011). For land use management and decision makers, land cover monitoring is important to quantify socio-economic changes. Analysis of the magnitude, causes and effects of land cover change is essential (Munroe et al. 2014). Established definitions describe land cover by physical and socioeconomic characteristics that are adduced for a certain spatial unit of the earth surface (Jansen & Gregorio 2002). The term land use rather describes the intended purposes by humans to exploit the land cover. The change of land cover is defined by Lambin et al. (2001) as changes in their characteristics, which can either occur in land cover conservation or in land cover modification. Land cover conservation represents a replacement of a spatial unit to another category, whereas land cover modification only relates to a narrow change of the surface attributes, without changing the category. This study focuses on the conservation of land cover and its use as it highlights socioeconomic processes and is mostly detectable with remote sensing imagery (Lambin et al. 2003).

Land use change in central Kenya

The explanation of land use change is usually based on multiple factors and cannot be traced back to just one major reason (Meyfroidt et al. 2013, Were et al. 2013). Typical factors in sub-Saharan Africa include among others economic, demographic and institutional aspects. In most empirical case studies a combination of factors with direct or indirect linked interactions is presented. The causes and effects of land use developments in central Kenya are an exemplary part of the changes in sub-Saharan Africa in a general context. They can be distinguished by demographical, economical and institutional factors. Demographical causes for land use changes in the research area are raised and discussed in many studies (Imbernon 1999, Klopp 2012, Were et al. 2013, Grace et al. 2014). On the basis of *The 2009 Kenya Population and Housing Census* (KNBS 2010) a general population growth is assumed in the Mt. Kenya region. The census reported an increase in population from about 4.6 million in 1999 to about 5.6 million in 2009 in Eastern Province. Jätzold et al. (2006) submitted similar numbers. The population projections show an increase of about 13% for Meru Central District and about 6.5% for Embu District between 2000 and 2010. Agricultural intensification and forest decline are typical indicators in land use science for this kind of growth. These factors are typical for landscapes under population pressure (DeFries et al. 2010, Lambin et al. 2003). In addition, urban growth is also detected by numerous authors (Mubea & Menz 2012, Jayne & Muyanga 2012, Muyanga & Jayne 2014) and strongly linked to a rising population.

The extensive expansion of croplands cannot only be linked to demographical factors: economic factors have been adduced in the context of profitable inclusion in global value chains. The integration of agriculture production in global value chains plays an important role for economic revenues in the Mt. Kenya region (Dolan & Humphrey 2004, Mithöfer et al. 2008, Krone et al. 2015, Ouma 2010). Especially FFV products are produced for export markets in the form of horticultural cultivation. This sector in the Mt. Kenya region is one of the major export industries in Kenya. It provides not only financial revenues, but also labour opportunities in the associated industries (Dannenberg & Nduru 2015). In addition to the international distribution of FFV, other agricultural crops are also part of production for export in Mt. Kenya region. The most important examples are tea and coffee plantations and cut flowers, which are mainly cultivated in greenhouses (Justus & Yu 2014). Whereas the export market enables opportunities for financial revenues and employment, the domestic agricultural market mainly contributes to the food security issues of the local population (Lenné et al. 2005).

For central Kenya, different studies focus on the effects on forest areas from the perspectives of an increase in settlements and agricultural land (Were et al. 2013, Justus & Yu 2014). Again the main reasons are a rising population and economic growth (Barbier 1997, Gibbs et al. 2010, Klopp 2012). Were et al. (2013) detected an average annual rate of deforestation in the west of the Mt. Kenya region of 1% between 1973 and 2011. Whereas Mwaniki & Möller (2015) reported in an investigation of a larger research area in central Kenya about a massive forest decline between 1995 and 2002, but only slightly rising forest areas between 2002 and 2010. It has to be pointed out that the Kenyan government has addressed the problem of deforestation through different control measures. One example is the protection of Mt. Kenya National Park as an area of protected natural forest. Among other intentions to force forest protection, the Nyayo Tea Zones were created as a "tea boundary" at the national park (Klopp 2012). Such measures of protection might hamper the progress of land use change and deforestation. However, recent developments of forest areas especially in a focused spatial observation in eastern parts of Mt. Kenya are generally missing. Given the recent trends of an increasing population on the one hand as well as agricultural expansion and intensification and on the other hand, further changes in land use and deforestation can be expected. This paper suggests a remote sensing based approach which outlines how far these expected developments have been taking place. Furthermore, it presents empirical results on land use change, deforestation and the role of the Tea Zone in Eastern Mt. Kenya region.

Research objectives

In the context of land use changes in the Mt. Kenya region documented in the literature, the study deals with the goals presented above. Methodical opportunities provided by RapidEye, support a more content-related perspective on the observed land use change in the Mt. Kenya region between 2010 and 2015. Indicators are the development of croplands and forest areas in eastern parts of the Mt. Kenya region.

Based on field work in March 2015 the following aspects were assumed. Relating to intensification of agricultural production, and due to the increasing importance of Kenyan export markets, an enlargement of agricultural land is expected. Especially in northern areas of Mt. Kenya, these processes can be expected due to higher land availability for intensive agriculture. At the expense of agricultural land, it is hypothesized that the area of forests has decreased. It is also assumed that this deforestation might be hampered in the case of the National Park by the Nyayo Tea zone. A comparison with other forest areas in the study region is applied to examine the effects of Nyayo Tea Zones. In addition, in the context of an increasing population pressure and a general development of infrastructures, an increase of transport infrastructure and settlement areas in the observed study region is also assumed. Porter (2007) underlines economic and especially agricultural growth to be linked to an extension of transportation infrastructure (for the Mt. Kenya region see Dannenberg et al. 2011).

3. Data and methods

The research approach used high-resolution multispectral satellite data to determine land cover change between 2010 and 2015. Qualitative interviews were conducted with local stakeholders including farmers, agricultural traders, scientists and experts from the Horticulture Crops Development Authority (HCDA) of Kenya.

Study area

The study area is the Mt. Kenya region in central Kenya ranging approximately from longitudes 36°45'E to 38°10'E and latitudes 0°50'N to 1°07'S (Fig. 1). This study area was chosen because it includes typical developments which can lead to land use change and deforestation. Apart from a growing population this includes a growing number of agricultural activities. Due to the favourable environmental conditions, the agro-climatic setting is especially advantageous for agriculture and for horticultural production (McCulloch & Ota 2002: 4). The location on the eastern African equator provides a monsoonal climate pattern (NE and SE) and an elevated topography. There are two rainy seasons ranging from April to June and from October to December. The average annual rainfall amounts from 1600 to 2000 mm. The eastern side of the Mt. Kenya shows a humid to sub-humid climate with increasing precipitation towards Mt. Kenya (Wiesmann et al. 2014). Rainy seasons are interrupted by dry conditions. Higher altitudes often show cloudy conditions. Average annual temperatures vary between 17 and 22 °C. Due to more rainfall at higher altitudes perennial production (e.g. tea or wheat) in upper areas of Mt. Kenya region is possible (Jätzold et al. 2006). Differences in precipitation and temperature between the seasons are increasing eastwards, which mostly leads to seasonal cultivation. The occurrence of fertile volcanic soils provides better conditions for farming in western parts of the study area as well. In the lower areas in the East, basement rocks (granites and gneisses) do not provide a high fertility.

Jätzold et al. (2006) derived a spatial classification of agro-ecological zones from the physical geographic characteristics of the region. According to natural differences they divided the study area amongst others in Forest Zones (UH 0), Tea-Dairy Zones (LH 1), different Coffee Zones (UM 1-3) and dryer cotton zones (LM 3-4). The spatial distribution of the zones shows a concentric pattern around Mt. Kenya that can be well detected on satellite images.

The Mt. Kenya region also benefits from the spatial contiguity to Nairobi with its international airport. Nairobi plays a key role for the export market of agricultural products. According to Dannenberg et al. (2011), the average transportation time from the study area to Nairobi is around 3 to 4 hours only.

Figure 1 shows the topography of the investigated area that is for the most parts very heterogeneous (Mwaniki & Möller 2015). In the extent of the satellite imagery, the altitude differs from about 800 to 3000 m (based on SRTM by NASA 2015). Especially Mt. Kenya with a maximum elevation of 5200 m a.s.l. has a great influence on regional clouding and precipitation. Relief intensity also has agro-economic effects: the average size of agricultural holdings in the southern part is relatively small (less than 15 ha; McCulloch & Ota 2002). Here, the fraction of horticultural farming is higher. Only in the northern parts, industrial agriculture is possible.

In our study, we focused on the eastern part of the Mt. Kenya region (Fig. 1), which is simultaneously the extent of the satellite imagery. We assume that this area is typical for general land use trends in the Mt. Kenya region, because its landscape contains the main characteristics of the superordinate region. It includes agricultural features such as tea plantations and horticultural production. Forest areas of the study extent are both national park dedicated and unprotected forests. Areas of Mt. Kenya National Park located in the west are widely surrounded by Nyayo Tea Zones. Other forest areas are not protected like this. Clouding occurs less frequently in the east of Mt. Kenya due to its local climate.

Data used

Optical RapidEye satellite imagery was used for land cover classification of the extracts shown in Figure 1. The imagery consists of quadratic tiles that cover 625 km^2 (25 x 25 km) each. To acquire multi-temporal information about land cover change in the study area, satellite images from 2010/09/27 and 2015/02/02 – 2015/02/05 were used. The RapidEye mission is a commercial earth observation system, which consists of a constellation of five satellites each carrying high-resolution cameras. These sensors acquire multispectral spatial data that give the user five individual optical bands in the blue, green, red, red-edge and near infrared portion of the spectrum. The images were ordered as Level 3A product (radiometrically and geometrically corrected). Spatial resolution of the sensor is 5 m pixel size. Ground truthing was done in March 2015. Regarding changes between the acquisition date of satellite imagery and ground truth observation in 2015, only explicit areas were observed. It was possible to survey a heterogeneous spectrum of different types of surfaces.

To get a broader picture of the observed structures, exploratory interviews with local farmers and expert interviews with brokers and administrative experts from HCDA were conducted in March 2015. Local scientific experts from Karatina University were interviewed. The surveys contained semi-structured questionnaires about the individual perception of the different stakeholders concerning land use and land cover changes in the region. Furthermore, the influence on land use of each individual stakeholder was explored. Interviews with resident farmers at the border area of forests provided insights about the protective effects of Nyayo Tea Zones. The interviews with members of the HCDA, which is the main supervisory institution for horticulture in Kenya, delivered insights about general historical land use and land cover changes in the Mt. Kenya region. The qualitative surveys were conducted to support the process of structuring explanations for observed land use changes.

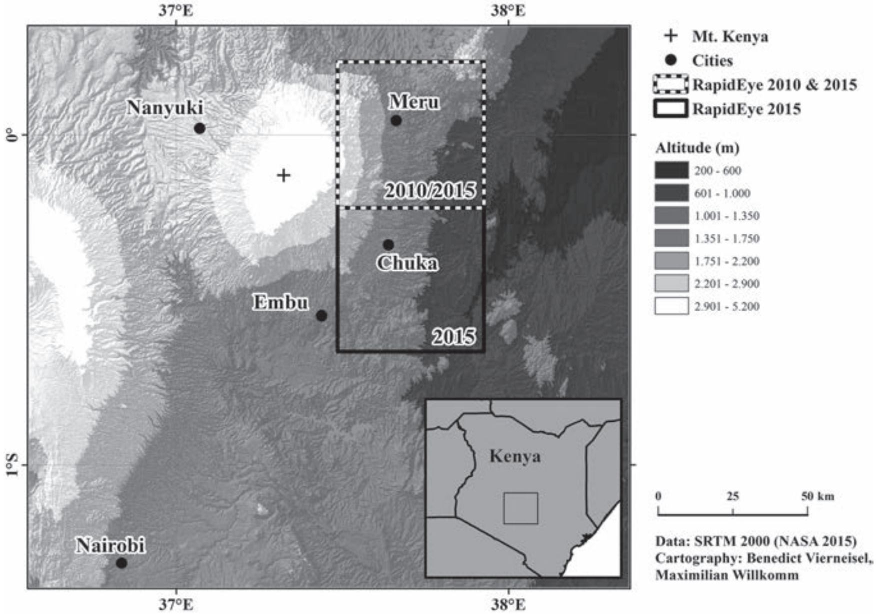

Fig. 1. Study area of the Mt. Kenya region and coverage of RapidEye satellite data.

Remote sensing approach

For the remote sensing approach the images of the RapidEye satellites offer a high spatial resolution (5 x 5 m pixels), providing a lot of options for the usage and detail of processed data. Studies showed that the multispectral bands of RapidEye imagery make it possible to distinguish between different vegetation covers and surfaces (e.g. Imukova et al. 2015). Also for small-scale analysis of urban vegetation, the RapidEye images were used and found to be fitting to adequately map different ground surfaces and vegetation based on the phenology and the plant species (Tigges et al. 2013). The details concerning the chosen period of time (2010–2015) and extent (eastern part of Mt. Kenya, see Fig. 1) of the RapidEye images were based on the availability of tolerably cloudless images. Since not all the images were taken during the same monthly periods, a comparison between classifications has to be done rather carefully. Thus, phenology, crop rotation and cultivation time are important factors that influence different land use patterns.

In order to classify the images with a supervised method, regions of interest (ROIs) have to be chosen and manually incorporated into a geographic information system (GIS). These ROIs were based on the ground truthing data collected. To minimize errors because of the time shift between the imagery by RapidEye and the collected ground truth data, additional interviews with local experts and farmers were conducted. These interviews during the fieldwork helped in the understanding of the growth of certain kinds of vegetation in the context of spatial distribution and temporal reasons for growth. The experts also helped in identifying crops.

The ENVI 5.1 software and a Maximum-Likelihood classification (Mubea & Menz 2012) were applied to the study sites. Based on the dispersion of the reflection values in the five bands and their combination in the presented RapidEye data, nine different classes for land cover were chosen. The classes are (1) water, (2) urban areas, (3) forests, (4) scrubland, (5) agricultural land and especially (6) tea and (7) fallow and barren land. Tea surfaces were handled as a discrete class, because its spectral information is very different to agricultural areas. The determination of other agricultural classes was not possible due to very small cultivation plots and intercropping. Additionally, the cloud cover (8) and their shadows (9) were detected and categorized.

First classification results deliver a land cover map that has a lot of scattering of different pixel classes. In order to eliminate scattering effects, image filters were used in post-processing methods. Smoothing and aggregation filters were applied. Smoothing removes speckling noise, while aggregation cleans the image for small regions (Vaiphasa 2006). This filtering process has a generalization effect on the imagery. After the filtering, there are two sets of images – one from 2010/09/27 (southern part) and another consisting of two images 2015/02/02 – 2015/02/05 (southern and northern part) – that are used for the classification comparison (Fig. 1). Here, it has to be kept in mind that the images from 2010 were taken at the end of September, while the others from 2015 are from the beginning of February. This has vegetative effects on the land cover depending on water regime and plant phenology. To be able to compare the images, the clouds and their shadows were clipped out with a buffer of 100 m. Only areas that are not influenced by the clouds or their shadows are used for the creation of the land cover statistics. To validate the classification results, an error and confusion matrix was applied. Thus, the observation of single classes and the calculation of the kappa coefficient can help to review the validity of the classification (Mwaniki & Möller 2015).

4. Results and discussion

Firstly, the potential of the RapidEye data for land cover classifications in the Mt. Kenya region is reviewed. Secondly, the detected land cover pattern from the images of February 2015 is described. Finally, the results of the images from 2010 and a comparison of the two classifications are presented. Thus, geographic changes are shown.

Land cover classification with RapidEye

The classification set up by RapidEye shows that it is generally possible to detect distinct land cover patterns supported by remotely sensed data. There were five major land cover classes to be identified (forests, agricultural land, and tea plantations, scrubland, fallow and barren land, urban areas). Water cover could be determined, but its spatial distribution is generally low. Further, detectable classes are cloud cover and their shadows. For the classification of the images from 2010, the kappa coefficient comes to about 0.82. For 2015, imagery the software computed a value of 0.85. Thus, both classification accuracies range in the commonly recommended minimum of 85% (Foody 2002: 188–189).

The research results indicate that it is generally possible to monitor land use structures in the Mt. Kenya region with RapidEye satellite data. Although the spatial extent of agricultural microstructures is very heterogeneous in the research area (McCulloch & Ota 2002), the presented land use types could be determined. The uncertainty of the classification units differs. For instance, an exact separation of agricultural land and scrubland is limited. These two land cover types have very smooth transitions and are spatially mixed. For the classes scrubland and agriculture, there are bigger rates of classified pixels to be found in other classes, thus the inaccuracy is greater. While 78% of all pixels in the ROIs in the scrubland class were correctly classified in the 2010 image, in the 2015 data the ratio is only about 37%. Especially the agricultural class covers many areas of scrubland in these surfaces. The accuracy of agricultural land in general is about 65% in both images. Similar methodical problems can be found in Were et al. (2013: 82) and Mwaniki & Möller (2015: 66–67). With the exception of the tea fields, this limitation rises with increasing heterogeneity of small-scale structures. This also includes a differentiation of single field crops, which was not possible with RapidEye data in this study. The small-scale farmers tend to use mixed cultivation with different crops in the same field in order to increase plant resilience and wider product variability (McCord et al. 2015).

Further mixing problems occur with the classified pixels of fallow and barren land and urban areas. Because there was a high proportion of barren ground in the settlements, the range of both reflection values cannot be distinguished clearly (see also the focused upper subset of Figure 2). This comes along with larger extend of urban areas in the south-eastern part of the study area, which could not be found in original RapidEye images. The error matrices show very low accuracies for urban areas (in 2010 about 23%; in 2015 about 52%). The development of settlements must be interpreted with caution because methodical classification of urban areas with RapidEye imagery has a great error rate. In addition, many pixels around cloud cover were allocated as urban areas. The applied buffer tool, which excluded many of these wrongly classified pixels, was calculated very short. An enlargement of the buffer excluded too many areas without errors and, thus, a 100 m buffer was applied. In contrast to the higher error rates, the accuracy of forest and tea areas is very high. The classification of forests delivered according to the error matrix an accuracy of about 94%. In the case of tea plantations, an accuracy of more than 98% is reached, which indicates a homogenous and separable structure of the spectral and spatial extent of forests and tea fields. Even though the classification of single agricultural crops on plot level was not possible, a comparison of land use in 2010 and 2015 is conducted on a larger scope of view and presented in the following section.

Classification results from February 2015

To get an overview of general land use structures in the Mt. Kenya region, the results from February 2015 are presented in the beginning due to its larger extent. Afterwards, land use changes since 2010 are discussed.

The output information of the data processing for February 2015 is shown in Figure 2. The forest as land cover in the western part of the image covered about 15% (about 750 km^2) of the research area. As most forest areas, it is rather dense and, therefore, builds up a homogenous surface cover. The forest is part of Mt. Kenya National Park and is separated very sharply from other areas. As the forest is secured and therefore untouched by human agriculture, its canopy has a very high density (Klopp 2012). The forest cover of the study area can be seen as the central part of a circular and zonal pattern. As Mwaniki & Möller

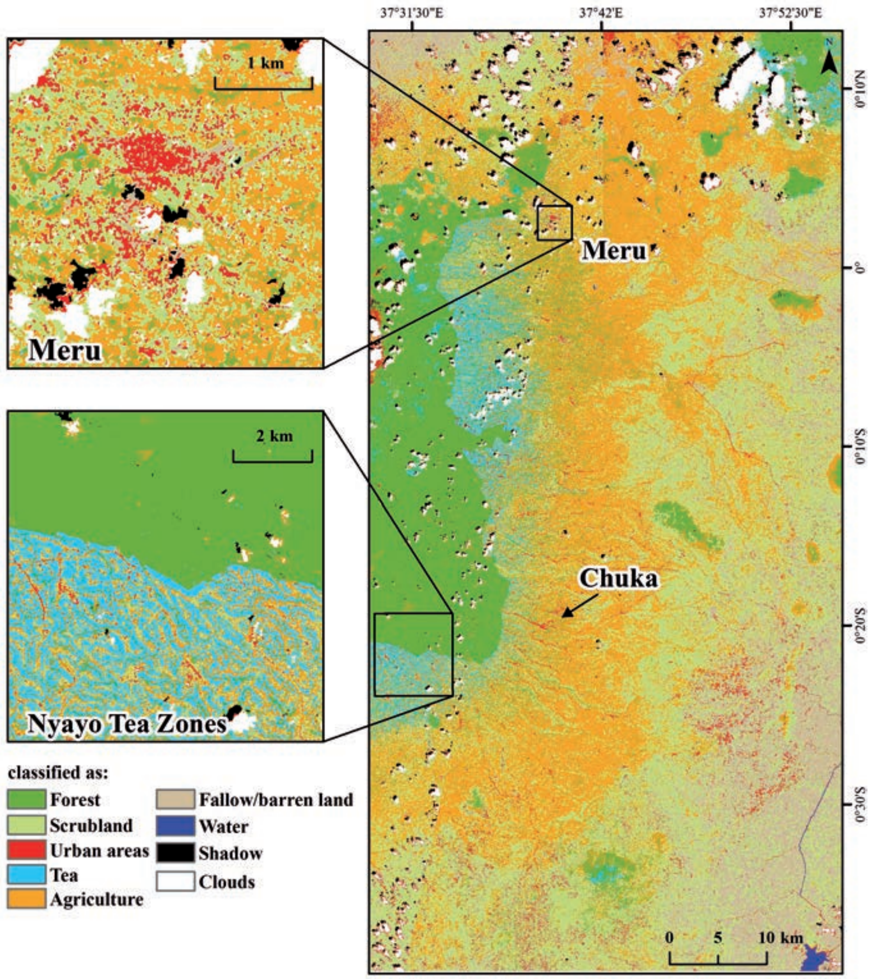

Fig. 2. Classification results of RapidEye imagery from February 2015.

(2015: 65) detected in their approach with a larger scale, further land cover classes were more or less arranged in a concentric way around Mt. Kenya. Jätzold et al. (2006) described this pattern in the context of the agro-ecological zones, which can be also found in this small-scale investigation. In addition to the national park forest in the west, there are different clustered forest areas in eastern parts. Smaller forests can be found at areas with a higher slope where cultivation is not possible.

Tea plantations around the edges of the national park forest are the second surface cover arranged around Mt. Kenya. It should be noted that these tea fields can only be found around the larger forest areas (also in the NE) and at regions with higher altitude and slope (see Fig. 1). The focused lower subset in Figure 2 and the error matrix show very clearly that the classes of forest and tea can be circumscribed very sharply. There is a strict border of the forest detectable and the shapes of the tea plantations orientate themselves to the valley configurations. The strict separation of forest and tea areas is inducted by Nyayo Tea Zones (Klopp 2012), which is intended to secure Mt. Kenya National Park from informal deforestation. This kind of institutional conservation strategy and its impact on land use change is discussed in detail afterwards.

The third and fourth classes are agriculture areas and scrubland. These classes are part of the concentric surface pattern as well. An "agricultural ring" around Mt. Kenya to an extent of about 1600 km^2 can be detected. These areas were not completely covered by agricultural land use but can be characterized by dominant small-scale agricultural plots in the east of Mt. Kenya (Lenné et al. 2005). Whereas, in the north, there was less scrubland found within the surfaces of intensive agriculture. The spatial extent of agriculture has a much broader scale than in the southern parts of the classification map. At the lower altitudes in the eastern parts of the images, there was a larger amount of scrubland and also fallow and barren ground in the classified image, which is also reported by Mwaniki & Möller (2015). In total, scrubland also covered circa 1600 km^2, which is about one third of the total image. The fallow and barren areas in eastern parts occur due to less precipitation in the Tana River Basin (SE). Jätzold et al. (2006) allocated this area to the Marginal Cotton Zone (LM 4), which only enables short and very short cropping seasons. Agricultural production in this area could not be monitored in the classification, because it is only possible in rainy seasons.

Further land cover classes represent lesser surfaces in the image considered. Namely, we detected the settlement areas and streets, which centre closer to Mt. Kenya, and the expanses of water in the SE. The image classification identified settlements with a certain minimum size. Thus, e.g. the expansion of the cities Meru highlighted in the upper subset in Figure 2 and Chuka located in the south-west of Mt. Kenya National Park are visible. As for the expanses of water, it should be noted that they can only be detected in the SE of the study area. Due to the acquisition of the image in the dry season in February 2015, wadi systems did not contain water in most cases. In the 2015 image, the influence of cloud cover is less than 4%.

Comparison between 2010 and 2015

The comparison of the classified images from 2010 and 2015 is shown in Figure 3. Two subsets (A and B) were chosen in order to see a direct comparison between the two dates on a larger scale. Thus, a focus on agricultural and forest areas is given.

The impacts of recent trends in agricultural production can lead to deforestation but are discussed controversially. The presented investigation shows that agricultural areas have a growing influence on land use structures in the east of Mt. Kenya region. The classification results show an increase of agricultural areas of more than 40%. This can be seen in an overall growth of the agricultural belt (Fig. 3). However, these results should be viewed critically due to methodical weakness. On the one hand the classification of agriculture features high error rates, on the other hand the acquisition dates of the compared satellite images vary in seasons (September 2010 and February 2015). High differences in the change detection method may occur due to differences in the growing seasons.

Even though the growth of croplands may not be as intense as calculated by the classification, a general growth of agricultural production is assumed (Mwangi 2008, Were et al. 2013). According to the statements of HCDA members, agricultural growth can be spatially divided into the northern part of Mt. Kenya that allows intensive, industrial cultivation, whereas the eastern and southern parts show a different mixed land use between scrubland and agriculture. The latter areas are more prone to be used for small-scale horticultural farming. This goes in line with our observations in the field, but cannot be spatially detected by the land cover classification. According to the interviews with local farmers, some reported a small growth in their cultivation area. Others recognized an increasing number of new farmers who are integrated in agricultural markets. Furthermore, the accretion of the tea areas between 2010 and 2015 (about 50%), which could be identified in this study with a much lesser error rate, represents the general growth of agricultural areas (Fig. 3A).

As tea is mainly produced for export (Gesimba et al. 2005), the increase of tea plantations between 2010 and 2015 can be strongly connected to economic causes for this kind of land use development. On the basis of the classification comparison, it is assumed that the ongoing processes of agricultural intensification went together with deforestation and land degradation. In general, the development of forests is marked by an extensive decrease of one quarter. As shown in both subsets in Figure 3, this decrease occurs in different spatial extents. On the one hand, the disappearance of forest areas can be detected in the valley systems around Mt. Kenya National Park. Here, the forests are mainly transformed into tea plantations or other agricultural applications. On the other hand, forest decline is located in aggregated regions at lower altitude. Subset B of Figure 3 points out a massive encroachment of human activities in former forest areas. Here, a continuous plot of forest was mainly transformed into agricultural land. An exception to the generally decreasing forest areas is represented by the spatial extent of Mt. Kenya National Park. This territory in the west of the research area, classified mostly as forest, is widely untouched by humans between 2010 and 2015.

A growth of urban areas in the context of an increasing population and, thus, increasing pressure on landscapes were expected in this study. This would include not only settlements, but also traffic infrastructure (Dannenberg et al. 2011). In contrast to these expectations, however, no evidence of cumulative urbanization was detected. The classification results show an urban area reduction of more than 60% in the time interval of 5 years. This inconsistency appears due to the poor classification results in the class of urban areas.

Impact of Nyayo Tea Zones on Mt. Kenya National Park

From the fact that natural land cover, such as forest areas, has generally positive effects on the environmental characteristics of a landscape, sustainable environmental strategies should be applied by governmental institutions (Were et al. 2013). In this context Mt. Kenya National Park was established as a natural conservation zone to reduce negative implications on climate, biodiversity, hydrology and other environmental aspects in 1949. This governmental protection and direct intervention can be seen as an institutional cause of land use development in the research area. By the use of our remote sensing approach, the effects of this intervention were emphasized. Especially the detection of spatial patterns caused by forest and tea cover shows that the installation of Nyayo Tea

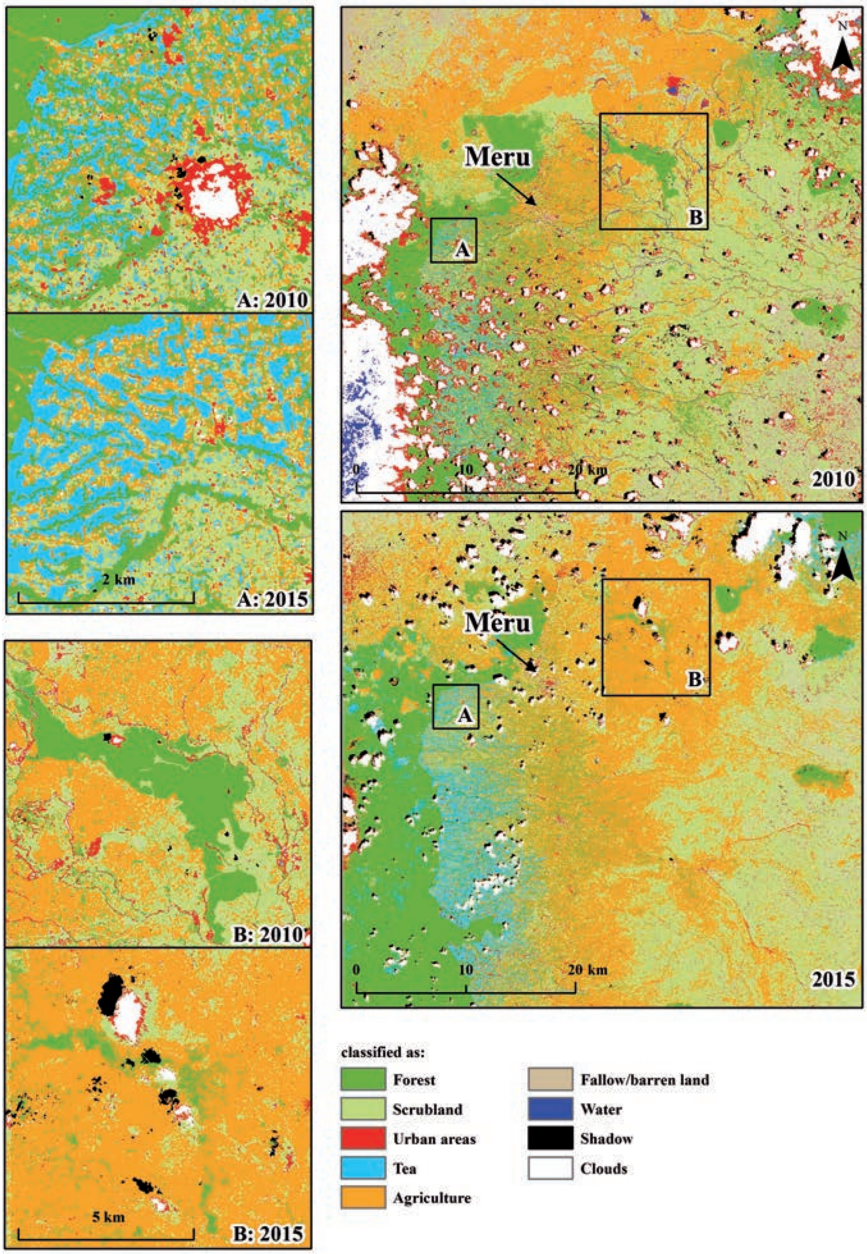

Fig. 3. Land cover change between 2010 and 2015 (for geographical location of the section see Fig. 1).

Fig. 4. Nyayo Tea Zones at Mt. Kenya National Park (M. Willkomm 03/2015).

Zones represents a positive example of successful forest conservation in the recent past. For environmental compensation strategies, this seems to be particularly important against the background of immense deforestation in other regions of the investigation area.

The methodical approach in this study provides an indication of how forests can be protected. The spatial allocation of the classified tea plantations around the boundaries of Mt. Kenya National Park gives evidence of successful elimination of informal deforestation. The classification results show very clearly that the extent of Mt. Kenya National Park is essentially identical in both satellite images considered. The arrangement of Nyayo Tea Zones indicates in how far the protection of forest areas can be realized. In the context of forest decline and land degradation, the creation of Nyayo Tea Zones plays a crucial role. Kenya´s government installed the "tea boundaries" at seven locations in central Kenya in the context of a World Bank funded project in 1984 (Klopp 2012). Protective buffer zones were created at the boundaries of forests in the form of tea plantations (Fig. 4). Although the project was discussed as an endorsement of tea production as well, it had a generally positive influence on forest protection. Because of the perennial cultivation of tea, local communities were not able to encroach on the national park areas. The results of this study are consistent with the evidence given not only by Klopp (2012), but also by local stakeholders and experts from the HCDA. These findings of institutional encroachments on land use especially are reasonable in the context of a general forest decline in other regions (see

Fig. 3B). By means of the positions of different tea farmers living in the study area, three main reasons for not encroaching on the national park forest can be identified. The first reason is better supervision of the national park boundary by governmental stakeholders. As shown in Figure 4, in comparison to trees, tea plants grow generally low. Thus, it is relatively easy to overview the area. Secondly, plantations are provided for local farmers to participate in tea farming, which can be an attractive sector for them. The third reason is about the all-season cultivation of tea. Thus, spatial access to the forest areas is predominantly restricted due to the tea plants as a physical barrier (Fig. 4).

5. Conclusion

This study provides new findings on recent land use change in eastern parts of the Mt. Kenya region in central Kenya. In land use science, especially the development of agricultural and forest areas is discussed in the context of general changes in sub-Saharan Africa. A remote sensing approach was applied to focus on these land use types between 2010 and 2015. Central questions concentrate on the methodical feasibility of RapidEye classifications in the region, major land use changes and the evaluation of Nyayo Tea Zones.

It is generally possible to determine major land use types with RapidEye satellite images in the Mt. Kenya region. The classification of the high resolution imagery delivered overall accuracies of 0.82 in 2010 and 0.85 in 2015 given by the kappa coefficient. Whereas the differentiation of spectral homogeneous areas, like forests or tea plantations, performed very well with very high accuracies, in other land cover classes, the error rate was bigger due to different limitations. In most cases, these limitations occur due to spectrally smooth transitions and spatial mixture between the classes. The differentiation of urban areas and fallow and barren land or agricultural types and scrubland were difficult. Especially in the latter case, the limitation rises with the increasing heterogeneity of small-scale structures with the exception of the tea fields. This also includes differentiation of single field crops, which was not possible with RapidEye data in this case study. Nevertheless, it was possible to classify and detect general land use types and changes between 2010 and 2015.

The land use structure in the eastern part of the Mt. Kenya region in 2015 can be described as a concentric arrangement of different types of land use around Mt. Kenya. In the middle of this system, Mt. Kenya National Park is located as a protected forest. At the edges of this forest area, tea plantations, Nyayo Tea Zones, orientate themselves according to the valley configurations. These structures merge into a belt of other agricultural uses, which are dominated by horticultural small-scale cultivation in the east and south and more industrialized agriculture in the north. Further land cover classes, such as scrubland and fallow and barren land, are located in eastern parts of the study region. Land use change detection between 2010 and 2015 shows a general increase in croplands and a decrease in forest areas. The accretion of the tea areas represents the growth of agricultural areas due to economic intensification. Scrublands also decreased in the context of the encroachment of agricultural production. Urban areas are surprisingly shrinking, but these results may occur due to methodical limitations of the classification given.

The development of forest areas can be distinguished in a spatial way. While single forest clusters in the middle of the research area are characterized by a massive decrease, the forests of Mt. Kenya National Park are widely untouched by human activities. This can be linked to the creation of Nyayo Tea Zones, which passes into the protection of the natural forest areas. This study detects the "tea boundary" had a very positive influence on forest protection. The spatial extent of the forest of Mt. Kenya National Park did not change in the period under observation.

Acknowledgements

The authors would like to give thanks to the Blackbridge Group and DLR (Deutsches Zentrum für Luft- und Raumfahrt) for the provision of the RapidEye satellite data. We would like to thank our translators and advisors from the Karatina University in Kenya who made it possible to investigate the area of Mt. Kenya as well as give us the opportunity to interview local farmers. A special thanks goes to Professor Gilbert Nduru who gave us insights into the research area. The authors acknowledge the research grant received from the University of Cologne for the financial support that made this project possible.

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