LARGE AREA QUICKBIRD IMAGERY FOR OBJECT-BASED IMAGE ANALYSIS IN WESTERN KENYA: PRE-PROCESSING DIFFICULTIES, WORKAROUNDS AND RESULTING BENEFITS AS WELL AS (FIRST) SEGMENTATION STRATEGIES

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ABSTRACT:

QuickBird imagery covering Kakamega Forest in Western Kenya and the surrounding farmland (i.e. a total area of 631 km²) has been acquired for the interdisciplinary BIOTA East Africa research project. Using these data, improvements through pre-processing techniques for object-based image segmentation and classification results are presented. Taking two test areas the effects of orographic correction in further classifications as well as the influence of different image mosaicing techniques on segmentation results are demonstrated by comparing results derived from unprocessed vs. pre-processed image data. Additionally, some image analysis strategies and classification results are presented for producing a binary mask of all tree and shrub vegetation and for deriving parcels' sizes and their distribution in the agricultural matrix. A thorough pre-processing of very high resolution satellite imagery is beneficial not only for more appealing visual results but also for subsequent object-based image analyses. First segmentation and classification results are promising, however, extremely small structured parcels demand complex analysis strategies. In the case of large area datasets, pre-processing can cause unexpected difficulties, sometimes require workarounds and be very time demanding.

1. INTRODUCTION

For the interdisciplinary research project Biodiversity Monitoring Transect Analysis in Eastern Africa (BIOTA East Africa) funded by the German Federal Ministry of Education and Research (BMBF), QuickBird satellite data (four multi-spectral and one panchromatic band with a geometrical resolution of 2.4 and 0.6 m, respectively) have been acquired in Feb/Mar 2005. With a total area of 631 km² the imagery covers Kakamega Forest in Western Kenya and surrounding farmland (Fig. 1).

Situated in the moist western part of Kenya (some 40 km north-east of Kisumu, Lake Victoria) with mean annual rainfall of 2,000 mm (Kokwaro 1988) and mean monthly temperatures between 17°C and 21°C (Jätzold and Schmidt 1982) Kakamega Forest is known for its unique biodiversity (Mutangah et al. 1992). However, starting with gold exploitation in the 1930s and severe logging activities until the 1980s the forest structure and diversity has undergone significant changes (Mitchell 2004). Especially at the forest edges the impact of human interference can be observed, further exacerbated by a steady increase in population. With a very high population density of about 600 persons/km² (Blackett 1994), the surrounding farmland is one of the most densely populated rural areas on earth. The agricultural matrix is predominantly composed of small sub-hectare sized parcels used for subsistence farming. Besides, cultivation of sugar cane (in the northern part) and tea (in the southern part) can be found.

The BIOTA East Africa project consists of fifteen subprojects investigating the influence of fragmentation and human use on biodiversity of East-African rainforests. Research is related to the vegetation structure, ecological interactions, certain animal groups (emphasizing invertebrates) and socio-economic issues (Schaab et al. 2005). Subproject E02 at Karlsruhe University of Applied Sciences supports biodiversity research with geoinformation system and remote sensing activities in an interdisciplinary and integrated approach (Schaab et al. 2004). Here, the acquired QuickBird satellite data are a valuable source for detailed up-to-date information on the forest and the surrounding farmland useful for spatial analyses. In particular, extrapolation of local field findings from the farms are aimed at in order to contribute to a sustainable land use and forest biodiversity conservation.

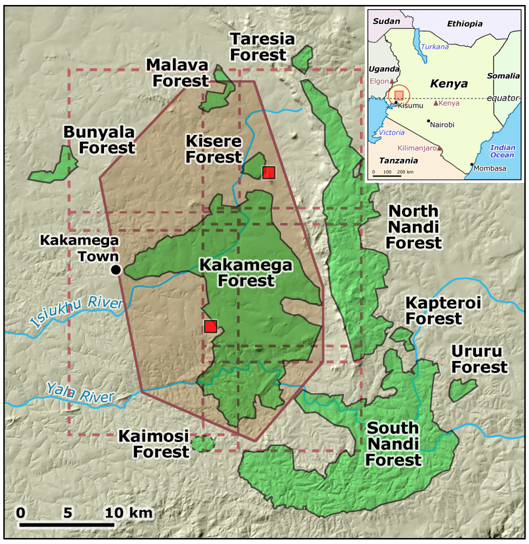

Fig. 1: Location of Kakamega Forest with its associated forest fragments, the coverage of the acquired QuickBird scenes, and the two test areas chosen for demonstrating benefits of pre-processing and segmentation strategies.

In order to completely cover the study area, five QuickBird scenes were recorded during two different overflights on February 21st (eastern swath) and March 6th 2005 (western swath). Hence, minor changes in vegetation cover as well as varying geometrical recording conditions have to be accepted. While the direction of the sun relative to the study area hardly changed (sun elevation: 63.5° and 64.5°; sun azimuth: 114.9° and 103.9°), the position of the satellite relative to the ground and accordingly the off-nadir angle changed significantly (satellite elevation: 86.4° and 74.5°; satellite azimuth: 277.5° and 104.6°). Because of the distinct azimuth angles of the sun and the satellite shadows appear to have different lengths in the two swaths (Fig. 2). In the case of the western swath, similar directions of the satellite and the sun relative to the study area have led to shadows half as long as compared to those on the imagery of the eastern swath (for details see Lübker 2005). Also, the atmospheric conditions changed over the recording period.

2. PRE-PROCESSING

In order to achieve a better comparability between the scenes and to create a homogeneous image mosaic certain pre-processing steps have to be applied before successful object-based image analyses can be carried out. Hence, for deducting true reflection properties of image objects or for pixels, different impacts have to be taken into account: e.g. the influence radiation is facing when passing through the atmosphere, irregular illumination of the objects, effects of neighbouring objects and effects due to sensor calibration. For accomplishing the goal, a correction of atmospheric and orographic impacts is to be preformed (Schowengerdt 1997).

The correction was carried out using the software Atcor 3 (Richter 2005). For counteracting atmospheric influences, a number of required input parameters are provided by the recording conditions (e.g. sun and satellite angles, date, terrain elevation) or estimated using the implemented tool Spectra (atmosphere type, aerosol type, scene visibility). Orographic effects are modelled applying a digital elevation model (DEM) and derivatives such as slope, aspect and sky-view factor, these leading to local illumination angles. Additionally, a correction

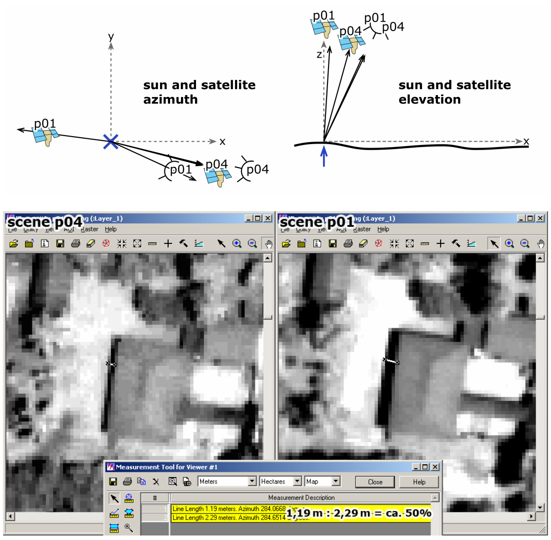

Fig. 2: Different azimuth angles of the sun and the satellite result in half as long shadows in the western swath image (p04) as compared to the eastern swath image (p01).

of effects described by the bidirectional reflectance distribution function (BRDF) is included. Values for the latter correction and the scene visibility were individually approximated for the two swaths in test series.

During processing a variety of problems and inconveniences occurred. These can be partly ascribed to the large size of the data set (approx. 7 GB). Thus, the single scenes had to be divided into subsets and mosaiced later on. For the complete processing (excluding test series) a total computation time of approx. 220 hours on commonly equipped PCs was needed. Observed artefacts (see Lübker 2005) included the appearance of 'contour lines' in the sky view image, abruptly or more smoothly decreasing digital number (DN) values towards sub-scenes edges, occasionally a superimposing of the DEM pixel resolution, and rectangular structures among others. A reduction of haze in parts of the western swath could not be achieved, presumably due to the small thickness of the haze layer. Furthermore, it has to be questioned if real reflectance values could be obtained. Tests with the so-called 'in-flight calibration' tool, where spectral curves from one image can be used to adjust the parameters simulating sensor settings applied to the other image, have not led to satisfying results. Therefore, spectral values in the overlapping area of the two swaths are still differing for one and the same image object. However, it can be concluded that the atmospheric and orographic correction carried out with Atcor 3 greatly improved the image quality and the comparability of the two swaths. In particular, orographic effects could be minimized successfully.

In a second step of pre-processing, a coherent image mosaic of the five QuickBird scenes acquired had to be produced. While the mosaicing of scenes originating from the same swath was straight forward, difficulties were encountered when bringing together the two swaths. Due to the lack of highly accurate reference data, the georeferencing delivered by the vendor (here QuickBird 'standard' product level) had to be accepted. This resulted in a mean horizontal aberration of approx. 5 m (or 8 pixels in the panchromatic band) for the two swaths relative to each other. To avoid a distinct join in the final mosaic, the two image swaths had to be geometrically adjusted to each other. This was performed within a narrow band on either side of the join. Since the aberration was not linear, a procedure was especially elaborated for this purpose making use of ERDAS Imagine 8.7, Leica Photogrammetry Suite and Excel. In a 1.5 km wide strip within the overlapping area tie points were collected. Additional 'fake' tie points prevent the image in the subsequent rubber sheeting transformation from adjusting outside the defined strip towards the original images. Then, within the adjusted strip an even smaller section was chosen for mosaicing with the two original swaths. Like this, a relative geometrical adjustment in only a very narrow strip was achieved by keeping most of the original data, i.e. no data resampling for most of the area. Even though atmospherically and orographically corrected, the swaths are not completely matching spectrally. Therefore, a local histogram matching algorithm was applied. In addition, a feathering within a 3 m distance was performed. In the thus derived mosaic, surprisingly, large areas of maximum value DNs could be found outside the valid image area. They had to be clipped. Most likely they originate from the large data size and the non-rectangular shape of the image. The final mosaic is convincing but not perfect. Differences in haziness, reflectance behaviours and of course shadow lengths could not be counteracted. Also geometrical inaccuracies could not be improved due to the missing availability of adequate reference data to start with.

3. INFLUENCES OF PRE-PROCESSING ON THE SEGMENTATION

The benefits resulting from in-depth pre-processing for object-based image analyses are investigated in case studies using Definiens eCognition 4.0 software. Two test areas have been exemplarily chosen to demonstrate the improvements on segmentation and classification obtained through a) the correction of influences caused by the terrain and b) the image mosaicing in the stitching area of the two swaths. Effects of the atmospheric correction will not be elaborated on their own as it is difficult to evaluate them independently. However, they are included in the testing results for the two study areas. The first test area is situated north-east of Kakamega Forest (see Fig. 1 and 3) covering parts of Kambiri Hill, a small edge of Kisere Forest and farmland including riverine vegetation and hedges. The second test area is situated at the western central edge of Kakamega Forest near Isecheno Forest Station (see Fig. 1 and 5) with a small section of Kakamega Forest in the north east margined by a strip of tea plantation (known as the 'tea zone'), parcelled farmland with tree/shrub vegetation as well as fallow areas. A segmentation and a classification are to be carried out for these test areas. A binary mask distinguishing the distribution of tree and shrub vegetation in the landscape surrounding the forest is the aim for the Kambiri Hill area. For the Isecheno area parcel sizes are to be revealed via a classification.

In Fig. 3 the result of the orographic correction is visualised: while the original image (left) shows a shadow on the western slope of the hill and a brightening in the middle part of the eastern slope, in the processed image (right) the whole hill appears more uniform. However, the two slopes of Kambiri Hill are not equal regarding their vegetation. As can be noticed in the processed image the north western part is covered by a denser shrub vegetation. In order to evaluate the impact of the orographic correction on object-based image analyses results, for each side of the hill image segments of similar vegetation were selected by means of visual interpretation and their object properties compared. In the processed image the objects show very similar characteristics. Here, the spectral object properties for mean Red, NIR and the Soil Adjusted Vegetation Index (SAVI) are partly overlapping or grouping in close vicinity when drawn in two-dimensional feature space plots (Fig. 4-right). In the graph brown dots are representing eastern, illuminated and yellow dots western, sun-exposed slope vegetation. In addition green crosses are shown for a comparison between the chosen objects and those of the binary tree/shrub mask. In the original image (Fig. 4-left) the object characteristics of the selected vegetation type vary to a significant degree: here, the vegetation on the two slopes form two separate clusters in the feature space plot. Objects on the eastern slope show higher values in the NIR and SAVI band and slightly higher values in the Red band.

For evaluating the impact of the mosaicing process, the original scenes have been mosaiced together without any further treatments and applying a histogram match for the overlapping area of the scenes. The second method simulates thus a common methodology (see e.g. Repaka et al. 2004). Fig. 5 is showing the result of the mosaicing approaches: In the simply stitched image (left) a large difference in spectral values between the eastern and the western part of the image can be observed with a very sharp join. In the mosaic with an applied histogram matching (middle) the difference has become less apparent but the join is still present. In the sophisticatedly-processed mosaic (right) the difference has become inconspicuous. Only in the southern part of the subset a leap in spectral properties is still existing for some parcels, likely to be caused by BRDF effects.

Impacts on spectral properties in object-based image analyses are demonstrated by means of segmentation behaviour instead of focusing on object properties. In the case of the simply mosaiced image, segments are found to highly orientate themselves to the join which is almost completely dividing the subset (Fig. 6-left). By looking at the segments (coloured according to their mean spectral values in the Green-Red-NIR composite) it is evident that object characteristics are dissimilar and are likely to lead to classification errors later on. Segments in the mosaic produced by applying a histogram matching also orientate themselves to the join though less strong (Fig. 6-middle). In the fully pre-processed image mosaic, segments do not orientate according to the join (Fig. 6-right). Only in the southern part of the image the above mentioned leap in spectral properties has influenced the segmentation.

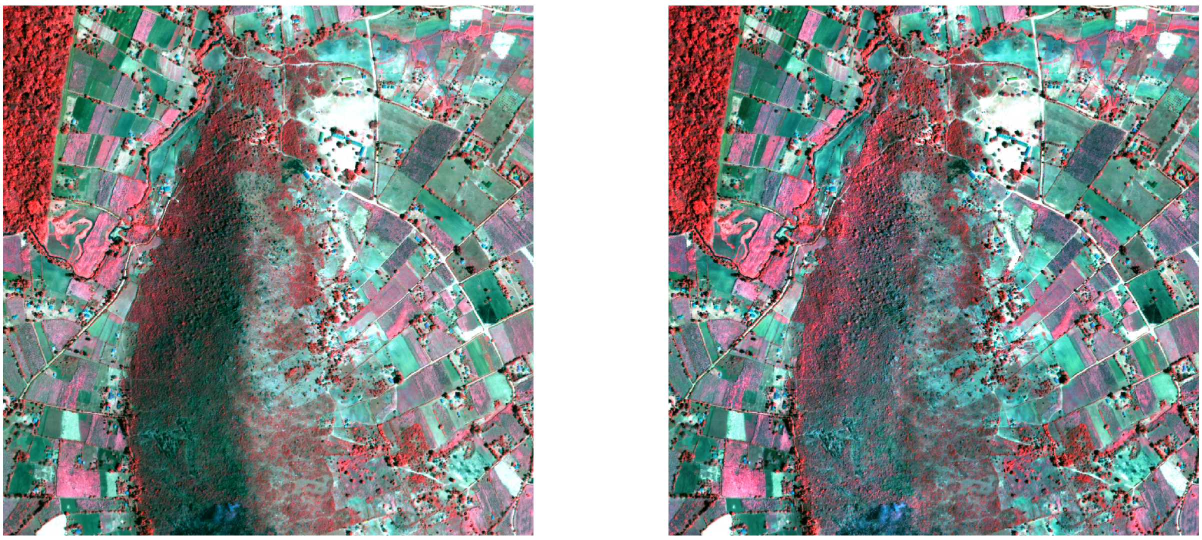

Fig. 3: Effects of orographic correction: in the uncorrected image subset (left) the western slope is shadowed, in the processed image subset (right) the slopes appear more uniform. Both images are pan-sharpened and displayed as Green-Red-NIR composites.

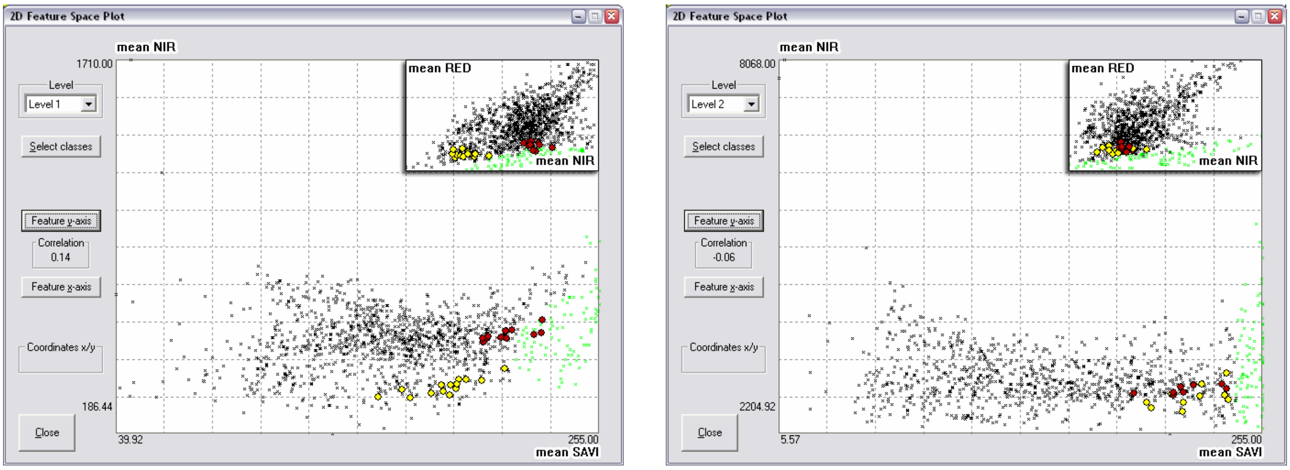

Fig. 4: Two-dimensional feature space plots demonstrate object characteristics for similar vegetation (grassy land cover with sparse shrubs) on a western (yellow dots) and an eastern slope (brown dots) for in the uncorrected image (left) and after pre-processing (right). Green crosses represent objects of the binary tree/shrub mask.

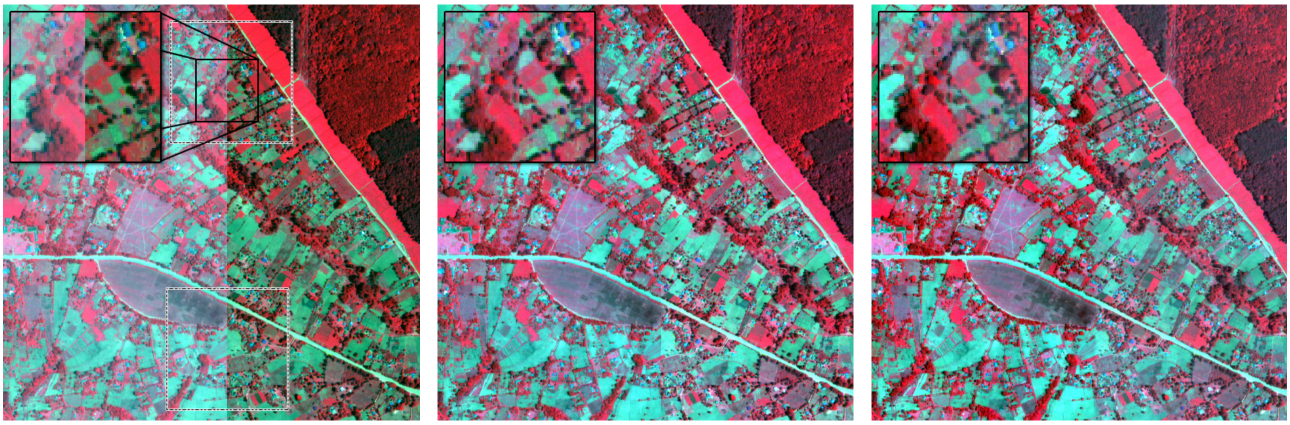

Fig. 5: Different mosaicing approaches tested: the simply mosaiced image (left) with large differences in spectral values for the two swaths, the mosaic applying a histogram matching (middle) with less differences but a still visible join, the thoroughly pre-processed image (right) with the best spectral and geometrical adjustment. Boxes (left) refer to the subsets as shown in Fig. 6 and 8.

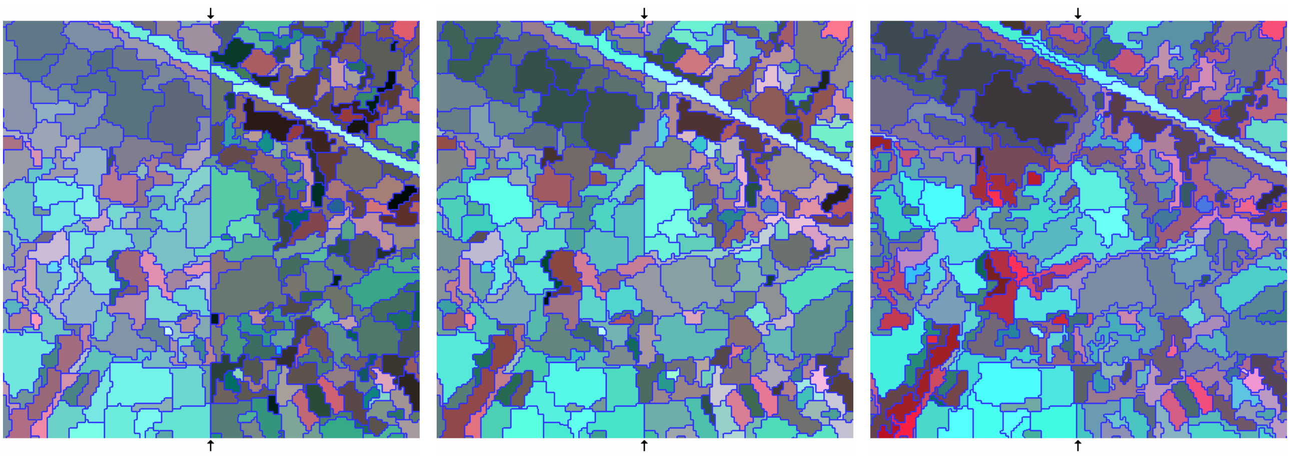

Fig. 6: Influence of different mosaicing strategies on segmentation results: in the simply mosaiced image (left) segments highly orientate to the join, in the mosaic with a histogram matching applied (middle) segments also orientate to the join but less strongly, in the pre-processed image (right) segments do not orientate to the join (except in the southern part due to BRDF effects). Segments are coloured according to their mean spectral values in the Green-Red-NIR composite.

4. IMAGE ANALYSIS STRATEGIES AND SOME CLASSIFICATION RESULTS

In the following, the segmentation and classification are shortly introduced even though they are not yet finalized and will be further investigated in the up-coming project work. The distribution of tree and shrub vegetation, finally to be represented in a binary mask, can for example be useful to identify possible forest corridors along remnant tree patches in the open landscape as stepping stones between forest fragments. These are of value for statements on the exchange potential between populations and the regeneration potential of rain forests (cf. Noss et al. 2006). Sizes of parcels in the farmland and their distribution can be used to estimate fence or boundary lengths between neighbouring plots. This information can play an important role for agro-economic estimations on the potential usability of fences for additional cultivation in a landscape having already reached its limits in carrying capacity (see Diwani and Becker 2005). On these two classifications the retrieval of structural patterns can be based leading finally to a typology of the farmland surrounding Kakamega Forest. This can then be used to model alternative futures (see e.g. Baker et al. 2004) via spatially explicit scenarios of rural livelihood depending on land use management planning recommendations which are aiming at forest biodiversity conservation.

For segmentation, the four multi-spectral and the panchromatic band as well as a derived SAVI and in the case of the parcels also a Prewitt-filtered image are applied but weighted differently according to the classification propose. While the Blue and Green channels are helpful to extract features for the tree/shrub vegetation mask, they are of little help for differentiating parcels. In contrast to this the panchromatic channel is weighted higher in the parcel classification process since parcel boundaries are small-scale objects in Western Kenya. Adding the SAVI channel is considered useful for both tasks since it allows for an easier separation of vegetation than via the NIR channel. For parcel detection the edge-enhancing Prewitt filter turned out to be useful since both boundaries and trees are well detected (cf. Wezyk and de Kok 2005). Although the tree and shrub vegetation cover differs a lot from other vegetation, rather small segments need to be produced so that single groups of trees still form individual objects. Hence, the homogeneity criteria 'scale parameter' in eCognition's multiresolution segmentation dialogue is set to small while the segment shape showed to be of minor importance too. By contrast, in the case of the parcels the shape and compactness is important considering that parcels are rectangular, compact objects.

For the tree/shrub vegetation mask object classification is carried out using membership functions to have a better control over the classification mechanisms. Three classes are defined: forest and tree groups (SAVI very close to 1.0), shrub vegetation (SAVI almost as high, but lower NIR to exclude parcels abundantly covered with vegetation), and single trees and small groups of shrubs (SAVI much lower, NIR high and Red low). These classes are joined together to produce the final binary mask. As Fig. 7 clearly indicates, Kisere Forest is classified very satisfactory but further refinement should still be possible separating riverine vegetation and hedges.

Elaborating a procedure for parcel detection is more complex. Not only parcels differently cultivated but also parcels that are equally cultivated are to be separated according to landownership. The agricultural matrix surrounding Kakamega Forest is characterized by small-scale subsistence farming and thus very different to Western Europe and North America where mostly industrialised farming is found. Plot sizes are very small, with typically between 1 and 7 ha (Jätzold and Schmidt 1982), mixed cultivations of maize, beans, bananas, vegetables, tea, nappier, cassava, sugar cane, sweet potatoes, and others. Parcel edges are often not distinct when next to shrub and tree vegetation, commonly found also within the parcels. Therefore, comparable results to classifications as achieved for a Bavarian test site with fields separated by paths and additional accurate cadastral information at hand (Fockelmann 2001) cannot be expected. At the current stage only the segmentation steps have been carried out leading to rather promising though not yet satisfying results (Fig. 8). While the tea belt along the forest edge is segmented very well and housings are also nicely separated, the actual parcel pattern is not always as clear. Improved results are anticipated with the help of cadastral

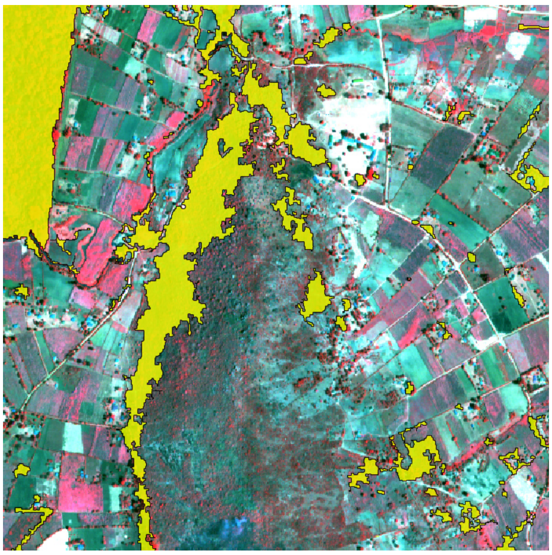

Fig. 7: Classification result for a binary mask separating tree and shrub vegetation close to Kisere Forest. For comparison see Fig. 3.

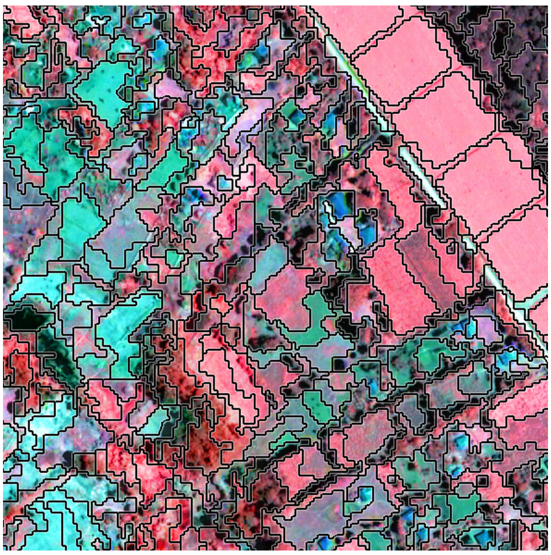

Fig. 8: Segmentation results for parcels in the agricultural matrix next to Kakamega Forest.

information that will be available in form of diazo copies for some parts of the Kakamega district. Digitised, this information will be a valuable further input source. Also a ground truthing is planned to better understand how the different kinds of cultivation are represented in the imagery.

5. CONCLUSIONS

It can be concluded that a thorough pre-processing of very high resolution satellite imagery is beneficial not only for more appealing visual results but also for subsequent object-based image analyses. The correction of influences caused by the orography and atmospheric conditions leads to a more homogeneous extraction of object features. Elaborative mosaicing methods coupled with atmospheric/orographic corrections do not only help to avoid objects of the same kind to be classified differently in the two image swaths but also prevent segments to be generated orientating themselves to the join. However, in the case of large area datasets pre-processing can cause unexpected difficulties, requires sometimes workarounds and can be very time demanding.

First segmentation and classification approaches show promising results for the masking of tree and shrub vegetation in the open landscape and the derivation of parcel structures in the farmland surrounding Kakamega Forest. The extremely small structured parcels of subsistence farming in one of the most densely populated rural areas of the world is challenging and demands complex analysis strategies. Additional information obtained through ground truthing and from cadastral maps is expected to improve the results of object-based image analyses. The anticipated results and future activities based on these are to play an important role in support of biodiversity research in Eastern Africa, as with this detailed as well as up-to-date information will be available for the interdisciplinary tasks of the project partners.

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Note