Remote sensing challenges in land cover and land use change detection in East Africa

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Remote sensing

Remote sensing is art, science and technology for acquiring reliable information from physical targets and environment through analysis of images and digital data describing the energy reflected or emitted from the ground. It is essential that the sensors used are not in the contact with the target. In remote sensing various wavelengths of electromagnetic spectrum from visible wavelengths to microwaves are used for sensing the reflected, emitted or backscattered energy from the Earth surface. The sensors applied may be mounted in airborne platforms as aerial photograph cameras or airborne laser scanners or in satellites platforms like SPOT HRV sensor or MODIS. Some sensors can also operate from land surface like terrestrial laser scanners or even photographic cameras. The data can be recorded in analogue form on film or more often nowadays as digital signal. In digital signal the Earth surface is registered as matrix in which each picture element (pixel) has position information (x,y) and intensity information (DN), which describes the reflectance of the surface in various wavebands.

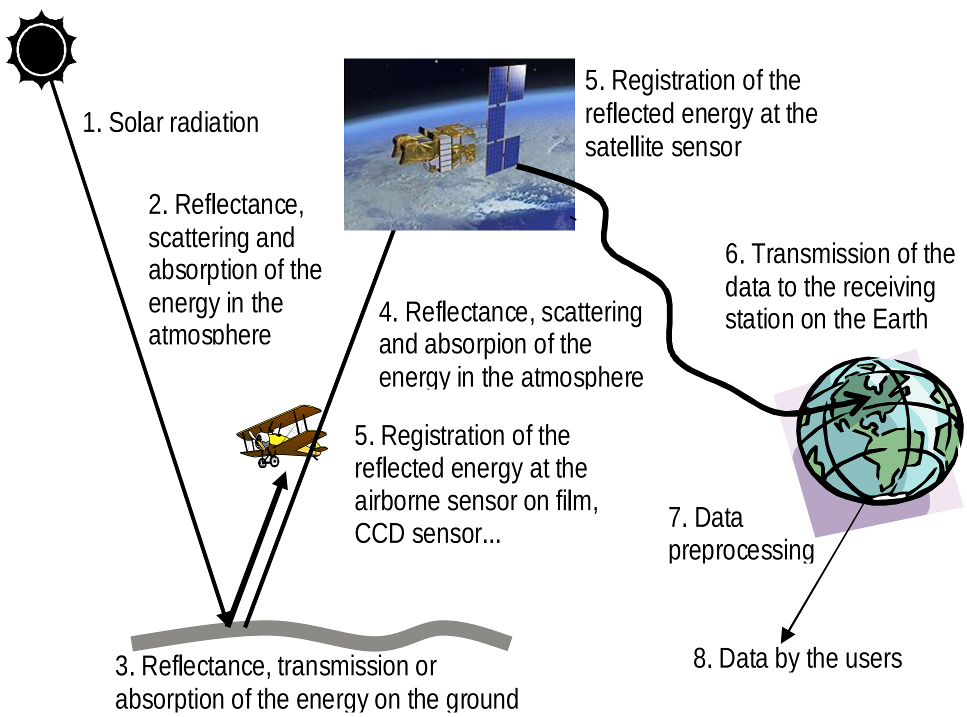

Figure 1. Simplified remote sensing process from solar radiation to data for the users.

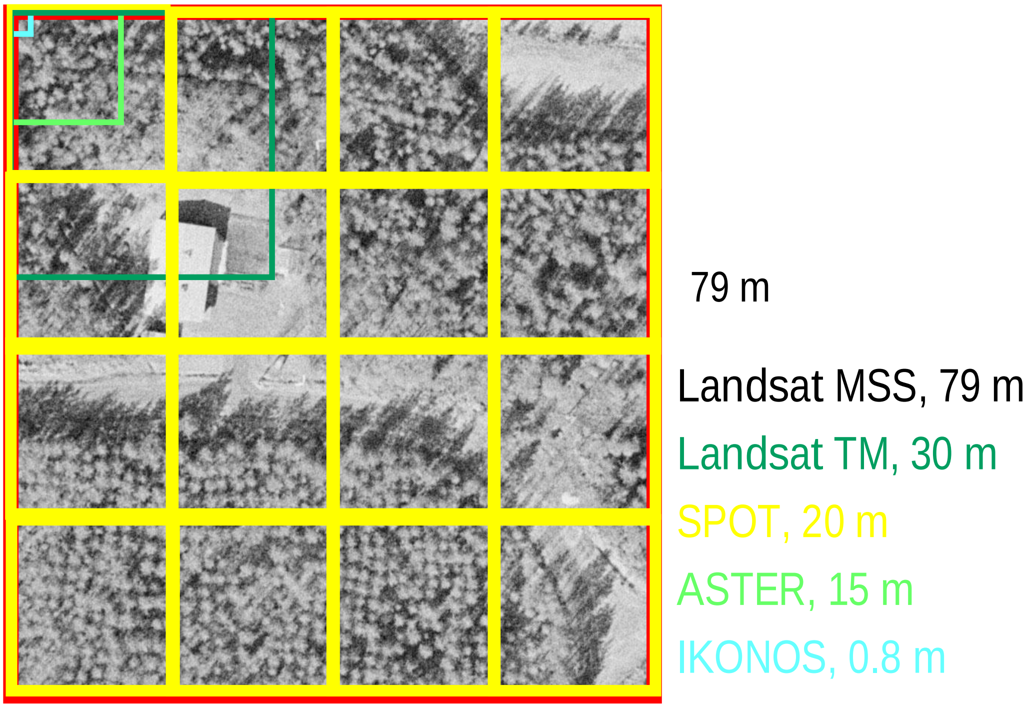

Figure 2. A land surface unit 79 x 79 m divided by Landsat MSS, Landsat TM, SPOT XS, ASTER and IKONOS ground resolution.

The remote sensing process is simplified in Figure 1. Simply as that the sun is shining and some of the radiation in scattered, reflected, transmitted or absorbed by the atmosphere. The transmitted radiation reaches the land surface, on which again some of the energy is reflected, absorbed or transmitted. In remote sensing in optical and near infrared wavelengths the reflected energy is recorded. In thermal infrared area, the longer-wavelength emitted energy is recorded. Some sensors are active meaning that they transmit the energy themselves and then record the energy which is backscattered from Earth surface. Examples of active sensors are laser scanners working in near-infrared wavelength area and radars working in microwave wavelength area. The reflected energy is recorded in the sensor, but during its path to sensor the reflected energy is again affected by the atmosphere. Once the signal reaches the sensor, it is transmitted to the Earth surface in the case of satellite sensor, or the aircraft simply lands on the land surface. Typically the data providers are carrying out essential preprocessing before the data is given for users. This preprocessing includes corrections for system induced distortions or georegistration.

Remote sensing resolutions

Remote sensing data has specific resolutions, which describe the data characteristics. Spatial resolution describes the area of land unit measured with brightness value (other expressions are digital number, DN or grey value). The spatial resolution is often referred also as pixel size. For satellite data it varies from 0.6 meters of the Quickbird data to 1,15 km of the SPOT Vegetation data. An example of spatial resolution is given in Figure 2, in which a land surface having forest, road, house and yard is presented in imaginary Landsat MSS pixel covering 79 by 79 meters. The reflectance in MSS data is covered by single brightness value, while in IKONOS data having spatial resolution of 0.8 meters the reflectance is recorded almost by 10.000 pixels for the same area, thus enabling the recording of the reflectance of road, house, lawn and even shadows and sunflecks in the forest separately. In MSS data the reflectance recorded is an average for all land cover types in the image.

Spectral resolution describes number of wavebands used for the measurement. The number of wavebands can change from 1 for black & white aerial photography to 300 in the case of hyperspectral data. Another measure for spectral resolution is how narrow are the sensed wavebands, in the other words how narrow wavelength region they cover. Radiometric resolution describes how small variations in reflectance can be measured. In 8-bit data 256 different digital numbers can be measured, but in 12-bit data 4096 digital numbers are measured. Higher radiometric resolution means that we can record finer differences in land surface reflectance. Temporal resolution describes how often the sensor passes same ground target and is able to record data. Some sensors pass the same land surface daily, while some sensors pass the same surface only every month. With sensors working in optical and infrared area the temporal resolution is reduced by cloud cover, while the sensors operating in microwave area can see thorough clouds.

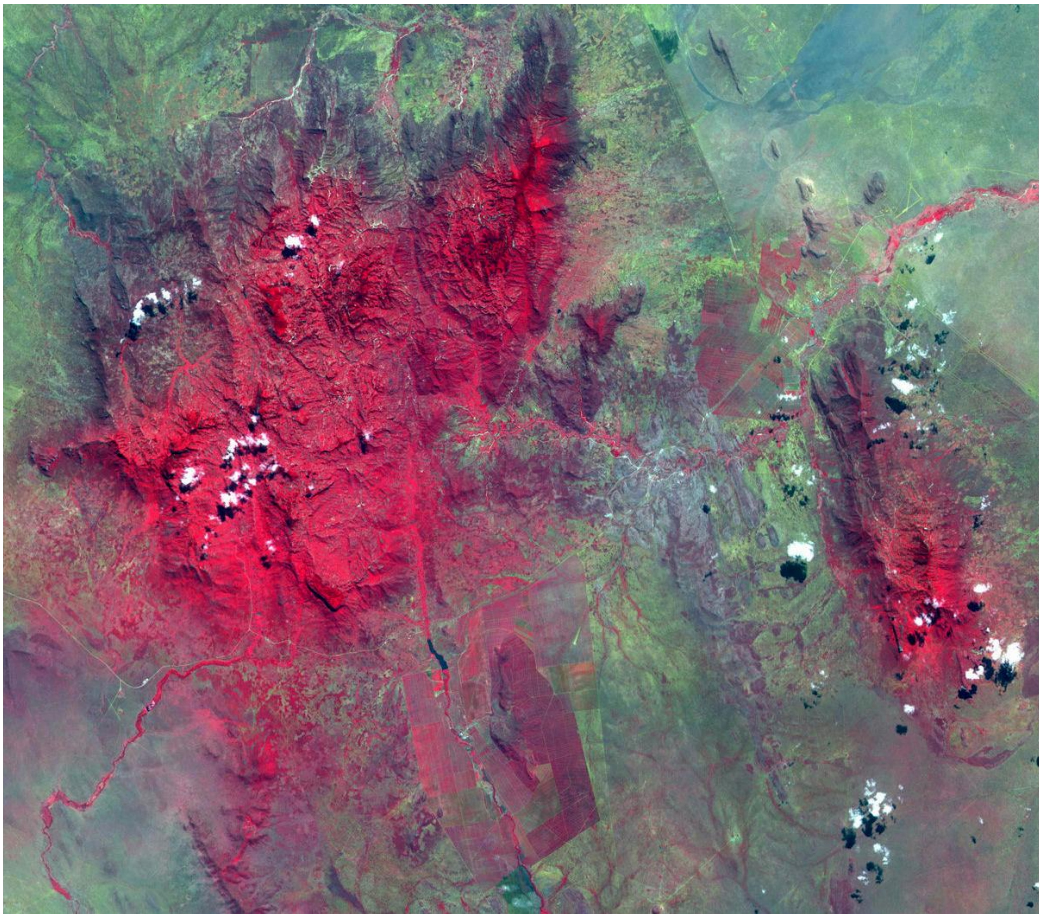

Figure 3. SPOT XS image over the Taita Hills, 1.7.1987.

SPOT XS data having spatial resolution of 20 meters and 4 wavebands is presented in Figure 3 over the Taita Hills, Kenya. With the given pixel size we can visually see wider roads, riverine forests and shadows casted by topography. We can also identify land cover pattern; sisal plantation in lower parts, indigenous forest fragments in the hills and a boundary between Tsavo East National Park and area under human impact. In false color composition image we see areas with green vegetation as red, while areas with low vegetation cover or with senesced vegetation are mixture of green and blue. In Figure 4, IKONOS image over Krakatau island in Indonesia is presented. While the spatial resolution is 0.8 meters we are able to identify individual tree crowns of *Casuarina equisetifolia* and even waves in the Sunda Strait. MODIS sensor was developed especially for climate change studies and it has 36 bands from red to infrared area with spatial resolution ranging from 250 to 500 m. In Figure 5 is an example of MODIS image showing part of Somalia, Kenya and Ethiopia. With this resolution it is possible to identify towns, dune fields, river valleys and large land units in general.

Figure 4. IKONOS satellite image over Krakatau island, Indonesia, 11.6.2005.

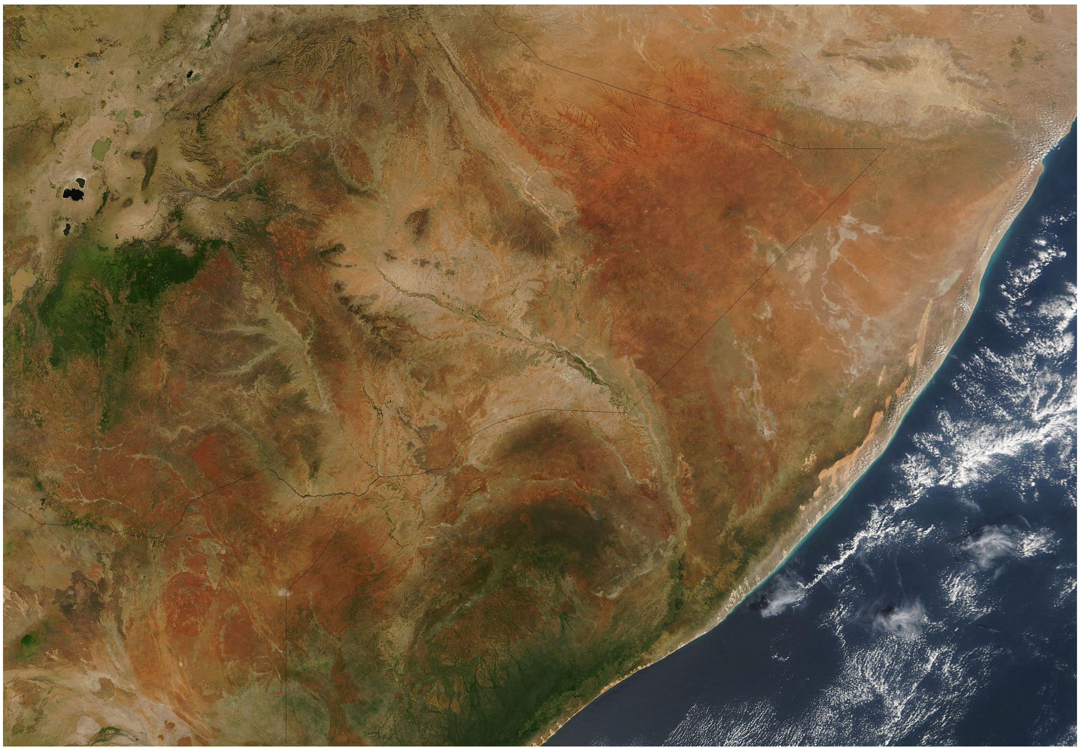

Figure 5. MODIS satellite image over Somalia.

Pre-processing prerequisites of remote sensing data

Remote sensing data requires preprocessing in order to carry out reliable analysis. The images are to be registered to national or international coordinate systems, like WGS 84 or UTM and the brightness values are to be converted to physical units as reflectances. However, some analysis, like land cover classifications or vegetation index calculations can be carried out also using brightness values only, but without georegistration the use of remote sensing data is more or less meaningless. In analysis, the reflectance values of the pixels are given thematic information (e.g. land cover class) or physical information (e.g. biomass). The results can be used together with other geospatial data (e.g. digital elevation models, road network, population data, rainfall data) in given coordinate system for spatial analysis of the environment.

Pre-processing also involves atmospheric correction in order to remove the impact of atmospheric scattering on image brightness values and topographic correction, which is a prerequisite in rough and mountainous environments. The topographic effect on image spectral characteristics is caused by uneven distribution of solar irradiance on slopes of varying steepness and exposed to varying directions. As slopes towards the sun receive more irradiance, they also reflect more back to space and towards the sensor. As a result, similar kind of vegetation sunny and shadowed slopes can be misinterpreted in different vegetation classes. The topographic correction is carried out using elevation model and it results to normalized solar irradiance distribution on every slope angle and exposure. The effect is not so significant in equatorial areas as in high latitude due to smaller solar zenithal angles.

Land cover, land use and change detection

Land use refers to human usage of land, which typically affects land cover. Typical land use types are forestry or agriculture. Land cover is a layer, typically a biospheric layer above the soil or bedrock. Land cover can be forest, maize field or even clay soil. The definitions of land use and land cover are sometimes overlapping and confusing. The change in land use changes land cover, for example when forest is cut and cleared for agriculture. Change in land cover, however, do not always change the land use. Land use is still forestry even though forest is felled or burned, but the use of land remains as forestry if the land is re-planted.

When studying environmental changes with remote sensing data, typically two or more remotely sensed images are used. It is a prerequisite that the geometric characteristics of the remote sensing data are similar in order to study the phenomena in the same place. It is also essential that the spectral characteristics are normalized in order to correct sensor and environment induced effects on the data.

For example the atmospheric conditions change between the imaging dates and the differences have an impact to image brightness. For example an observed brightness value of 56 can be a result of surface reflectance (brightness value 45) and atmospheric scattering (brightness value 11). As satellite images cover large areas, the impact of atmospheric scattering on image brightness varies in the image area as the atmospheric conditions vary. Using only a single date image the impact is quite harmless, but in change detection applying two or more images, the impact of varying atmospheric conditions between the dates can cause significant differences on image brightness – which are not caused by land cover changes.

Technical challenges

The technical challenges in change detection studies applying remote sensing data in East Africa are related to ancillary datasets needed for preprocessing of the data. We need ground control points for georegistration of the imagery to coordinate system. These can be acquired from digital maps, maps or using GPS, but quite often maps are not available or the access to the field is restricted.

Atmospheric correction and multitemporal relative spectral calibration

Several methods are developed for atmospheric corrections. Physical models, like LOWTRAN 7 and MODTRAN, attempt to model the physical process of scattering for given date, time and area. Their advantages are accuracy, rigor and applicability, but their advantages are numerous especially related to applications in Eastern Africa. They are complex, require computer programmes, but the most limiting factor is the requirement for detailed meteorological information pertaining to atmospheric humidity and the concentration of atmospheric particles (Campbell 2002). Such information may be difficult to obtain in the necessary detail, and may apply only to few points of Landsat image, for example. Also atmospheric conditions vary with the altitude, and radiosonde data are routinely collected only at few locations. In many cases standard atmospheric conditions embedded in algorithms need to be used, but those are only models and not as precise as real measurements.

For East Africa, relative methods may provide more straight forward possibilities. In relative methods reflectances from targets of known brightness in multispectral imagery are examined. Ideally the targets are observed at the time of image acquisition, but in practice we seldom have the possibility for such measurements and therefore we must look for features of known brightness that commonly appear in the imagery. At its simplest form a very dark object is used, such as water body, coniferous forest, or shadows cast by clouds or mountains. The principle of using water surface, for example, is that in near infrared (NIR) portion of the spectrum the brightness should be zero as clear water absorbs NIR wavelength. Thus all the brightness values above zero are caused by atmospheric scattering and should be subtracted from the all the brightness values in that image in that band. As the same is done for every band, the black colour is assumed to be the correct tone for a dark object in the absence of atmospheric scattering. This method, first introduced by Chavez (1975) is known as histogram minimum method. It is simple, direct and almost universal, though not very accurate. In addition, in relation to East Africa, there are not much open water surfaces or coniferous forests and the mountains with high sun angles do not cast long shadows. Fortunately, clouds and cloud shadows exist, but not in very image and sometimes the shadows are not deep.

Multitemporal relative spectral calibration becomes more accurate when instead of one target, both dark and bright targets are used. These targets should be from the end of the dynamic range of the image, for example water surface or dense forest as dark target and open sandy area as bright target. The targets should be visible in every image to be calibrated and their reflectance characteristics should not change significantly year by year or according to season. Using the mean and standard deviation of these reference areas a regression function is created in order to normalize the brightness (Pellikka 1998). As a result, the mean brightness value of the dark and bright targets become similar thus indicating that brightness is normalized in the whole dynamic range.

In the historical empirical line method (HELM) reflectance measurements are carried out in the reference areas having stable surface reflectance (Clark & Pellikka 2005). The main idea in HELM is that reflectance from stable and in-variant areas is used for conversion of brightness values to reflectances. In the TAITA project, for example a water surface of Mwatate reservoir was used as dark target and a road side quarry on Taveta road was used as bright area.

Figure 6. Indigenous woodland and exotic woodland (1), bushland (2), agricultural land (3), some open area features; road, rock, yard (4).

Table 1. Land cover classes of visual interpretation of the Taita Hills using LCCS nomenclature and classes (Lanne 2007).

Own Classification Level I	Own Classification Level II	LCC Label	LCC Code	LCC Level
Woodland	Indigenous	Broadleaved Deciduous Trees, Single Layer	20642	A3A10B2C1D1E2F1
	Exotic	Needleleaved Evergreen Trees, Floristic Aspect: Cypress	20092-Zt1	A3A10B2XXD2E1-Zt1
		Broadleaved Deciduous Trees, Floristic Aspect: Eucalyptus	20090-Zt2	A3A10B2XXD1E2-Zt2
		Needleleaved Evergreen Trees, Floristic Aspect: Pine	20092-Zt3	A3A10B2XXD2E1-Zt3
		Needleleaved Evergreen Trees, Floristic Aspect: Grevillea	20092-Zt4	A3A10B2XXD2E1-Zt4
Bushland	Bushland	Closed to Open (100-40)% Thicket, Single Layer	21600-121340	A4A20B3XXXXXXF1-A21
Agricultural land	Grassland	Closed Grassland, Single Layer	21299	A6A10B4XXE5F1
	Shamba	Small Sized Field(s) Of Rainfed Herbaceous Crop(s)	11251	A3B2XXC2D1
	Terrace	Small Sized Field(s) Of Rainfed Herbaceous Crop(s)	11251	A3B2XXC2D1
Open area	Rock	Bare Rock(s)	6002-1	A3-A7
	Road	Linear Built Up Area(s)	5002	A3
	Yard	Urban Area(s)	5003-9	A4-A13

Elevation models

In rugged terrain and in mountains, simple 2-dimensional georegistration is not enough to fit the satellite image or especially airborne remote sensing image to ground coordinates. In these areas orthorectification applying digital elevation model needs to be carried out. The problem is that elevation models are not available for every areas or they are not high resolution enough or they are too costly. The same challenge implies for topographic correction. For the correction we need an elevation model at least in the same resolution as the remote sensing data applied (Sandmeier & Itten 1997). If the elevation data is not available, it has to be done for example by digitizing the contour lines from topographic maps (Pellikka et al. 2005).

Classification systems and algorithms

In land cover change detection we are typically classifying the land cover by visual analysis, pixel based classification algorithms like maximum likelihood classifier or by object oriented classification. All these classification methods require training areas and validation areas from the ground and the challenge is to get satisfactorily enough training and validation areas for statistical tests of classification accuracy. The questions are that are these areas accessible technically, logistically and safely?

Another challenge related to classifications is with the classification schemes, classes and nomenclatures. For example, what is the physical requirement of an area to be named forest in terms of canopy cover, density, tree height, species? In addition, various scientists are making classifications and the question is that are the classifications made out by various scientists comparable for the same area, for neighbouring areas or regions. A remedy for this problem are international classification schemes like land cover classification system (LCCS) developed by UNEP and FAO. In Figure 6 four digital camera images are shown over the Taita Hills (Lanne 2007). The images cover classes like indigenous forest, plantation forest, bushland, agricultural land, road, rock, yard. The land surface units are principally understandable, but very descriptive. However when applying the LCCS code and level for the classes, they become more understandable and comparable (Table 1).

There are also some technical challenges related to analysis. However, in this case only classification methods are discussed. Traditional visual analysis is reliable, but it suffers from subjectivity and it is laborious. Pixel-based classifiers such as maximum likelihood classification ignore useful spatial information surrounding the pixel as well as uni-scale approach ignore multi-scale information within the image. Object oriented classification is a fairly new method, which is based on user-defined parameters for the scale, for the weighting of the shape factor versus ‘color’ (spectral) information, and for the balance in smoothness and compactness parameters. Also named as segmentation, instead of pixels areas are classified and for each area recognised weight of belonging to several classes can be given. In subsequent iterations, smaller image objects are merged into larger ones and the classification can be manually improved by user-knowledge (Clark & Pellikka, in print). In Figure 7, the differences of the classifications applying maximum likelihood and segmentation are presented on the northern foothills of the Taita Hills. The maximum likelihood classification shows very distinctive salt-and-pepper kind of pattern since individual pixels are classified according to their spectral characteristics including much of the information from neighbours. In segmentation areas are classified. Figure 8 presents the various levels of object-orientated classification of a SPOT HRV 2003 image for a circa 6 km by 6 km of northern foothills of the Taita Hills. In a, a red band of a 2003 SPOT is presented

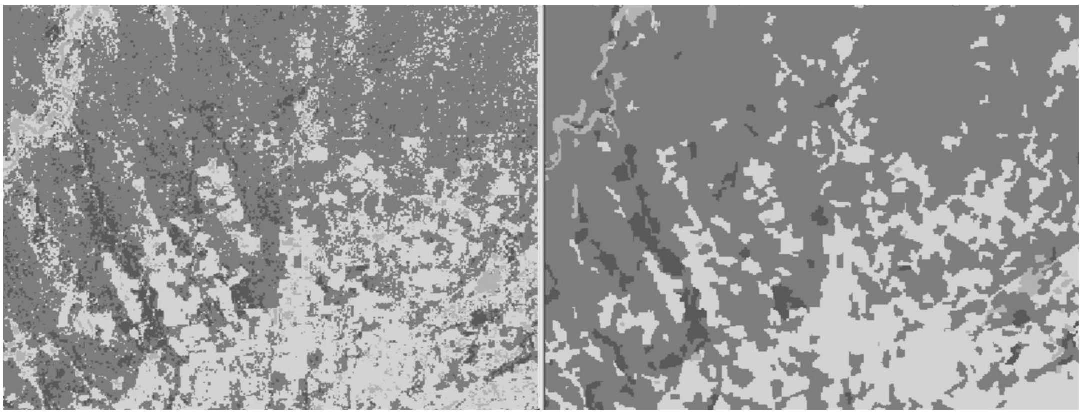

Figure 7. Pixel based classification on the left and object orientated classification on the right over the northern foothills of the Taita Hills.

with darker shrubland and lighter patches indicating encroaching croplands. In b, image objects derived from a level 1 segmentation do not coincide with the focal scale of cropland patches. In c, level 2 segmentation successfully captures the field boundaries deriving ecologically meaningful landscape patches. In d, level 3 segmentation delineates general areas of cultivation but has amalgamated the smaller within- and between-field shrubland patches into the croplands polygons. A comparison of the classification using visual analysis, object oriented classification and pixel-based classification over Ngangao forest in the Taita Hills applying digital camera imagery of 0.5 m resolution is presented in Figure 9 (Lanne 2007).

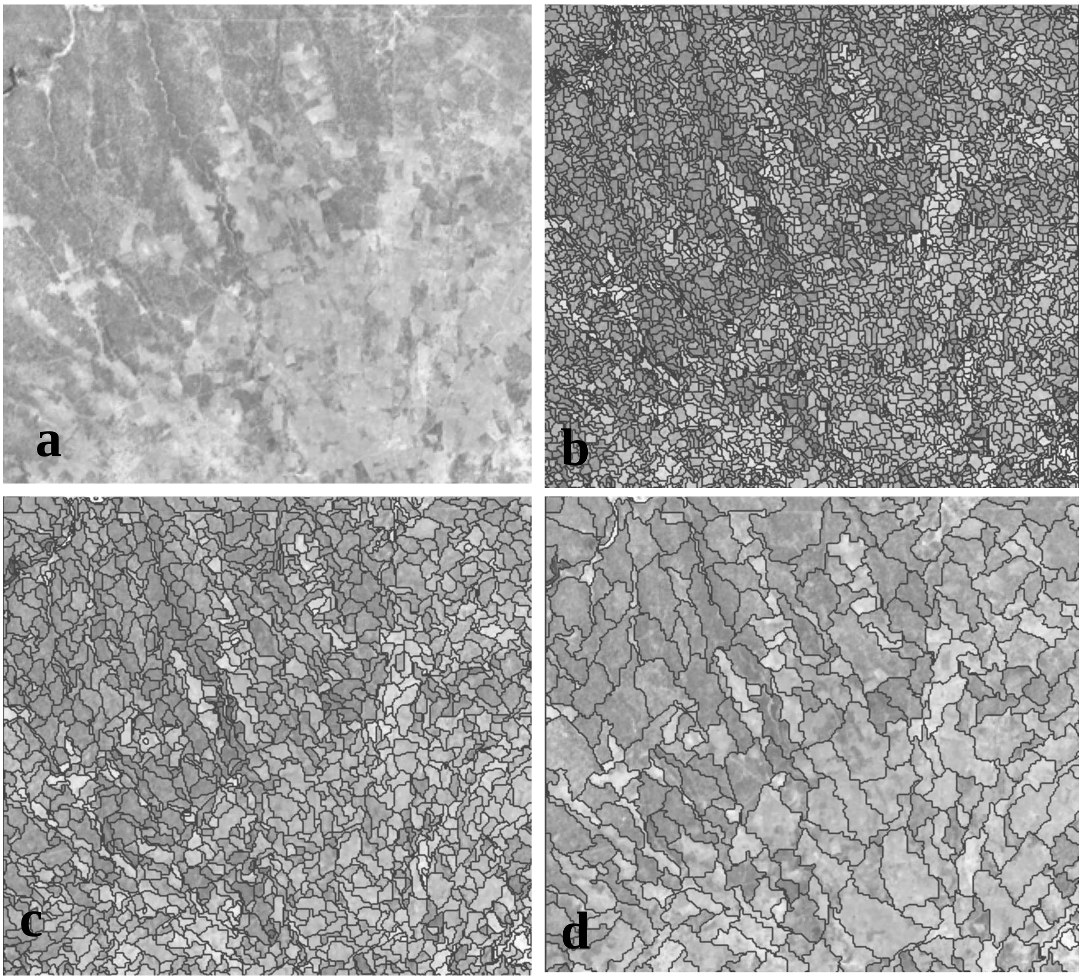

Figure 8. Segmentation using level 1, 2 and 3 over the foothills of the Taita Hills.

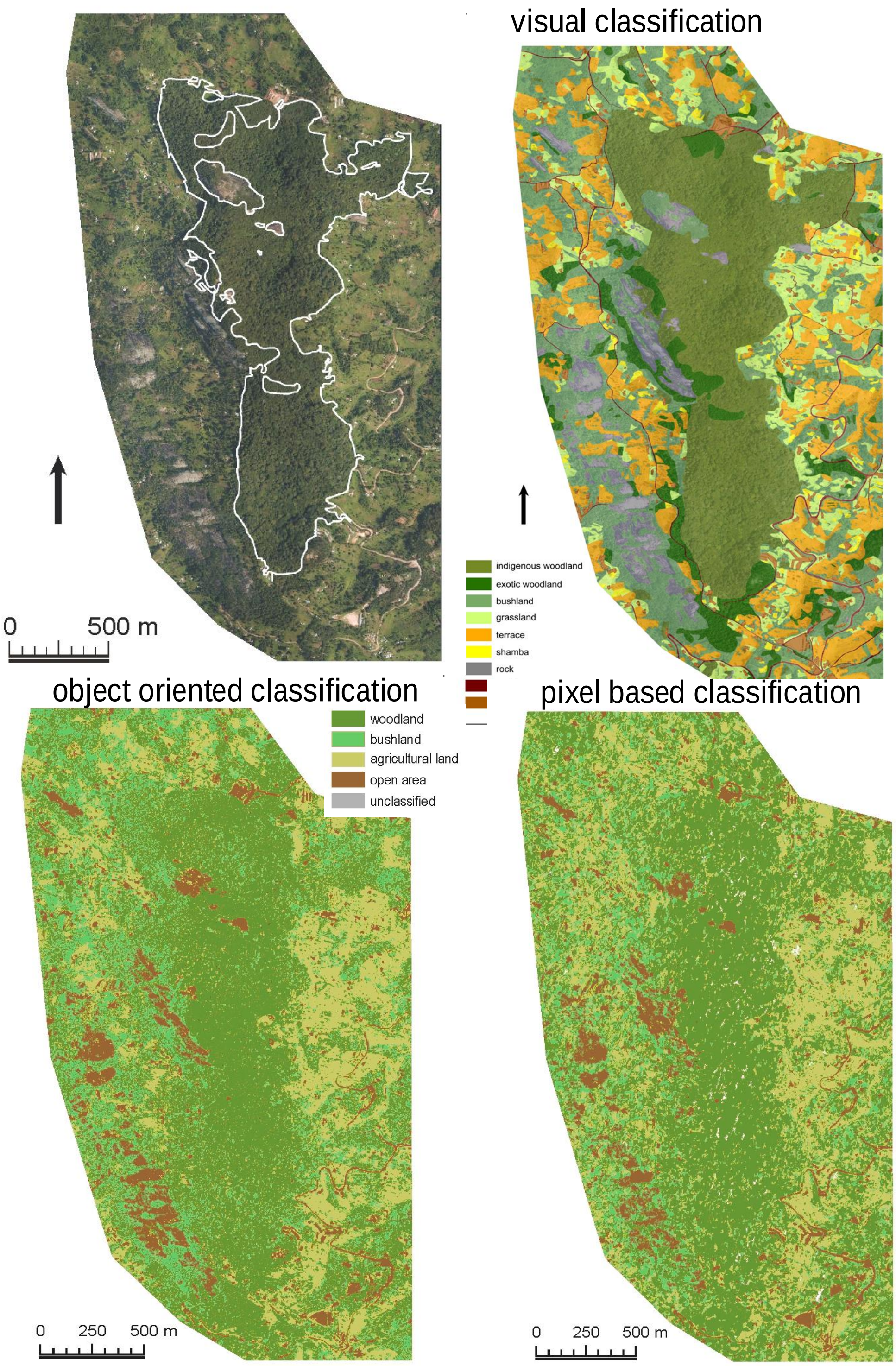

Figure 9. Visual forest delineation, visual classification, object orientated classification and pixel based classification using airborne digital camera mosaic over the Taita Hills (Lanne 2007).

Spatiotemporal challenges

There exist also several spatiotemporal challenges. First of all, there is not one individual scale which is appropriate for mapping a landscape and for each case a suitable scale (spatial resolution is to be identified). Remotely sensed images are also imperfect capturing of patterns, while patterns are an imperfect mirror of ecosystem processes. We also have to acknowledge that land cover / land use change is a continuum of change. While we are often carrying out change detection studies using two or more dated images we are restricted to the available imagery. Also having more imagery would require more work and more cost. However, the question remains: how we can be sure that the dates we have are the most suitable ones?

Phenology

Vegetation phenology is described as a study of the relationship between vegetation growth and environment; often it refers specifically to seasonal changes in vegetative growth and decline (Campbell 2002). A simple example in high latitudes is opening of the leaves in the spring, flowering during the summer and senescing and dropping the leaves in the fall. Many phenological changes can be monitored by remote sensing because plants change in appearance and structure during the growth cycle. Each period plant experience chemical, biological and physical changes that result in progressive deterioration of leaves, stems, fruit and flowers. Evergreens in tropical areas experience much more elaborate phonological cycles; for example in the cloud forests of the Taita Hills, individual leaves may experience senescence separately, in the other words trees do not necessarily shed all the leaves simultaneously. Also individual trees or branches of trees may shed leaves on cycles quite distinct from others in the same forest. Phenology does occur in the evergreen tropical forest even they have leaves throughout the year. In the Taita Hills there are much less leaves in cloud forests at the end if the dry season as at the end of the rainy season. A study in Amazonia recently revealed that the leaf area index (LAI) increased by 25% by the peak of the dry season (Myneni et al., 2007). The phenological differences are more significant in lowland forests due to the fact that some tree species, like *Adansonia digitata* and some Acasia species shed the leaves for the dry season and also because the field layer is senesced and it is more visible in sparse woodland or bushland compared to montane forests. Phenological phenomena are also significant in agricultural areas.

Related to temporal challenges the phenological variations in land cover affect the interpretation of land use and land cover change. The land cover, for example, can still be the same although the bushland is leafless in dry season and with leaves during wet season. Not knowing the phenological rhythm or not having ancillary data such as rainfall data before the image acquisition can lead to serious misinterpretations. Think for example the difference of the reflectance of a maize field with full height and green leaves between the situation when leaves are senesced to brown or when the residuals are collected from the field. The phenological cycle may turn the interpretation of the field from field

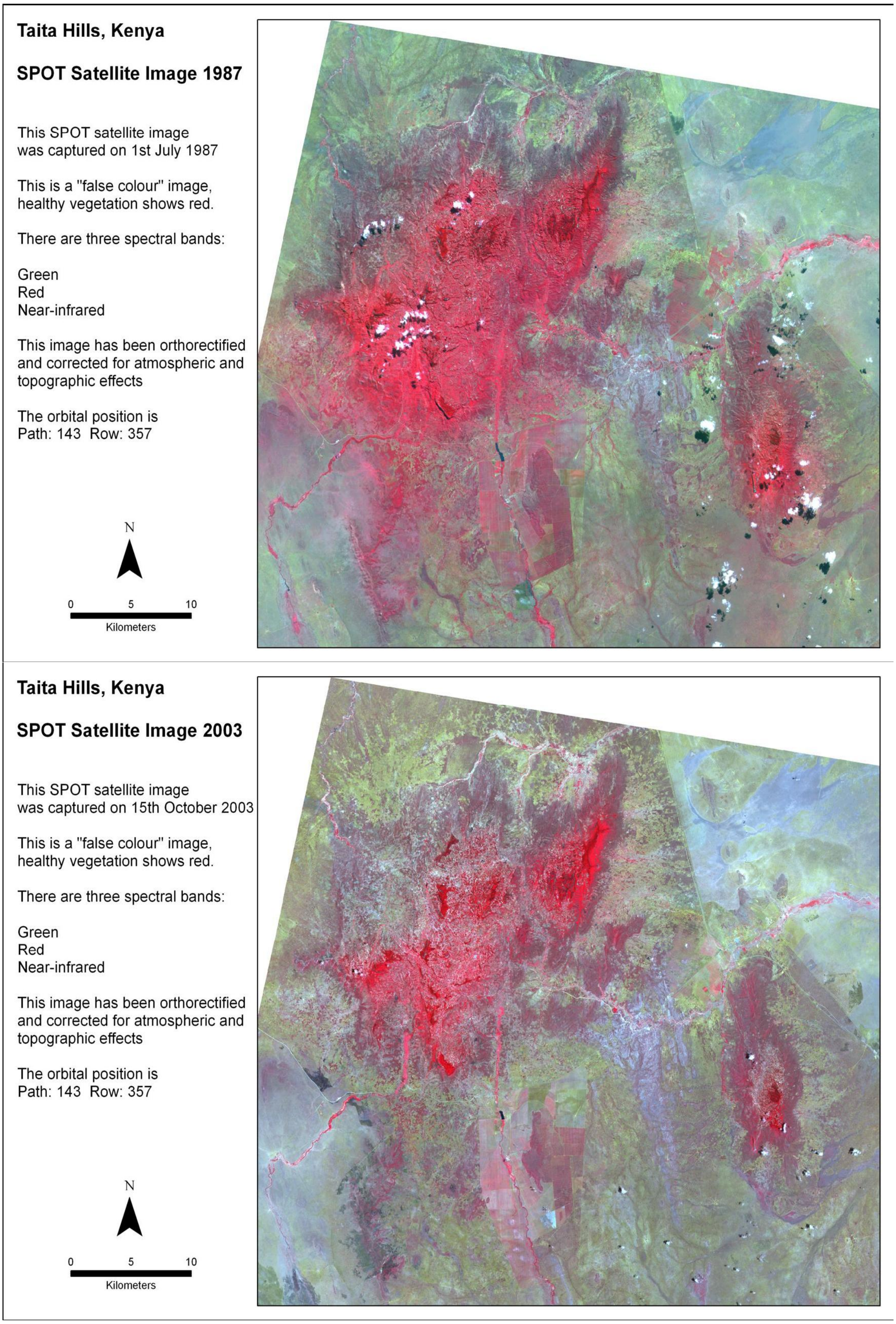

Figure 10. SPOT XS satellite image of July 7, 1987 at the top and October 15, 2003 below.

to barren area or to erosion area. However, phenology does only hamper, since it can be also the subject of the study itself (Pellikka 2001).

Figure 10 presents a pre-processed SPOT image over the Taita Hills acquired on July 1, 1987 after the rainy and cool season and the same area in October 15, 2003 at the end of dry season. While the images are taken at different time of the year, the amount of green vegetation changes enormously between the images. It can be seen that in false colour composite the July image is much redder indicating more green vegetation (leaves in dryland bushes, green grass, maize crop green), while at the end of the dry season the maize is harvested and grasses dead and trees leafless in the lowlands. According to Kenya Meteorological Department rainfall before the image acquisition in July 1987 was 457 mm during the four previous months (March-June) in Mgange at 1768 m a.s.l. and 214 mm in Voi at 560 m a.s.l. The rainfall before the image acquisition in October 2003 was 74 mm during the four previous months (June-September) in Mgange and 10 mm in Voi. The difference in the image greenness (or redness) in false color image can be clearly seen.

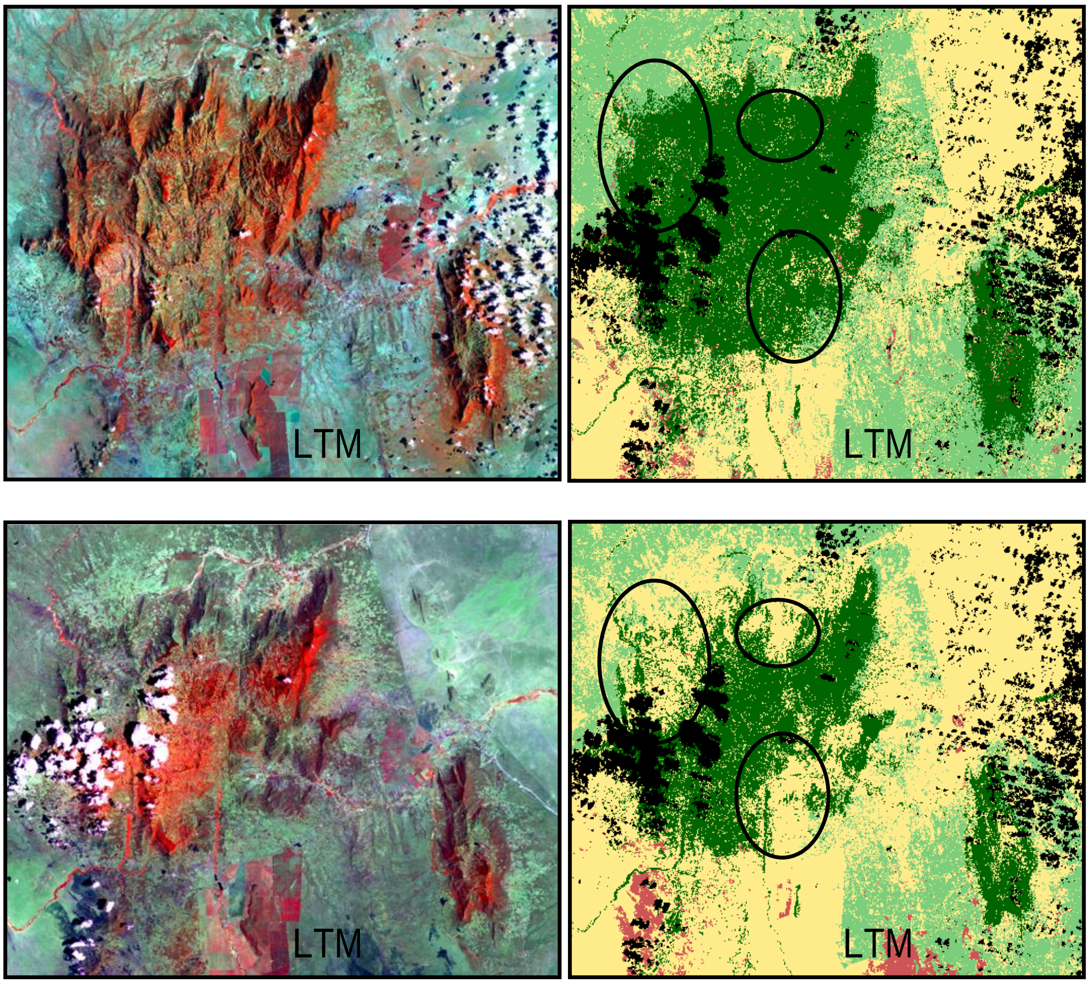

Figure 11. Land cover classification of Landsat TM images of 1987 and 1999 into four classes: forest, grassland, bushland and clouds (Ward et al. 2004).

Figure 11 presents serious misunderstanding in the amount of forest cover because ignoring vegetation phenology. When comparing Landsat TM scenes from 1987 and 1999 phenological changes are not taken into account and the imagery is not preprocessed. Even the dates of the images are not given, but the analysis ahs resulted in 37 % decrease in forest cover in circled areas (Ward). In reality, the areas indicated are dry bushland areas, which are leafless in dry season with dead grass cover.

Dissemination

Dissemination of information and providing results to decision makers is also significant part of the remote sensing work. We have to give the results for the decision makers in understandable form. We should visualize the changes in maps, since they tell more than 10 000 words. Questions like where, what and maybe even why should be answered. The information collected should not also remain in the bookshelf or in computer hard-drives. It should be disseminated and shared for the wider use of the data and for capacity building. Having good data storage system or map servers allows also the data to be used in the future in many applications.

The results of land cover change can be like change in area or percentages of varying classes, but that kind of information does not answer us where the environmental change has occurred. When making a pair of maps like in Figure 10 or change maps like in Figure 12 we are able to show where the changes occurred and also what changed in to what (Lanne 2007). There are also numerous change visualization techniques developed, like vegetation index differencing, image reflectance value differencing and post classification comparison.

The produced data or used data can also be compiled into geographic databases or map servers. In the Taita project digital geographic database managed by ArcIMS and accessed by the Internet was set up. The Taita Hills Environmental Monitoring System (THEMS) compiles the geographic data of TAITA project of the University of Helsinki (http://www.helsinki.fi/science/taita) and other organizations working in the area. The purpose of the THEMS is to avoid overlapping work between collaborators, to enhance multidisciplinary cooperation, and build capacity of local environmental authorities and Kenyan partners.

Conclusions

The use of universal and commonly applicable land cover classification system and nomenclature like LCCS from FAO is encouraged for wider use since it gives an understandable code for land cover classes created. Even old classification systems can be translated to LCCS system and is currently done for example for European CORINE system, which is a Europe-wide land cover classification. Such commonly used systems would avoid uncertainties in naming forest or other land cover types or when comparing classification for same or neighbouring areas made by various scientists.

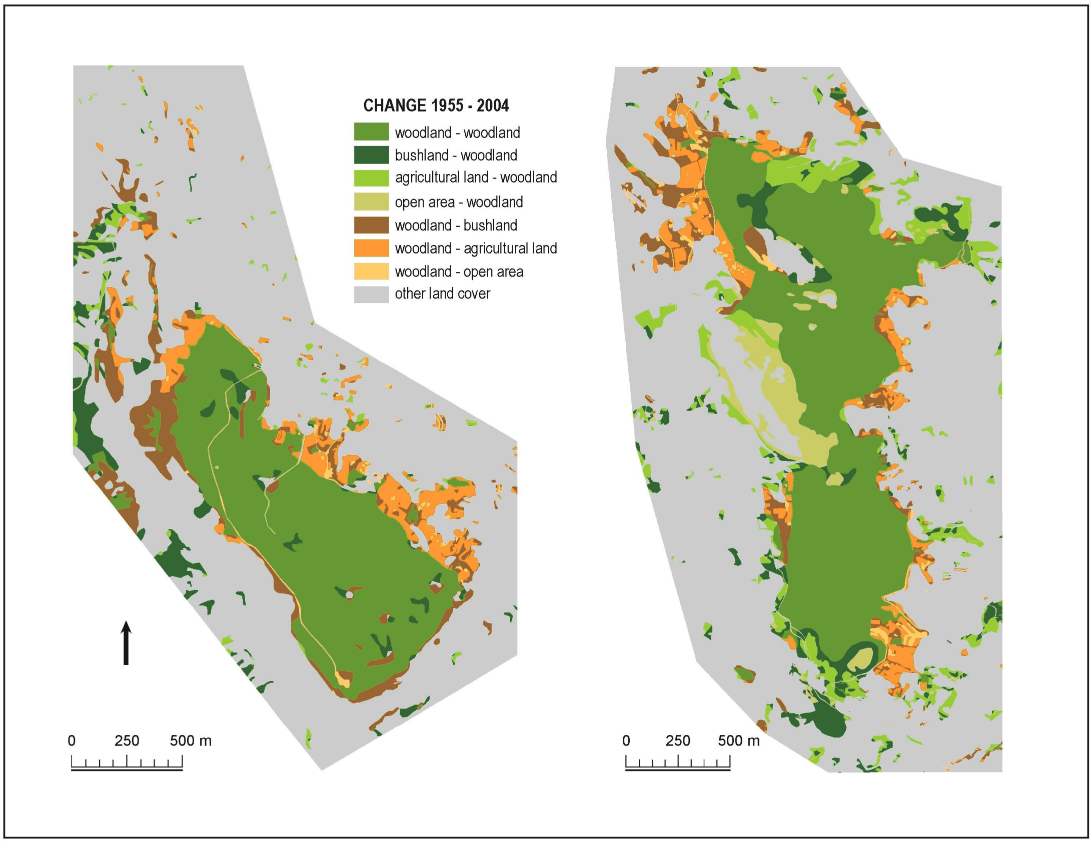

Figure 12. Land cover change of Chawia and Ngangao forests of the Taita Hills between 1955 and 2004 (Lanne 2007).

Some ancillary datasets are needed for satellite and airborne data preprocessing, like training areas for classification and test areas for classification accuracy assessment, elevation models for orthorectification and topographic corrections of remotely sensed images over rough terrain and atmospheric data for physical models of atmospheric correction. Related to understanding vegetation phenology in the imagery rainfall data for the previous months over the study area would be very helpful.

If carrying out land cover, land use or other kind of environmental change detections studies with varying remote sensed data types one has to be careful that the change detected is not because or varying data used. For that purpose one should carry out the study using the same data, like Landsat TM, for example. The reason is that when the spectral and spatial resolution change between various sensors, the change detected may be due to data and not to phenomena. The possible range of data used for mapping same phenomena is for example black & white aerial photographs from the 1960s, Landsat MSS satellite images from the 1970s, Landsat TM images from the 1980s, Landsat ETM data from 2000s, ASTER data from 2005 and IKONOS data from 2007. All these data have varying spectral and spatial resolution.

After carrying out the environmental studies and compiling extensive dataset it would be very good if the data would be available for wider use. Well documented dataset with metadata descriptions could be a gold mine for other scientists in wide range of applications. The end of a project of remote sensing specialist can be the start if the research for a GIS modeler. By sharing the data among various scientific disciplines, overlapping work can be avoided and for example an ecologist could get the data from a remote sensing specialist without the need to learn the topographic corrections for satellite data. The data can be put to map servers, like ArcIMS from ESRI or to GeoNetwork developed by FAO. For example the datasets fro FAO SWALIM project is available for further use without any specific cost.

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