Environmental change monitoring applying satellite and airborne remote sensing data in the Taita Hills, Kenya

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ABSTRACT

This paper presents environmental change monitoring in the Taita Hills, Kenya applying SPOT XS satellite imagery, aerial photography and digital camera data. The paper presents the data, methods for atmospheric correction, and results from land cover change detection and soil erosion change detection. The results indicated that gully density has doubled in the test sites during the observation period since 1955 and the area of Mwatate reservoir has decreased 25% due to siltation. SPOT satellite image analysis indicates that erosion areas have increased 33% (10 km^2) and built-up areas, indicating urban growth, have doubled between 1987 and 2002. The area of coniferous plantation forests has increased 32%, while the area of broad-leaved forest types (indigenous and plantation) has decreased 3% (1.6 km^2). Based on the results, the gully erosion and land degradation is an on-going process in the area, while forest cover does not show such a dramatic trend.

Keywords: land use change, soil erosion, satellite and airborne remote sensing

1 INTRODUCTION

Climate changes and population growth cause increasing pressure on the East African highlands. The results of the pressure are manifold: urban growth, intensified agriculture, decrease of forested areas, loss of biodiversity, accelerated land degradation and soil erosion. The consequences introduce great demands on land use planning. Remote sensing data and techniques, and geographic information systems (GIS), provide efficient methods for analysis of land use and tools for modelling and planning. By understanding the driving forces of land use development in the past, managing the current situation with modern GIS tools, and modelling the future, we are able to develop plans for multiple uses of natural resources and nature conservation.

The Taita Hills in SE-Kenya is one of the risk areas in East Africa. Many research groups have been studying the biodiversity and population dynamics [1] as well as urban growth in the area [2]. The TAITA project, entitled *Development of land use change detection methodology applying geographic information systems in East African highlands,* aims to develop a practical land use change detection methodology and to create a geographic database for the land use and its changes in the area. The aim of this multidisciplinary project is divided into four sub-objectives: studies in land use change, urban growth, spatio-temporal changes in land degradation, and development of the management systems for naturally protected forests. The aim of this paper is to present the preprocessing of the satellite imagery, land cover change detection methods and results, and preliminary results of the gully erosion studies. The data and results from the project are available for regional decision-makers in the Taita Taveta district in Kenya.

2 STUDY AREA

The Taita Hills (Latitude 3°25′, longitude 38°20′) cover an area of 1000 km^2 and are surrounded by both western and eastern sections of Tsavo National Park (figure 1). While the surrounding dry savannah grassland is at an elevation of 700 m, the average height of Taita Hills is 1500 m, the highest peak, Vuria, being at 2208 meters (figure 2). The annual rainfall varies from 500 mm in the plains to 1500 mm in the hills and there are two rainy seasons: the long rains in March-May/June and the short rains in October-December. Variability of precipitation from year to year is high, especially in lower altitudes. A great number of ecological regions are based mainly on the relief and climatic conditions in the area.

Being part of the Eastern Arc, the Taita Hills are very valuable and rich in biodiversity and have many endemic mammal, bird, and butterfly species. The hills were once covered with cloud forest, but after 1960s the forests have suffered substantial loss and degradation. To date, less than 400 ha of original forest is retained in a scatter of three larger remnants, Chawia (50 ha), Ngangao (92 ha) and Mbololo (220 ha), and nine tiny remnants embedded in a

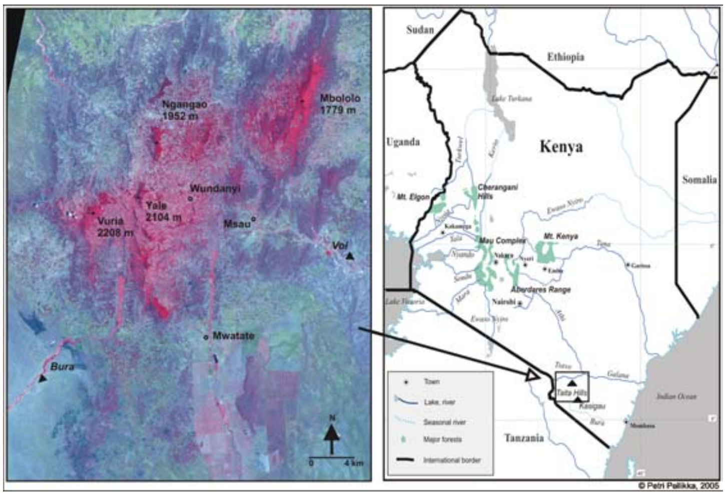

Figure 1. Taita Hills in Kenya. SPOT XS satellite image in false colour composition, Oct. 15, 2003 presents the area under investigation.

Figure 2. Taita Hills rise from the plains at 700-1000 m to 2208 m a.s.l. (Photo: P. Pellikka, 2004).

mosaic of human settlements, small-holder cultivation plots and exotic plantations. The characteristic tree species in the indigenous forests are *Magaranga conglomerata*, *Ochna holstii* and *Newtonia buchannii* and various *Acasia* species in the lowlands. The population of the whole Taita-Taveta district has grown from 90 146 (1962) persons to slightly over 300,000, of which 42,000 are residing in urban areas. The spatial distribution of population in the area closely follows climatic and other ecological conditions.

Land use in the Taita Hills is dominated by intensive agriculture, the typical crops being maize, peas, sugar canes, beans, tomatoes and banana in the highlands. Extensive agriculture with sorghum and millet cultivation and grazing are dominant land use types on the foothills and plains. The scarcity of arable land has forced the local communities to take more land under agriculture, which has caused dynamic changes in land use patterns and has led to serious land degradation (e.g. deforestation & soil erosion). Due to poor agricultural management, erodible soils and the large relative height differences of the hills, the foothills especially are subject to land degradation and accelerated soil erosion.

3 DATA

3.1 Cartographic Data

Nine 1:50 000 scale Survey of Kenya topographic paper map sheets were digitally scanned and utilized in the generation of a GIS database, including layers such as a road network, hydrography and administrative borders. The digital elevation model (DEM), used for the topographic correction and orthorectification of the satellite imagery, was generated from the scanned maps. The 50-feet interval contour lines were captured automatically from the nine map sheet areas and merged together in ArcGIS. Utilising the TOPOGRID function in ArcINFO workstation, a 20-metre planimetric resolution raster DEM for the Taita Hills study area was interpolated. As a final stage in the DEM preparation, the attribute values were converted from feet to metres to ensure compatibility with other metric measurements. The outcome of this process was a raster DEM in a UTM Zone 37 projection with a Clarke 1880 Spheroid, a planimetric accuracy of +/- 50 meters and an altimetric accuracy of 8 metres [3]. Raster models of slope and aspect were derived from the 20-metre DEM utilising ERDAS IMAGINE.

3.2 Remote Sensing Data

SPOT XS satellite imagery from 1987, 1992, 1999, 2002 and 2003 form the main data for land use change detection (table 1). The data have a 20-metre spatial resolution and are orthorectified, calibrated, and corrected for topographic effects [4, 5]. Also, black and white aerial photography from 1955, 1986 and 1993 has been scanned

Table 1. SPOT satellite data in the TAITA project. θ_{VA} = Sensor Azimuth Angle, θ_{ZA} = Solar Azimuth Angle, θ_V = Sensor View Angle (+/- 27° for SPOT), θ_Z = Solar Zenith Angle.

Date	Image	Sensor	Bands	θ_V	θ_{VA}	θ_Z	θ_{ZA}
July 1, 1987	143-357	SPOT 1 HRV 1	Green, Red, NIR	R 10.3°	98.91°	36.35°	41.37 °
Mar. 25, 1992	142-357	SPOT 2, HRV 1	Green, Red, NIR	R 13.8°	98.9°	26.5°	79.0°
Mar. 25, 1992	143-357	SPOT 2, HRV 2	Green, Red, NIR	R 9.3°	98.9°	26.0°	78.7°
Feb. 12, 1999	143-357	SPOT 4, HRVIR 2	Green, Red, NIR, MIR	L 4.2°	278.7°	27.7°	113.7 °
June 6, 2002	142-357	SPOT 4, HRVIR 1	Green, Red, NIR	L 20.2°	278.6°	32.4°	36.9°
Oct. 15, 2003	143-357	SPOT 4, HRVIR1	Green, Red, NIR, MIR	R 10.4°	98.8°	21.0°	104.3 °

and orthorectified using an elevation model generated as part of the correction process (table 2). The ground resolution varies between approximately 0.14 and 0.46 m depending on the flight altitude above ground, photo scale and scan resolution. New airborne digital camera data were acquired in March 2003 and January 2004 using a true-colour NIKON D1X digital camera. The digital camera data were used in EnsoMOSAIC software to construct digital image mosaics over several study sites [6, 7].

In this study, the land use change between 1987 and 2002 was analyzed in an area of 1000 km^2 covering the hills and the sisal plantations in the south. The soil erosion was studied in the south-western foothills in the communities of Msau and Mwatate using airborne remote sensing data from 1955, 1986, 1993, 2003 and 2004. The areas studied are depicted in figure 1.

Table 2. Characteristics of the airborne remote sensing data.

Sensor	Photogrammetric Camera	Photogrammetric Camera Leica RC10	Photogrammetric Camera Leica RC10	Small Format Digital Camera NIKON D1X
Year	1955	1986	1993	2003, 2004
Date	Jan.- Feb.	Feb.		March 23-25, 03 Jan. 25-28, 04
Mode	Black & white	Black & white	Black & white	Blue, Green, Red
Camera focal length	152.3 mm	151.68 mm	151.21 mm	14 mm
Scale/ ground resolution	~1:30000	~1:10000	~1:10000	~0.26-0.64 m
Scan resolution	14 µm	21 µm	21 µm	
Ground resolution	~ 0.46 m	~ 0.21 m	~ 0.21 m	

4 METHODS

4.1 Preprocessing of SPOT Imagery

4.1.1 Topographic normalization and orthorectification

Topographic normalization is used for correcting the so called slope and aspect effect. Given a uniform land cover, the brightness values in the remote sensing data are higher on sun-exposed slopes than on the slopes oriented away from the sun since they receive more direct solar radiation. Although the effect is not so serious with the small solar zenith angles in the tropics, it causes misclassification and hampers multi-temporal analysis and has to be corrected. In the several correction methods developed [5], slope and aspect models derived from the DEM are used in the normalization. In this study, the C-factor correction is used [8]. Orthorectification is also necessary for precise registration of the satellite imagery with a national or international coordinate system.

4.1.2 Atmospheric correction applying the Historical Empirical Line Method (HELM)

Accurate land-use classification and change detection in a set of multi-temporal SPOT XS data is dependent on the ability to successfully relate differences in corrected radiance or reflectance measurements to actual changes in vegetative state or land-cover on the ground. Consequently, the initial processing stage was to make the imagery spatially and spectrally comparable. It was also necessary to retrieve surface reflectance (P_s) from the imagery and therefore an *absolute* radiometric calibration, as opposed to a relative normalization, was required. However, no detailed overpass concurrent atmospheric measures were available for the TAITA project SPOT data. The Historical Empirical Line Method (HELM) was developed to account for these circumstances and limitations.

The basic premise behind HELM is that the reflectance properties of a spatially extensive, spectrally bright and invariant-in-time calibration ground target can be measured in the field, using a spectrometer, and utilized in conjunction with image derived dark object radiance values to calibrate the at-sensor radiance (L_{SAT}) at the various image dates to a stable surface reflectance (P_s). Where the calibration targets are spectrally pseudo-invariant over time, the measurement of P_s need not coincide with the image data acquisition [9]. To account for the variable off-nadir view angle of the SPOT sensors it is necessary to capture the Bidirectional Reflectance Distribution Function (BRDF) of the calibration site. The main assumptions of HELM are that the atmosphere is approximately homogenous throughout the image area and that there is a linear relationship between L_{SAT} and P_s. Although this relationship is quadratic for the full range of reflectance (0-100%), it is sufficiently linear over the range 0-70% to allow linear interpolation with negligible error (all P_s for the Taita Hills were less than 70%).

Because of this near-linear relationship, the empirical line correction can be implemented utilizing a standard linear regression equation in the form $\boldsymbol{y = ax + b}$; where $\boldsymbol{a}$ is the slope of the regression line, representing the atmospheric attenuation, and $\boldsymbol{b}$ is the intercept with the x-axis, representing the atmospheric path radiance. A separate correction is derived for each spectral band in the data (figure 3). For HELM it is argued that an accurate estimation of the correction line can be obtained using detailed field measurements of only *one* appropriate within-scene “bright” calibration target, and image based measures of radiance for an assumed 1% reflectance “dark” target. Field measurements at further ground sites are recommended, however, for verification and accuracy assessment purposes. The objective of HELM is, therefore, to (re)construct the historical linear relationship between L_{SAT}, as recorded by the multi-temporal satellite imagery, and P_s for the Pseudo-invariant Pixels (PIPs), as measured in the field.

The main difficulty with applying HELM to SPOT data is to identify calibration targets that are large enough to counter the contaminating effects of the point spread function on the instantaneous field of view of the sensor. The calibration and validation targets need to be at least three times the pixel size (60 x 60m for 20m resolution SPOT 1-4 XS data) to derive “true” L_{SAT} pixel values [10]. For the TAITA project, a roadside quarry was chosen as the main bright calibration target and half-day long measurements were made in an attempt to measure changes in P_s with $\boldsymbol{\theta_z}$ and $\boldsymbol{\theta_v}$ (+/- 27° for SPOT) [11]. In the event, it was found that the noise level of the handheld spectrometer measurements exceeded the signal of variation in P_s with $\boldsymbol{\theta_z}$ and $\boldsymbol{\theta_v}$, so it was not possible to quantify these relationships. However, it can be inferred from this that these variations must be relatively small and therefore that the calibration target exhibited near-Lambertian reflectance behaviour. It was thus considered that the average nadir reflectance characteristics of the target had been accurately captured and that the SPOT imagery with varying $\boldsymbol{\theta_v}$ could be normalized to this data with minimal error, given the measurement noise (coefficient of variation 12.7%).

The spectrometer derived P_s data were processed to synthesis the SPOT response for the PIPs at each date based on the specific spectral sensitivities of each band (obtained from the SPOT website) for the SPOT sensor involved. The L_{SAT} values for the darkest in-scene object and the bright calibration site were determined for each spectral band from the SPOT images and regressed to the synthesized P_s to derive a correction equation which was then applied to the whole scene (figure 3). The HELM technique has been successfully applied to the TAITA project multi-temporal SPOT XS dataset and, as is shown in table 3, it gives more accurate results than using either simple image based correction methods (DOS and COST), 6S with generalized atmospheric parameters, or no correction at all (uncorrected top-of-atmosphere reflectance - P_{TOA}). The main disadvantage of applying HELM was that the SWIR band available for the 1999 and 2003 images had to be left out of correction, as the spectrometer used for the field measurements only covered the 0.325 to 1.075 μm (VIS/NIR) range.

4.3. Land Cover Change Detection

4.3.1 Classification method

The land cover classification methodology utilized for the SPOT data was a stepwise process combining both unsupervised ISODATA and supervised maximum-likelihood classification stages within ERDAS IMAGINE. In the first step, the 2002 image was classified into 100 clusters using the ISODATA algorithm. Then, in conjunction with GPS referenced land cover field data from the Taita Hills, four spectral clusters best representing each of the desired output land cover classes were identified and written to a signature file. This signature file was then used as the basis for a supervised maximum-likelihood (re-)classification of the image. As a final stage, the related spectral

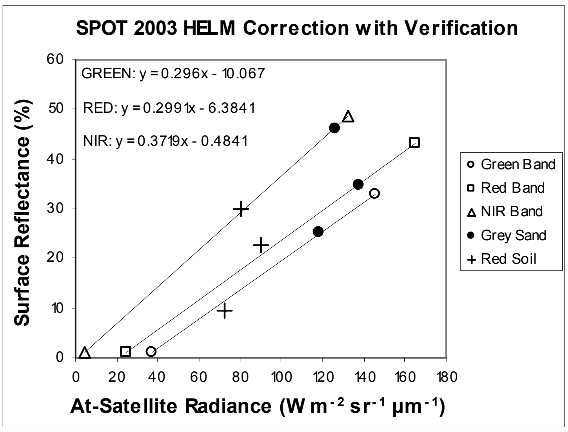

Figure 3. 2003 SPOT-4 Image HELM correction.

Table 3. Average RMSE % P_s for all field sites, all bands and all dates.

Method	Accuracy
P_{TOA}	8.05%
DOS	10.18%
COST 1	7.99%
COST 2	9.10%
6S	7.01%
HELM	1.80%

clusters (such as agriculture-1, agriculture-2, agriculture-3, and agriculture-4) were grouped and merged to give the finalized 8 land cover classes, as listed below. Subsequent to the classification of the 2002 image, the edited signature file was then applied directly to the 1987 scene as well to derive a maximum-likelihood classification, followed by the same spectral class grouping and merging process to give the finalized 8 land cover classes. Given the image-to-image orthorectification and radiometric calibration pre-processing steps, this enabled direct comparisons for the same land cover classes to be made between the 1987 and 2002 SPOT images.

Additionally, it should be noted that the sisal plantations located on the plains to the south of the Taita Hills were masked out from the rest of the image area and classified separately, because of the similar spectral characteristics they shared with rest of the land cover. The classes identified within the sisal plantations were water, agriculture, young sisal, middle-aged sisal, mature sisal, erosion areas, thicket, grasslands and bushlands. The sisal plantations covered 108.3 km^2 and the rest of the area 905.8 km^2.

The rest of the image area, including the Taita Hills and lowlands, was classified into 8 classes: forest, coniferous forest, agriculture, erosion areas, barren land and built-up areas, thicket, bushlands and grasslands. The forest class includes indigenous closed canopy forests and other dense broad-leaved forests, which are mainly exotic eucalyptus and grevillea forests. In addition, riverine forests with typical species *Acacia xanthophylla*, *A. eliator* and *Newtonia hilbrandtii*, belong to the forest class. Coniferous forests are pine (mostly *Pinus patula*) and cypress (*Cypressus lusitanica*) plantations. The differences in grasslands, bushlands and thickets are caused by tree height and density. The same species can be found in each of these three classes, but the characteristic tree and shrub species in the bushlands typically belong to *Acasia* ssp., *Grewia* ssp. and *Commiphora* ssp., and the tree species in the thickets typically belong to *Euphorbia* ssp. and *Commiphora* ssp. The grasslands are normally 20 to 50 cm high and their spectral characteristics vary strongly according to precipitation.

4.3.2 Results

The land cover changes within the sisal plantation express mainly management changes of the plantation and phenological differences. Some aspects, however, are interesting from the land management and land degradation point of view. Based on personal communication with the plantation owner the whole area of the world's largest plantation is 9800 ha [12]. Based on the classification, 6 985 ha was under sisal management in 1987 and 5 913 ha in 2002 showing a decrease of 15%. The area of grasslands has increased 134% from 1987 to 2002, and erosion areas 121%, while agricultural areas other than sisal plantations decreased 75% and area of Mwatate reservoir 37%. The changes in areas for the sisal plantations indicate the management practices and rotation cycle of the sisal plant. The area of the reservoir fluctuates strongly according to yearly rainfall and the use of water upstream from the reservoir. Overall, the reservoir has been shrinking steadily year by year. The changes in percentages and absolute areas are shown in table 4.

The land cover changes in the rest of the image area show that the agricultural area has decreased by 35%, while coniferous forests have increased by 32%, thickets by 35%, grasslands by 31%, erosion areas by 33% and built-up areas and barren land by 171%. Broad-leaved closed canopy forests have decreased by only 3% during the observation period of 15 years. The growth in area of coniferous forests evidently relates to maturing of the trees and therefore strengthening of the reflectance signal from the trees. The changes in percentages and absolute areas are shown in table 5 and the classification in figure 4. From table 5 it can be seen that the decrease in agricultural land is strong, from 29 359 ha to 19 019 ha, while thickets have been expanding from 15 724 ha to 21 170 ha and grasslands from 17 241 ha to 22 536 ha. The reasons for the strong decrease in agricultural fields might lie partly in the phenology of agricultural plants and natural vegetation. The large agricultural areas in the south and south-west of the 1987 image (figure 4) may have been misclassified as agriculture instead of grasslands. Since there is no field data from 1987 this cannot be ascertained conclusively. In addition, the small fields and mixed crop systems cause a lot of mixed pixels and the growth cycle of various crops affects the reflectance. The expansion of grasslands from 1987 to 2002 may be explained by this misclassification in the 1987 scene.

Table 4. The area (ha), percentage and change of land cover types within sisal plantations.

Year/Class	Water	Agriculture	Sisal mature	Sisal young	Sisal middle-aged	Thicket	Grass-land	Bush-land	Erosion areas	Total
1987 ha	28	133	3314	1721	1950	1631	410	1171	473	10831
1987 %	0.3	1.2	30.6	15.9	18	15.1	3.8	10.8	4.4	100.1
2002 ha	18	33	1701	1904	2308	1206	959	1660	1044	10833
2002 %	0.2	0.3	15.7	17.6	21.3	11.1	8.9	15.3	9.6	100
1987-2002 %	-37	-75	-49	11	18	-26	134	42	121	

Table 5. The area, percentage and change of land cover types in the Taita Hills and lowlands.

Year/Class	Coniferous forest	Forest	Agriculture	Thicket	Grass-land	Bush-land	Erosion areas	Barren & built-up area	Total
1987 ha	988	4815	29359	15724	17241	19196	3178	75	90576
1987 %	1.1	5.3	32.4	17.4	19.0	21.2	3.5	0.1	100
2002 ha	1301	4655	19019	21179	22536	17456	4228	202	90576
2002 %	1.4	5.1	21.0	23.4	24.9	19.3	4.7	0.2	100
1987-2002 %	32	-3	-35	35	31	-9	33	171	

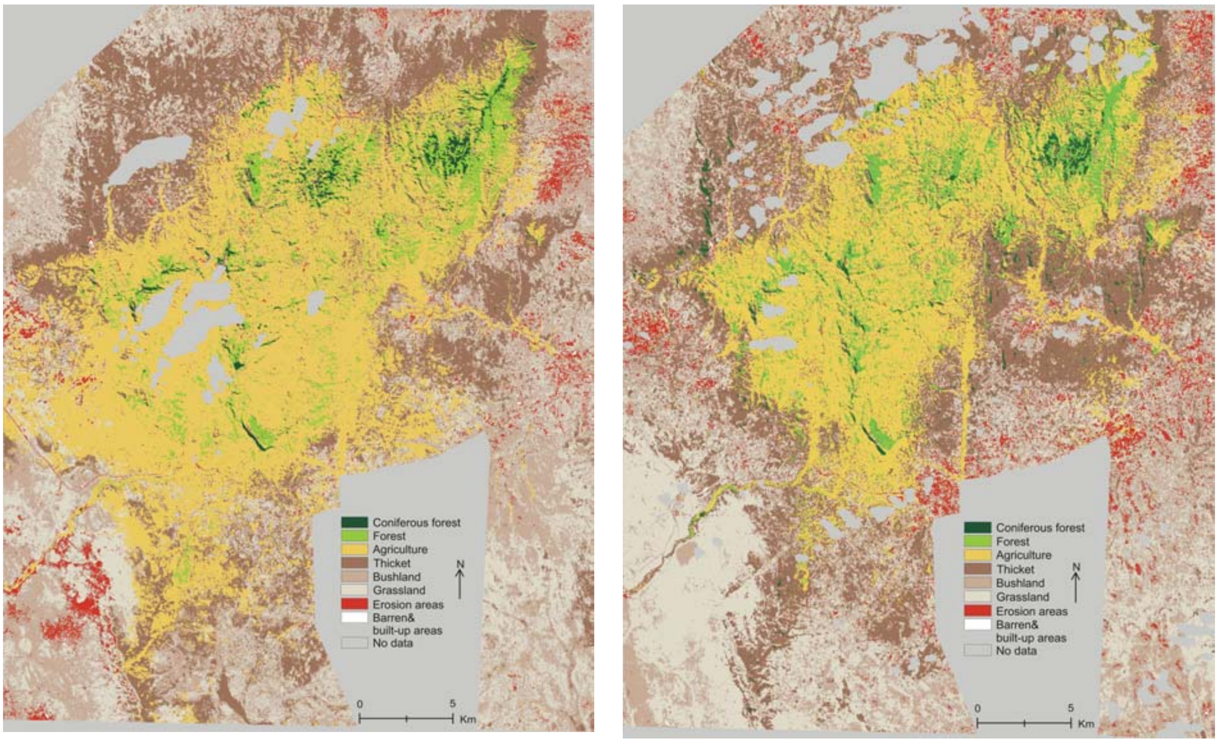

Figure 4. Land use in the Taita Hills in 1987 (left) and 2002 (right). The area of sisal plantation is masked by legend.

4.4 Gully Erosion Changes between 1955-2004

4.4.1 Introduction

Gullies (figure 5) are “relatively permanent steep-sided watercourses, which experience ephemeral flows during rainstorms” [13]. Gullies normally have a distinctive propagating head [14], which extends upslope due to three main processes: 1) slumping, 2) piping or tunnelling and 3) incision of rills due to excessive overland flow. Gully erosion is a very serious form of water erosion causing severe on-site effects, such as damage to the productive land (e.g. agriculture, forests, grazing land) and constructed sites (e.g. roads and bridges). Off-site effects of gully erosion consist of siltation of rivers and reservoirs and damage to the local soil-water balance (e.g. lowering of ground water table) [15].

Figure 5. Gully erosion site in Mwatate (Photo: T. Sirviö, 2004).

Land degradation and gullying are caused by vegetation loss, inadequate land management and non-sustainable land use. During recent years gully erosion has been studied within a wide range of environments [16, 17, 18]. According to these studies, the contribution of gully erosion on water erosion varies significantly between 10-94%, ranging from 0.1-64.9 tons $ha^{-1}y^{-1}$ [15].

Gully erosion is studied in two different locations within the Taita Hills foothills; in Mwatate and Msau (figure 1). Land use types within these areas typically range from squatter homesteads to abandoned sisal plantations, and from cultivated fields to overgrazed degraded forests. Except for 1) detection of gully erosion changes and rates within the Taita Hills between 1955-2004, the general objectives of the gully erosion studies within the area include 2) determination of the main factors affecting gully growth in the area [19, 20, 21] and development of the GIS-based methodologies for erosion hazard assessments.

4.4.2 Methods

All the airborne remote sensing data over the gully study sites were processed into projected and seamless ortho-rectified mosaics representing the study areas, utilizing bilinear interpolation and histogram matching techniques. The final mosaic is geometrically and spectrally accurate due to the application of a camera calibration model, and an ortho-correction process including corrections for light falloff and for bi-directional effects conducted for each individual image in the mosaic [3]. The resolution of the final mosaics was set to 0.3 m. The high resolution (1 m) DEM was produced from the digital aerial images based on air GPS –coordinates and elevation values calculated for each tie point used in image rectification and block adjustment. The DEMs are corrected by filling the sinks with *fill* –function (ArcGIS® 9.0) to derive hydrologically sound DEMs [22].

All the gullies in the study areas are identified and digitized using the digital or scanned aerial images and subjected to manual stereoscopic investigation. Single gullies and their branches with IDs and gully length (meters) form a basis for the GIS gully database. Gully densities (m/ha) are calculated with basic GIS-tools using one-hectare-grid with IDs as a reference (figure 6). Finally, gully densities within each year and within the grid cells are compared to each other showing the density changes during the last 50 years.

4.4.3 Preliminary Results

Gully erosion density has increased remarkably in the Taita Hills from 60.6 m/ha to 126.9 m/ha during the last fifty years (1955-2004) and the highest densities are found in the middle parts of the Mwatate study area (figure 6). Density changes and accelerated erosion in the area are related to the increased population density, and especially construction and poor management of land. At the same time the total length of the gullies in the area has grown from 55.62 to 110.29 km. The average length of the gullies has remained almost at the same level (slight increase from 97.9 to 99.0 meters), but the total number of gullies has increased from 568 to 1 114. Figure 7 shows rapid gully head propagation in Mwatate triggered by a road cutting. Accelerated erosion is also revealed by the rapid siltation of the reservoir (figure 6), the size of which has decreased from 25.84 to 20.27 ha during the last 50 years.

5 DISCUSSION

The processing chain developed for the SPOT data included orthorectification, HELM atmospheric correction, and topographic normalization applying C-correction factors. While the orthorectification and topographic corrections

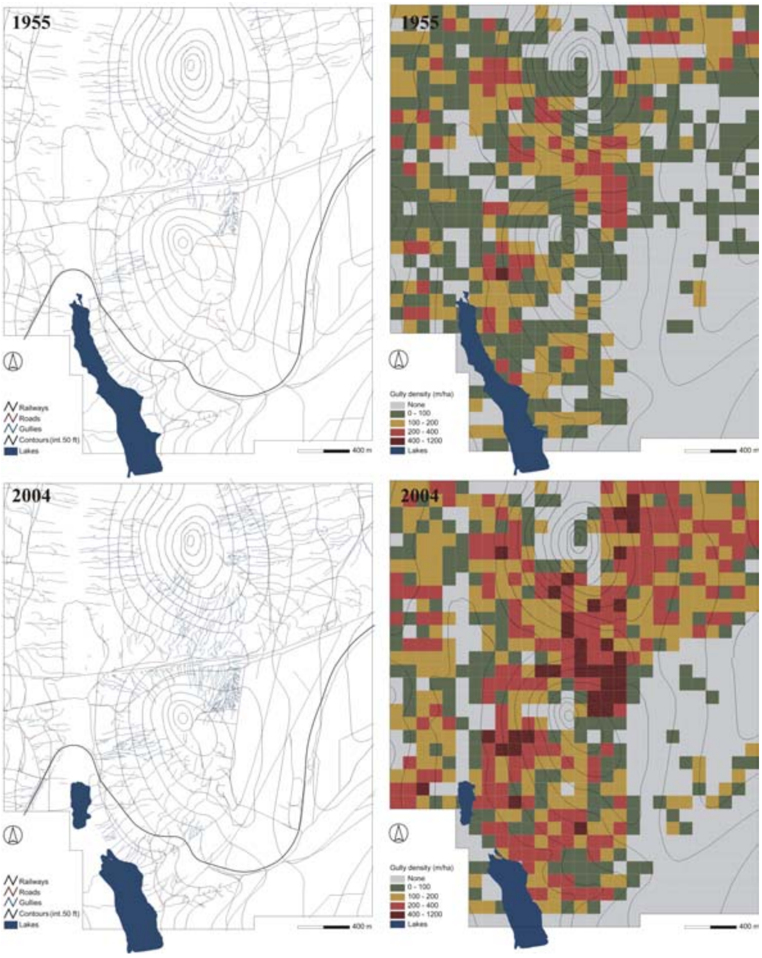

Figure 6. Gully extension (left) and gully density maps (m/ha) (right) within Mwatate study area between 1955 and 2004.

are "off-the-shelf" techniques, the HELM is a first of a kind developed for SPOT XS data. It proved to be most suitable for SPOT data where no detailed overpass concurrent atmospheric measurements are available for absolute radiometric correction. In order to further validate HELM and to provide quantified BRDF measurements for a main calibration ground target, further research has been carried out in the Helsinki metropolitan area. With the assistance of the Finnish Geodetic Institute, BRDF measurements have been made at a large car park using a goniometer, and additional verification points have been taken using a handheld ASD spectrometer. Multi-temporal SPOT imagery and detailed atmospheric data will be acquired for the Helsinki metropolitan area and an in-depth accuracy assessment and comparison of HELM will be undertaken.

The land cover change in the area showed only a small decrease of 1.6 km^2 in forest cover in the Taita Hills. This represents a 3% loss, which is much less than that presented by Ward et al. in 2004, who used Landsat TM data from 1987 and 1999 and calculated a 37% loss of closed canopy forest in the same study area [23]. The main reason for this big difference is that the TM data were not atmospherically or topographically calibrated and the data were from different seasons. The SPOT data utilized in this study are from July (1987) and June (2002), both acquired during dry seasons, but recently after long rains. The growth in area of coniferous forests evidently relates to maturing of the trees and therefore strengthening of the reflectance signal from coniferous tree species, like pine and cypress. Although the data was carefully pre-processed for this study, the classification still includes misclassifications caused by phenological differences of natural and agricultural plants. This is the case especially with grasslands and agriculture and this misclassification is very difficult to avoid.

Figure 7. Rapid gully headcut propagation in Mwatate, as shown in aerial photographs in 1955 (left), 1993 (centre) and 2004 (right).

The change detection also indicates a small increase of erosion areas and built-up areas and a decrease of water surface. The decrease in water surface seems to be taken place during the last 15 years. Within the sisal plantations the study revealed an increase of bushlands, grasslands and soil erosion areas and less land under sisal management.

The gully erosion studies expressed significant land degradation in the area. Extremely high densities of gullies in the area are related to the poor soil conservation practices and ill-managed construction. Rapid degradation of the landscape is shown by both the large increase in number and total length of the gullies in the area during the last fifty years.

ACKNOWLEDGMENTS

The study is funded by the Academy of Finland, Council for Development Studies and the University of Helsinki. The local cooperation partners University of Nairobi, Department of Geography, World Agroforestry Centre (ICRAF) and East African Wildlife Society are acknowledged for the field work assistance and cooperation. The Ministry of Education of the Republic of Kenya and the Taita Taveta District Office are acknowledged for the research permit and local assistance. Mr. Christopher Cheseny from Voi helped us with the plant identification. Dr. Petri Pellikka is the principal investigator of the TAITA project. Mr. Barnaby Clark has been responsible for the data preprocessing, Ms. Katja Masalin for the land use classification and Mr. Tommi Sirviö for the land degradation studies.

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