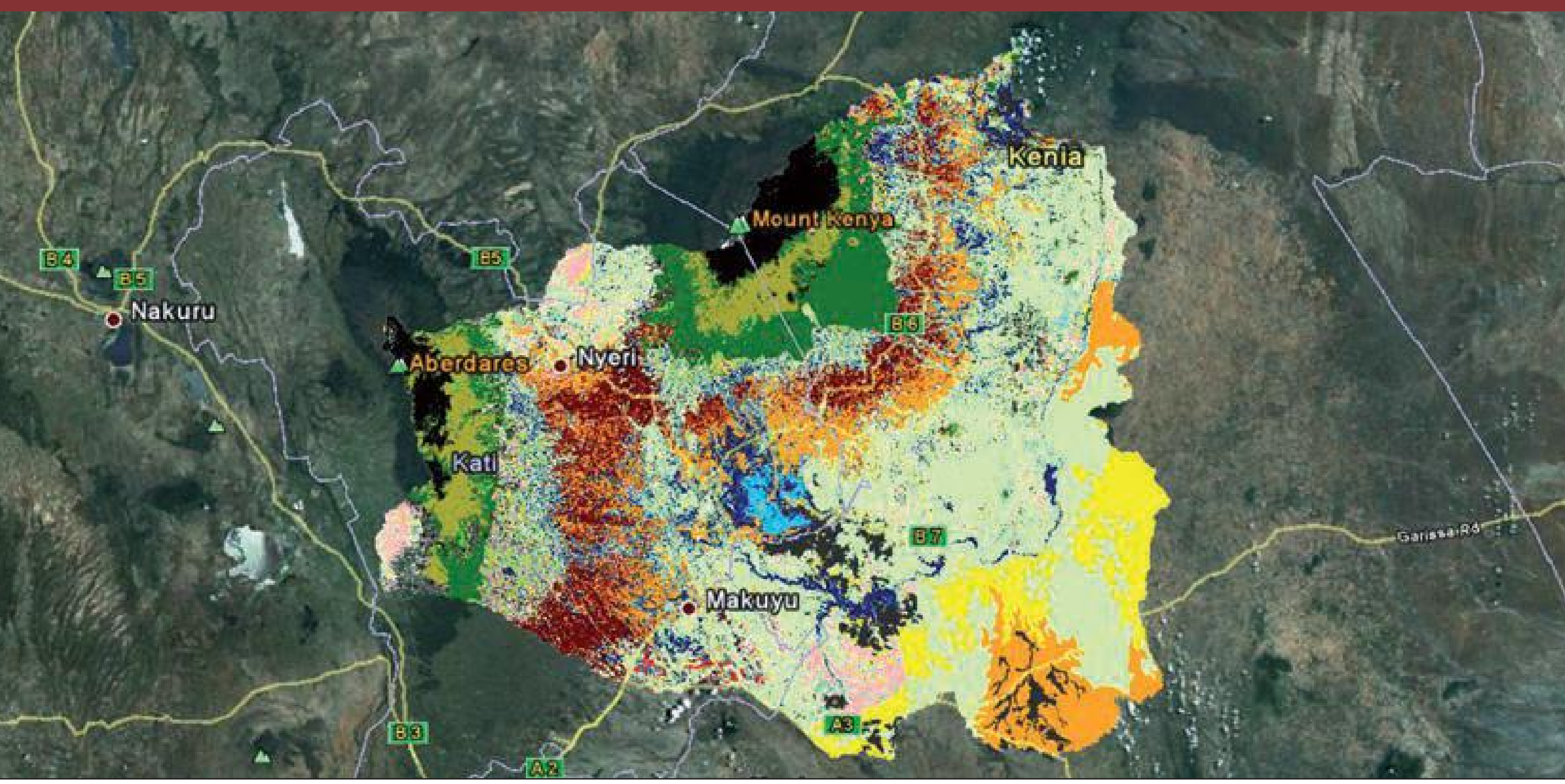
Land Use Map of the Upper Tana, Kenya

Based on remote sensing

World Soil Information

Green Water Credits Report 9



L.I. Wilschut

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ISRIC World Soil Information

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Foreword

ISRIC – World Soil Information has the mandate to create and increase the awareness and understanding of the role of soils in major global issues. As an international institution, ISRIC informs a wide audience about the multiple roles of soils in our daily lives; this requires scientific analysis of sound soil information.
The source of all fresh water is rainfall received and delivered by the soil. Soil properties and soil management, in combination with vegetation type, determine how rain will be divided into surface runoff, infiltration, storage in the soil and deep percolation to the groundwater. Improper soil management can result in high losses of rainwater by surface runoff or evaporation and may in turn lead to water scarcity, land degradation, and food insecurity. Nonetheless, markets pay farmers for their crops and livestock but not for their water management. The latter would entail the development of a reward for providing a good and a service. The Green Water Credits (GWC) programme, coordinated by ISRIC – World Soil information and supported by the International Fund for Agricultural Development (IFAD) and the Swiss Agency for Development and Cooperation (SDC), addresses this opportunity by bridging the incentive gap.

Much work has been carried out in the Upper Tana catchment, Kenya, where target areas for GWC intervention have been assessed using a range of biophysical databases, analysed using crop growth and hydrological modelling.

This report addresses the need for a more updated and higher resolution land use map than the Africover 2000 map used to date. Remote sensing analysis was applied using two classification methods. On the basis of overall accuracy, the Support Vector Machine method was selected for the classification of land use. The SVM map is based on satellite images from 2000; however land use changes have occurred between 2000 and 2009. The Green Water Credits Pilot Implementation phase will require an updated detailed land use map.

Dr ir Prem Bindraban
Director, ISRIC – World Soil Information

Key Points

- The Green Water Credits Pilot Operation Phase for the Upper Tana catchment requires a more updated and higher resolution land use map than the Africover 2000 map used to date.
- Remote sensing analysis was applied using two classification methods. On the basis of overall accuracy, the Support Vector Machine method was selected for the classification of land use.
- The single land use classes given by the Africover map are, in reality, a mix of land cover types. The new higher resolution map provides an improved description of the mixture of land use types for each zone.
- Rangeland is dominant in the lower elevation dry area. The Africover map shows an overestimation of the rainfed cereal class in this area.
- Forest cover is overestimated in the Africover map, especially on the eastern side of Mount Kenya. The new map shows that this area contains large areas of tea, coffee and maize.
- The new land use map will be used to improve hydrological and erosion modelling. This will lead to a more accurate estimation of the current situation regarding water resources and land degradation, and will also lead to improvements in the choice of GWC target areas.
- Unresolved uncertainty in the new land use map involves the distinction between bare/degraded lands and rainfed agriculture in dry areas. The occurrence of rice in areas outside the Mwea scheme also requires further investigation.
- The SVM map is based on satellite images from 2000; however land use changes have occurred between 2000 and 2009. The Green Water Credits Pilot Implementation phase will require an updated detailed land use map.
- The observations made in May 2009 confirm that accelerated erosion is a serious issue in the Upper Tana catchment. The main contributing factor to accelerated erosion is inappropriate soil and water conservation in farmland, in particular within maize and coffee fields.

Contents

Acronyms and Abbreviations

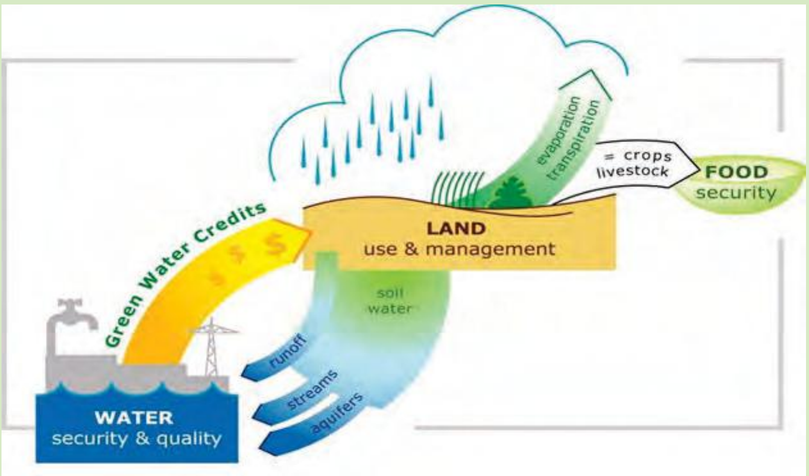
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AEZ	Agro-Ecological Zone
Africover	Africa's Land Cover Map (2000)
ENVI	Environment for Visualising Images
FAO	Food and Agriculture Organisation
GEF	Global Environment Facility
GWC	Green Water Credits
IFAD	International Fund for Agricultural Development
KARI	Kenya Agricultural Research Institute
KenGen	Kenya Electricity Generating Company Ltd.
ML	Maximum Likelihood (classification)
NASA	National Aeronautics and Space Administration
NWC	Nairobi Water Company
POC	Proof-of-Concept
ROI	Region of Interest
SVM	Support Vector Machine
SWAT	Soil and Water Assessment Tool
UNEP	United Nations Environment Programme
WOCAT	World Overview of Conservation Approaches and Technologies

Green Water Credits: the concepts

Green water, Blue water, and the GWC mechanism

Green water is moisture held in the soil. Green water flow refers to its return as vapour to the atmosphere through transpiration by plants or from the soil surface through evaporation. *Green water* normally represents the largest component of precipitation, and can only be used *in situ*. It is managed by farmers, foresters, and pasture or rangeland users.

Blue water includes surface runoff, groundwater, stream flow and ponded water that is used elsewhere - for domestic and stock supplies, irrigation, industrial and urban consumption. It also supports aquatic and wetland ecosystems. *Blue water* flow and resources, in quantity and quality, are closely determined by the management practices of upstream land users.



Green water management comprises effective soil and water conservation practices put in place by land users. These practices address sustainable water resource utilisation in a catchment, or a river basin. *Green water* management increases productive transpiration, reduces soil surface evaporation, controls runoff, encourages groundwater recharge and decreases flooding. It links water that falls on rainfed land, and is used there, to the water resources of rivers, lakes and groundwater: *green water* management aims to optimise the partitioning between *green* and *blue water* to generate benefits both for upstream land users and downstream consumers.

Green Water Credits (GWC) is a financial mechanism that supports upstream farmers to invest in improved green water management practices. To achieve this, a GWC fund needs to be created by downstream private and public water-use beneficiaries. Initially, public funds may be required to bridge the gap between investments upstream and the realisation of the benefits downstream.

The concept of green water and blue water was originally proposed by Malin Falkenmark as a tool to help in the understanding of different water flows and resources - and the partitioning between the two (see Falkenmark M 1995 Landwater linkages. FAO Land and Water Bulletin 15-16, FAO, Rome).

1 Introduction and objectives

Green Water Credits (GWC) is an environmental reward system that promotes sustainable land and water management by farmers, so that land and water degradation diminish and both water quantity and quality increase. Farmers on rainfed land will receive investment support to apply simple, but effective, soil and water conservation measures, which lead to an increase in the amount of *green water* upstream and *blue water* downstream (see “GWC – the concepts” on page 10).

Phase I of the GWC programme, the Proof-of-Concept (POC), finished in December 2007 and work for phase II, the *Pilot Operation*, was started. The POC identified the benefits of the GWC programme and explored the feasibility of the programme in the Middle and Upper Tana catchment in Kenya.

For the Pilot Operation, an up-to-date and high resolution land use map is required, both for hydrological modelling and for the implementation of the Green Water Credits programme itself. The POC used the Africover map (FAO 2000), a 1:250,000 land use map based on Landsat images from 1999. In recent years, however, there have been major land use changes in the Upper Tana catchment. Therefore, it was decided to develop a new land use map based on remote sensing analysis and supported by fieldwork.

The main goal of this study is to come up with a higher resolution, and more up-to-date, land use map compared to the Africover 2000 map. To reach this goal, a remote sensing analysis was performed, using ASTER and Landsat satellite images. The two image analysis methods used are 1) Maximum Likelihood (ML) classification and 2) Support Vector Machine (SVM) classification. The main question addressed by this study is:

What is the current land use in the Upper Tana?
This report provides the results of the research; it describes the methods used and displays the final land use map of the Upper Tana.

The report is constructed as follows. Chapter 2 describes the Tana basin in Kenya. In chapter 3 the methods of both the fieldwork and the remote sensing analysis are outlined. In chapter 4 the results of the fieldwork and of the Maximum Likelihood classification are presented and interpreted. Chapter 5 discusses the validation of the land use map, and looks towards future research actions, then reaches conclusions.

2 Upper Tana catchment

2.1 Location

The Upper Tana catchment is located 50 km northeast of Nairobi and covers an area of approximately 16,000 km^2 (Figure 1). There are 11 districts in the catchment: Thika, Maragua, Murang'a, Nyeri, Kirinyaga, Embu, Mbeere, Meru South, Meru Central, Meru North and Tharaka (World Bank 2007; World Resources Institute 2007).

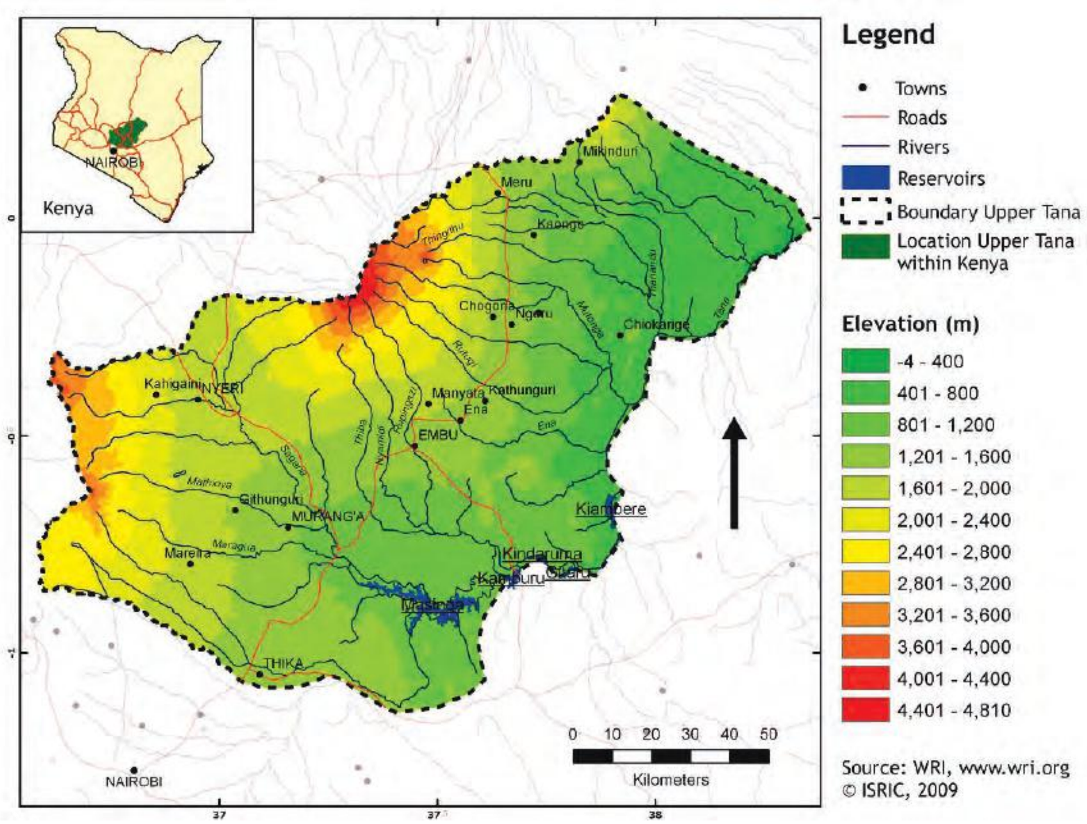


Figure 1
Location and elevation of the Upper Tana catchment, Kenya

2.2 Climate

The Upper Tana area experiences two rainy seasons a year as a result of the Inter-tropical Convergence Zone; the *long rains* last from around March to June and the *short rains* from September to December. The rainy seasons vary considerably from year to year in their duration and rainfall totals. Figure 2 shows the total precipitation in a wet year (2006). Rainfall patterns in the mountainous catchments are very heterogeneous. Average annual precipitation increases from 400 mm in the savannah to 2300 mm on the windward south-eastern side of Mount Kenya and drops to 800 mm in the summit region (IFAD/UNEP/GEF 2004; Notter *et al.* 2007).

Figure 3 shows the variability of precipitation over twelve years, as measured in Embu (located at 1493 m) and Meru (1554 m) for 1996-2008[1].

Potential evapotranspiration ranges from around 1700 mm in the low elevation savannah zone to less than 500 mm in the summit region. All areas below the forest zone have a rainfall evapotranspiration deficit. As a consequence, the high elevation forest and moorland zones provide most of the discharge of the rivers in the dry periods (Notter *et al.* 2007).

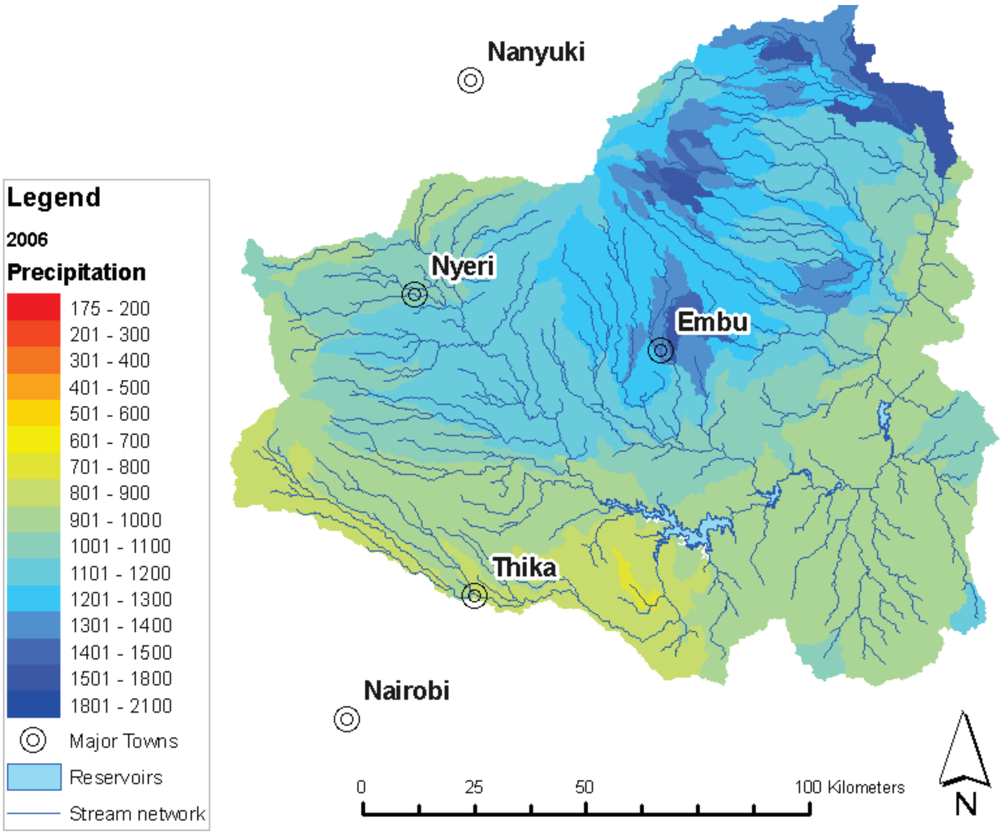


Figure 2
Precipitation in a wet year (2006)

[1] Data source: www.tutiempo.net

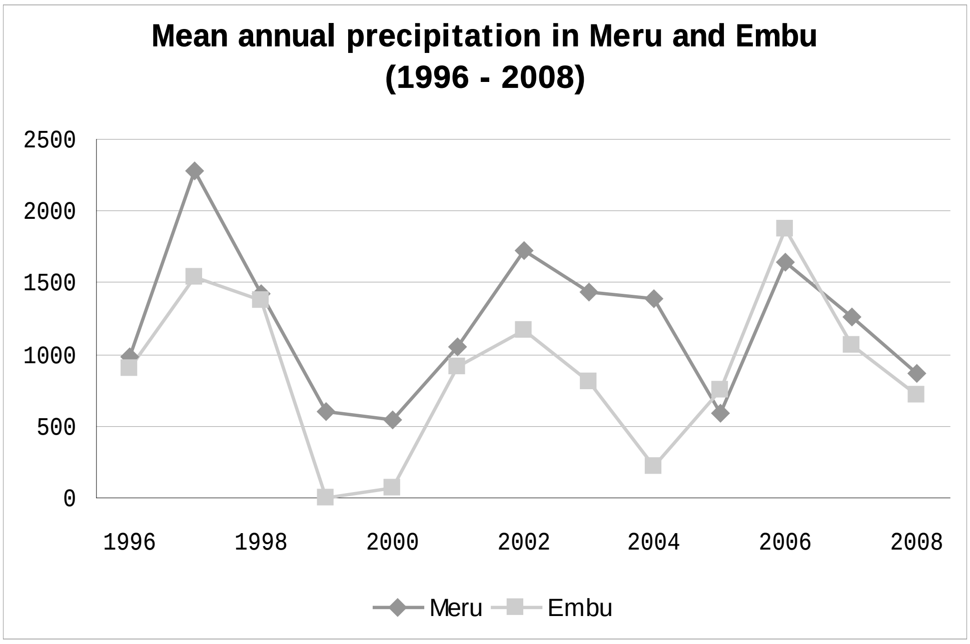


Figure 3
Precipitation as measured in Meru and Embu, Kenya

2.3 Hydrology

The main river in the catchment is the Tana, which supplies water to 17 million people, about 50% of the country's population (IFAD/UNEP/GEF 2004). The Upper Tana river receives its water from the higher elevation regions, in particular from the Aberdares range and Mount Kenya. Rivers originating from Mount Kenya are: the Thingithu, Rutugi, Ena, Rupingazi, Nyandi and Thiba. Mathioya, Maragua and Sagana drain from the Aberdares. The Nairobi Water Company (NWC), that delivers water to the municipality of Nairobi, extracts about 75% of its demand from the Thika river through the Ndakaine reservoir.

The water resources of the Upper Tana catchment provide water for 1 million ha of rainfed agriculture and 68,700 ha of irrigated land (Hoff and Noel 2007), which accounts for over 75% of total water demand (IFAD/UNEP/GEF 2004). There is increasing demand for irrigation water on the slopes of Mount Kenya, particularly to support horticulture production. Water usage in the upstream areas however affects water availability in the lower drier areas. Water is also important for electricity generation, industry (3% of total demand) and livestock (4%) (IFAD/UNEP/GEF 2004; Mogako *et al.* 2006).

KenGen, Kenya's power company, has 7 hydropower stations in the Upper Tana, of which Masinga Dam, holding up to 1560 million cubic metres, is the largest. This so called 7-Forks cascade delivers up to 65% of the country's electricity (Droogers *et al.* 2006).

2.4 Geology

The Upper Tana can be divided into two main geological structures: volcanic rocks of the Cenozoic Era are found in the west while in the east the bedrock consists of metamorphic rocks of the Mozambique belt. Mount Kenya, an extinct volcano formed between 100-400 million years ago, is located in the west of the catchment (IFAD/UNEP/GEF 2004).

2.5 Land use

Land use in the Upper Tana can be divided into three main classes: *natural vegetation* (forest, grassland and wetlands), *rainfed and irrigated agriculture* (tea, coffee, maize and rice) and *rangeland*. Figure 4 shows the Africover 2000 land use map. More detailed information on land use will be given in Chapters 3 and 4.

2.6 Population

Approximately 3.1 million people live in the Upper Tana (World Resources Institute 2007). The largest towns are Thika and Nyeri, with respectively about 90,000 and 100,000 inhabitants[2]. Figure 5 shows the population density of the Upper Tana. Population density declines with elevation, due to decreasing rainfall and soil fertility.

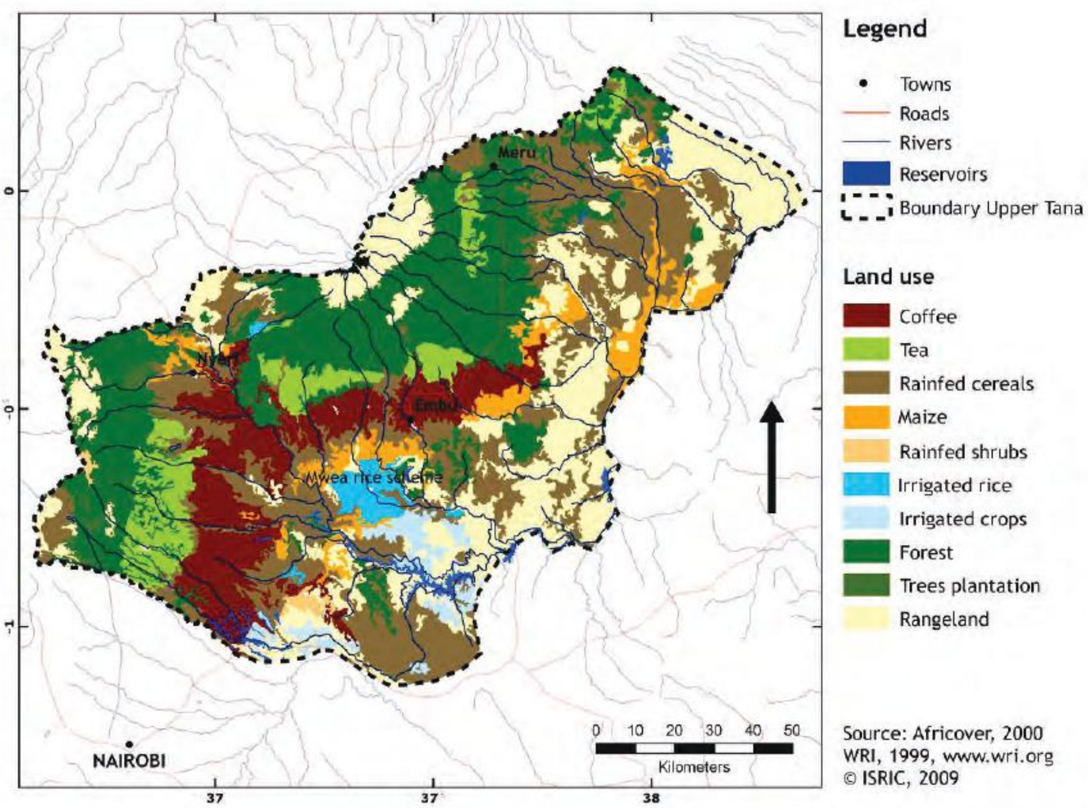


Figure 4
Africover 2000 land use map of the Upper Tana

[2] According to Kenya's last official census in 1999, but both the towns are estimated to have grown by at least 50,000.

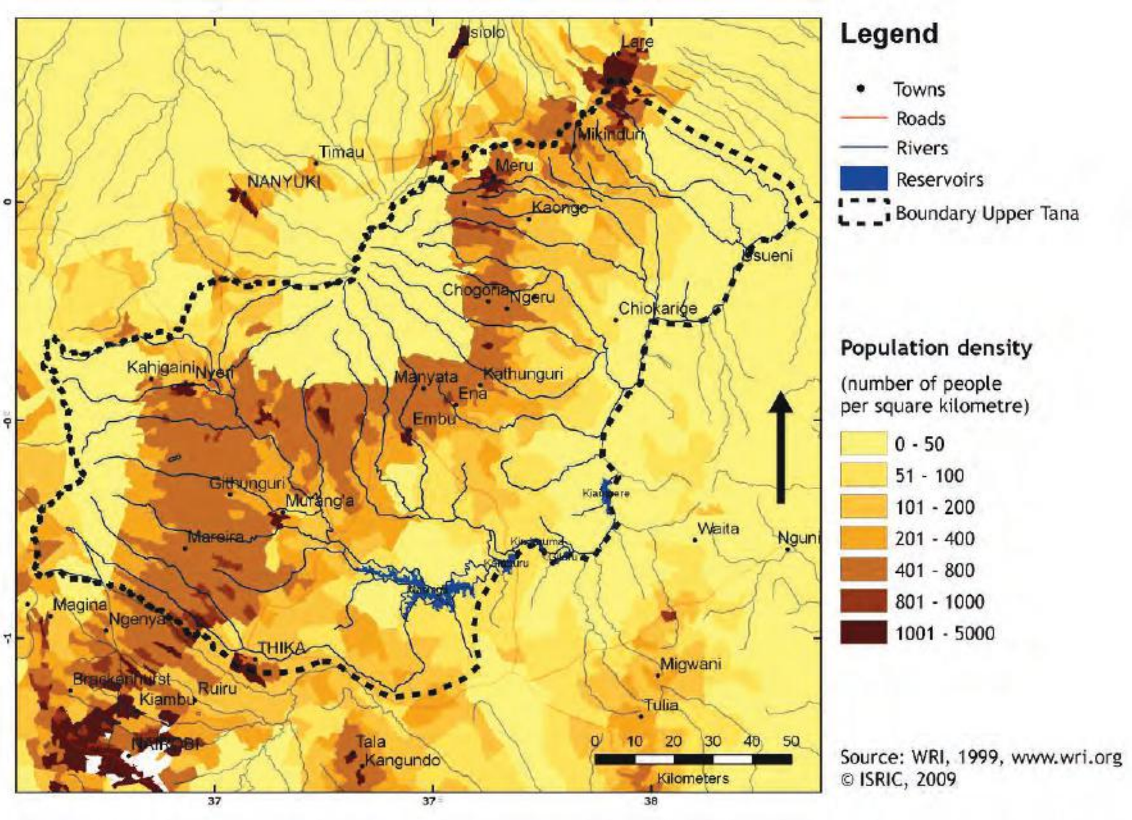


Figure 5

Population density in the Upper Tana (1999)

3 Methods

3.1 Fieldwork

The purpose of the fieldwork was twofold:

– to ground truth points of different land use types for the land use classification;
– to observe erosion features (results are given in Annex 1).

The field observations were collected at 364 sites. Observation areas were selected in advance based on ASTER satellite images, the KenSOTER soil map and the Africover land use map, in order to get a representative sample of the area. In the field, local conditions, such as accessibility by car and the presence of fences determined whether or not to sample a plot.

Coordinates were recorded using a GPS receiver on land plots larger than 20 m x 20 m. For each site its land use class, land management practice, vegetation cover and erosion severity was described and photographs were taken to complement the observations.

The fieldwork focused on an area covered by ASTER image 1 (Figure 6).

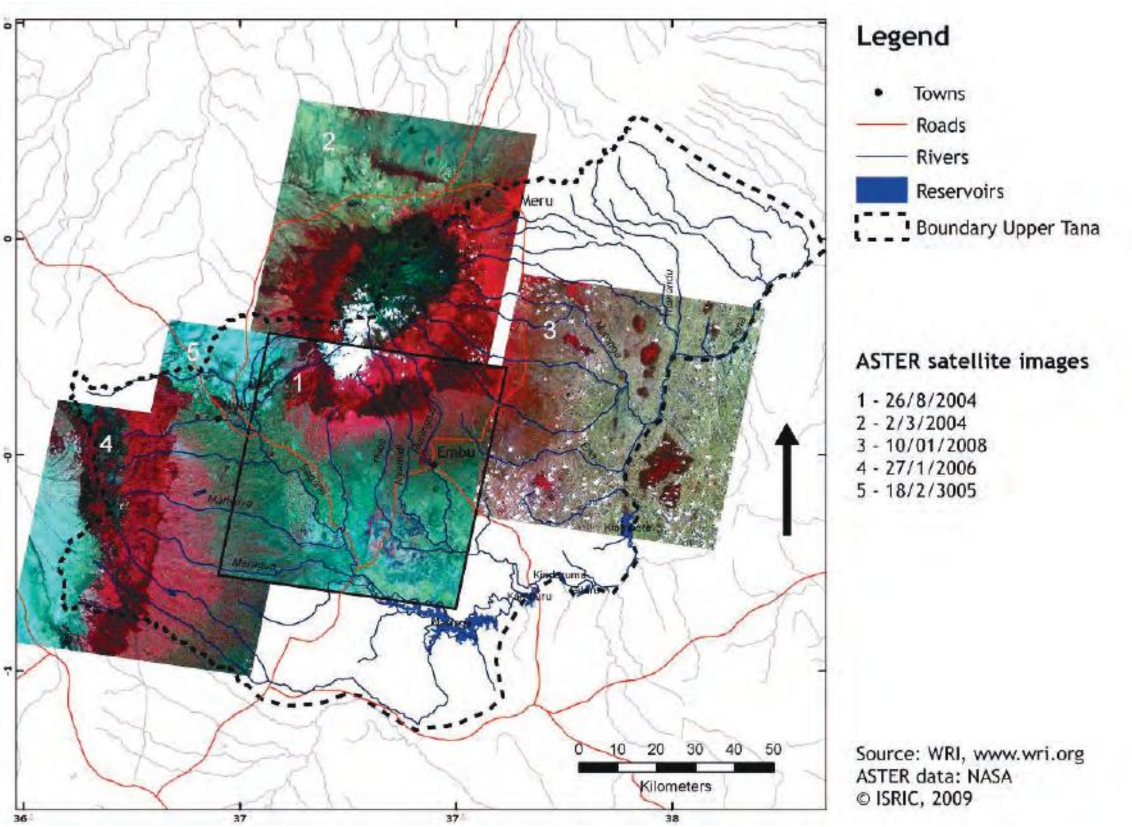


Figure 6
ASTER images. Image no. 1 is used for the initial remote sensing analysis

The central ASTER image (no. 1 in Figure 5, see also Figure 8) was chosen because it covers a large part of the *rainfed agricultural land*. The image dates from 26 August, 2004. The most preferable image would have been one dating from April or May 2008 or 2009, since these months coincide with the cropping season of most important crops[3], but from this period no cloud-free (< 20% cloud in the Upper Tana) images are available between 2000 and 2009. Figure 7 shows the Landsat images that were used for the analysis of the entire Upper Tana catchment. These images date from February 2000.

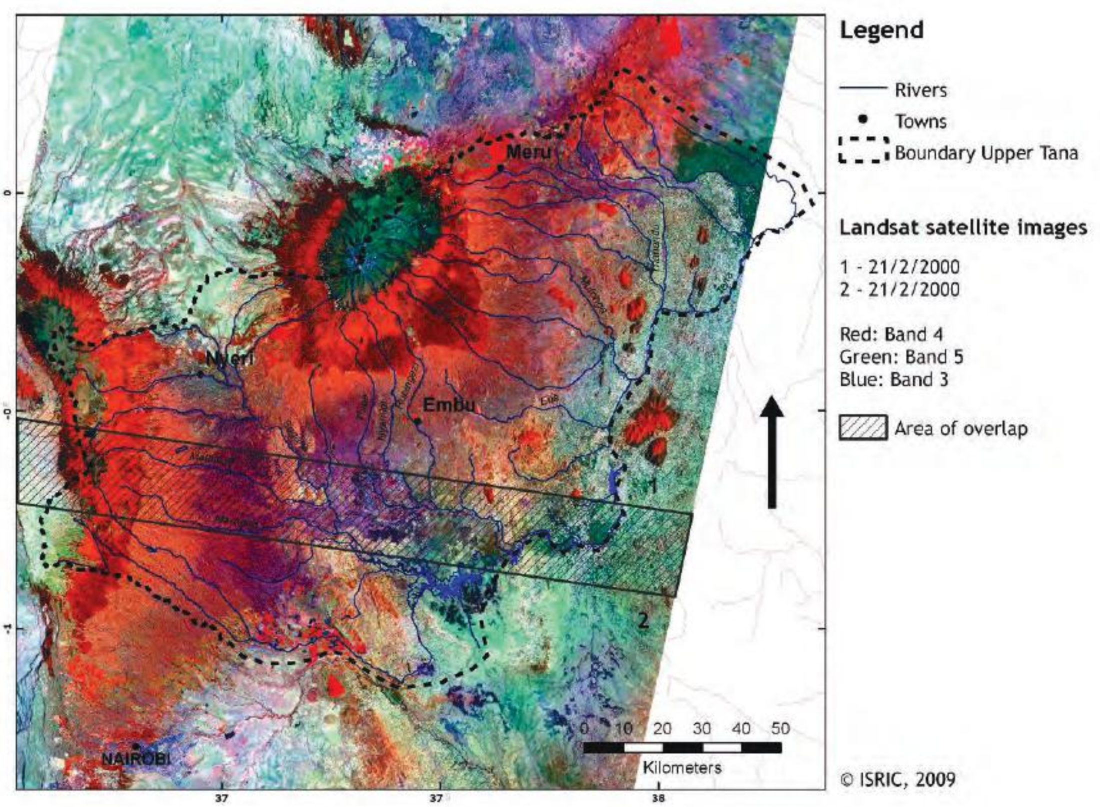


Figure 7
Two Landsat images (2000) covering the Upper Tana

3.2 Remote sensing analysis

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is an imaging instrument flying on a satellite launched in December 1999 as part of NASA's Earth Observing System. It has a spatial resolution of 15 m in the visible and near-infrared bands. The swath width[4] is 60 km.

Landsat 7 has eight spectral bands, with resolution ranging from 15 to 60 meters. It has a swath width of 185 km. Combined, two images dating from 2000 cover the Upper Tana catchment almost entirely; only the

[3] This is most important for maize and beans, as tea and coffee are grown year-round.
[4] This is the width of the covered area on the earth that is sensed with the satellite image.

upper east is excluded. The first Landsat satellite was launched in 1972. Landsat 7 experienced a failure in 2003; therefore correct images are only available until then.

ASTER was chosen for the first detailed analysis, because of its high resolution, its recurrence interval of 48 days, and the availability of cloud-free images between 2000 and 2009.

Landsat was chosen for the construction of the land use map of the whole Upper Tana catchment, because it is the only satellite with images available that cover such a large surface area; thus only 2 images are necessary to make the land use map. The main drawback of the Landsat images are that they date from 2000, but the advantage is that two Landsat images combined cover almost the whole Upper Tana (Figure 7).

ASTER could have been used as well, but there are disadvantages when satellite images of different acquisition dates are combined. Differences between the images that occur due to season, time of day, meteorological conditions and environmental factors, make it more difficult to form consistent classes and perform a classification. Pre-processing of the images is then necessary, which is a demanding job.

The analysis of the ASTER image consists of three steps:

1. Construction of Regions of Interest (ROIs)[5] for the different land use types. This is done on basis of the ground truth points collected in the field.
2. Classification with a
   - Maximum Likelihood (ML) classifier in ENVI[6] (see Box 1); and
   - Support Vector Machine (SVM) (Box 1).
3. Validation of the outcome with
   - Rule images[7], which show the probability that a pixel belongs to a certain class;
   - Google Earth images; and
   - Field observations.

These three steps are repeatedly performed in order to achieve the best result. In this process land use classes are combined or split, ROIs are changed or added and the probability threshold for the classes is increased or decreased.

After the analysis of the ASTER image, the same method was applied to the Landsat images. The classification of the Landsat images was compared to the result of the ASTER classification.

5 ROIs (Regions of Interest) are regions selected from the satellite image, that represent a certain class, such as *maize* or *water*.

6 ENVI is a software product used for processing and analysing geospatial imagery.

7 Rule images are automatically generated when a classification is performed. The images show for each class the probability (0-1) that a pixel belongs to this class, or in other words, they show the levels of classification confidence for each class. From these images one can, for example, determine which areas cannot be classified with high accuracy.

Box 1
Automatic Classification methods

Maximum Likelihood classification method
The Maximum Likelihood (ML) classification is based on the assumption that the cells in each class sample in the multi-dimensional space are normally distributed. A class can be characterised by a mean vector and covariance matrix. Given these two characteristics for each cell value, the statistical probability is computed for each class to determine the membership of the cells to the class. The result is a map in which each cell has been assigned to its most likely class.

Support Vector Machine Method
SVM is a method used for classification. A SVM seeks to fit an optimal hyper plane between the classes and uses only some of the training samples that lie at the edge of the class distribution in feature space (support vectors) (Foody 2002; Mathur and Foody 2008; Oommen et al. 2008). The advantage of this method is that, unlike the Maximum Likelihood method, only a few training samples are necessary. The disadvantage of this method is the long computation time..

Data sources:
http://www.pmel.noaa.gov/tao/elnino/el-nino-story.html
http://en.wikipedia.org/wiki/El_Ni%C3%B1oSouthern_Oscillation#Causes_of_El_Ni.C3.B1o

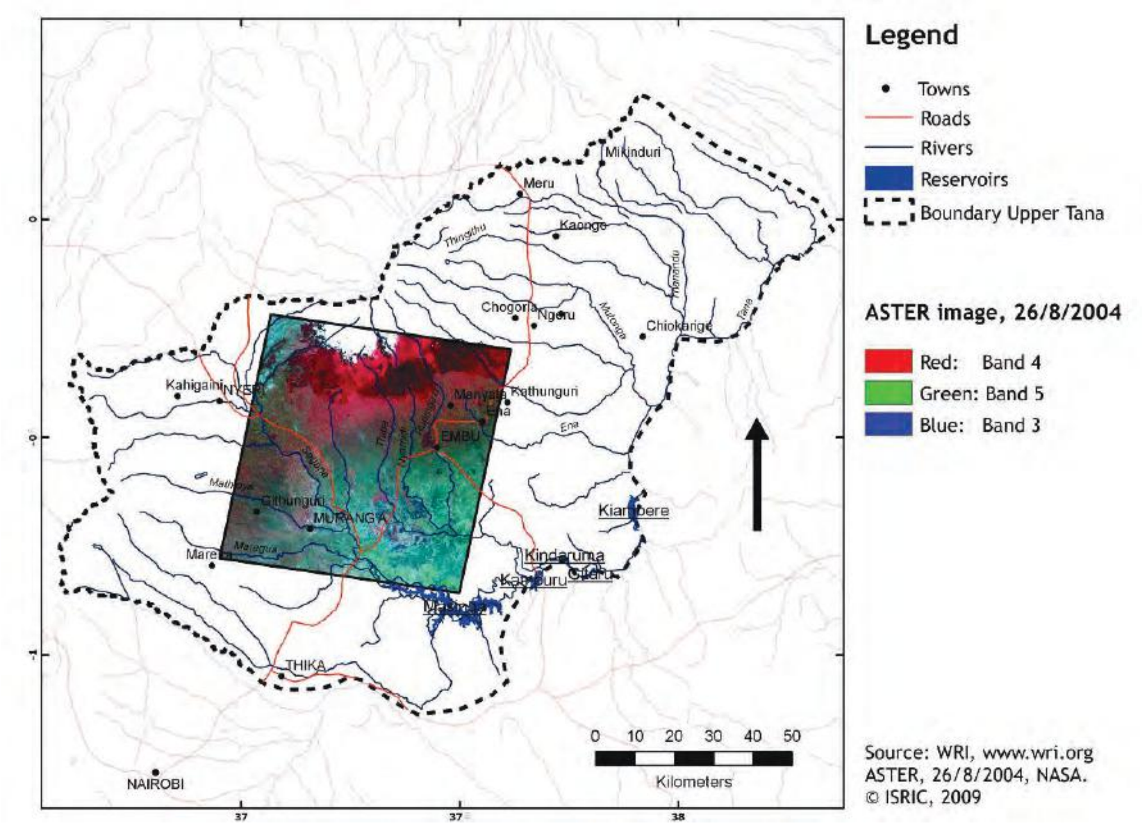


Figure 8
The ASTER image used for the remote sensing analysis

4 Results

4.1 Fieldwork

In total 364 sites were visited and characterised. Figure 9 shows the groundtruth points.

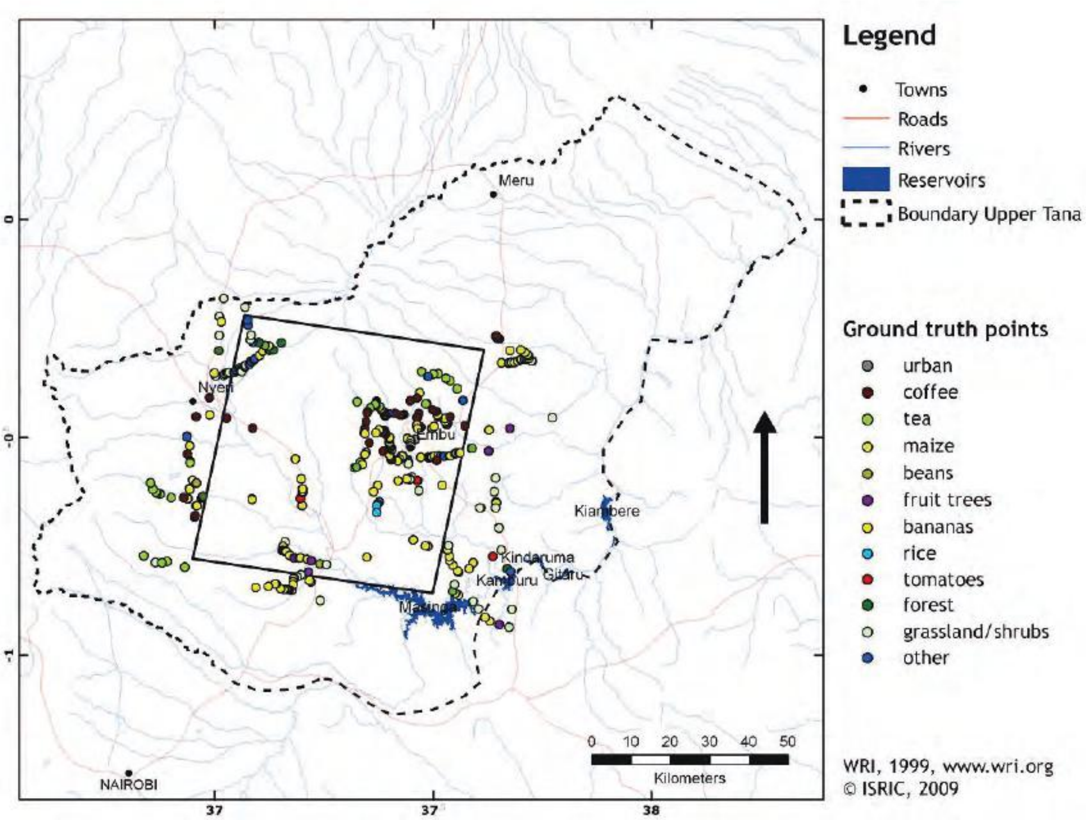


Figure 9
Groundtruth land use observations

Many different land use types were observed during the fieldwork. They can be grouped into four main classes: rainfed crops, irrigated crops, natural vegetation and semi-natural vegetation. These classes can be further subdivided as follows:

1. Rainfed crops:
   a. Coffee
      i. Monocropped plantations
      ii. Combinated with banana and *Grevillea robusta* trees
      iii. Intercropped with beans, passion fruit, napier grass or maize
   b. Tea

c. Maize
   i. Maize only
   ii. Maize and beans (the most common combination)
   iii. Combined with trees, potatoes or napier grass
d. Beans
e. Potatoes
f. Banana plantations

g. Trees
   i. Macadamia
   ii. Avocado
   iii. Mango
   iv. Coniferous plantations
   v. Eucalyptus plantations

2. Irrigated crops:
   a. Rice
   b. Tomatoes
   c. Passion fruit

3. Natural vegetation:
   a. Forest
   b. Moorland
   c. Shrubs
   d. Wetland
   e. Riverbank vegetation

4. Semi-natural vegetation:
   a. Grassland/Rangeland

Figure 10 shows the distribution of ground truth observations. Some land use types, such as *tomatoes*, have only few observations; these classes cannot be used in the remote sensing analysis, because their spectral signal is not distinctive enough. Sub-classes, such as the four types of coffee plots, are grouped into one class for the classification, because spectrally they cannot be distinguished from each other.

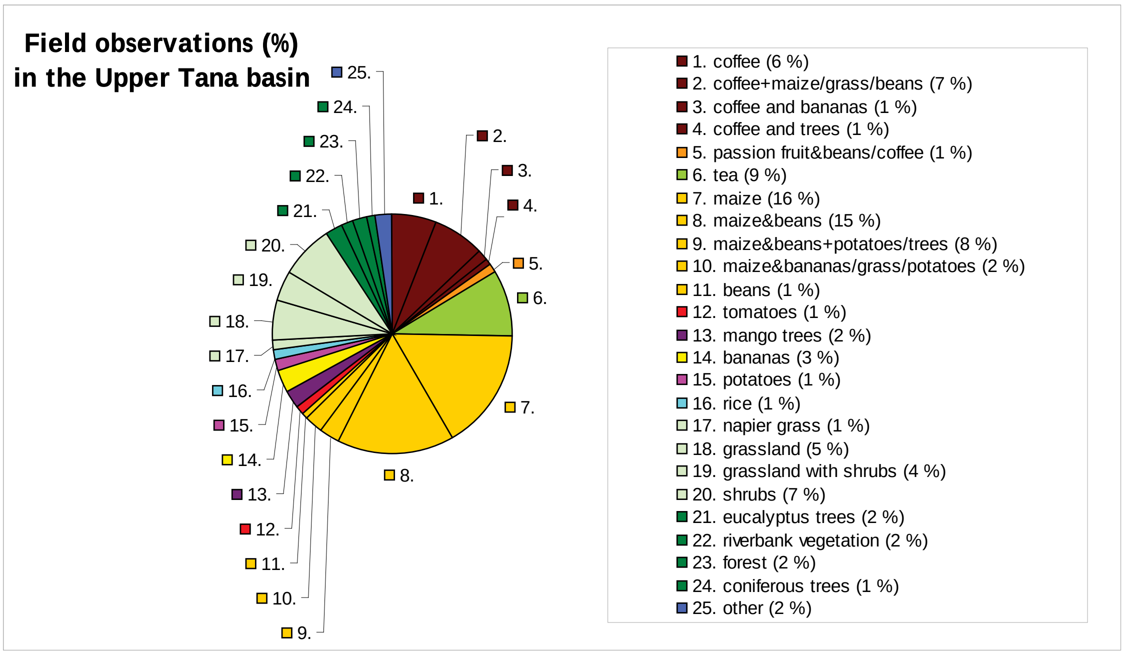


Figure 10
Distribution of groundtruth observations in the Upper Tana

4.2 Maximum Likelihood classification

For the spectral information based land use classification, it is necessary to group the land use types into classes based on spectral separability. The following classes have been used for the classification: *coffee*, *tea*, *forest*, *rice*, *rangeland* (grassland and/or shrubs), *urban*, *bare/degraded land*, *rainfed agriculture in dry areas*, *rainfed agriculture on black soils*, *water* and *cloud*.

The *rainfed agriculture in dry areas* class represents the lower elevation and low rainfall areas, where mostly maize and sorghum are grown. In these areas, the crops are widely spaced on the fields because of the water deficit. The spectral signature therefore is different from the signature of *maize*.

Rainfed agriculture on black soils is agriculture (dominated by maize and sorghum; though millet and cotton are also grown[8]) on black clay-rich soils, which are classified as vertisols (FAO 1988). In this area there are also irrigated tomatoes. The image below (Figure 11) shows the result when the probability threshold for all classes is set to 0.4.

[8] Confirmed by Dr P. Macharia, Kenyan Soil Survey.

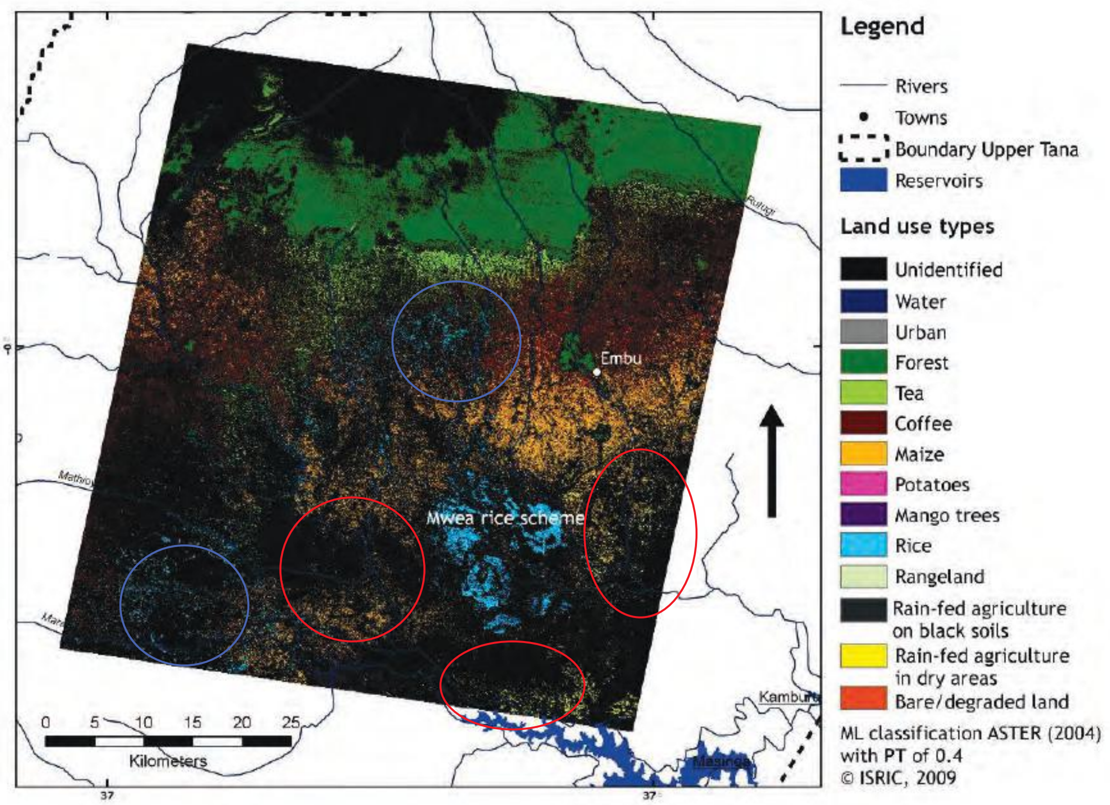


Figure 11
Land use map made with a ML classification, with a probability threshold of 0.4

The black pixels in this map represent pixels that cannot be classified with a probability higher than 0.4. Especially in the areas south, east and west of Mwea rice fields, pixels are difficult to classify (indicated with red circles). Apart from a shortage of groundtruth data, one difficulty in these areas is the heterogeneous character of present soil types, specifically the vertisols. Vertisols are black, fertile soils that have a distinct spectral signal that overwhelms the signal of the land use type.

Apart from the Mwea rice scheme, rice is rarely grown in the catchment. Therefore, the pixels of *rice* west of Embu and west of Murang'a are probably incorrectly classified (indicated with blue circles). Annex 2 shows the separability between the classes. It indicates that the classes *maize* and *coffee*, and *maize* and *urban* have spectral signatures that are overlapping.

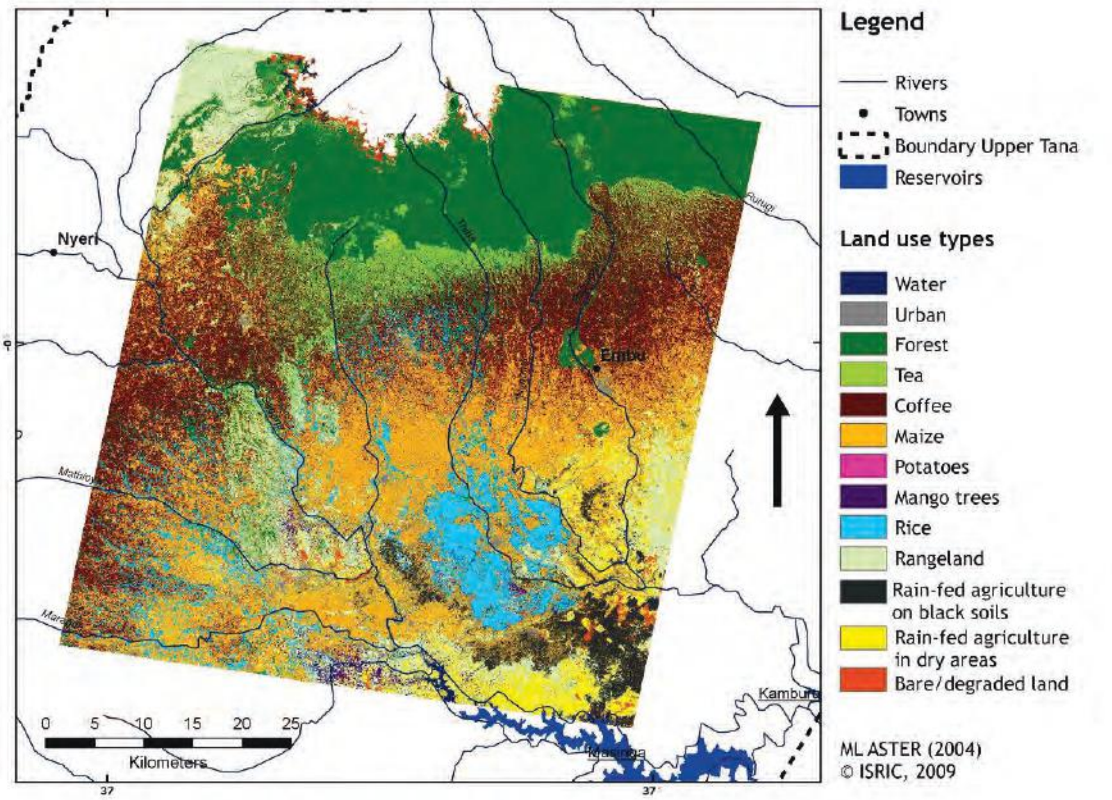


Figure 12
Land use map made with a ML classification, without applying a probability threshold

Figure 12 shows the ML result when no probability threshold is applied. To further improve this image, the satellite image was classified again, without the *rice* ROIs. The *rice* fields at Mwea were extracted from the original image and added to this new classification. In the resulting image (Figure 13) the *rice* pixels have mostly been replaced by *coffee* or *maize*.

The cloud in the north of the image has been removed by replacing it by *forest*. Forest is the dominant land cover in this zone (Jaetzold and Schmidt 1983), which can be seen on high resolution images released by Google Earth. The result is shown in Figure 13.

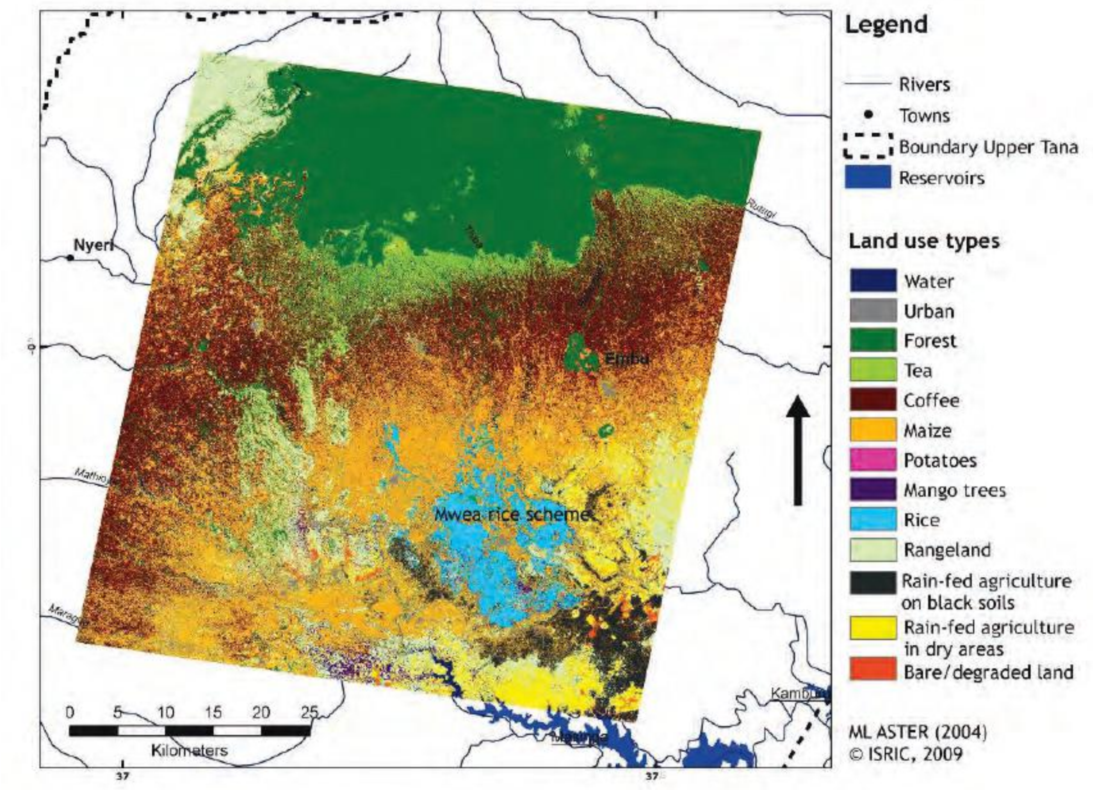


Figure 13

Final land use map made with Maximum Likelihood method and improved using Google Earth. Rice only appears at the Mwea rice scheme in the south east of the image and the cloud in the north has been replaced by forest

4.2.1 Validation

The overall accuracy of the image is 80.4 %, with a Kappa Coefficient[9] of 0.87. The producers' accuracy was lowest in the following classes: *rice*, *potatoes* and *coffee*. The users' accuracy was lowest for *maize*, *coffee* and *potatoes* (for more information on the validation method, see Box 2).

[9] The Kappa Coefficient (0-1) is a statistical measure of agreement, beyond chance, between the ground truth data and the output of the classification.

Box 2
Validation method

To investigate the accuracy of the classified image, an error matrix has been constructed. An error matrix shows for each class the amount of pixels that belong to the class (based on groundtruth) and the number of pixels that have been classified to each class.

95% of the ROIs (selected stratified randomly) has been used for the ML classification. The remaining 5% was used to validate the classified image. As these 5% are located within or close to the ROIs that have been used for the classification, the outcome is biased: the overall accuracy is overestimated. Nevertheless, it gives an indication of the heterogeneity within the land use classes and it assesses whether the ROIs have been chosen well.

From the error matrix an overall accuracy, producer accuracy and user accuracy can be calculated.

Producer's accuracies are calculated from dividing the number of correctly classified pixels in a category, by the number of training set pixels used for that category. This figure indicates how well training set pixels of the given cover type are classified (Lillesand and Kiefer 1987).

User's accuracies are computed by dividing the number of correctly classified pixels in a category by the total number of pixels that were classified in that category. This figure is a measure of commission error and indicates the probability that a pixel classified into a given category actually represents that category on the ground (Lillesand and Kiefer 1987).

4.2.2 Comparison with Africover 2000 land use map

Compared to the Africover 2000 map (Figure 14), the new classified image (Figure 13) shows more detail. The main differences are:

- The *Forest* area in the Africover 2000 map is 10% higher;
- The Africover map shows homogenous *coffee* and *tea* zones; however the *coffee* and *tea* zones have mixture of various crops which is shown on the newly classified map;
- The Africover map shows "irrigated unspecified", however the main crops in this area are maize, sorghum and tomatoes; and
- The new map shows also areas that are classified as bare land, which is often seriously degraded (*Bare/degraded land* class).

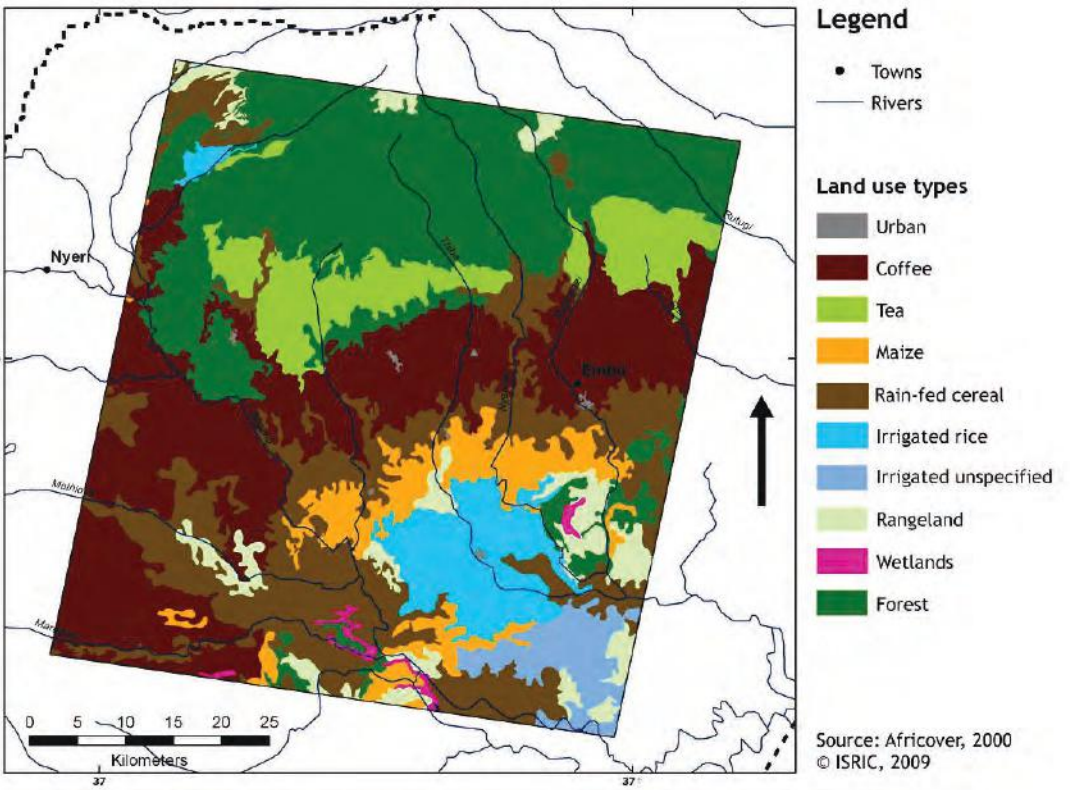


Figure 14
Land use according to the Africover (2000) map

4.2.3 Comparison with the ML classification of the Landsat image

To assess whether or not the Landsat image shows comparable outcomes to the ASTER image, a ML classification has been performed on the Landsat image for the same extent of the ASTER image (Figure 15).

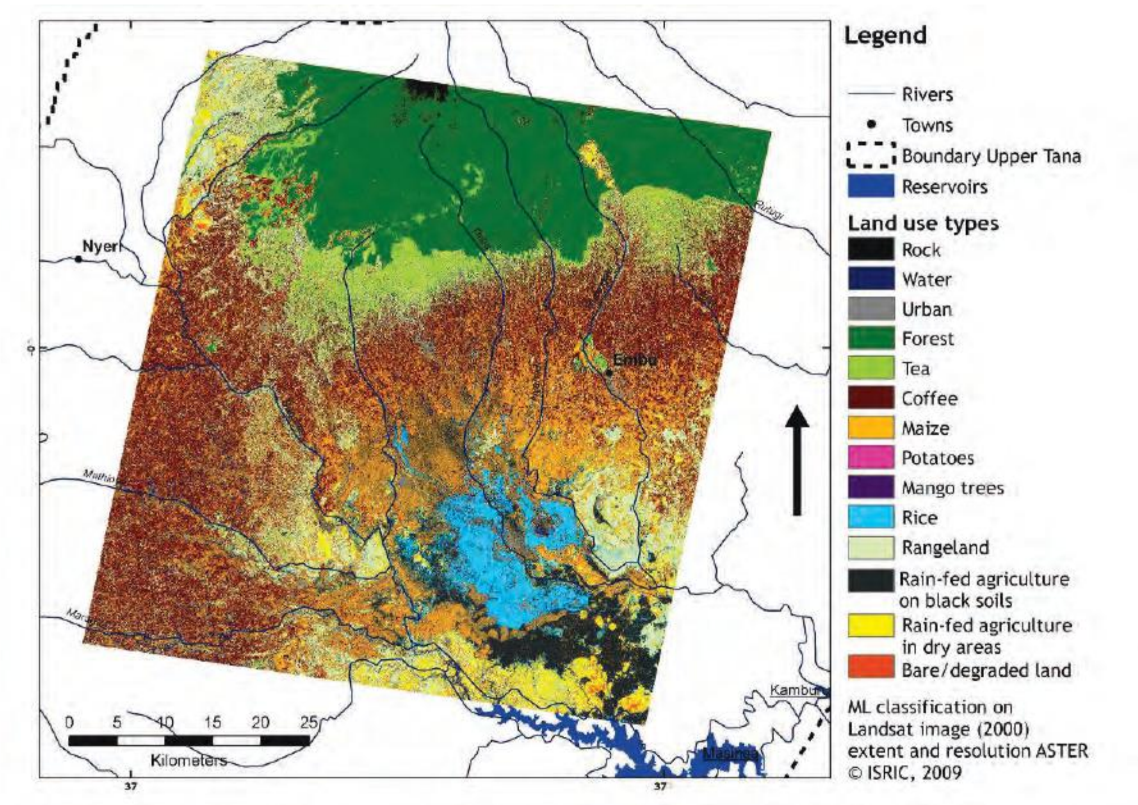


Figure 15
ML classification on a Landsat (30 m resolution) image from 2000

The main difference is the presence of *maize*: there is 5.5% more *maize* in the ASTER classification (see for comparison of all values Table 1). The *maize* is mainly substituted by *water*, *coffee*, *rice* and *rangeland*. One other remarkable difference between these images is the occurrence of *coffee*: in the Landsat (2000) image there is 1.5% more *coffee*, which is more widely spread and extends to lower elevations than in the ASTER classification. Another difference occurs as a result of the *cloud* in the ASTER image. The Landsat image is cloud-free and it is likely that the image therefore has a higher reliability in the centre northern part of the image. This part will be added to the final result. In general the maps show correlating land use patterns.

It can therefore be concluded that although the Landsat images date from 2000, they are suitable for the land use classification. The Landsat images cover the entire Upper Tana catchment and are therefore useful for the construction of a new land use map.

Table 1

Land use in percentages as result of ML classification of an ASTER (2004) and Landsat (2000) image, SVM classification on an ASTER image (2004) and the Africover land use map

Land use	ML Aster (%)	ML Landsat (%)	Africover (%)	SVM (%)
Rock	-	0.6	-	-
Water	1.2	4.2	1.2	2.9
Urban	3.3	5.1	0.1	10.8
Forest	24.6	18.1	34.6	29.9
Tea	4.0	4.2	4.5	3.2
Coffee	18.9	20.4	24.9	7.9
Maize	22.1	14.6	4.4	9.9
Rainfed cereal	-	-	17.6	-
Potatoes	0.0	-	-	0.0
Mango	1.0	-	-	0.9
Rice	2.8	3.6	3.4	6.3
Rangeland	13.6	15.6	6.8	22.1
Rainfed agriculture on black soils	3.4	6.2	-	2.7
Rainfed agriculture in dry areas	2.8	3.5	-	0.7
Bare/degraded land	2.0	3.7	-	2.4
Pineapples	-	0.1	-	-

4.3 SVM classification

The ASTER image has also been classified using a Support Vector Machine (SVM; Figure 16). The main difference of SVM compared to the ML classification of the ASTER image is the change from 14.6% *maize* in the ML image, to 9.9% in the SVM image. The *maize* has been replaced by *rangeland*, which covers 13.6% in the ML image and 22.1% in the SVM image. This change from *maize* to *rangeland* occurs particularly in the dry southeast part of the image. Validation on Google Earth shows that most of the south-east, east of the Mwea rice scheme, comprises a significant amount of *rangeland*, although not as much as is displayed on the SVM classification. According to Africover, only a small part consists of *rangelands*, and part of this area is forest, which can neither be seen on the ML, the SVM, or on Google Earth. The large amount of *rice* outside of the Mwea rice scheme is probably due to a classification error, as happened with the ML classification. When the image is classified without including *rice*, the pixels west of the Mwea rice scheme are classified mostly as *water*; indeed the pixels are located close to rivers. The pixels to the north of the rice scheme are classified as *urban*, which cannot be correct. The overall accuracy of the image is 88.9%, with a Kappa Coefficient of 0.88%.

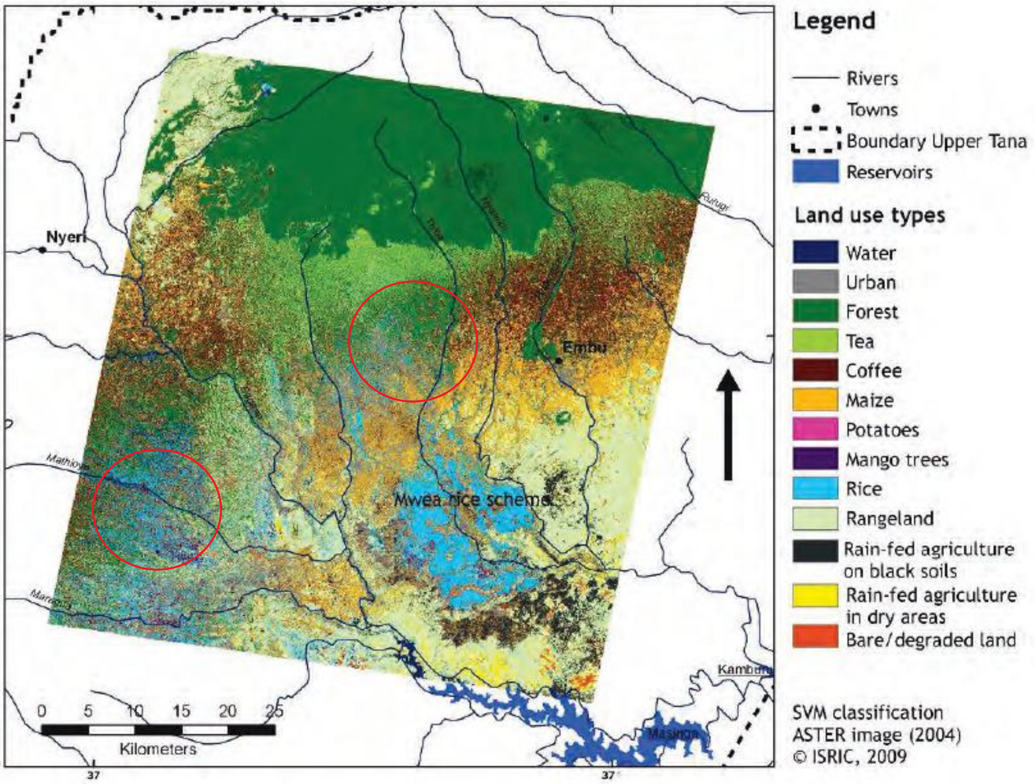


Figure 16
SVM classification on ASTER image (2004). The red circles indicate areas with rice pixels

4.4 Extrapolation: classification of Landsat images

The Green Water Credits programme focuses on the Upper Tana catchment. Therefore, it is useful to use Landsat images for the construction of the final land use map, as explained under Methods (3.2).

The Landsat images were mosaiced into one image that was classified twice: using the ML (Figure 17) and SVM method (Figure 18). An *afro-alpine flora & rock* and *pineapple* class were added to the ROIs. These ROIs were selected using Google Earth.

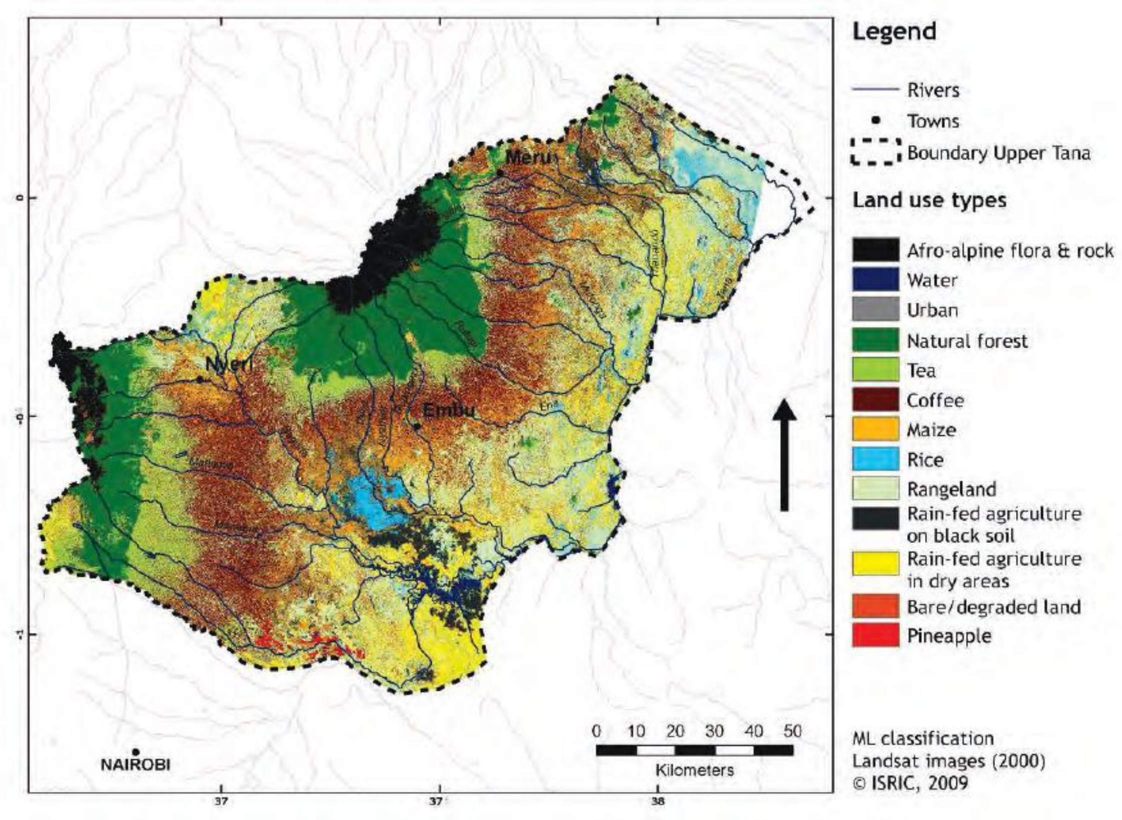


Figure 17
The land use map made with a ML classification on two Landsat 2000 images

The results of the both methods are comparable. The ML classification gave an overall accuracy of 76.1%, with a Kappa Coefficient of 0.7; the SVM classification has an overall accuracy of 77.7% with also a Kappa of 0.7. It should be noted that for the classification of the SVM only 10% of the data was used, and 90% for the validation. The SVM is therefore an excellent method when only few observations have been made.

The main differences between the land use images lie in the change of the *rainfed agriculture dry areas* with *bare/degraded land*. *Coffee* fields are denser in the ML classification; they occupy 5% more area in the ML image.

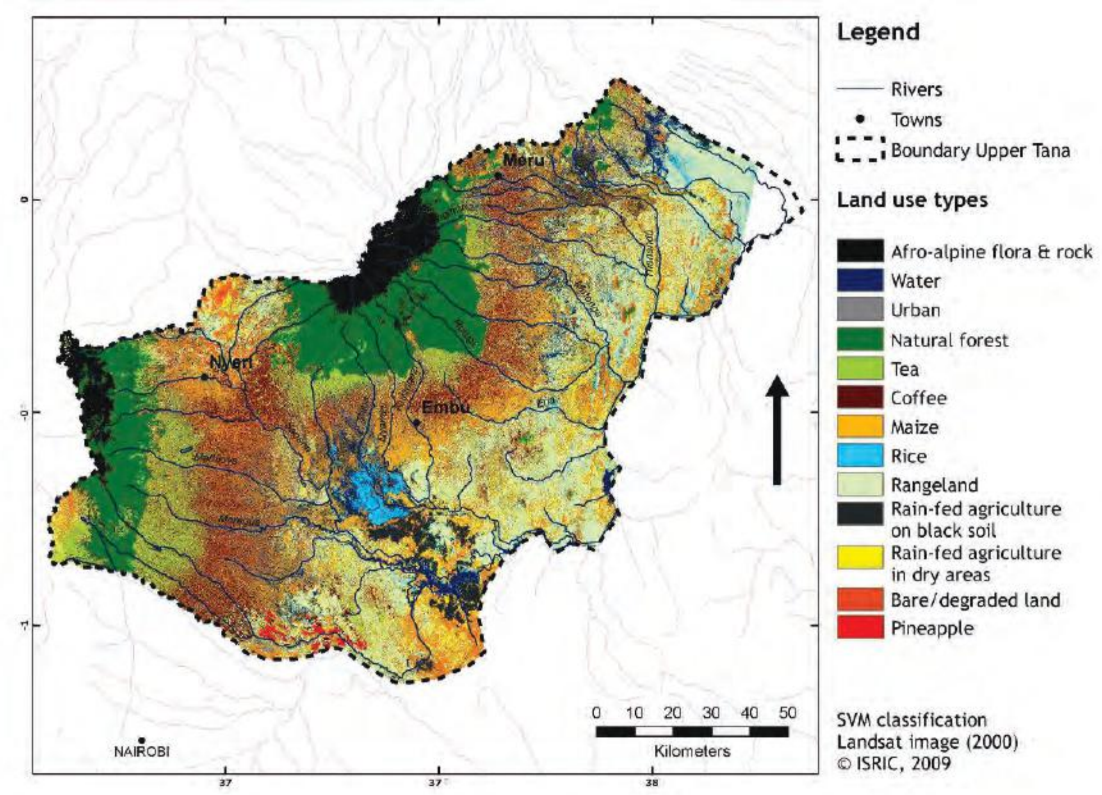


Figure 18
SVM classification of Landsat images (2000)

Table 2
Land use as calculated using ML and SVM for the Upper Tana catchment

Land use	ML (ha)	ML (%)	SVM (ha)	SVM (%)	AFR (ha)	AFR (%)
Afro-alpine flora and rock	697,829	4.0	8196	5.2	1823	0.1
Water	648,967	3.7	107,259	6.8	11,428	0.7
Urban	571,472	3.3	73,485	4.7	1862	0.1
Forest	211,697	11.9	208,393	11.7	409,741	25.7
Tea	803,990	4.6	890,918	5.1	83,611	5.3
Coffee	2,388,228	13.7	133,459	8.5	174,420	11.0
Maize	1,806,829	10.3	176,612	11.2	88,690	5.6
Rainfed cereal	-	-	-	-	390,759	24.5
Rice	574,713	3.3	37,119	2.4	23,232	1.5
Rangeland	4,451,349	25.5	376,663	23.9	362,511	22.8
Rainfed agriculture on black soils	810,700	4.6	63,727	4.1	-	-
Rainfed agriculture in dry areas	1,418,829	8.1	74,252	4.7	-	-
Bare/degraded land	909,591	5.2	153,355	9.7	-	-
Pineapple	45,071	0.3	6,785	0.4	8,470	0.5
Wetlands	-	-	-	-	8,919	0.6
Irrigated unspecified	-	-	-	-	24,564	1.5
TOTAL	1,573,178	100	1,573,208	100	159,0031	100

4.5 Final Land use map Tana

To produce the final land use map of the Tana, the SVM classification of the Landsat (Figure 18) was chosen because of slightly higher overall accuracy and the possibilities of using this method when only few field data have been collected. Statistics about the land use, in comparison to Africover data can be found in Table 2.

It should be noted that a large part of the map is based on Landsat images of 2000. The *coffee* zones have declined since then and possibly the *tea* zone has expanded.

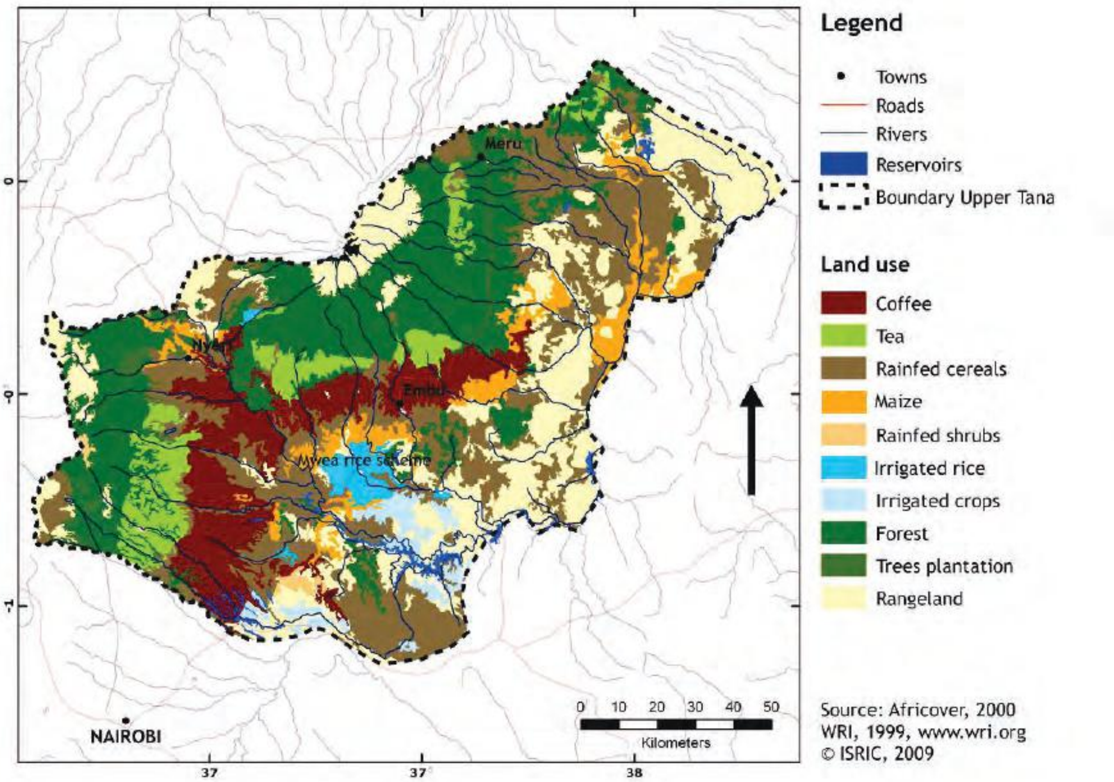


Figure 19
The Africover 2000 map

Now the major changes between the Africover (Figure 19) and SVM land use map (Figure 18) will be discussed.

4.5.1 Forest area

The extent of the *forest* in the Upper Tana is overestimated on the Africover map, the *forest* is almost twice as extensive as on the SVM land use map. This is shown in Figure 20. The major differences are seen in particular on the east and south-west side of the Mount Kenya forest.

Figures 21A and B show zooms of Google Earth, which concur with the forest areas on the SVM land use map. It should be mentioned that some small patches of *forest* that are visible on Google Earth, are not displayed on the SVM.

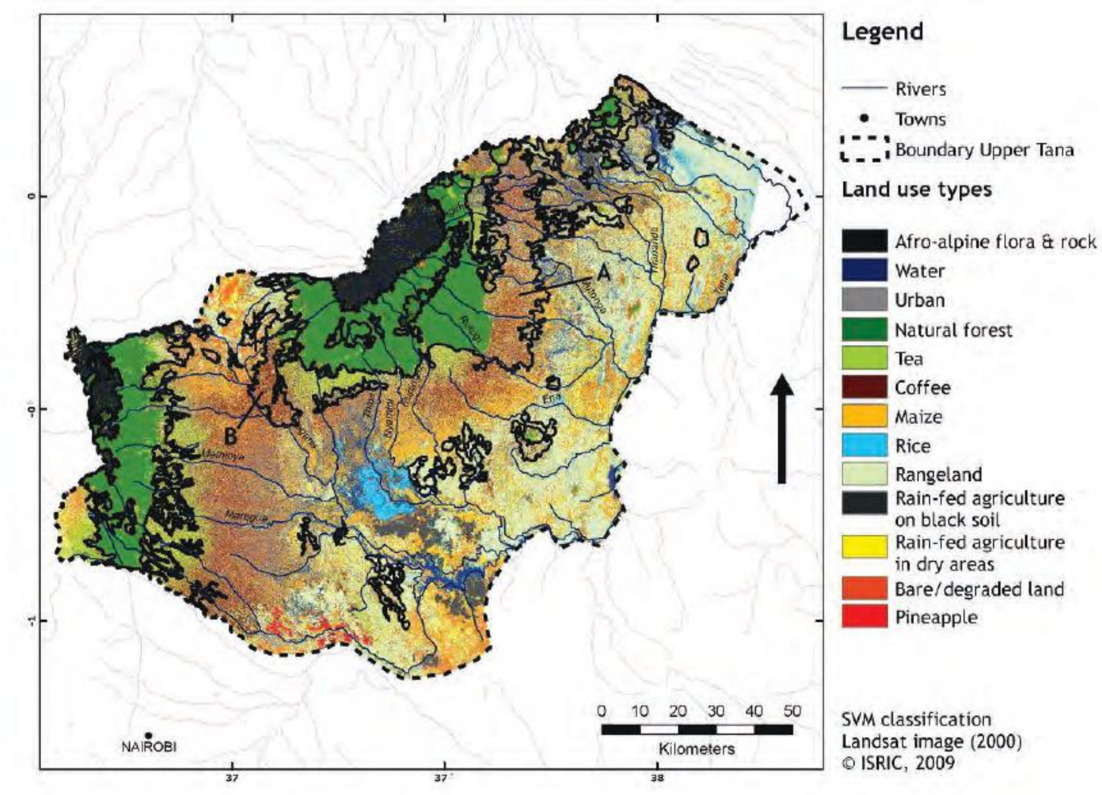


Figure 20
Africover forest extent superimposed on the SVM land use map. "A" and "B" indicate the areas for which a zoom has been made of Google Earth in Figure 21

Figure 21
Zooms of Google Earth showing coffee and tea fields. "A" is located to the east of Mt Kenya and south of Meru, "B" is located to the southwest of Mt Kenya

4.5.2 Tea zone

Figure 22 shows the *tea* zones from the Africover superimposed on the SVM classification. There is 1.8% more tea in the SVM map compared to the Africover map. The tea is spread over a larger area, and the *tea* zone includes also *coffee* fields. East of the Aberdares, the *tea* zone extends further to the north according to the SVM classification and groundtruth observations on Google Earth. In the Africover tea zone the SVM land use map consists of 37.1% tea, 15.8% *coffee*, 14.6% *rangeland*, 10.7% *bare/degraded land*, and 3.8% *maize*. The large amount of *rangeland* could be an overestimation, because in these zones there is not much rangeland; however, grasslands do occur. *Bare/degraded land* accounts for a high percentage, probably because of pruned tea fields. The *tea* west of the Aberdares seems to be an overestimation (see blue arrow in Figure 22); Google Earth images confirm this.

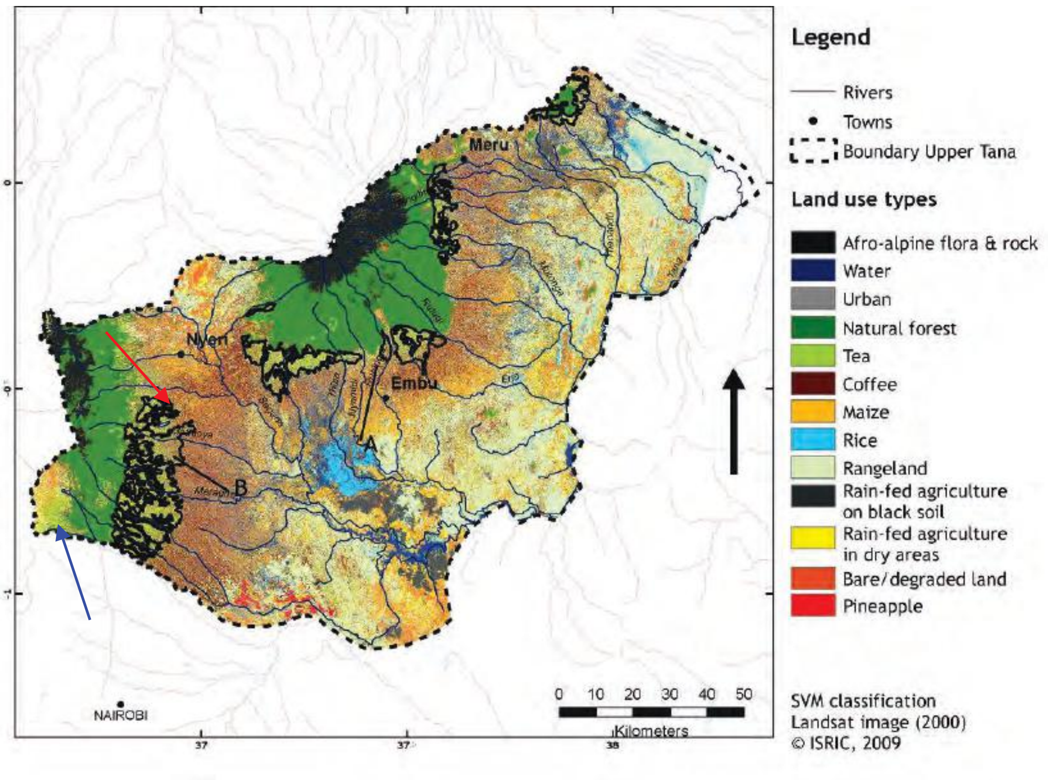


Figure 22

Tea zones as defined by Africover displayed on the SVM land use map. "A" and "B" indicate zoom-ins showed in Figure 23. The red arrow east of the Aberdares indicates the extension of the tea zone in this area to the north. The blue arrow indicates the area where tea is likely to be overestimated by the SVM method

Figure 23

Zoom of the tea zone (indicated as "A" in Figure 22). The black line is a border of the tea zone according to Africover (right-side tea, left-side rain fed cereal). As can be seen, on the left part of the image there is a lot of tea (green box indicates an example of a tea field). Coffee is also present in the tea zone (an example is shown by the red box)

Figure 24
This image is a zoom in of the area east of the Aberdares (B). There are many coffee fields (example indicated by red box), but only few tea fields (indicated by green box), or they are all bare

4.5.3 Coffee zone

The Africover map has 1.3 times more *coffee* as the SVM map (Figure 25). However, *coffee* on the SVM map is spread more; into the *tea* zone and to the east of Mt Kenya (as explained in 5.5.1).

"A" and "B" indicate areas for which a view of Google Earth is shown. “A” shows a *rangeland* area, where Africover indicated *coffee*; “B” shows an area where no *coffee* was indicated but is indeed present. “C” (as shown on Figure 25) indicates an area where there are only some large-scale *coffee* plantations. In between these *coffee* plantations, there are shrubs and grassland. At the location of “D”, Africover indicates some more areas as *coffee*. Although there are some *coffee* plantations, the area here is mostly covered by *rangeland* and partly by *irrigated pineapple*.

In the *coffee* zone as defined by Africover, SVM indicates the following distribution of land use types: *coffee* 29%, *maize* 22%, *urban* 14%, *rangeland* 11% and *water* 9%.

It is concluded that the SVM shows a more realistic image of the *coffee* area. The *coffee* zone is broader than the Africover indicates, as it extends also to the *tea* zone. The area indicated by "B" does contain *coffee*, as does the area east of Mt Kenya. The extension of the *coffee* zone up to "D" (Figure 25) is questionable, since the main land use in that area seems to be *rangeland*. The *coffee* zone as shown on the Africover map does not consist of *coffee* alone; there are a variety of land use types in the *coffee* zone, of which *coffee* and *maize* are dominant.

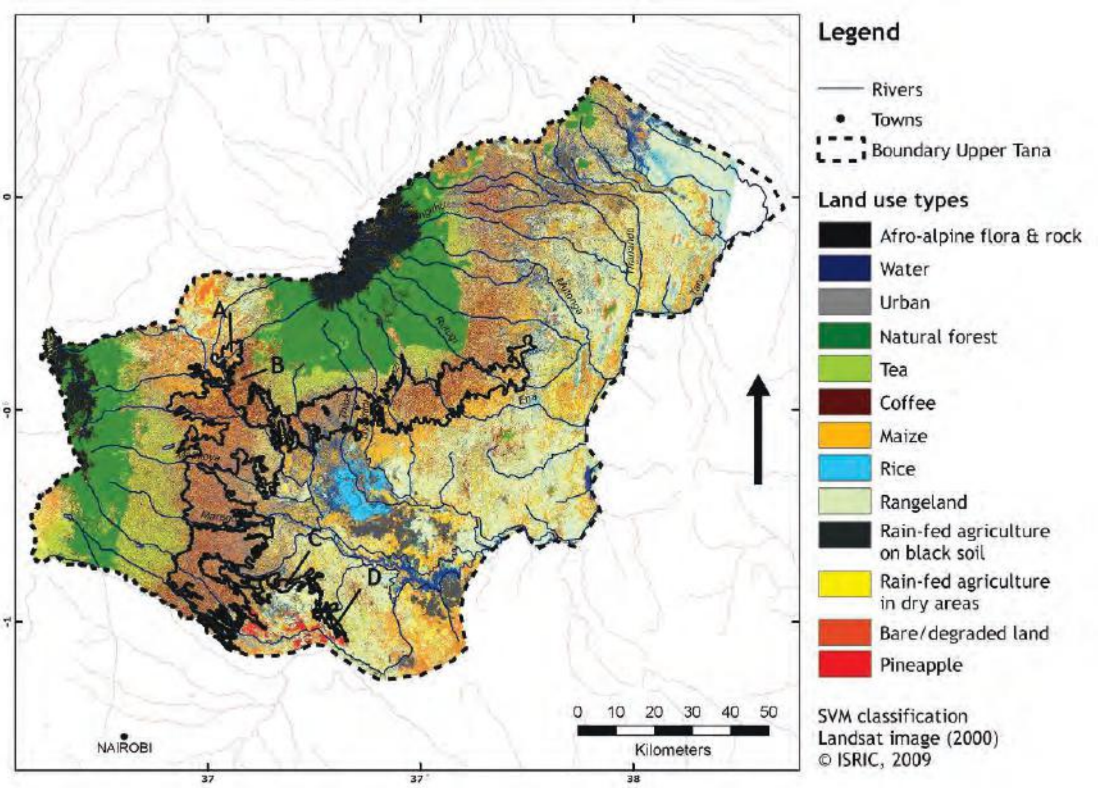


Figure 25
Coffee as indicated by Africover, superimposed on the SVM land use map

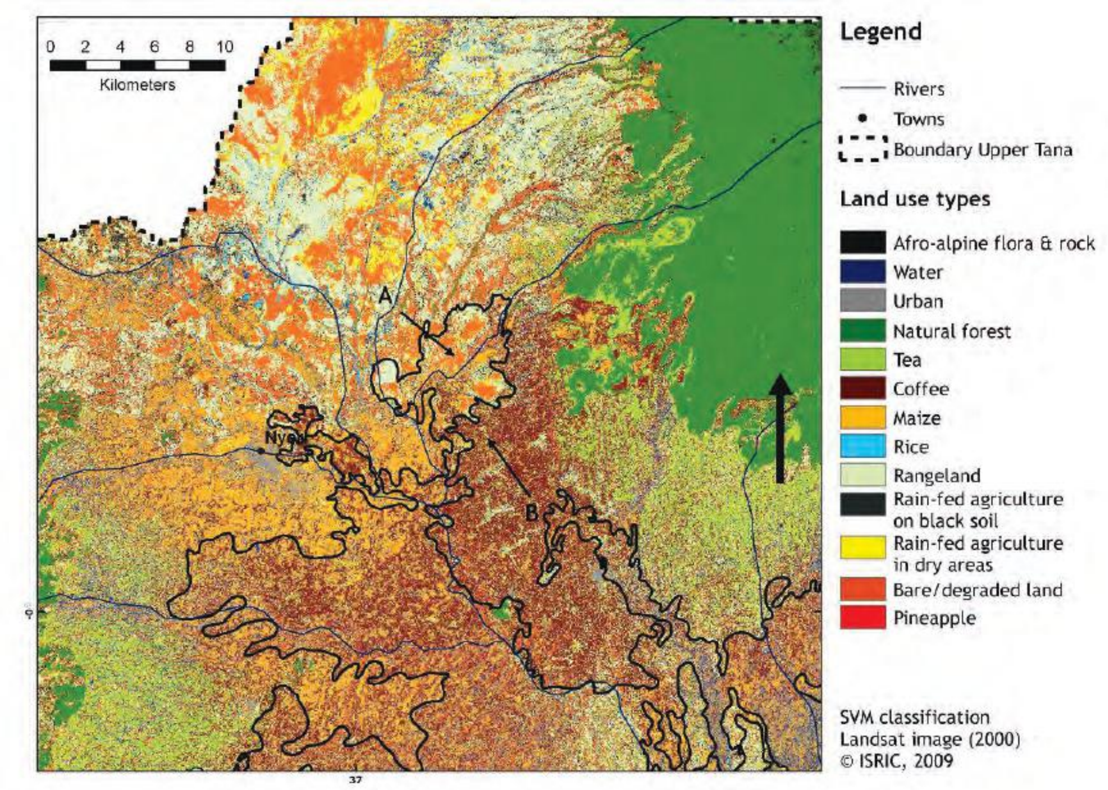


Figure 26
Zoom of the coffee area. "A" shows an area where there is no coffee present; "B" shows an area outside the Africover coffee zone, where there is considerable coffee

Figure 27
A. Zoom of a rangeland area, which was indicated as coffee by Africover
B. Zoom of an area outside the coffee zone. There are many coffee fields in this area

Figure 28
C. Coffee plantations in a relatively dry area
D. This zoom in of Google Earth shows rangeland; there are hardly any coffee fields

4.5.4 Irrigated areas

The irrigated area is overestimated on the Africover map (Figure 30). The SVM land use map show that a part of this area consist of dominantly rainfed cereals, which is confirmed by field and Google Earth observations (Figure 29A and B).
Figure 29A shows a zoom of *rainfed agriculture* on Vertisols. There are, however, also some irrigated tomato-fields in this area, but the majority consists of rainfed maize or sorghum[10]. In the "irrigated unspecified areas" as indicated by Africover, the SVM map consists of 67% *Rainfed agriculture on black soils*, 6.5% consist of *maize* and 6.1% is classified as *rangeland*.

[10] This was confirmed by P. Njuguna, MKEPP Officer (personal communication, 2009).

Figure 29
A. Zoom of an area with rainfed cereals on Vertisols
B. Zoom of rice fields at Mwea rice scheme

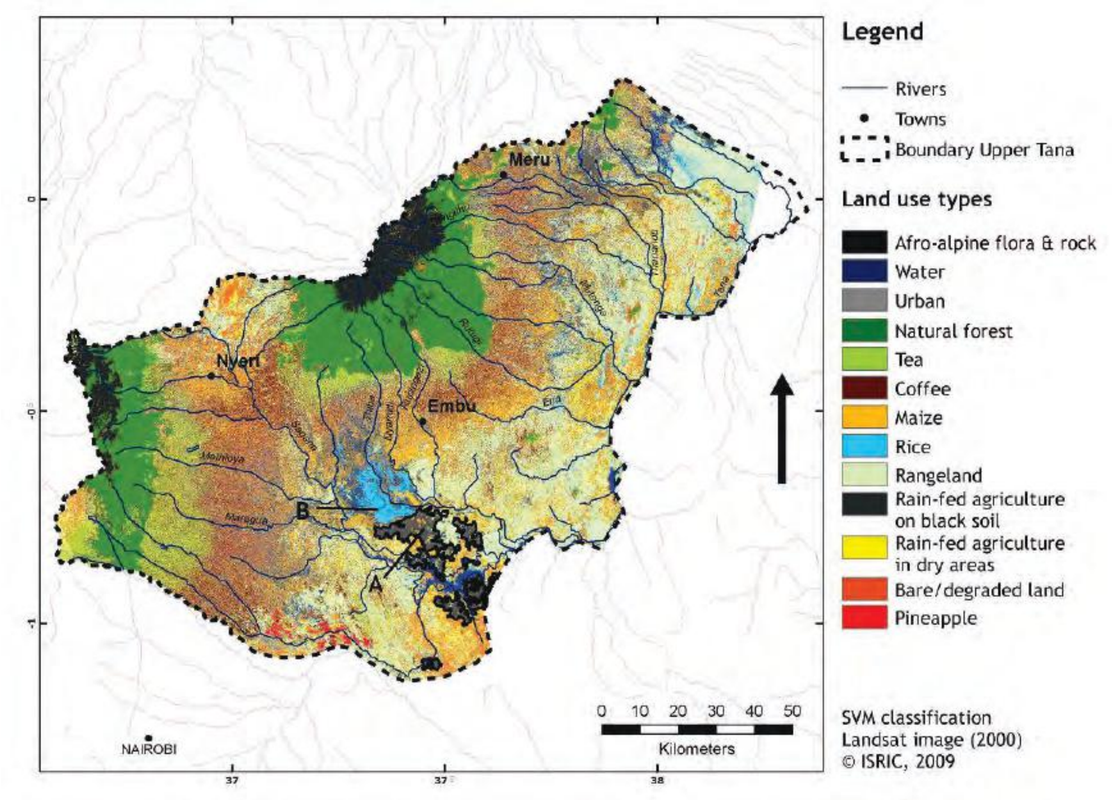


Figure 30

Irrigated unspecified as classified by Africover superimposed on the SVM land use map. In the SVM classification the irrigated unspecified areas are classified as rainfed agriculture (mainly maize/sorghum) on black soils. "A" and "B" indicate areas on which has been zoomed in on Google Earth

4.5.5 Rainfed cereal and maize

The map below (Figure 31) shows the *rainfed cereal* and *maize* classes from the Africover map. The maize patches compare well with the SVM map, although *maize* is also distributed widely over the *coffee* zone and in the lower zones on the SVM map. The *rainfed cereal* area however, includes mainly *rangeland* on the SVM map: 29%. According to the SVM, there is also a lot of *maize* and *bare/degraded land*, respectively 16% and 13%, which concurs with field and Google Earth observations.

Figure 32A and B show zooms of the *rainfed agriculture* and *maize* area on Google Earth. Both images show there is a lot of rangeland in these areas.

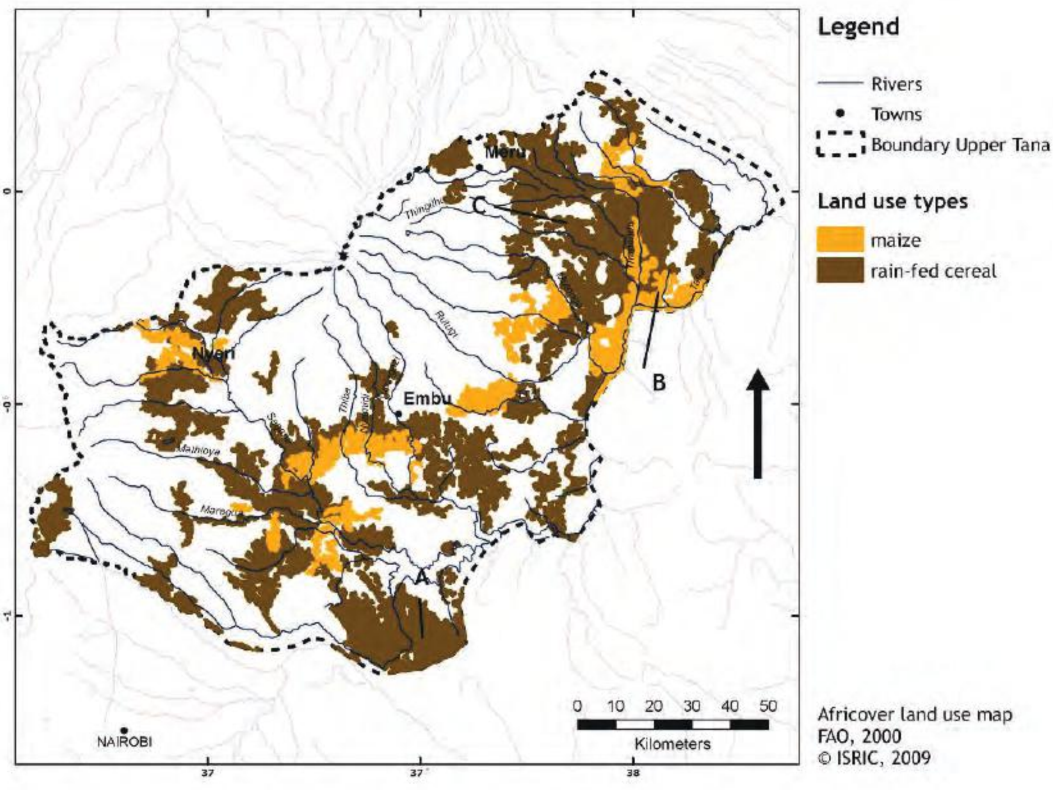


Figure 31
Maize and rainfed cereal from the Africover land use map

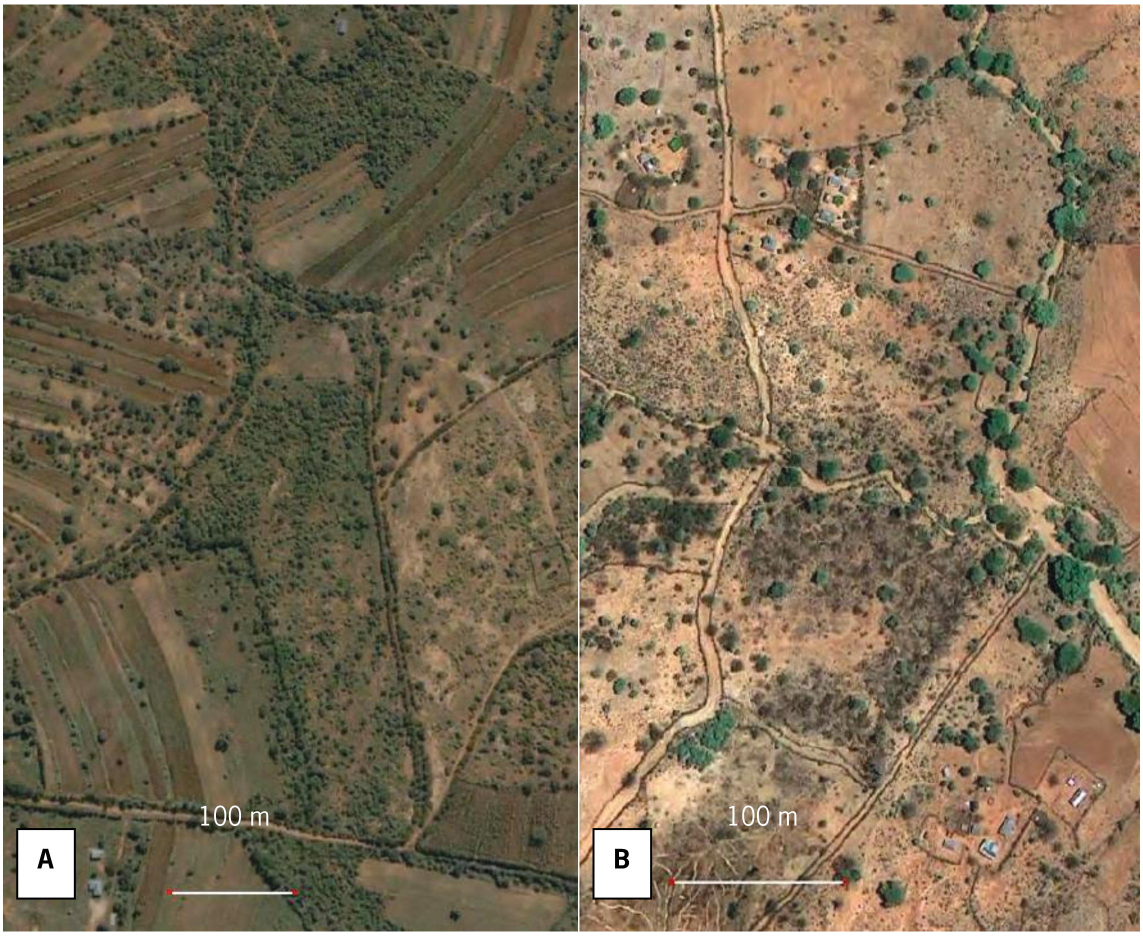


Figure 32
A. This is a zoom of the rainfed cereals area, where there is in fact also a lot of rangeland (grassland/shrubs)
B. This is zoom of the maize area in the north-east, where there are indeed maize fields, but a large part of the area consists of rangeland

4.5.6 Rangeland

Rangeland comprises almost 24% of the catchment according to the SVM. The main difference with the Africover is that Africover defined the high elevation parts of Mt Kenya and the Aberdares as *rangeland*. On the SVM map this zone was defined as *afro-alpine zone and rock*, because literature resources indicate that the vegetation is a combination of moorland (between 3500 and 3800 m) and grasses and lobelias between 3800 and 4500 m (UNEP 1997; World Bank 2007).

4.6 Comparison with Agro-Ecological Zone maps

In Figure 33 the land use map is shown with the agro-ecological zones as proposed by Jaetzold (Jaetzold and Schmidt 1983). The zones are defined in Table 3.

Table 3
Definition of Agro-ecological zones (Jaetzold and Schmidt 1983)

Agro-ecological zone	Climate	Key crop or land use
I	Humid	Tea and forestry
II	Sub-humid	Coffee, maize
III	Semi-humid	Coffee, maize, cotton
IV	Semi-humid to semi-arid	Maize, cotton
V	Semi-arid	Rangeland
VI	Arid	Rangeland
VII	Very arid	Rangeland

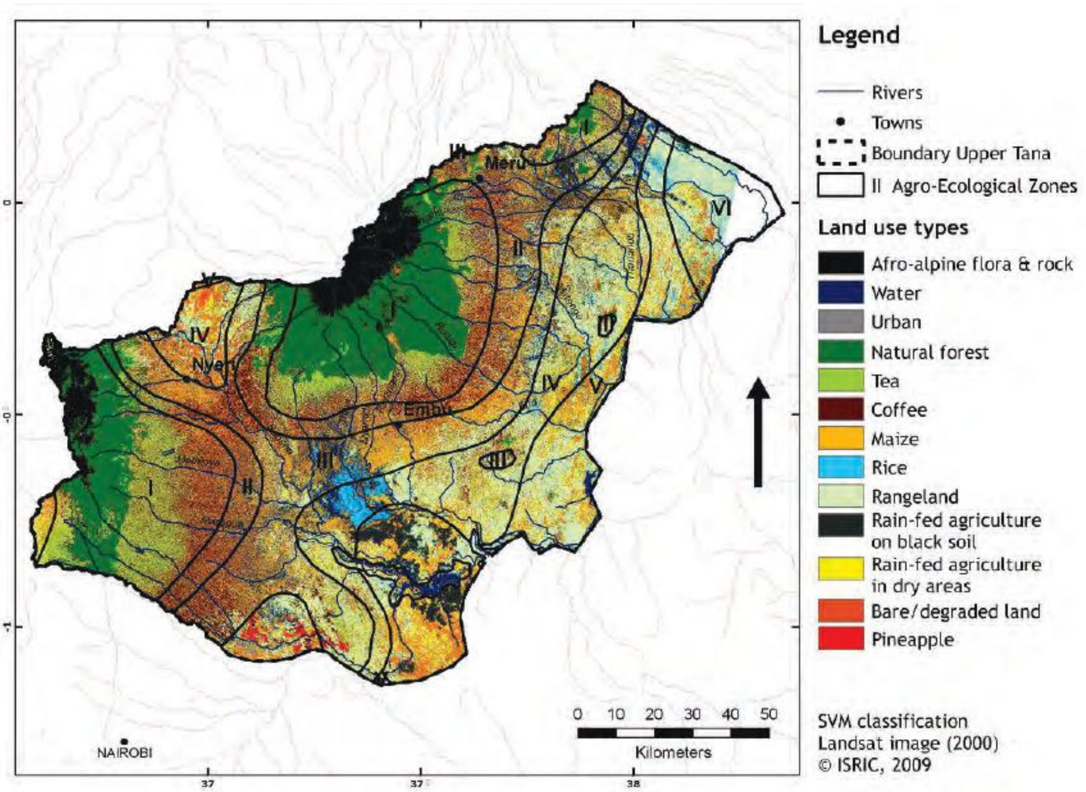


Figure 33
SVM land use map, with the AEZ zones as defined by Jaetzold and Schmidt (1983)

As can be seen, most AEZ zones do not match the current land use situation.

5 Conclusions and recommendations

The first steps of the GWC programme are defined as follows:

1. Perform hydrological and erosion modelling with the SWAT model, using meteorological, hydrological, land use and land management data[11].
2. Define focus areas and *green water* management packages.
3. Model the planned improvements in *blue water* due to changes in land management
4. Implement the most economically viable and effective *green water* management techniques via farmer groups.

Green Water Credits focuses on rainfed agriculture. Coffee and maize are the dominant crops; there is much scope to improve their land management (more information on land uses and their management in the Upper Tana is given in Annex 1). The distribution and extent of *coffee*, m*aize* and *rainfed agriculture* is significantly different in the new SVM land use map. *Coffee* and *maize* are more widely distributed and the *rainfed agriculture* class consists of mainly *rangeland* and *maize*.

The new land use map should be used to improve the modelling results. This will lead to a more accurate estimation of the current situation regarding water resources and land degradation, and also to the choice of GWC target areas.

In summary the following are the main observations and conclusions:

- The SVM land use map provides a more reliable land use map (accuracy 78%, resolution 30 m) than the Africover and the ML classification map;
- The classes as proposed by the Africover map are in reality a mix of land cover types;
- The distribution of the *tea* and *coffee* zones extend over a larger area on the SVM map;
- The Africover map overestimates the *rainfed cereal* in the low elevation drier areas; *rangeland* dominates on the SVM map
- The SVM derived map is suitable for hydrological modelling
- Uncertainties of the SVM are:
  - the distinction of bare/degraded lands and rainfed agriculture in dry areas
  - the occurrence of rice outside the Mwea scheme
- The SVM map is based on images of 2000; however land use changes have occurred between 2000 and 2009. The Green Water Credits Implementation phase will require a detailed updated land use map. Updates can be carried out using recent ASTER images, covering part of the Upper Tana.

[11] This has been done by FutureWater using the Africover land use map. In the implementation phase of GWC, the modelling will be out carried by WRMA.

Recommendations:

- A land use map should be updated every 5 to 10 years.
- It is recommended that a procedure should be followed such as that described in Methods (Chapter 3). This procedure includes:
  1. Sampling
  2. Classification of up-to-date cloud-free satellite images using a Support Vector Machine approach
  3. Validation
- Remote sensing can be used to monitor changes in land use and land degradation as a result of *green water* management.

References

Clampett WS, Nguyen VN and Tran DV 2002. Sustainable rice production for food security. The development and use of Integrated Crop Mangement for rice production. In: FAO (Ed.) 20th Session of the International Rice Commission. FAO, Bangkok.

Droogers P, Kauffman JH, Dijkshoorn JA, Immerzeel W and Huting JRM 2006. Green Water Credits: Basin identification. Green Water Credits Report 1, ISRIC - World Soil Information, Wageningen.

Facon T 2000. Water Management in Rice in Asia: Some Issues for the Future. In: FAO (Ed.) Regional Office for Asia and the Pacific, FAO.

Falkenmark M and Rockström J 2004. Balancing water for humans and nature. Earthscan, London.

FAO 1988. FAO/Unesco Soil Map of the World, Revised Legend, with corrections. FAO, Rome.

FAO 2000. East Africa Module Land Cover mapping based on satellite remote sensing. Food and Agriculture Organisation of the United Nations, Rome.

Foody GM 2002. Status of land cover classification accuracy assessment. Remote Sensing of Environment 80: 185-201.

Hoekstra AY 2003. Virtual Water Trade. Proceedings of the International Expert Meeting on Virtual Water Trade, pp 244.

Hoff H and Noel S 2007. Quantifying water usage and demand in the Tana River basin: an Analysis using the Water and Evaluation and Planning Tool (WEAP). Green Water Credits Report 4, ISRIC - World Soil Information, Wageningen.

IFAD/UNEP/GEF 2004. Mount Kenya East Pilot Project for Natural Resource Management, Project Brief Report.

Jaetzold R and Schmidt H 1983. Farm management handbook of Kenya. Ministry of Agriculture, Nairobi.

Kauffman JH, Droogers P, Odada E, Macharia P, Gicheru P and Dijkshoorn JA 2007. *Green* and *blue* water services and assessment of improved soil and water management scenarios using an integrated modelling framework. Green Water Credits Report 3, ISRIC - World Soil Information, Wageningen.

Lillesand and Kiefer 1987. Concepts and foundations of remote sensing. In: Remote sensing and image interpretation, J Wiley and Sons.

Mathur A, Foody GM 2008. Crop classification by support vector machine with intelligently selected training data for an operational application. *International Journal of remote Sensing* 29: 2227-2240.

Mogako H Gichere S, Davis R and Hirji R 2006. Climate variability and water resources degradation in Kenya: *Improving water resources development and management*. World Bank, Washington DC.

Notter B, MacMillan L, Viviroli D, Weingartner R and Liniger HP 2007. Impacts of environmental change on water resources in the Mt. Kenya region. *Journal of Hydrology* 343: 266–278.

Oommen T, Misra D, Twarakavi NKC, Prakash A, Sahoo B and Bandopadhyay S 2008. An objective analysis of support vector machine based classification for remote sensing. *Mathematical Geosciences* 40: 409-424.

Pratt DJ, Le Gall F and De Haan C 1997. Investing in Pastoralism. Sustainable Natural Resource Use in Arid Africa and the Middle East. World Bank, Washington.

UNEP 1997. World Heritage Sites. Protected Areas and World Heritage. Mount Kenya National Park/Natural Forest Kenya. In: UNEP (Ed.). UNEP pp 7.

UNEP/SEI 2009. Rainwater harvesting: a lifeline for human well-being. A report prepared for UNEP by Stockholm Environment Institute. In: Barron J (Ed.) SEI/UNEP pp 80.

Ward RC, Robinson M 2000. Principles of hydrology. McGrawhill (p.450).

WOCAT 2007. Where the land is greener - case studies and analysis of soil and water conservation initiatives worldwide. Editors Liniger HP and Critchley WRS. CTA, FAO, UNEP and Centre for Development and Environment, Bern.
World Bank 2007. Project appraisal document on a proposed credit in the amount of sdr 46.0 million (US$68.5 million equivalent) to the government of Kenya for a natural resource management project. World Bank pp 176.
World Resources Institute 2007. Nature's benefits in Kenya: an atlas of ecosystems and human well-being. World Resources Institute, Washington DC and Nairobi.

Annex 1

1. Land and water degradation in the Upper Tana

1.1 Introduction

Land and water degradation are core problems in Kenya. The Upper Tana catchment provides water for about 50% of the population of Kenya. It is therefore of crucial importance that water and soil resources are maintained or improved. This Annex gives an overview of the signs of land degradation as observed in the field in the period 13 to 27 May 2009.

Soil erosion in the Upper Tana is in most cases the result of a lack of soil cover by crop or mulch. Increasing the covered area will result in a higher infiltration rate, lower evaporation, lower runoff values and consequently, less soil erosion.

In order to decrease soil erosion and to increase yields, the general objective is therefore to increase soil cover. In this report, recommendations will be given per land use on how to reach this objective.

1.2 Soil erosion

Soil erosion is defined as the detachment and movement of the topsoil by wind and water. Soil erosion is a natural process, but can be accelerated by human influence.

With soil erosion, the quality and quantity of the soil decreases; this has a negative effect on agricultural yields. Soils are of vital importance to the growth of crops, because they contain important minerals and micro-organisms. Another important function of the soil is its filtering effect on water. Without soil filtration, agricultural pollutants will move faster into the groundwater, or will flow downstream. The lower infiltration capacity of eroded soils causes an increase in runoff, resulting in the occurrence of more and severe flooding events (Ward and Robinson 2000). Sediment deposited on roads and the silting up of reservoirs are yet other consequences of soil erosion.

1.3 Land degradation in the Upper Tana

During the fieldwork in May 2009, observations on soil erosion were carried out to estimate the degree of erosion. The main question was: where and in what form does land degradation occur in the catchment?

Figure 34 shows the slope and the sample sites in the Upper Tana catchment. At each observation point, the erosion severity was estimated. Signs of erosion are: splash erosion, rills, gullies, sediment deposition and landslides. A steep slope, low vegetation cover, erosive soil, high intensity rainfall and improper soil, crop and water management are factors leading to, or increasing, erosion.

It should be noted that during the long rains in 2009 (March-May) relatively little rain fell. The average rainfall in the period March-May in Embu is 357 mm, rain fell. The average rainfall in the period March-May in Embu is 357 mm, calculated for the years 1996-2009. Over this period in 2009 there was only 247 mm of precipitation, mostly consisting of low intensity rain (Mrs A.N. Muchira: pers. comm.). During years with more and higher intensity rainfall, erosion increases. Gullies are often permanent features; rills can be recovered.

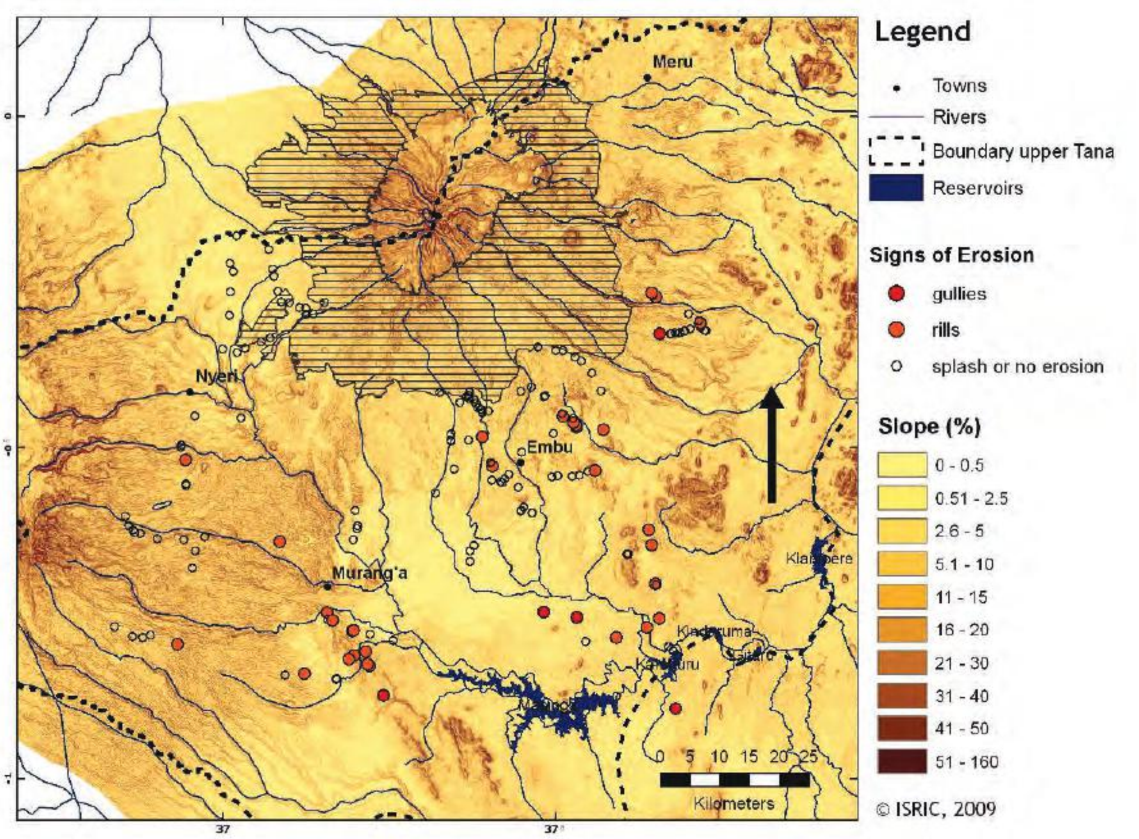


Figure 34
Locations where rills and gullies where observed

1.3.1 Signs of erosion

Rills were observed in 9% of the total observations; gullies in only 1%. Erosion is widespread in the Upper Tana catchment, but some regions showed more severe erosion than others.

Table 4 gives an overview of the percentage of gullies and rills per land use type. It should be kept in mind that the total number of observations is limited and therefore the percentages are only a first indication of the degree of erosion per land use type.

Table 4
Overview of field observations per land use type

Land use	Number of observations	Percentage gullies/rills per land use	Average vegetation cover (% (+σ))
Coffee	56	8.9	53 (± 24)
Tea	32	3.1	93 (± 15)
Maize (total)	135	11.9	60 (±27)
Maize	72	11.4	54 (±29)
Maize & Beans	63	12.3	68 (± 24)
Mangos	9	33.3	51 (±29)
Bananas	11	0.1	54 (± 14)
Rangeland	66	12.1	70 (±23)
Total	444		

Although these numbers indicate that erosion is widespread in the Upper Tana, there are too few observations to make any statistically valid statements. The occurrence of erosion is probably mostly dependant on vegetation cover: rills or gullies occur at 29% of the observation sites that have a vegetation cover equal to or lower than 50%. At sites where the vegetation cover is higher than 50%, rills or gullies occur only in 6.8% of the cases. This indicates the importance of maintaining a high vegetation cover throughout the year. This can be done by conventional biomass or by synthetic mulching. Also, the use of manure and/or fertilizer significantly increases the plant density, and therefore the vegetation cover.

The erosion observations were also plotted on the soil map of the Upper Tana, to be able to view possible links between erosion and soil type in this area (Figure 35). Worth mentioning is the occurrence of erosion in the area where regosols are the dominant soil type (indicated by black circle). In this area all the sites visited contained rills or gullies.

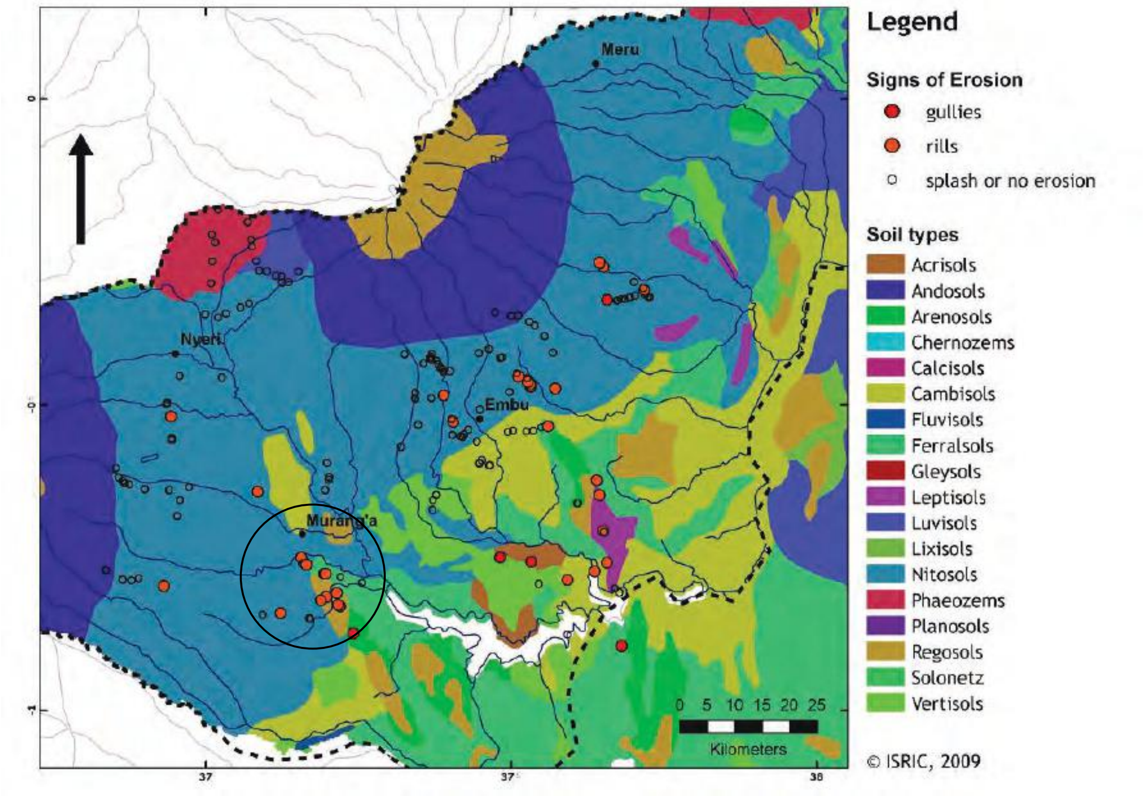


Figure 35
Soil type map of the Upper Tana with erosion features

Table 5
Erosion features per soil type

Soil type	Total Number of observations	Amount of gullies/rills	Percentage of gullies/rills
Andisol	5	0	0
Acrisol	1	0	0
Arenosol	3	1	33.3
Cambisol	38	2	5.3
Ferralsol	24	5	20.8
Leptosol	6	2	33.3
Luvisol	8	0	0
Nitisol	247	17	6.9
Phaeozems	8	0	0
Regosols	5	5	100
Vertisols	15	2	13.3
Total	360	34	

1.4 Land use & land and water management

1.4.1 Tea

In tea fields hardly any erosion occurs, because the vegetative cover of tea is dense (Figure 36). The rivers in this zone are nearly free of sediment. However, when the soil is left uncovered, erosion will increase rapidly due to the steep slopes (Figure 37).

Figure 36
The vegetative cover of tea is nearly 100%; therefore the soil is well protected

Figure 37
In the tea zone, erosion easily occurs when the soil is left uncovered

1.4.2 Coffee

Considerable erosion occurs in coffee fields. In 9% of the coffee fields signs of erosion are found. Coffee plantations are often poorly managed, because of the decline in coffee prices (Figure 38). This can be noticed from the poorly maintained *fanya juu* terraces and low amount of mulch on the fields. The intercropping of beans and maize in the coffee fields and the presence of weeds and grass however limits the soil somewhat from eroding. This is, however, a short-term solution. In the long-term, farmers will decide whether to continue with growing coffee or not. If they continue to grow coffee, it will be important to develop stable and vegetated terraces in the fields and to mulch between the coffee plants. Intercropping in coffee is often not permitted, because coffee quality will decrease.

If farmers decide to switch from coffee to another crop, it is important to choose a suitable crop for the area and to incorporate, for example, agroforestry techniques. The Green Water Credits programme should anticipate changes in the *coffee* zones and be able to provide sustainable solutions to coffee-farmers that decide to change their crop and management.

Figure 38
Poorly maintained terraces in a coffee plantation

1.4.3 Maize (and beans)

Gullies or rills occurred in 12% of the maize fields visited (Figure 39). This often occurs in fields where there is mono-cropping of maize and when the maize is widely spaced. When no fertilizer or manure is applied, maize is often widely spaced because of a lack of nutrients. In many fields, maize is intercropped with beans; together they provide a good vegetation cover. The soil remains covered which prevents erosion and the farmers reduce the risk of a failed harvest: if the maize fails, the beans may still survive. The combination of maize and beans is only suitable for manual cultivation and not for machines. Before the planting season, the maize fields lack vegetation cover and the soil is therefore subject to erosion.

To meet the objective of increasing soil cover (a combination of) the following actions can be taken:
- Application of fertilizer or manure
- *Green water* management
  - Mulching
  - Intercropping
  - Agroforestry
  - Vegetative strips

Another point Green Water Credits could consider in the drier areas, is the recommendation of replacement with more drought resistant crops like sorghum.

Figure 39
Rills in a maize field

1.4.4 Rice

Rice is cultivated in the Mwea rice scheme approximately 20 km southwest of Embu and on a small scale along rivers and streams west of Embu. Evaporation is very high on rice fields. According to Hoekstra (2003), rice has a virtual water content of 2656 m^3/tonne, compared to 450 m^3/tonne for maize[12]. Rice thus is a highly water-intensive product. Because the cropping of rice demands a lot of water, this has a negative effect on the quantity of water downstream (Hoekstra 2003).

Improvement of water management in rice production can be achieved using techniques to reduce evaporation or evapotranspiration, losses through seepage and percolation, and surface runoff. Practices and strategies to improve rice water productivity include development of improved rice varieties, changing the planting/sowing schedule, making more effective use of rainfall and developing better water distribution strategies (Clampett *et al.* 2002; Facon 2000). Especially the choice of an optimal planting and sowing period could, in particular, be a relatively easy to implement strategy to save water.

Another option is to replace rice with rainfed maize, as suggested in GWC report 3 (Kauffman *et al.* 2007).

[12] Virtual water is defined as the volume of water required to produce a commodity or service. Water use efficiency at global scale can be achieved in a water scarce region by adopting a policy to grow and export products with relatively low virtual water content and import products having higher virtual water content (Hoekstra 2003).

Figure 40
Rice fields at Mwea rice scheme

1.4.5 Eucalyptus and other firewood trees

The planting of eucalyptus trees is quite common in the Upper Tana catchment and should be changed for other types of trees, since eucalyptus trees use a lot of water. The most suitable alternative is *Grevillea robusta* (WOCAT 2007)[13].

1.4.6 Rangeland

In rangeland, erosion often develops as a result of overgrazing. Figure 41 illustrates a gully complex in grassland near Murang'a. On the opposite side of the road, where soil type, slope gradient and land use are the same, but only land management is different (no overgrazing), hardly any signs of erosion were observed.

This illustrates that erosion can be prevented when the appropriate land management techniques are applied. Eroded rangelands are common near the large reservoirs of the catchment. A lot of sediment ends up in the reservoirs, causing the productivity of the hydrological power station to decline. Green Water Credits phase I focused on upstream rainfed farmers. The degradation of rangelands is an important problem (Pratt *et al.* 1997) that will be included in phase II analysis for the management of the Upper Tana. For suggestions for sustainable management is referred to WOCAT (Pratt *et al.* 1997; WOCAT 2007).

[13] For other suitable agroforestry options refer to WOCAT 2007 "Where the land is Greener" and the WOCAT database: www.wocat.net

Figure 41
Gullies to the south of Murang'a

1.4.7 Fruit trees

In mango tree plantations, rills and gullies occur often, because of a lack of vegetation cover between the mango trees. In banana plantations, if adequately mulched, there is hardly any erosion. Mango trees are suitable for dry, hot areas. Mulching between the trees will decrease evaporation, erosion and surface runoff.

1.4.8 Urban

Road erosion is a common problem in the Upper Tana (Figure 42). Other problems in urban areas include water pollution, poor sanitation and forest degradation for the use of fuel wood. Although these issues are related to land and water management, the solutions are the responsibility of public administration agencies. Some recommendations for improvement could be to use rainwater roof harvesting systems, which would reduce surface runoff in villages and towns and therefore decrease road erosion and improve fresh water quantities for household water use (Centre for Science and Environment 2009[14]; UNEP/SEI 2009).

[14] Centre for Science and Environment 2009: Rainwaterharvesting.org

Figure 42
Road erosion occurs on many roads in the Upper Tana catchment

1.4.9 River bank and wetland management

Another problem is wetland or riverbank cropping. Although forbidden by law, agricultural fields can often be found on sides of the river. The natural ecosystem is hereby disturbed; soil flushes away from the land into the river and evaporation is increased (Figure 43).

Figure 43
Farming on the riverbank

2. Conclusions: possible solutions to land and water related problems in the Upper Tana

The field observations made in May 2009 confirm that man induced accelerated erosion is a serious issue in the Upper Tana catchment. The main contributing factors to accelerated erosion are:

- Inappropriate soil and water conservation in farmland, in particular in maize and coffee fields;
- Soil type;
- Inappropriate rangeland management; and
- Road erosion.

The following actions are proposed to improve the use of land and water in the Upper Tana and move towards sustainable land use:

1. Application of appropriate *green water* management techniques on agricultural land;
2. Riverbank farming and wetland cropping should be put to a halt by giving farmers other options;
3. The main land use types Green Water Credits should focus on are maize (and beans) and coffee;
4. Enhance the use of fertilizer or manure; and
5. Irrigation should be used effectively by for example drip-irrigation

Annex 2 Pair Separation (least to most), ML ROIs

- Coffee 591 points and Maize 1260 points - 1.54579436
- Urban 2889 points and Maize 1260 points - 1.78828290
- Maize 1260 points and Rangeland 7251 points - 1.80152150
- Rangeland 7251 points and Bare land/degraded land 1365 points - 1.81590637
- Rangeland 7251 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 1.86642367
- Bare land/degraded land 1365 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 1.86680009
- Urban 2889 points and Rangeland 7251 points - 1.87137657
- Coffee 591 points and Tea 700 points - 1.87364291
- Coffee 591 points and Natural Forest 3856 points - 1.88031517
- Maize 1260 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 1.88718130
- Tea 700 points and Natural Forest 3856 points - 1.94957050
- Maize 1260 points and Bare land/degraded land 1365 points - 1.95190155
- Urban 2889 points and Coffee 591 points - 1.95370203
- Coffee 591 points and Rangeland 7251 points - 1.95476560
- Rangeland 7251 points and Mango trees 227 points - 1.95561881
- Urban 2889 points and Bare land/degraded land 1365 points - 1.96070334
- Rice 2731 points and Water 1115 points - 1.96337093
- Natural Forest 3856 points and Coniferous trees 1178 points - 1.96817620
- Natural Forest 3856 points and Rice 2731 points - 1.97424687
- Rangeland 7251 points and Natural Forest 3856 points - 1.97506193
- Rangeland 7251 points and Rice 2731 points - 1.97592320
- Urban 2889 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 1.97609383
- Maize 1260 points and Rainfed agriculture on black soils - mostly maize 1390 points - 1.97630207
- Rangeland 7251 points and Rainfed agriculture on black soils - mostly maize 1390 points - 1.97933796
- Maize 1260 points and Rice 2731 points - 1.98023047
- Coffee 591 points and Rice 2731 points - 1.98254014
- Maize 1260 points and Natural Forest 3856 points - 1.98385683
- Urban 2889 points and Rainfed agriculture on black soils - mostly maize 1390 points - 1.98532323
- Mango trees 227 points and Bare land/degraded land 1365 points - 1.98629578
- Coffee 591 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 1.98749295
- Rainfed agriculture on black soils - mostly maize 1390 points and Bare land/degraded land 1365 points - 1.98775091
- Maize 1260 points and Mango trees 227 points - 1.98846554
- Mango trees 227 points and Rice 2731 points - 1.98906748
- Coffee 591 points and Bare land/degraded land 1365 points - 1.98985852
- 3856 points and Water 1115 points - 1.99163319
- Urban 2889 points and Rice 2731 points - 1.99279970
- Tea 700 points and Rice 2731 points - 1.99302101
- Rice 2731 points and Bare land/degraded land 1365 points - 1.99413291
- Rainfed agriculture on black soils - mostly maize 1390 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 1.99450236

– Maize 1260 points and Water 1115 points - 1.99491613
– Urban 2889 points and Mango trees 227 points - 1.99506176
– Mango trees 227 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 1.99533917
– Tea 700 points and Maize 1260 points - 1.99599632
– Natural Forest 3856 points and Moorland 1051 points - 1.99604556
– Urban 2889 points and Natural Forest 3856 points - 1.99636447
– Coffee 591 points and Water 1115 points - 1.99641462
– Natural Forest 3856 points and Bare land/degraded land 1365 points - 1.99755822
– Rangeland 7251 points and Water 1115 points - 1.99785226
– Tea 700 points and Rangeland 7251 points - 1.99790363
– Water 1115 points and Bare land/degraded land 1365 points - 1.99810366
– Coffee 591 points and Mango trees 227 points - 1.99833145
– Urban 2889 points and Water 1115 points - 1.99876714
– Natural Forest 3856 points and Rainfed agriculture on black soils - mostly maize 1390 points - 1.99877772
– Rice 2731 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 1.99884850
– Coffee 591 points and Rainfed agriculture on black soils - mostly maize 1390 points - 1.99914738
– Rice 2731 points and Rainfed agriculture on black soils - mostly maize 1390 points - 1.99927451
– Maize 1260 points and Potatoes 59 points - 1.99932099
– Mango trees 227 points and Natural Forest 3856 points - 1.99938088
– Urban 2889 points and Tea 700 points - 1.99940145
– Rangeland 7251 points and Potatoes 59 points - 1.99955422
– Urban 2889 points and Potatoes 59 points - 1.99961317
– Tea 700 points and Bare land/degraded land 1365 points - 1.99969352
– Rainfed agriculture on black soils - mostly maize 1390 points and Water 1115 points - 1.99970369
– Rangeland 7251 points and Coniferous trees 1178 points - 1.99981316
– Mango trees 227 points and Rainfed agriculture on black soils - mostly maize 1390 points - 1.99989842
– Tea 700 points and Water 1115 points - 1.99990114
– Mango trees 227 points and Water 1115 points - 1.99992322
– Water 1115 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 1.99993516
– Natural Forest 3856 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 1.99994256
– Coffee 591 points and Potatoes 59 points - 1.99995575
– Potatoes 59 points and Bare land/degraded land 1365 points - 1.99996143
– Tea 700 points and Moorland 1051 points - 1.99997784
– Coffee 591 points and Moorland 1051 points - 1.99997899
– Coniferous trees 1178 points and Moorland 1051 points - 1.99998353
– Coffee 591 points and Coniferous trees 1178 points - 1.99998920
– Coniferous trees 1178 points and Water 1115 points - 1.99999025
– Tea 700 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 1.99999026
– Rangeland 7251 points and Moorland 1051 points - 1.99999107
– Potatoes 59 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 1.99999417
– Tea 700 points and Mango trees 227 points - 1.99999423
– Coniferous trees 1178 points and Bare land/degraded land 1365 points - 1.99999477
– Potatoes 59 points and Natural Forest 3856 points - 1.99999899
– Bare land/degraded land 1365 points and Moorland 1051 points - 1.99999907
– Tea 700 points and Potatoes 59 points - 1.99999934
– Rice 2731 points and Coniferous trees 1178 points - 1.99999941
– Urban 2889 points and Coniferous trees 1178 points - 1.99999952
– Maize 1260 points and Coniferous trees 1178 points - 1.99999988
– Potatoes 59 points and Rainfed agriculture on black soils - mostly maize 1390 points - 1.99999992
– Tea 700 points and Rainfed agriculture on black soils - mostly maize 1390 points - 1.99999994

- Tea 700 points and Coniferous trees 1178 points - 1.99999997
- Water 1115 points and Moorland 1051 points - 1.99999998
- Potatoes 59 points and Rice 2731 points - 1.99999999
- Mango trees 227 points and Potatoes 59 points - 1.99999999
- Potatoes 59 points and Water 1115 points - 2.0
- Maize 1260 points and Moorland 1051 points - 2.0
- Urban 2889 points and Moorland 1051 points - 2.0
- Cloud 704 points and Bare land/degraded land 1365 points - 2.0
- Cloud 704 points and Water 1115 points - 2.0
- Coniferous trees 1178 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 2.0
- Potatoes 59 points and Coniferous trees 1178 points - 2.0
- Mango trees 227 points and Coniferous trees 1178 points - 2.0
- Cloud 704 points and Rainfed agriculture on black soils - mostly maize 1390 points - 2.0
- Cloud 704 points and Coniferous trees 1178 points - 2.0
- Cloud 704 points and Coffee 591 points - 2.0
- Rainfed agriculture on black soils - mostly maize 1390 points and Moorland 1051 points - 2.0
- Cloud 704 points and Mango trees 227 points - 2.0
- Cloud 704 points and Moorland 1051 points - 2.0
- Potatoes 59 points and Moorland 1051 points - 2.0
- Mango trees 227 points and Moorland 1051 points - 2.0
- Cloud 704 points and Rangeland 7251 points - 2.0
- Cloud 704 points and Natural Forest 3856 points - 2.0
- Cloud 704 points and Maize 1260 points - 2.0
- Rice 2731 points and Moorland 1051 points - 2.0
- Cloud 704 points and Potatoes 59 points - 2.0
- Cloud 704 points and Rice 2731 points - 2.0
- Coniferous trees 1178 points and Rainfed agriculture on black soils - mostly maize 1390 points - 2.0
- Cloud 704 points and Urban 2889 points - 2.0
- Moorland 1051 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 2.0
- Cloud 704 points and Rainfed agriculture in dry areas - bare land - red soil 741 points - 2.0
- Cloud 704 points and Tea 700 points - 2.0

GWC Reports Kenya

GWC K1	*Basin identification*	Droogers P and others 2006
GWC K2	*Lessons learned from payments for environmental services*	Grieg Gran M and others 2006
GWC K3	*Green and blue water resources and assessment of improved soil and water management scenarios using an integrated modelling framework.*	Kauffman JH and others 2007
GWC K4	*Quantifying water usage and demand in the Tana River basin: an analysis using the Water and Evaluation and Planning Tool (WEAP)*	Hoff H and Noel S 2007
GWC K5	*Farmers' adoption of soil and water conservation: the potential role of payments for watershed services*	Porras IT and others 2007
GWC K6	*Political, institutional and financial framework for Green Water Credits in Kenya*	Meijerink GW and others 2007
GWC K7	*The spark has jumped the gap. Green Water Credits proof of concept*	Dent DDL and Kauffman JH 2007
GWC K8	*Baseline Review of the Upper Tana, Kenya*	Geertsma R, Wilschut LI and Kauffman JH 2009
GWC K9	*Land Use Map of the Upper Tana, Kenya: Based on Remote Sensing*	Wilschut LI 2010
GWC K10	*Impacts of Land Management Options in the Upper Tana, Kenya: Using the Soil and Water Assessment Tool - SWAT*	Hunink JE, Immerzeel WW, Droogers P, Kauffman JH and van Lynden GWJ 2011
GWC K11	*Soil and Terrain Database for the Upper Tana, Kenya*	Dijkshoorn JA, Macharia PN, Huting JRM, Maingi PM and Njoroge CRK 2010
GWC K12	*Inventory and Analysis of Existing Soil and Water Conservation Practices in the Upper Tana, Kenya*	Muriuki JP and Macharia PN 2011
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GWC K15	*Cost-Benefit Analysis of Land Management Options in the Upper Tana, Kenya*	Onduru DD and Muchena FN 2011
GWC K16	*Institutes for Implementation of Green Water Credits in the Upper Tana, Kenya*	Muchena FN and Onduru DD 2011
GWC K17	*Analysis of Financial Mechanisms for Green Water Credits in the Upper Tana, Kenya*	Muchena FN, Onduru DD and Kauffman JH 2011

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