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Land cover change and its influence on soil erosion in the Mara region, Tanzania

Using satellite remote sensing and the Revised Universal Soil Loss Equation (RUSLE) to map land degradation between 1986 and 2013

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Cover photo: View from a hilltop in Rorya, Mara, Tanzania (Århem 2014)

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Abstract

Sub-Saharan Africa suffers from land degradation, depletion of natural resources and rural poverty. In the Lake Victoria Basin, where large parts of the population are small scale farmers, people are facing such issues coupled with altered climatic conditions. The focus area of this study is the Mara region in northern Tanzania, situated on the eastern lakeshore. Mara has experienced a doubling of its population during the past four decades and is subsequently suffering from land scarcity, deforestation, erosion, lake eutrophication, soil fertility decline etc. The main objective is to assess land cover change in Mara between 1986 and 2013, and to estimate soil erosion as an effect of land cover change by using the Revised Universal Soil Loss Equation (RUSLE). Supervised classification was done using the maximum likelihood method on Landsat TM and ETM+ images from 1986, 1999 and 2013 to generate thematic land cover maps. To isolate the effect of land cover change on erosion, all other factors affecting soil loss were kept constant in the modelling process. Fieldwork was carried out in order to gather ground truth data and to obtain an overview of the land cover dynamics as well as the living situation of the rural population. The results show an increase in the extent of agriculture, mainly at the expense of woodlands, shrublands and grasslands. The RUSLE calculations suggest that, if rainfall is fixed at the 1950-2000 mean, the annual average soil loss increases over the study period. The erosion changes can be attributed to the ongoing cropland expansion and the woodland degradation. A continuously growing population accompanied by higher demand for agricultural land and fuel wood will likely exacerbate deforestation and erosion in the future, especially as the climate is getting drier. Unless precautionary measures are taken the study area is likely to experience extensive future land degradation and poverty increase.

Keywords: Geography · Physical geography · Soil erosion · Land degradation · Land cover change · Revised Universal Soil Loss Equation (RUSLE) · Remote Sensing · Landsat

Sammanfattning

En stor del av Östafrikas landsbygdsbefolkning är självförsörjande jordbrukare som på grund av begränsade markytor och förändrade klimatförhållanden riskerar misslyckade skördar och ökad fattigdom. I takt med att befolkningen växer blir miljöproblem som avskogning, erosion och urlakade jordar, samt övergödning av vattendrag och sjöar alltmer påtagliga.

Syftet med den här studien är att kartlägga markanvändningsförändringar i en del av Victoriasjöns avrinningsområde mellan år 1986 och 2013, och att undersöka om förändringarna har någon påverkan på jorderosion. Studieområdet ligger i norra Tanzania på gränsen till Kenya, i en region som heter Mara. Satellitbilder tagna av Landsat TM och ETM+ från åren 1986, 1999 och 2013 användes för att kartlägga markanvändningen. Erosionen beräknades med RUSLE (”Revised Universal Soil Loss Equation”) som är en ekvation i vilken jordförlust som orsakas av regn och ytavrinning uppskattas. I RUSLE multipliceras parametrar som representerar hur nederbörd, jordart, sluttning och markanvändning påverkar erosionen. För att få fram de förändringar i erosion som orsakats av markanvändningsförändringarna har variationer i nederbörd inte inkluderats i modellen, istället användes medelnederbörden mellan åren 1950-2000. Det innebär att slutresultatet inte reflekterar de årliga regnvariationerna.

Fältarbete i studieområdet gjordes mellan december 2013 och mars 2014. Det innefattade intervjuer med lokalbefolkningen och insamling av lägesbunden kontrolldata och utfördes för att få en grundläggande uppfattning om förändringar i landskapet och markanvändning samt för att få inblick i den lokala befolkningens levnadssituation.

Analysresultaten påvisade en ökning av arealen jordbruksmark som framför allt har skett på bekostnad av skogsområden, buskmarker och gräsmarker. Förutsatt att nederbörden motsvarar medelsnittet mellan åren 1950-2000, antyder modellresultatet att jorderosionen ökade från 1986 till 2013. Om trenden med växande befolkning följd av ett ökat behov av jordbruksmark och bränsle fortsätter riskerar studieområdet att i framtiden drabbas av omfattande problem vad gäller erosion och fattigdom.

Nyckelord: Geografi · Naturgeografi · Jorderosion · Markanvändningsförändring · Revised Universal Soil Loss Equation (RUSLE) · Fjärranalys · Landsat

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List of abbreviations

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
DEM	Digital Elevation Model
DN	Digital Number
DOS	Dark Object Subtraction
ENSO	El Niño-Southern Oscillation
EPSG	European Petroleum Survey Group
ETM+	Enhanced Thematic Mapper Plus
GCP	Ground Control Point
GDEM	Global Digital Elevation Model
GDP	Gross Domestic Product
GIMMS	Global Inventory Modeling and Mapping Studies
GIS	Geographical Information Systems
GPS	Global Positioning System
HH	Household
ITCZ	Intertropical Convergence Zone
LPGS	Level 1 Product Generation System
m.a.s.l.	Meters above sea level
MMF	Morgan, Morgan and Finney model
MODIS	Moderate Resolution Imaging Spectroradiometer
MSS	Multispectral Scanner
NDVI	Normalized Difference Vegetatiuon Index
NGO	Non-Governmental Organisation
NIR	Near infrared
NOAA	National Oceanic and Atmospheric Administration
OM	Organic matter
PAN	Panchromatic
RUSLE	Revised Universal Soil Loss Equation
SI	International System of Units (*Systeme International d' Unites*)
SLC	Scan Line Corrector
SLEMSA	Soil Loss Estimator for Southern Africa
SWIR	Short wave infrared
TFM	Triangular Form-Based Multiple Flow
TIR	Thermal infrared
TM	Thematic Mapper
TOA	Top of Atmosphere
TZS	Tanzanian Shilling
USD	United States Dollars
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
WEPP	Water Erosion Prediction Project
WGS 84	World Geodetic System 1984

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1. Introduction

In the Lake Victoria basin the rural people are faced with environmental degradation. Population increase has led to deforestation and intensified agriculture which in turn have resulted in erosion and severe eutrophication of Lake Victoria along with declines in soil fertility and fuel supplies in the lake's vicinity (IRA 2001, Sterner & Segnestam 2001, Verschuren et al. 2002). The ongoing climate change is further aggravating the circumstances with less rainfall and higher temperatures in many areas (Mwiturubani & van Wyk 2010).

A large part of the rural population in the Lake Victoria basin is poor, has a low adaptive capacity and depends on subsistence farming which makes them vulnerable to altered environmental conditions (UNEP 2005, Claessens et al. 2008). Many small scale farmers in the region face food insecurity as a result of ongoing land degradation (Lufafa et al. 2003, Awange & Ong'ang'a 2006). If the land degradation is to be mitigated it is crucial that the current state and potential change of land cover and erosion rates are well known. This study focuses on addressing the land cover change since the 1980s in a rural area in the Mara region of northern Tanzania, and its relations to changes in erosion. The land cover change is determined using remote sensing and geographical information systems (GIS). Additionally the changes in erosion resulting from the land cover changes are estimated by applying a soil loss equation. In order to investigate the particular effect that land cover change has on soil loss other model parameters that affect erosion (e.g. rainfall, soil moisture) are held constant from year to year. The satellite monitored land cover changes and modelled erosion are integrated with fieldwork observations as well as experiences and thoughts of local inhabitants.

Earlier studies have focused on land cover changes in the bigger catchments that fall into Lake Victoria. One of them is the Mara river basin on the eastern lake shore. This watershed has its headwaters in Kenya and flows into Tanzania were it ends up in the lake. The upper reaches of this basin has been investigated by for example Defersha et al. (2012), Odada et al. (2004) and Verschuren et al. (2002) but few studies have focused on the soil loss rates and factors contributing to soil erosion in the lower part of the Mara river catchment, and none have studied the smaller river catchments in the region. In this study it is investigated whether land degradation along the lakeshore is similar to the larger scale patterns seen in the bigger catchments. Further focus lies on how the inhabitants perceive, and are affected by the changes.

1.1 Aim and specific objectives

The main objective of this study is to assess land cover change between 1986 and 2013 in a rural area of northern Tanzania, and to estimate soil erosion as an effect of land cover change by using the Revised Universal Soil Loss Equation (RUSLE). To isolate the effect of land cover change on erosion, all other factors affecting soil loss are kept constant between the studied years.

Since monetary expenses can limit research, especially in the developing world, one goal was to primarily base the study on data which is free of charge.

1.1.1 Research questions

The following questions will be addressed in this thesis:

- Are there any land cover changes in the study area between 1986 and 2013 which can be detected in Landsat images with 30 m spatial resolution? If so, what are the main drivers of the changes and where have the main changes taken place? Are there any reasons to protect the woodlands of the study area?
- By studying satellite images with a 30 m spatial resolution, is it possible to detect signs of improved environmental conditions in areas where Non-Governmental Organisations are working to support farmers?
- Can the change in soil loss attributed to land cover change be obtained by applying RUSLE modelling in the study area? Has the land cover change had an effect on the soil loss rate?
- Do the results obtained from the analyses correspond to the observations of the people inhabiting the study area?

1.1.2 Fieldwork objectives

Fieldwork was carried out with the purpose of collecting geographical data for land cover mapping and for an accuracy assessment of the land cover classification. Another purpose was to obtain a clear overview of the current land cover patterns, causes of potential changes in land cover, and the living situation of the rural population of Mara.

1.2 Collaborators and study context

The fieldwork was carried out in collaboration with Vi Agroforestry and one of its partner organisations MVIWANYA (Mtandao wa Vikundi vya Wakulima na wafugaji Nyancha, which means Network of farmers and herders groups of Nyancha). Vi Agroforestry is a Swedish-based international Non-Governmental Organisation (NGO) which is working on improving the general living conditions for the rural population of the Lake Victoria basin, mainly through advice and training in sustainable land management. One of the fundamental aims in the work of Vi Agroforestry is to aid famers in their adaptation to climate change. This is implemented through education and counselling so that farmers are able to adopt sustainable agricultural practices in order to cope with e.g. increased frequency of droughts and strong winds. Raised levels of erosion are also among the major issues that can be mitigated by appropriate agroforestry techniques. The organisation started its operations in 1983 and is currently active in four countries, namely Tanzania, Kenya, Uganda and Rwanda. Vi Agroforestry has been working in the Mara region since 1994. Many of the early programme activities in the region have gradually been phased out and the work has been taken over by local partner and national farmer organisations (e.g. MVIWANYA). The outcome of the organisations' work in the region has not yet been fully examined. This study will contribute to a better understanding of the current environmental situation in Mara. It will hopefully help for the planning of future sustainable development.

2. Background

2.1 Land degradation

Land degradation is the temporary or permanent lowering of ecosystem function and the land's productive capacity. According to UNEP (1997) it is one of the world's biggest socio-economic and environmental problems. The factors causing land degradation are either natural or anthropogenic (Kiunsi & Meadows 2006). Natural factors are for example heavy rainfalls, drought and tectonic processes whereas anthropogenic factors include unsustainable farming and overgrazing etc. (Darkoh 2003, Thomas & Middleton 1994). Climate change is also a major factor which sometimes is considered to be a natural and sometimes an anthropogenic source of land degradation (Kiunsi & Meadows 2006).

FAO (1994) lists three groups of causes of land degradation: natural hazards, direct causes and underlying causes. Natural hazards are environmental conditions that lead to high risk of degradation, for example steep slopes, torrential rains, arid climates or soil types susceptible to erosion. Natural hazards may degrade agricultural land and reduce the productivity naturally but usually human interference is the primary cause, or the *direct* cause of land degradation. Human induced deforestation can for example, although it does not degrade land *per se*, cause extensive degradation when it occurs on unsuitable land such as sloping land or land with shallow soils, especially if it occurs in combination with water erosion. Another direct cause of land degradation, similar to deforestation, is the overcutting of vegetation in order to get for example firewood and timber. When the tree cutting activities exceed the natural regrowth rate the land is put in great risk of getting degraded (FAO 1994). This is a common problem in areas throughout the world where fuel shortage is an issue, like in the Mara region of Tanzania.

Other direct causes of land degradation are unsustainable management of agricultural land (FAO 1994). Improper or non-existent soil conservation measures and farming practices which are too intense or not suitable for the particular land can lead to severe land degradation and erosion. The direct causes are often triggered by underlying causes such as population increase and land scarcity. For example, the originally sustainable practice of shifting cultivation, which is the traditional farming method of the study area, gets unsustainable and potentially harmful to the land productivity when the pressure on the land render the fallow periods too short.

The drylands of Africa and the rest of the world are very sensitive to intense livestock grazing (FAO 1994). In dryland biomes grazing lands are dependent on a relatively thin layer of protecting vegetation (Nana-Sinkam 1995). Overgrazing occurs when the livestock carrying capacity is surpassed. When the soil is subject to trampling and overgrazing the land becomes susceptible to wind and water erosion. South of Sahara, soil erosion caused by overgrazing and other factors has degraded about half of the dryland extent (Nkonya et al. 2008). Figure 1 shows the difference between protected land and overgrazed land in the Mara region.

Figure 1. Overgrazing in southern Mara. There is a clear difference between the public land on the left side of the road (where cattle grazing is common) and the protected Serengeti National Park, famous for its vast grassy plains, on the right side of the road. Photos: Århem 2014.

Economic hardship can also be an underlying factor as it often results in the counteractive behaviour of neglecting long term sustainable agricultural measures in order to achieve short term profits (FAO 1994). Poverty is probably one of the main reasons for land degradation in sub-Saharan Africa where almost half of the population lives below the poverty line (World Bank 2007). The relationship between poverty and land degradation is multilateral. As communities get poorer they are forced to employ more desperate methods to survive, methods which often are detrimental to the environment (Lufumpa 2005). Just like poverty and land degradation are intertwined, all the factors of land degradation are interrelated and thus often occur simultaneously or as a result of each other. This could be depicted as a “cause and effect chain” (Figure 2) where increase in rural population and limited land resources are driving forces.

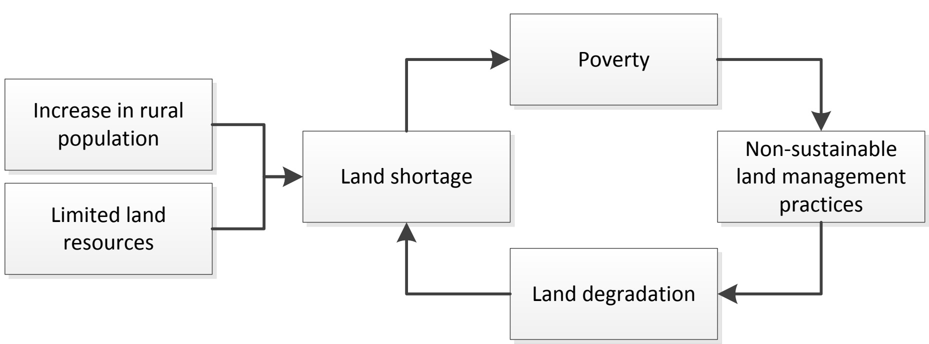


Figure 2. Chain of causes and effects of land degradation triggered by an increase in rural population and limited land resources. Source: Based on FAO 1994.

2.1.1 Soil erosion

Soil erosion and land degradation are closely related. The process of soil erosion is characterized by the removal of soil by exogenic factors such as water flow, wind, waves, and glacier ice (Morgan 2005). Erosion is a two-phased geomorphological process in which individual soil particles firstly are detached from the soil mass and then transported by natural erosive agents. Detachment of soil particles is often accelerated by animal or human activities (Tefera et al. 2002). The rate of soil erosion (generally given in mass or volume per area and time) is determined by three main factors: 1) the erosivity of the erosive agents, i.e. the potential ability of rain, runoff and wind to cause erosion; 2) the resistance or erodibility of the ground, which signifies how susceptible the soil is to detachment and transport; and 3) the protecting cover of the soil by vegetation (Morgan 2005, Tefera et al. 2002).

The consequences of natural and human induced soil erosion can be very costly for both the individual farmers and for the society as a whole. The consequences may be divided into on- and off-site effects (Morgan 2005). The on-site effects such as lowered fertility and soil depth are usually the effect of decline in inorganic matter and nutrients as well as soil loss and breakdown of soil structure. These problems are usually most problematic for the farmer or land owner that has to deal with declines in productivity and land value. On the other hand, off-site effects often afflict local authorities or the community. Typical off-site effects are downstream sedimentation, reduction in river and lake capacity as well as siltation of reservoirs and dams that increase the risk of flooding, calling for high costs of e.g. clearance and maintenance. Another off-site soil erosion effect is the downstream eutrophication of pollutants and fertilizers absorbed to the sediment, which is a big issue in the Lake Victoria basin.

Rill and interrill erosion

Erosion is often classified into different types depending on the erosive agent and further based on the movement of particles in the landscape and what land features it causes. Since the erosion model used in this project (RUSLE) is designed to assess rill and interrill erosion this section will shortly explain these two kinds of erosion.

Rill and interrill erosion are caused by water and are thus two types of water erosion. Water is the most important erosive agent and running water has carved and shaped most of the earth’s land surface (Strahler & Strahler 2006). Interrill erosion occurs on sloping land during rain events which are either very intense, or prolonged so that the infiltration capacity of the soil is exceeded (Morgan 2005). Interrill erosion is characterized by mass movement of water and sediment running over the surface in no defined channels, often in a braided pattern. When the sheet wash is merged into a channelized flow, that acts as a conduit for water and sediment it is called rill erosion. The rills normally collapse and change location between each runoff event (Holden 2008). When the rills become permanent and large enough to be obliterated by weathering and ploughing they are referred to as gullies (Morgan 2005).

2.2 Monitoring land degradation

2.2.1 Geographical Information Systems (GIS)

Geographical Information Systems, abbreviated as GIS, are helpful in the field of land degradation monitoring. GIS are computer based systems used for assembling, storing, analysing, managing, interpreting, manipulating and displaying geographically referenced data. There are many different types of GIS-software; in this study ArcGIS 10.0 has been used.

In GIS the geographical data is structured either as vector layers or raster layers (Harrie 2008). In the vector structure different features (e.g. lakes, forests, rivers) are separated into polygons, lines or points (Figure 3). Raster grids, on the other hand, represent continuous surfaces, and are therefore suitable for continuous variables such as elevation, precipitation, temperature etc. Raster layers are built up by pixels or cells and the larger the pixels, the lower the spatial resolution. In GIS it is possible to combine different layers and thus examine the spatial relationship between features. If studying Figure 3, simple examples could be to determine the dominant land cover in a certain district, or to find the land cover at the highest elevation. This ability to provide a basis for spatial analysis is what makes GIS differ from other types of data management systems.

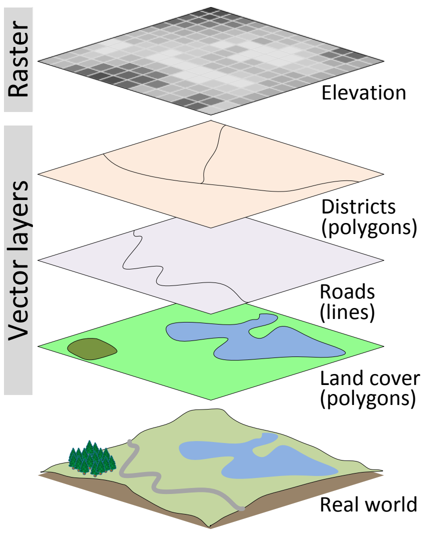


Figure 3. Data layers in GIS. Example of raster and vector layers that could be used for spatial analysis.

2.2.2 Remote sensing

Basics of remote sensing

Remote sensing is basically the "acquisition of physical data from an object without touch or contact" (Lintz & Simonett 1976). When it comes to earth sciences, remote sensing refers to the practice of deriving data containing information about the earth's surface from an overhead perspective (Campbell 1996). This is done by sensors that detect electromagnetic radiation (energy) reflected or emitted from the earth[1].

Nearly everything emits or reflects energy. How much energy an object emits depends on its temperature (Lillesand et al. 2008). Humans can see objects that reflect or emit energy in the visible wavelength spectra, 0.4µm-0.7µm (Figure 4). Since the earth's ambient temperature is relatively low (~27ºC) its surface material emits energy of lower wavelengths than our eyes can detect (thermal infrared energy). We can thus only see or photograph the earth's features when they *reflect* solar energy. The most obvious source of electromagnetic radiation for remote sensing is therefore the sun, but many sensors can detect energy of longer wavelengths as well.

[1]Sensors that detect energy emitted from the object itself or reflected by the object with the sun as an external energy source are called "passive" sensors. There are also "active" sensors that emit energy and detect the radiation that is backscattered or reflected from the target, e.g. radar and lidar.

Satellite sensors are often constructed to be able to measure energy in several specific wavelength bands. They are so-called multispectral. This is a great advantage because many objects reflect similarly in one wavelength band but differently in another (for example vegetation, see next section). All features have a specific spectral signature, or reflectance curve, and by recognising this signature different objects can be separated (Lillesand et al. 2008).

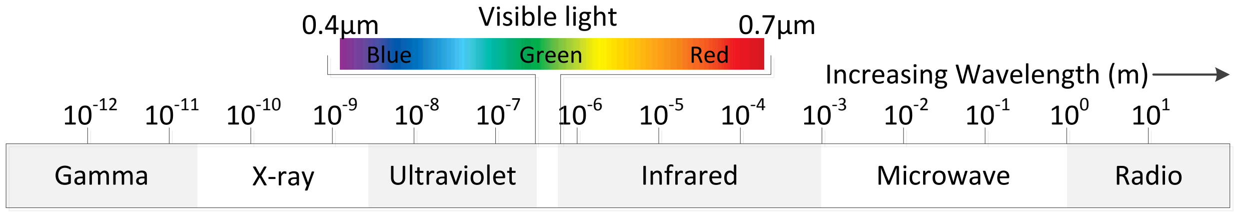


Figure 4. Electromagnetic spectrum. The longer the wavelength, the lower the energy content.

When working with remote sensing data there are many possible sources of error to be aware of. The radiation used for remote sensing must pass through the earth's atmosphere and is thus subject to modification by physical processes such as scattering, absorption and refraction (Campbell 1996). Also, dust, smoke, haze and clouds directly affect the image quality.

A great advantage of remote sensing is that it makes it possible to gather information over large areas at the same time without costly and time consuming fieldwork. Remote sensing also offers the possibility to examine remote locations where fieldwork is difficult (or impossible) due to inaccessibility (Lillesand et al. 2008). It should, however, be noted that remote sensing cannot replace fieldwork in all aspects. Despite the emerging availability of high resolution images, some detailed information is preferably gathered in field. The combination of fieldwork and remote sensing often constitute a good basis for comprehensive studies.

Vegetation mapping and spectral characteristics of plants

Vegetation maps "are scientific tools for analysing the environment and the relationships between vegetation and the site on which it occurs" (Küchler & Zonneveld 1988). Accurate and updated vegetation maps are important for e.g. conservation planning and natural resource management, and for monitoring changes in vegetation and land degradation. When mapping vegetation, the nature of vegetation needs to be considered. This includes, among other things, the plant morphology, seasonal differences, i.e. the phenology, and geographical distribution. It is also important to decide which scale to use, it is for example rarely practical to use the individual plant as the unit of mapping vegetation (Campbell 1996).

The spectral reflectance of vegetation differs from that of other surface features (e.g. soil and water). A typical vegetation spectral reflectance curve is shown in Figure 5. As can be seen in Figure 5a, chlorophyll controls much of the spectral response in the visible portion of the electromagnetic spectrum (Campbell 1996). Chlorophyll enables plants to absorb sunlight and use the energy for photosynthesis. But the chlorophyll molecules mostly use blue and red light for photosynthesis and the green light is reflected (which is why vegetation appears green). In the near infrared spectrum (NIR) the plant's reflectance is controlled by its internal structure. Very little of the NIR radiation is absorbed and the reflectance peak of living vegetation is therefore in the NIR spectrum. The differences between plant species are often more pronounced in the NIR spectrum than in the visible spectrum. A plant's spectral signature is also dependent on the age of the plant, or if it is subjected to stress by for example disease or insect attack. Dead or stressed vegetation generally reflects more red light (which is why it appears yellowish-brownish) and less NIR light. The differences are once again more pronounced in the NIR spectrum (Figure 5b). NIR radiation is therefore important when it comes to mapping vegetation in general or more specifically, e.g. when mapping the spread of crop diseases (Campbell 1996). In the longer infrared wavelengths, water content of the leaf controls the reflectance. At certain wavelengths (approx. 1.4µm and 2.5µm) water greatly absorbs the mid infrared light (Figure 5a).

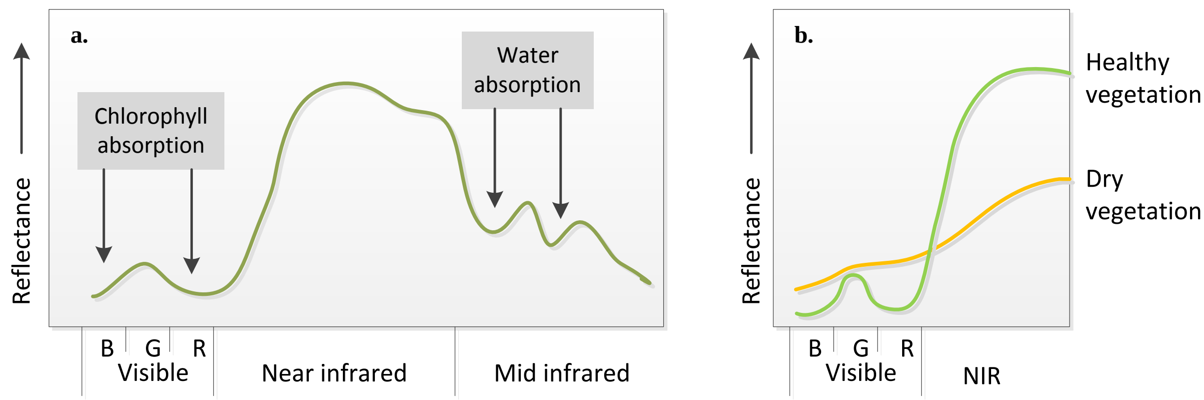


Figure 5. Typical vegetation reflectance curves. Roughly sketched examples of (a) a general reflectance curve including chlorophyll absorption in the visible spectrum and water absorption in the mid IR spectrum (b) differences between healthy and unhealthy vegetation, the biggest difference is most often found in the NIR spectrum. Source: Modified from Campbell 1996.

Vegetation indices: NDVI

Various vegetation indices that utilise the spectral reflectance of vegetation to highlight specific properties of plants have been developed. The normalized difference vegetation index (NDVI) is one of the most widely used vegetation indices (Campbell 1996, Mbow et al. 2013). It was developed by Rouse et al. (1974) and it is a measure of photosynthetic activity or the plant "greenness". The index is based on the normalized difference between the NIR and red spectral bands of a satellite image. It is calculated on a per-pixel basis as follows:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$ **Equation 1.**

where NIR is the NIR-band value from a pixel and Red is the red-band value from the same pixel. Mathematically NDVI-values can range between -1 and 1. Healthy vegetation will have high NDVI-values because of the spectral characteristics of plants, with low reflectance in the red spectrum and high in the NIR spectrum (as discussed in the previous section). Unhealthy or dead vegetation will have lower values and features such as soil and bare rock will have a NDVI-value close to zero due to their similar reflectance in the two wavebands. Whereas water, clouds and snow reflects more in the visible range than in the NIR spectrum and therefore will have negative NDVI-values (Lillesand et al. 2008).

Being a ratio of two bands NDVI helps compensate for changing illumination conditions, surface slope, aspect and other extraneous factors (Lillesand et al. 2008). NDVI is therefore suitable for time series analysis. Studies have shown that NDVI is correlated to for example crop biomass accumulation, leaf chlorophyll levels, leaf area index values, and the photosynthetically active radiation absorbed by a crop canopy (Clevers & Verhoef 1993, Lillesand et al. 2008). NDVI is, thus, commonly used by researchers investigating vegetation dynamics etc.

2.2.3 Soil erosion modelling

Field measurements of soil loss are the most reliable sources of accurate erosion data (Morgan 2005). Actual measurements are however not very useful for determination of the main causes of erosion since environmental conditions vary in time and space. Field measurements are also costly and cannot cover every point in the landscape. Therefore it is common to estimate soil erosion using models. In erosion models it is possible to predict erosion under various different conditions and thus evaluate which factors are most important for the rate of erosion. This makes models valuable in the field of soil conservation planning and management. Erosion models have for example been used since the mid 1940's by the United States Department of Agriculture to select suitable field management practices on cropland (Spaeth et al. 2003).

Over the years many different types of models have been developed to estimate soil erosion. Erosion models can be physical (hardware models usually built in the laboratory), analogue (uses mechanical or electrical systems analogous to the studied system) or digital. Digital models are based on the use of computers and can be either physically based, stochastic or empirical (Morgan 2005). Most erosion models are of the empirical type, i.e. based on empirically found, statistically significant relationships between different variables. Empirical models are the simplest types, requiring the least amount of data and has low computational base (Oliveira et al. 2013). Examples of commonly used empirical models are the Morgan, Morgan and Finney (MMF) model, the Soil Loss Estimator for Southern Africa (SLEMSA), and the Universal Soil Loss Equation (USLE) which has an improved, revised version called the Revised Universal Soil Loss Equation (RUSLE).

USLE and RUSLE

USLE is one of the earliest and most comprehensive soil loss models. It was developed as a tool for farm practice decision making and is based on a set of parameters that are produced from large experimental datasets from different parts of USA (Young 1989). In the USLE equation the factors are calibrated to be multipliable but there is no intrinsic reason for the relationship. RUSLE is an updated version of USLE with some changes of how the factors are estimated (Renard et al. 1991, Jones et al. 1996). The equation is however the same for both USLE and RUSLE and it is given as:

$$A = R \times K \times LS \times C \times P$$ **Equation 2.**

Where ***A*** is the average annual soil loss (in $\mathbf{t\ ha^{-1} yr^{-1}}$);

R is the rainfall-runoff erosivity factor (in the SI unit $\mathbf{MJ\ mm\ ha^{-1}\ h^{-1} yr^{-1}}$);

K is the soil erodibility factor (in the SI unit $\mathbf{t\ ha\ h\ ha^{-1} MJ^{-1}\ mm^{-1}}$);

LS are the slope length and steepness factors (unitless);

C is the cover and management factor (unitless); and

P is the support practice factor (unitless).

There are several differences between USLE and RUSLE. For the R-factor (erosivity) a new improved isoerodent map was created for the western U.S. (Renard et al. 1991, Jones et al. 1996). The K-factor was adjusted to include seasonal variability of freeze-thawing actions. Slope length and steepness (LS-factor) were updated with new algorithms. A number of subfactors, representing for example former land use and surface cover/roughness, were added to the C-factor (cover and management) in order to account for tillage changes. The P-factor was also revised in terms of new values for croplands and rangelands.

Since USLE, and later RUSLE were designed for rill and interrill erosion they should only be used for this purpose (Wischmeier & Smith 1978, Renard et al. 1991). The use of USLE or RUSLE for predicting gully erosion or sediment yield from drainage basins will not give proper estimates. USLE and RUSLE do not estimate the deposition of material or include a sediment delivery ratio and are thus not suitable for approximations of the contribution of hill slope erosion to basin sediment yield (Morgan 2005).

The USLE/RUSLE approach was chosen in this study because the data needed to run the model was available and because the approach has been widely applied in previous studies from different parts of the world, including East Africa (e.g. Angima et al. 2003, Nyssen et al. 2009, Omuto et al. 2009, Mutua et al. 2006).

2.3 Prevention of land degradation

Measures to prevent land degradation and erosion could be done by reducing the causes of degradation, e.g. deforestation and overgrazing. In Tanzania there are legislations to protect the public woodlands and to decrease free grazing, but the laws are rarely followed. Other ways to protect the land are different mechanical structures and the plantation of protective vegetation. Generally it is advisable to combine mechanical and agronomic measures (use of vegetation) for land degradation control.

2.3.1 Mechanical measures for control of land degradation

There are various techniques for mitigating and controlling land degradation and many of them include the construction of physical structures (Morgan 2005, Dejene et al. 1997). They do not only protect agricultural land but also common lands and roads (Keller & Sherar 2003). Some examples are terraces, the construction of natural or artificial windbreaks and ditches, and dam constructions (Dejene et al.1997).

Common for all the physical structures is that they try to manipulate topography and runoff regimes (Morgan 2005). Although physical methods and structures are efficient in controlling sediment transport and water/wind flow they do not fully control the soil particle detachment especially from rain splash, nor do they control the major part of the dissolved pollutants (Morgan 2005, Toy et al. 2002). There are some structures that are considered generally better than others, such as terraces, contours and ridges. But in many cases of water erosion only the coarser particles are contained by the mechanical measures whereas the finer soil particles will still be washed away, carrying adsorbed pollutants (Morgan 2005). In the case of terraces, which are often seen as a good preventive measure, the construction of these on too shallow soil may cause declines in crop yields due to the exposure of less fertile subsoils. In addition, physical structures are often expensive to construct and maintain and they may cause severe damage if they collapse during heavy storms.

2.3.2 Agronomic measures for control of land degradation

Agronomic measures to prevent and control land degradation can include the addition of organic matter to the soil to prevent the land from losing its fertility, or to leave the land in fallow for certain periods of time. It can also be the plantation of deep rooted plants such as trees or certain grasses, e.g. napier grass (*Pennisetum purpureum*) in slopes or around agricultural fields. The practice of planting and integrating woody perennials with other crops in some form of spatial mixture or temporal sequence is often referred to as agroforestry (Lundgren & Raintree 1982). In other words, agroforestry is a combination of forestry and agriculture (Figure 6). Since agroforestry is the main method for preventing land degradation that has been introduced in the study area, this section will explain some important characteristics of agroforestry.

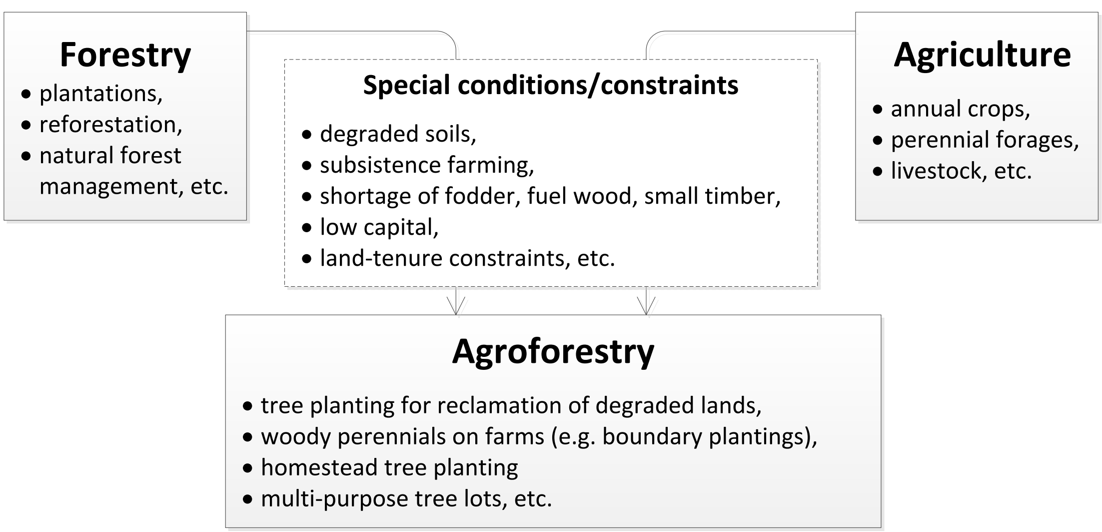


Figure 6. Agroforestry is the combination of forestry and agriculture. It, thus, includes at least two species of plants of which one is a woody perennial. This means that an agroforestry system always has two or more outputs. Definitions of agroforestry often include that there must be a significant interaction, both ecologically and economically, between the non-woody and woody components (Lundgren 1982). Source: Modified from Nair 1993.

The concept of agroforestry as a deliberate farming system is a relatively new phenomenon (FAO 1991, Alavalapati & Mercer 2004). The name "agroforestry" was introduced in the end of the 1970s when the interest of the practice was raised significantly by international scientific and development groups thanks to its possibility to combat poverty, famine and environmental problems (Alavalapati & Mercer 2004). Since then research, education and training have increased significantly on the subject and it is now recognized as an agricultural system with high potential for soil conservation and improvement (Nair 1993). It is however only the term agroforestry that is new, farming that involve crop and tree cultivation on the same fields have existed since ancient times throughout the world. One example is slash-and-burn agriculture which was common in Europe and still is practiced in the highlands of South Asia (King 1987). Another example is the shifting cultivation system that existed in the Asian tropical lowlands where some trees were left to provide coverage for the soil against the sun during non-growing rice season, but where slash and burn was not included (Conklin 1957).

Possible benefits of agroforestry

There are many possible socio-economic and environmental benefits of agroforestry which is suggested by Leakey's (1996) definition of agroforestry as:

> "a dynamic, ecologically based, natural resources management system that, through the integration of trees in farms and in the landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels"
>
> (Leakey 1996, adopted by ICRAF 1997)

The potential of agroforestry to prevent land degradation involves an interplay of many factors. Different environmental functions of agroforestry are summarized in Figure 7. One advantage of combining trees with other crops is the increased nutrient circulation and its impact on the soil fertility. Forest ecosystems often have an efficient and nearly closed nutrient cycle with high rates of turnover and low rates of outputs/losses (and low rate of inputs) whereas agricultural monocrop systems are "open" (Rhoades 1997). Much of the nutrients in many agricultural monocrop systems are leached below the rooting zone and are thus, at least temporarily, lost from the system (Lehmann & Schroth 2003). When adding trees (which generally have deeper roots) to the system, much of the nutrients may be recycled as litter or decomposed roots. Many trees produce large amounts of litter which increases the organic matter, or humus content, of the soils around the tree (Nair 1993, Rhoades 1997). The organic content of soils have been proven to decrease the soil erodibility (Wischmeier & Smith 1978). The planting of trees with nitrogen fixating capabilities can additionally increase the nitrogen content of the soil (Nair 1993).

In monocrop systems there is generally high loss of nutients by soil erosion, which is inhibited in agroforestry systems by deep roots binding the soil, addition of mulch and by the tree cover's protection against wind erosion (Young 1989). Likewise a dense canopy of low trees or shrubs reduces erosivity. However, when raindrops accumulate in high tree canopies and subsequently falls to the ground with a high velocity the raindrop erosion is likely to increase if there is not enough ground cover.

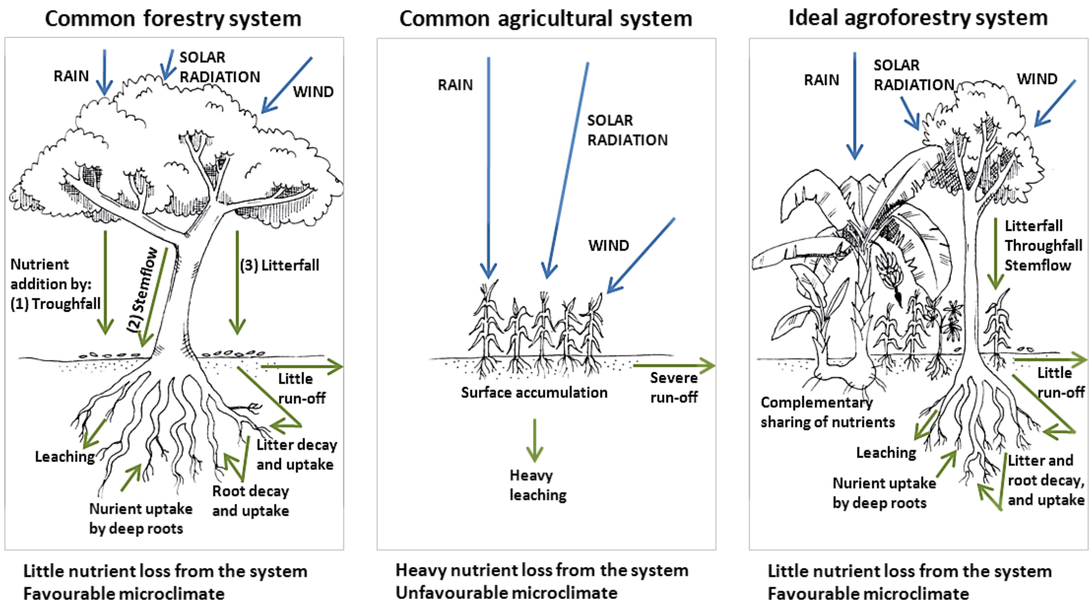


Figure 7. Schematic representation of nutrient inputs (blue arrows) and outputs (green arrows) in common forestry systems and agricultural systems compared to an ideal agroforestry system. It shows how trees and crops in combination result in complementary sharing of nutrients. Sources: Based on Nair 1993 and Rhoades 1997.

Other potential benefits of agroforestry include an improved sub-canopy microclimate (an advantage in semi-arid areas) since the shade from the tree canopies increases the minimum air temperature and decreases the maximum air temperature (Table 1). The shade also contributes to less water loss from evapotranspiration and an increase of the relative humidity of the air and an increase of the soil moisture. Trees also improve the water infiltration rate (Place 2012) which reduces the soil erosivity (Wischmeier & Smith 1978).

Table 1. Summary of the possible changes in microclimatic conditions and soil conditions after introducing a sustainable agroforestry system. Source: Rhoades 1997.

Associated microclimatic conditions		Associated soil conditions	
Increasing	**Decreasing**	**Increasing**	**Decreasing**
▪ Minimum air temp. ▪ Relative humidity	▪ Radiant energy ▪ Evapotranspiration ▪ Maximum air temp. ▪ Air movement	▪ Organic matter ▪ Cation exchange capacity ▪ Nutrient conc. ▪ Soil moisture ▪ Moisture retention ▪ Soil structure	▪ Bulk density ▪ Surface temp.

The environmental benefits are naturally entwined with a bunch of socio-economic benefits. For example increased soil fertility leads to increased productivity which means increased outputs and the possibility of higher nutrient intake. In East Africa it is common to plant e.g. *Calliandra calothyrsus* as fodder for dairy cows. This increases milk production and expensive dairy meal can be substituted which in turn improves the household economy (Franzel et al. 2003).

Increased productivity, whether it is crops or animal products, means that families can get access to markets, for the selling of farm products and in turn buying other necessities.

Agroforestry is often brought up as a good way of climate change adaption, partly for all the abovementioned reasons and partly for the carbon sequestration capacity of trees. If rightly implemented agroforestry can provide farmers with the ”five f:s” which are fuel, fodder, food, finance and fertility. Agroforestry could, in other words, bring a decrease in cutting of natural woodlands to obtain fuel, a decrease of grazing, a healthier, wealthier population, and less degraded soils – factors which all have been noted to affect land degradation. It should however be stated that, just as any other land use may fail, agroforestry does not necessarily provide any benefits if the wrong species combinations or management practices are chosen; or if there is a lack of understanding and/or motivation by the farmers (Lundgren 1982). When trees for example compete with the crops about water, nutrients and light it can be devastating for the crop production. Therefore it is necessary to combine trees and crops that favour each other. Figure 8 shows some examples of agroforestry in the Mara region.

Figure 8. Some examples of agroforestry in the study area. (a) *Grevillea robusta* planted together with cassava in slope. (b) Sorghum in between contours of napier grass and *Grevillea robusta*. (c) Boundary planting of sisal (*Agave sisalana*, which also is a very important source of fibre and building material) around field with scattered acacia trees. Photos: Århem 2014.

3. Study Area

3.1 The United Republic of Tanzania

3.1.1 General facts

Tanzania is located in East Africa, just south of the equator (Figure 9a). It is bordered by Kenya, Uganda, Rwanda, Burundi, Congo-Kinshasa (Democratic Republic of Congo), Zambia, Malawi and Mozambique. Tanzania is divided into 30 administrative regions, 25 on the mainland and five on the islands of Zanzibar (Figure 9b). The country measures 945 000 km^2, has a population of 49.1 M (in 2013) and a natural population increase of 2.9% per year (NE 2014). The national language is Swahili, but more than 120 native languages are spoken. The economy is dominated by agriculture, and the most commonly grown crops are cassava, maize, sweet potatoes, bananas and paddy rice. Tanzania has one of the world's lowest GDP per capita (USD 609 in 2012) and more than a fifth of the country's population lives in poverty (less than USD 2 per day). In 2012, about 5.1% of the population had HIV (NBS 2012).

Most of Tanzania consists of flat land and plateaus. But as part of the Great Rift Valley, which stretches through the country from north to south, Tanzania also contains Africa's highest mountain (Mt Kilimanjaro: 5895 m.a.s.l.) and the world's 2nd deepest lake (Tanganyika: 1435 m deep). The world's 2nd largest freshwater lake, Lake Victoria, is also partly located in Tanzania (Figure 9). The Mara region is located adjacent to Lake Victoria.

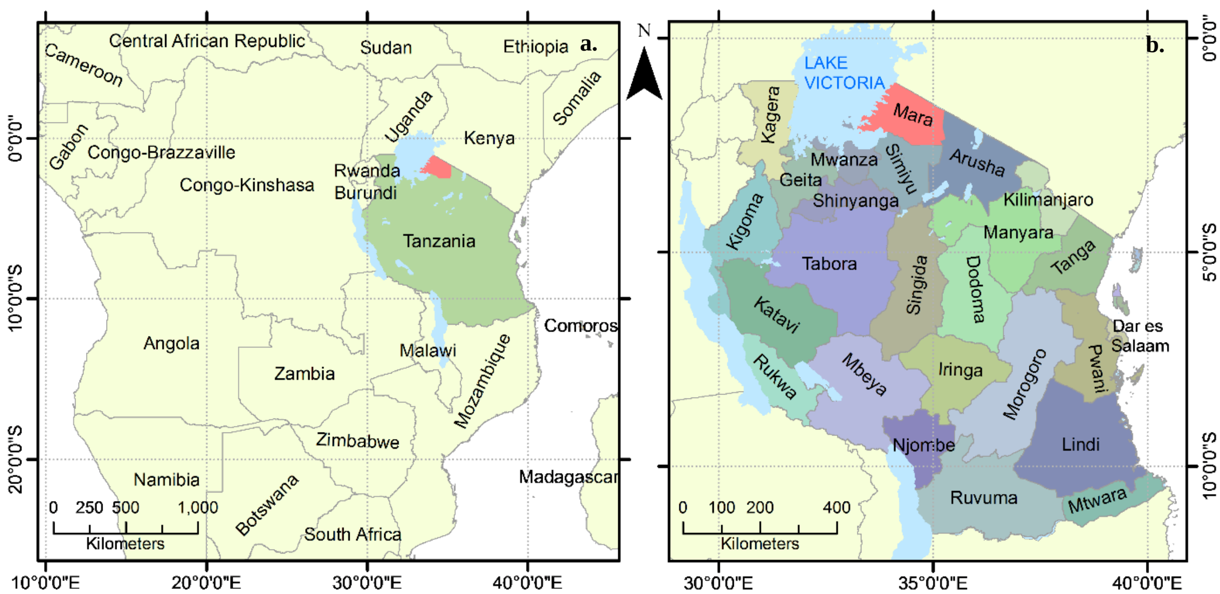


Figure 9. Maps of Tanzania. (a) The location of Tanzania in East Africa. (b) The regions of Tanzania (names of regions located on Zanzibar are excluded). The Mara region is marked with red in both maps.
Source: Vector data from NBS 2014 and Openmicrodata.org 2014.

3.1.2 Rural development in Tanzania

The traditional farming system in Tanzania was based on a nomadic way of living (FAO 1974). It involved land clearing and cultivation with scattered trees serving as a resource for food and protection from erosion and wind. As the fertility of the soil declined the farmers moved on to a new area. However, due to population increase and political reforms in the middle of the twentieth century the nomadic lifestyle was not sustainable anymore and the farmers had to settle and start to intensify the farming.

Between the 1880s and the 1960s Tanzania was a colony, initially under German rule and later under British rule (Kikula 1997). During this period a number of cash crops were introduced such as tea. Large plantations with tea, sisal etc. were established which brought about resettlements in order to vacate land. After the independence in 1961 the first Prime Minister and soon-to-be President of Tanzania, Julius Nyerere (born in the Mara region), set out to reform the agricultural system of the country with collectivization policies under the name of *Ujamaa* ("familyhood") (Ibhawoh & Dibua 2003, Kikula 1997). The concepts of agricultural modernization and villagisation were part of the new government's goal to raise the living standard of the people (Kikula 1997). This was implemented through population resettlements along with concentrations of rural settlements. The idea was to improve farm output by increasing the intensity (i.e. abandoning the traditional shifting cultivation) and to, by villagisation, facilitate the production, trade, acquisition of equipment and farm inputs etc. Furthermore this reform aimed at improving the accessibility to e.g. transport, electricity, social services and health care. Also, the government had a vision that this could be favouring military, political and economic activities among other things. Consequently, the rural population which was traditionally living in scattered transient homesteads was moved to permanent villages and began to gradually abandon the traditional agriculture practices. This resettlement, claimed to be the largest in the third world history (Mascharenhas 1981, Barke & O'Hare 1984), resulted in a faster population growth rate and an increased demand for resources (Kikula 1997).

Unfortunately the reforms had adverse effects on the environment with increased rates of deforestation, soil degradation and erosion. Studies suggest that when shifting conservation was no longer possible, because of the increased population and the consequent land scarcity, people eventually lost environmental conservation awareness and know-how (Allan 1965, Nye & Greenland 1965, FAO 1974). The fallow periods got unsustainably short and therefore caused conversion of woodlands into grasslands. Another cause of diminishing woodlands was the increased resource demand. Also, the grazing pressure around the settlements got proportionally higher which lead to land degradation and soil erosion.

3.2 Lake Victoria

Lake Victoria, which is essential for the livelihood of the larger part of the population living adjacent to it, is afflicted with eutrophication as a result of massive outflow of pollutants and fertilizers from factories and agricultural activities around the lake (UNEP 2005, Odada et al. 2004, Verschuren et al. 2002). Another factor contributing to the eutrophication of the lake is deposition of nutrient rich sediments. This is mainly due to another major environmental issue, namely deforestation and land use conversion (into agriculture and built up areas) which lead to reduced soil quality, erosion and siltation of river outflows (Odada et al. 2004, Verschuren et al. 2002). Climate change also poses a threat with the increase in heavy rainstorms that can cause landslides, flooding and higher rates of erosion.

The pollution and eutrophication have harmful consequences since the lake water is used for drinking, agriculture and not least fishing. The pollution causes diseases and degrades soils (when lake water is used for irrigation) whereas the nutrient runoff leads to an increase of algae and water hyacinth growth which subsequently create anoxic environments with low biodiversity and unsuitable breeding conditions for fishes (UNEP 2005, Odada et al. 2004, Verschuren et al. 2002). Increased rates of erosion as a consequence of climate change and land use conversion around the rivers in the lake basin, such as the Mara River, will also have negative effects on the water quality and supply, especially for the rural population (GU 2007).

3.3 The Mara region with special focus on the Rorya district

3.3.1 Districts and major urban areas of Mara

The Mara region of Tanzania is located at the eastern shore of Lake Victoria and borders to Kenya in the north. Mara is divided into seven districts (as of 2012) which are further divided into divisions. The districts are shown in Figure 10a. The largest city in the region is Musoma which in itself constitutes one of the districts, the Musoma Urban district, and has about 135 000 inhabitants. The second largest urban area is Tarime located about 65 km north-east of Musoma in the district with the same name. Mara has a total population of 1 750 000 (Sensa 2013).

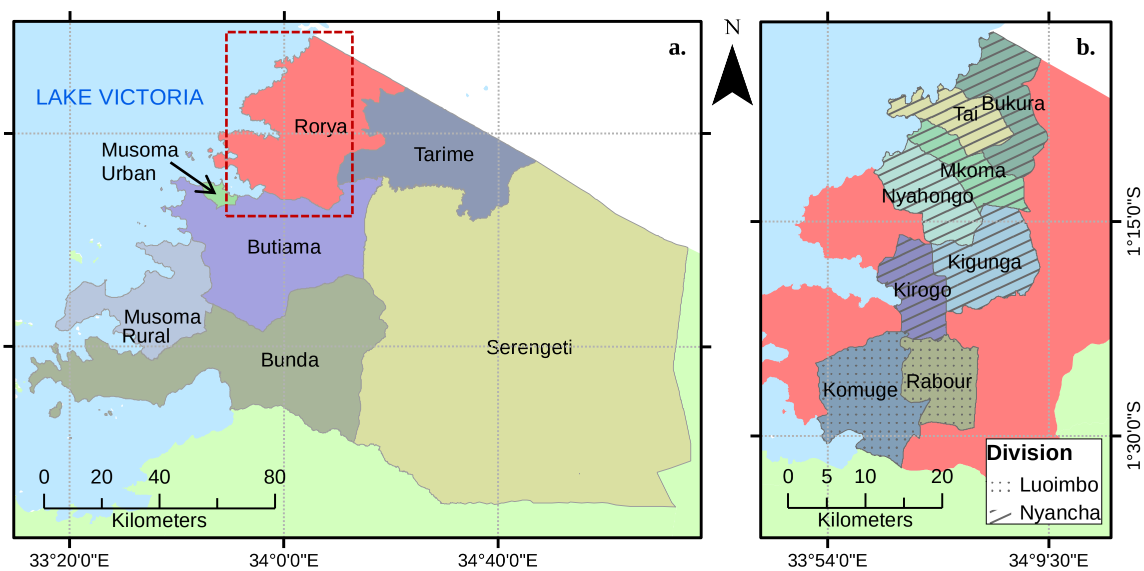


Figure 10. Maps of Mara and Rorya. (a) The seven districts of Mara. The area within the red square is shown in Figure 10b. (b) The wards of the study area, all located in the Rorya district. The six northern wards Bukura, Tai, Mkoma, Nyahongo, Kigunga and Kirogo belong to the Nyancha division (striped wards). The two southern wards Komuge and Rabour belong to Luoimbo (dotted wards). Source: Vector data from NBS 2014 and Openmicrodata.org 2014.

Fieldwork was carried out in the Luiombo and Nyancha divisions located in the Rorya district (Figure 10). Rorya is a relatively newly established district (belonged to Tarime until 2007/2008) and contains four divisions which encompass 21 wards. Eight of these wards were visited, namely Bukura, Tai, Mkoma, Nyahongo, Kigunga, Kirogo, Rabour and Komuge (Figure 10b). These wards together, hereafter referred to as the study area, cover an area of 808 km^2.

3.3.2 Socio-economic profile

Since the eastern part of Mara constitutes the Serengeti National Park and the region borders to Lake Victoria and Kenya to the west and north, the Mara region is relatively remote and sparsely populated (Odada et al. 2006). The infrastructure is still at a development stage and most of the roads are still gravel or dirt explaining why Mara has the lowest contribution to the national economy among the regions around Lake Victoria (Odada et al. 2006, RCO 2003). Still, access to public health and social services is fairly good (Odada et al. 2006). The region holds great potential for increased market opportunities in a developing world thanks to its geographical location close to both Kenya and Uganda. The construction of a tarmac road to the Kenyan border in the 1990s has alleviated trade and communication (RCO 2003).

The rural population of Mara largely exceeds the urban dwellers which only make up about 10% of the total population (RCO 2003). The majority of people are therefore involved in the agricultural sector. The farming systems of the lake shore are subjective to high population pressure and many households suffer from chronic food deficit (RCO 2003). About half of the agricultural households in the Rorya district are suffering from food shortage (7% always, 26% often, and 18% sometimes; NSCA 2012). The crop production of Mara is low due to infertile sandy soils and unreliable rainfall patterns resulting in long periods of droughts and crop failures. Livestock husbandry and fishing are other important sources of income in the region (RCO 2003). The HIV prevalence in the Mara region is about 4.5% (NBS 2012). Rorya has the highest prevalence of the region.

The largest ethnic groups of Mara are Kuria, Luo and Jita (in Swahili: Wakurya, Waluo and Wajita). The Kuria mostly live in the Serengeti district and in the Tarime and Rorya districts by the border to Kenya. The latter districts are also inhabited by many people from the Luo tribe. The Jita tribe is most common in the districts of Musoma, Butiama and Bunda. The ethnic division that was caused by the European colonial states in the 19^{th} century largely affected the tribes of present-day Tanzania, Kenya and Uganda. Many tribe members and relatives of for example Luo and Kuria were unwillingly separated from each other due to the frontier demarcation that cut straight through their villages and land. A lot of people have suffered in the border regions due to this but lately the integration between East African Community states has improved reunification of relatives and culture (RCO 2003).

Population increase in the study area

The total population of the study area increased from 90 569 to 109 304 in the ten-year period between 2002 and 2012. Nyahongo and Mkoma (where the major village of the study area, Shirati, is located) have the largest populations and Kirogo has the smallest (Figure 11). Mkoma and Nyahongo also have most people per km^2 while Komuge has the lowest population density (Figure 12).

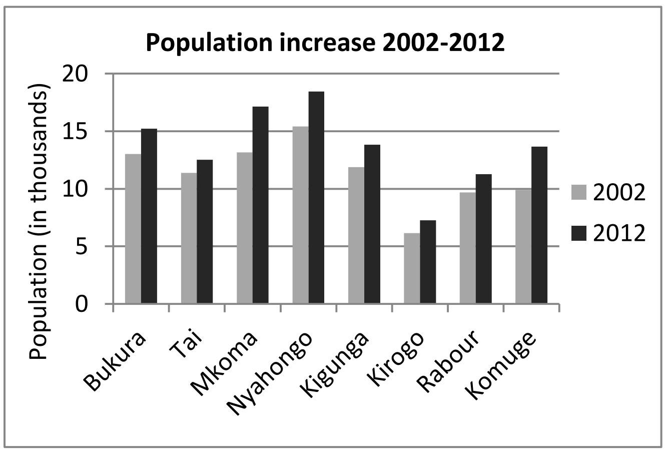


Figure 11. The population increase of the studied wards. Source: NBS 2014.

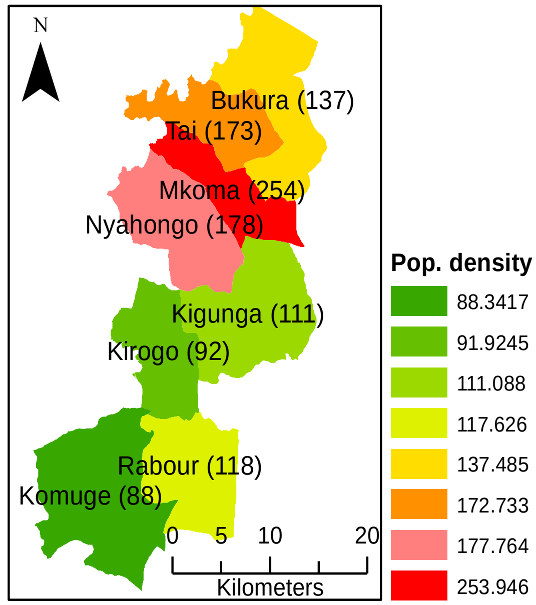


Figure 12. Population density 2012 (pop. per km^2) Source: NBS 2014.

3.3.3 Biogeophysical features

The landscape of the western Mara region, which lies within the Lake Victoria basin, is characterized by plains and valleys in between hills of gentle as well as steep slopes. Rocky hills with inselbergs known as *kopjes*, which were formed when the softer surroundings eroded away, are common features. The Mara River is the only larger perennial river but there are many smaller non-perennial streams that lead to the lake during the rain seasons (RCO 2003). As can be seen in Figure 13 the lakeshore is gently undulating around 1130 m.a.s.l. while the more hilly areas reach up to about 1600 m.a.s.l. Mara can be divided into three geographical regions: the lowland zone, the midland zone and the highland zone. The lowland zone is situated in the west along the shore of Lake Victoria and western Rorya is mainly located within this zone. Eastern Rorya is located in the midland zone which is characterized by flat areas and flat foothills. The highland zone is confined to the hilly areas in the northeast of the region. In this zone rainfall is relatively high and support humid forests and highly fertile land (RCO 2003).

Soils and bedrock of Rorya

The bedrock of Rorya mainly consists of plutonic (intrusive) rocks, i.e. igneous rocks that were formed deep underground from melted magma. The rock types are mainly granite, granodiorite and gneiss (mostly Archaean; Empson 1959). Soils of the lowland zone are quite sandy but there are soils with higher clay content in moister areas such as river valleys and ephemeral swamps (RCO 2003). According to the most recent soil map over Tanzania three soil types dominate in the study area, namely chromi-ferric acrisols, eutri-pellic vertisols, and calci-hyposodic planosols (ARI Mlingano 2006). There is also a small portion of humi-umbric nitisols in the study area. The chromi-ferric acrisols which are dominating in northern Rorya (Figure 14) are easily crusting, strongly weathered, acid soils with a low natural fertility. They are not suitable for low-input farming. Eutri-pellic vertisols are dark-coloured cracking and swelling clays that mainly occur in the river basins. They have a moderate to high fertility and can be productive if properly managed. The calci-hyposodic planosols are soils with a degraded, eluvial surface horizon. They have very low fertility and are mainly suitable for extensive grazing or paddy rice cultivation (ARI Mlingano 2006).

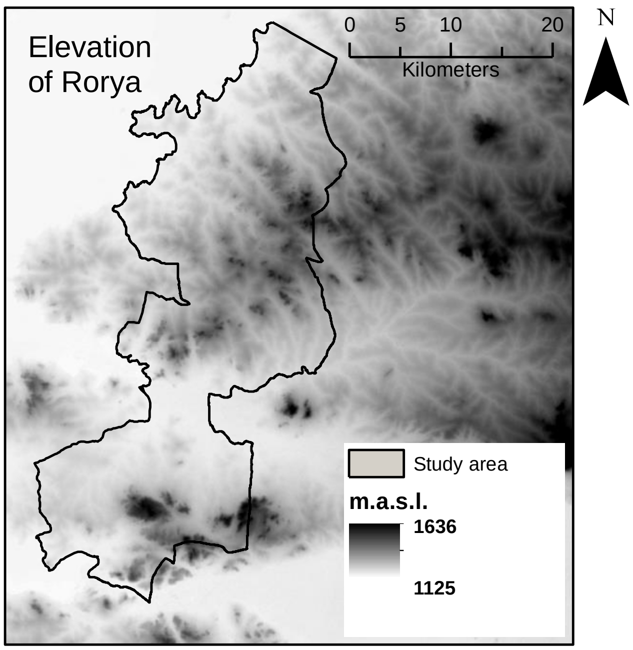


Figure 13. Elevation of the study area produced from ASTER GDEM2, 30 m resolution.
Source: NASA and Japan Space Systems 2014.

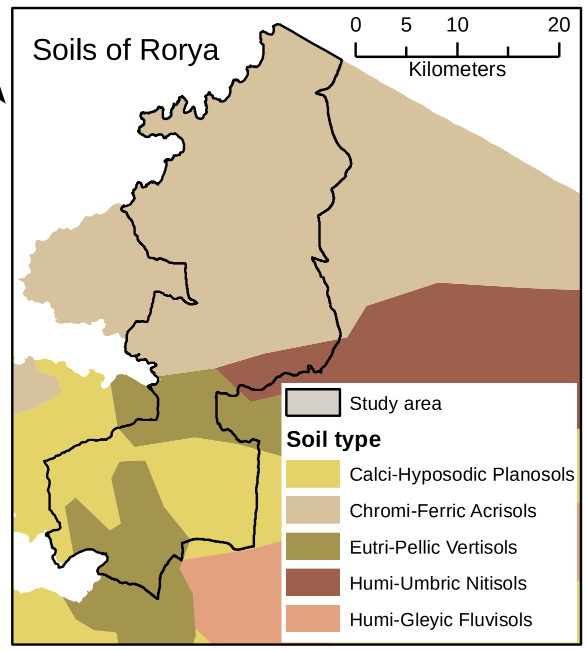


Figure 14. Soils of the study area. Four soil types are present within the studied wards.
Source: Digitized from ARI Mlingano 2006.

The vegetation of Rorya

Most of Rorya is agricultural land with scattered shrublands, grasslands and woodland areas. There are no considerable forests anywhere in the Mara region which is one of the regions in mainland Tanzania with the lowest forest cover. In contrast to forests, which are normally defined as relatively large areas with a dense tree cover, woodlands are small areas of trees and they have a more open canopy (Thomas & Packham 2007). The vast majority of Rorya's woodlands are located on hills and they are heavily exploited and highly degraded. They mainly consist of different *Acacia* species. Many of the trees are, due to the high rate of tree cutting, very young and nearly bush-sized (Figure 15).

Most people are dependent on firewood and/or charcoal for food preparation. This means that an enormous amount of wood is cut for energy purposes. Especially around the urban centres where charcoal is the main source of wood fuel. One large tree is needed to produce one sack of charcoal, and every day hundreds of sacks are transported to Musoma alone. A small survey on the extent of this business was done within the scope of this project and the results are found in Appendix I. Some of the thousands of men and women involved in the wood fuel business are shown in Figure 16.

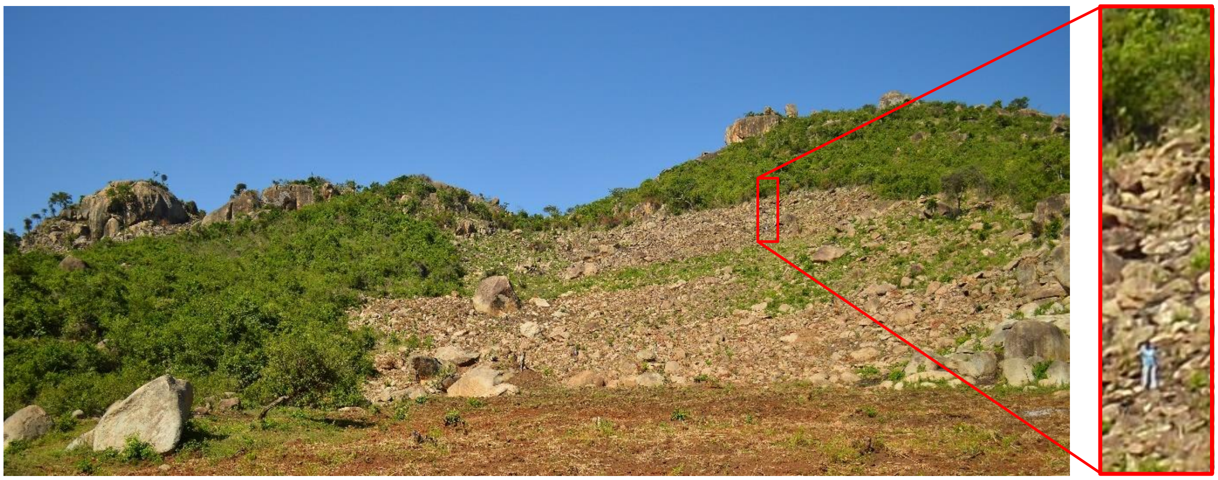


Figure 15. Newly deforested woodland in the Kirogo ward of Rorya. At the foot of the slope there were remnants from charcoal burning. To the right is an enlarged part of the picture showing a man, for scale clarification. Photo: Århem 2014.

Figure 16. Wood fuel businessmen. (a) Man on his way to Shirati town with a bundle of firewood. (b) Two men on their way to Musoma town with charcoal bags. (c) Man repacking and filling up his charcoal bag at a gathering spot for hawkers. A bag filled above the edge, like the one in the photo, could be sold in town for 30 000 TZS (approximately USD 17). Photos: Århem 2014.

3.3.4 Climate

According to the Köppen climate classification Mara has a tropical savannah climate (Aw) with a significant dry season that experiences less than 1/25 of the annual precipitation (Strahler & Strahler 2006). In contrast to most of the country the annual cycle of rainfall in the northern part of Tanzania is bimodal, i.e. there are two distinct rain seasons (Figure 17). The "long rains" usually begin in March, peak in April and end in May, whereas the "short rains" generally last from October to December. The bimodal pattern is mainly associated with the northward and southward movement of the Intertropical Convergence Zone (ITCZ; Kabanda & Jury 1999). Interannual climate variations have sometimes been linked to El Niño-Southern Oscillation (ENSO) or to other oceanic or atmospheric signals, but many aspects of the East African climate are still poorly understood (Camberlin & Philippon 2002, Nicholson 1996).

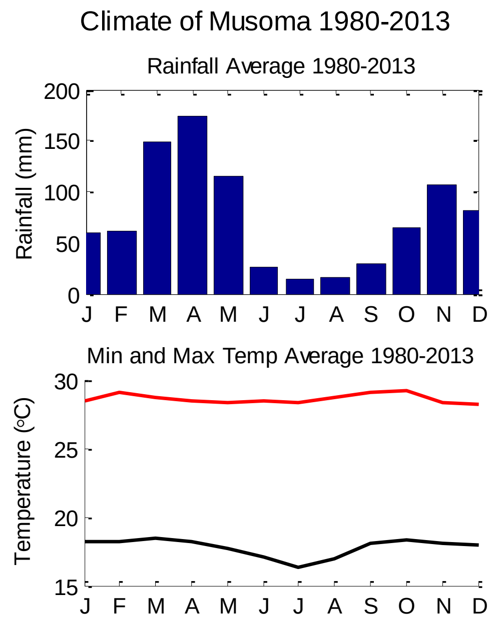


Figure 17. Average rainfall, minimum (black) and maximum (red) temperatures of Musoma between 1980 and 2013. Source: TMA 2014.

The average annual temperature varies between about 20-23°C with the highest averages in the lowland areas along the Lake Victoria shore (Figure 18a). The annual rainfall in the lowlands is around 900 mm, in the highlands it can reach up to about 1500 mm (Figure 18b).

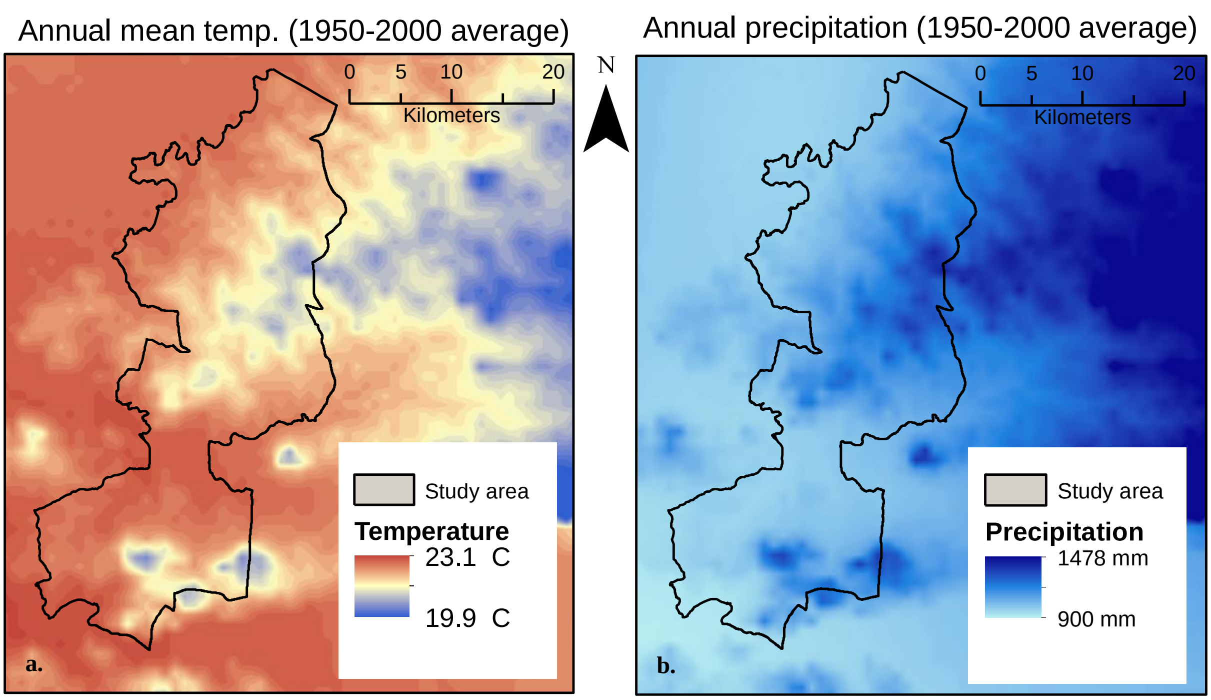


Figure 18. Spatial distribution of climate averages between 1950 and 2000. (a) Average annual temperature based on monthly averages. (b) Average total annual precipitation. Source: WorldClim 2014.

3.4 The selection of fieldwork sites

The Luoimbo and Nyancha divisions were selected as fieldwork sites for several reasons. Before deciding which locations to visit a set of criteria was set up. The major criterion was that the study sites had to be located somewhere in the non-striped mid-area of the Landsat 7 ETM+ imagery (see 4.2.5). Furthermore the sites had to:

- contain woodlands, bushlands and agricultural land;
- have a relatively high rural population;
- have some differences in soil, annual precipitation and topography;
- be located in the Lake Victoria basin;
- be easily accessible – not too far from Musoma or alternatively close to another town where short time stay-over was possible;
- and have inhabitants that were or had been involved with Vi Agroforestry or any partner organisation (so that farmers would agree on being interviewed and so there were field officers present who could assist with arrangements)

Luoimbo is located close to Musoma and was, at the time of the fieldwork, undergoing an exit survey, i.e. a survey carried out after Vi Agroforestry has finished working in an area, to evaluate the achievements and potential progress. This meant that there were personnel from Vi Agroforestry who could be of assistance during the fieldwork. Luoimbo also contains woodlands. The Mara River serves as a natural border in the south part of the division and part of Luoimbo is included in the Mara River catchment which has been studied in previous research (e.g. Defersha et al. 2012).

Nyancha was chosen because of the presence of MVIWANYA, a farmers' groups network and a partner organization to Vi Agroforestry. The organization had personnel which were willing to help with transport, interpretation and introduction to farmers. The major town of Nyancha was Shirati where it was possible to stay for a few weeks. Furthermore the soils in Nyancha are quite unique for the Mara region and they differ from those in Luoimbo which made the area suitable for a comparative study. Some of the wards of Nyancha were only recently incorporated in the MVIWANYA network and had therefore not yet started any land degradation management practices. Discussions on problems encountered by the farmers in these wards were, therefore, especially interesting.

4. Methods and materials

4.1 Fieldwork

4.1.1 GPS coordinate sampling

Coordinates representing different land cover classes (ground control points, GCPs) were gathered using GPS devices. Due to the lack of rights of public access to most of the land, many places could not be visited on spot and Google Earth imagery was therefore used to find the correct coordinates. GPS-points were taken along roads at approximately equal intervals. The points were supplemented with photographs and notes on the land cover at estimated distances (approximately 20 m, 100 m, 500 m and 1 km) in both cardinal directions off the road (with the aid of binoculars and compasses). Both the collected GPS-points and high-resolution Google Earth images were added to ArcGIS 10.0 and points were placed at the correct land cover, i.e. for each road point about two to four points were added at each side of the road. GPS-points were also gathered at all of the visited farms, both in the fields and in the farmers' homesteads. 81 points were sampled in areas with agroforestry. These points were, however, excluded from the final set of GCPs and instead treated separately.

To cover a larger part of the study area some control points were added in areas that were never visited. Control points were only placed on land covers that were easily distinguishable based on field observations and Google Earth, and in areas where the land cover was considered continuous over at least 3×3 pixels (8100 m^2).

According to Congalton and Green (1999) a good rule of thumb when gathering geographical field data is to collect a minimum of 50 samples for each land cover class if the map is smaller than 4050 km^2 and has fewer than 12 classes. Since the study area was only about 800 km^2 and some of the classes (e.g. water and wetland) covered very small areas, the goal of 50 samples per class was not fulfilled. However, for most classes around 40 or more points were collected. The final dataset contains 323 control points covering nine different land cover classes. The spatial distribution of the GCPs can be seen in Figure 19.

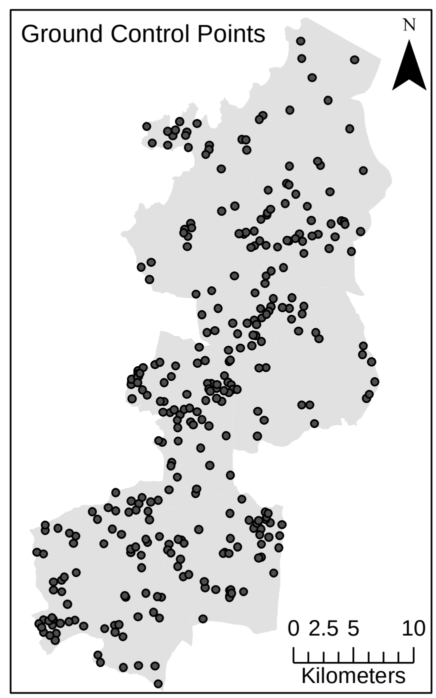


Figure 19. Spatial distribution of the ground control points (GCPs).

4.1.2 Soil sampling

At 40 locations a small soil sample was collected at a depth of about 10 cm. On each location a GPS-point was taken and the soil texture was determined using Thien's (1979) texture-by-feel analysis method. Since no lab equipment was available, no other soil features were determined. All farmers were also asked about soil texture during interviews. The information was summarised and combined with a soil map from 2006 for further analysis.

4.1.3 Interviews

Interviews were held with 64 individual farmers representing 64 different households, 27 in Nyancha and 37 in Luoimbo. The interview questionnaire was developed to get an overview over the respondents' current farming situation (productivity, the planted crops and trees etc.) and if/how it had changed, the water availability, wood fuel consumption, if the farmer experienced any problems with soils or erosion, if livestock were held and if they were grazing freely, etc. Furthermore each farmer was asked about changes in the landscape, regarding the expansion of agriculture and deforestation. Test interviews were held before the first farmer interview, but still slight adjustments to the questionnaire were made after a few interviews. The full final questionnaire is found in Appendix II.

The informants were reached either by motorbike or by a four-wheel-drive car and the interviews were conducted in the farmers' homesteads. For nearly all of the farmer interviews an interpreter who translated between Kiswahili and English was hired. During three interviews an additional interpreter was employed to translate between a tribal language and Swahili. The majority of questions were quantitative and thus asked in a closed-ended manner with only a few possible answers. The aim of using quantitative questions was to reduce errors that may emerge when asking many different people using several different translators, and to be able to convert the answers into numbers. The rest of the questions were qualitative, with an open-ended format, and the respondent was encouraged to express her or his own opinions. The data from the quantitative answers was used for numerical summaries of the living situation of a typical farmer and for a clearer overview and a better understanding in general. The qualitative data was mainly used as guidance for the interpretation of different causes of land cover changes, and to get a perception of the primary problems in the region as perceived by the farmers themselves.

To complement the farmer interviews, three employees at the Ministry of Natural Resources and Tourism ("Maliasili") were interviewed, the Assistant District Manager, the Forest Officer and the District Officer. Raymond Moshi and Joseph Bugwema from the MVIWANYA organisation were also interviewed. Furthermore several meetings and consultations with staff from Vi Agroforestry were held.

4.2 Digital data and pre-processing

All geographical data has been projected to WGS 84/UTM zone 36N even though the study area in reality is located about 150 km south of this zone. The reason for choosing WGS 84/UTM zone 36N was that it is the projected coordinate system used by Landsat for the area.

4.2.1 Vector data

The most recent vector data of Tanzanian borders are from 2012 and was provided by the National Bureau of Statistics (NBS). These data did however not contain villages and was therefore combined with an older version of the same map (with slightly less detailed borders) downloaded from openmicrodata.org. The vector layers were transformed from Arc 1960 to WGS 84/UTM zone 36N using the EPSG code 1285.

4.2.2 Digital Elevation Model (DEM)

The second version of the ASTER Global Digital Elevation Model (ASTER GDEM2) was downloaded from NASA and Japan Space Systems (2014). ASTER elevation data has a high accuracy and a spatial resolution of 1 arc-second (~30 m). The DEM was projected from WGS84 to WGS 84/UTM zone 36N using a bilinear resampling technique. A depressionless DEM is required when running flow accumulation algorithms. Before calculating the slope and aspect, all sinks were therefore filled to produce a DEM with no depressions.

4.2.3 Soil data

A soil map was digitized in ArcGIS 10.0 from a soil and physiology map over Tanzania produced by Mlingano Agricultural Research Institute (2006). The map was covering the whole nation and was thus quite generalized, it was still the most detailed and recent map available. Information on soils came mainly from ARI Mlingano (2006).

4.2.4 Climate data

Climate data was obtained from two sources. The first set of climate data was measured data obtained from Tanzania Meteorological Agency (TMA). The data came from a climate station in Musoma, about 15 km southeast of Rorya. The data sets contained monthly rainfall and maximum and minimum temperatures from 1980 to 2013. Very little data were missing, totally three months of temperature data were missing, but no rainfall data. Since the temperature does not vary much over the year the missing data was linearly interpolated (Falge et al. 2001) from the average value of the months before and after the same year and the same month from the year before and the year after. No other climate stations were located nearby so no other measured data was obtained.

The second set of climate data was raster data layers with monthly precipitation and temperature, as averages between 1950 and 2000. These were acquired from a global dataset produced by Hijmans et al. (2005) (www.worldclim.org). Hijmans et al. (2005) interpolated rainfall from gauging stations on a grid with a spatial resolution of 30 arc-seconds (926.1 m). They used monthly rainfall data that was derived from large climate databases such as WMO (World Meteorological Organization) and FAO as well as several regional and national counterparts. Since there were numerous sample stations in the Lake Victoria region the accuracy of the interpolation was considered satisfactory in the study area.

4.2.5 Satellite imagery

Satellite images from three sources have been used in this study. The land use classification was performed on images produced by Landsat sensors, but the selection of Landsat imagery was based on NDVI data from the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS). This section provides short descriptions of the three satellite systems followed by an explanation of how the Landsat images used for analysis were selected. Lastly the pre-processing procedures are presented.

NOAA AVHRR NDVI data

AVHRR are radiation-detection sensors designed for monitoring clouds and the earth's surface cover and temperature (NOAA 2013). The AVHRR sensors have been carried by the National Oceanic and Atmospheric Administration (NOAA) platforms since 1981. The most commonly used product generated from the sensor is the GIMMS (Global Inventory Modeling and Mapping Studies) series which contains globally processed NDVI data from 1982-2011 (Tucker et al. 2005). The GIMMS dataset was compiled by NASA and has a spatial resolution of 8 km and a temporal resolution of 15 days (USGS 2013a, NASA 2014a). The GIMMS series has been used in this study, but since it only covers the years 1982-2011 it does not account for the most recent years, i.e. 2012-2014. Therefore the NOAA AVHRR images were supplemented with NDVI data from MODIS.

Terra MODIS NDVI data

MODIS is an instrument which is providing information on large-scale global dynamics by acquiring data in 36 spectral bands, covering the entire earth's surface (NASA 2014b). MODIS instruments are carried by the Terra and Aqua satellites which were launched in 1999 and 2002 respectively. In this study NDVI produced from Terra MODIS data was used. The Terra satellite was designed for earth observing research and it has five different sensors on board. The MODIS sensor has a spatial resolution of 1 km and a temporal resolution of 16 days.

Landsat imagery

The Landsat Program is managed by the U.S. Geological Survey and NASA. It began in the 1970s and is still operating with the program's seventh and eighth satellites (USGS 2013b). The program provides the world's longest continuous space-based record of the earth's surface with images covering the whole world. The Landsat sensors have a moderate spatial resolution which today is 30 m for most bands (Table 2). The temporal resolution of Landsat is 16 days.

There have been several Landsat sensors over the years. In this study images from Landsat 5 TM and Landsat 7 ETM+ have been used. Landsat 5 was launched in March 1984 and was originally designed to a minimum life of three years, which it outlived by far (NASA 2013c). The satellite was active for 29 years, which is the longest operating time in space for an earth observing satellite, until it was decommissioned in June 2013. During its last years of commission the TM (Thematic Mapper) sensor stopped working and between 1995 and 2012 the MSS (Multispectral Scanner) was shut down. In April 1999 Landsat 7 was sent to space with the mission to deliver high quality satellite data without clouds (NASA 2013d). This was successfully achieved until May 2003 when the SLC (Scan Line Corrector) failed which has caused some missing scan lines, i.e. stripes of missing data, in the satellite imagery. Still, Landsat 7 operates today acquiring around 75% of the ground scenes. In the scene covering the Mara region there are stripes in the major part of the satellite image but most of Nyancha and Luoimbo are not affected. Landsat 7 was joined by Landsat 8 in February 2013 (NASA 2013e), the last of the launched Landsat satellites. Landsat 8 has the purpose of ensuring a continued supply of satellite data after the eventual failure of Landsat 7 (USGS 2013c).

Table 2. Band specifics (wavelength and spatial resolution) for the tree latest Landsat sensors.

	Landsat 5 TM			Landsat 7 ETM+			Landsat 8		
Description	Band	Wavel. (µm)	Res. (m)	Band	Wavel. (µm)	Res. (m)	Band	Wavel. (µm)	Res. (m)
Coastal/Aerosol	-	-	-	-	-	-	1	0.43-0.45	30
Blue	1	0.45-0.52	30	1	0.45-0.52	30	2	0.45-0.51	30
Green	2	0.52-0.60	30	2	0.52-0.60	30	3	0.53-0.59	30
Red	3	0.63-0.69	30	3	0.63-0.69	30	4	0.64-0.67	30
NIR	4	0.76-0.90	30	4	0.77-0.90	30	5	0.85-0.88	30
SWIR-1	5	1.55-1.75	30	5	1.55-1.75	30	6	1.57-1.65	30
TIR	6	10.40-12.50	120	6	10.40-12.50	60	10	10.60-11.19	100
							11	11.50-12.51	100
SWIR-2	7	2.08-2.35	30	7	2.09-2.35	30	7	2.11-2.29	30
PAN	-	-	-	8	0.52-0.90	15	8	0.50-0.68	15
Cirrus	-	-	-	-	-	-	9	1.36-1.38	30

Selection of satellite images

There are many factors to consider when selecting satellite images for land cover classification. Even though Landsat acquires two images each month the access to interannually comparable images is limited. In this study the selection of Landsat images began with the exclusion of all images with haze, high cloud cover and/or poor image quality. After this only a few images remained for most years. During some years no images remained at all, for example in the 1990s there were only three usable satellite images, all in 1999. Due to the cyclicality of crop growth and harvest and the phenology of natural vegetation, comparable images should be from roughly the same time of the year. In Mara the two rain seasons (Mar-Jun and Oct-Dec) generally had high cloud cover so images had to be selected from either of the two remaining periods.

For comparability, images with roughly the same vegetation cover are preferable. Vegetation cover is highly dependent on the amount of rainfall, and the rainfall in Mara is variable. In Musoma, the total annual rainfall ranged from 616 mm to 1271 mm during the 1980-2013 period, i.e. the wettest year (2011) had more than double amount of rainfall than the driest year (1992). The monthly rainfall is also highly variable (see Appendix III). Thus large annual differences in vegetation cover can be expected. To get images with approximately the same vegetation cover the selection of images was based on NDVI. As mentioned, no full dataset containing NDVI data from 1984 (the year of the first available Landsat image) to 2013 exists, and AVHRR data was therefore supplemented with MODIS data. To see how comparable these data were, the last three years of AVHRR data (from one pixel in the centre of the study area) were compared with MODIS data (from the 10×10 pixels that corresponded to the AVHRR pixel). The mean values of the MODIS pixels were fairly correlated to the AVHRR pixel (R^2=0.63) but, as can be seen in Figure 20, the MODIS mean values were generally lower. The maximum values of the MODIS pixels were slightly less correlated (R^2=0.62) but were more similar to the AVHRR values (Figure 20) and therefore MODIS maximum values were used to compare images from 2013 with earlier images.

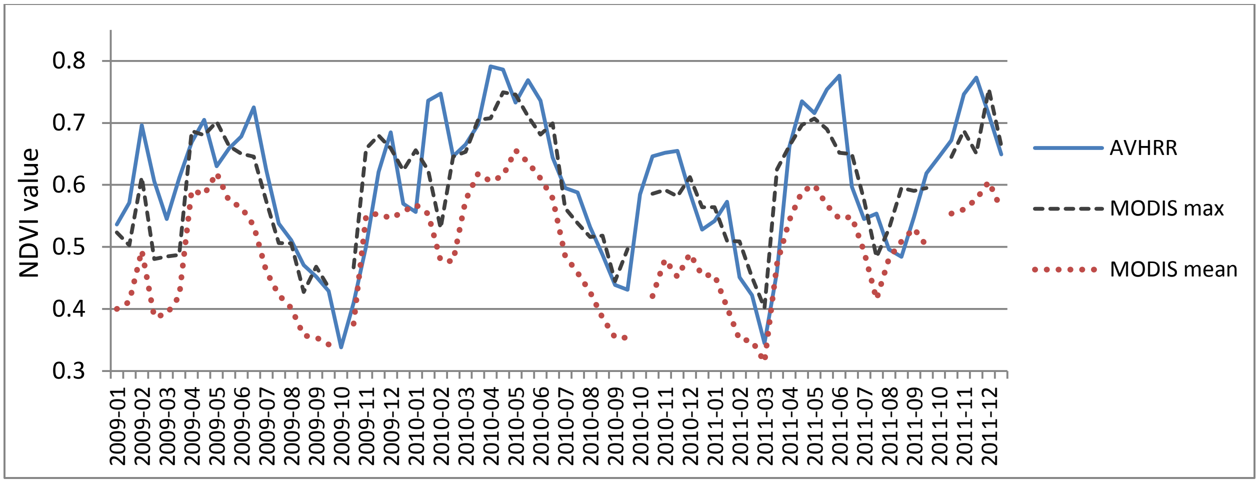


Figure 20. Comparison of NDVI data from AVHRR and MODIS 2009-2011. The AVHRR data comes from one pixel in the centre of the study area and it is compared to the MODIS mean and maximum values from the 10×10 pixels that corresponded to the AVHRR pixel. Because of the different temporal resolution of the sensors the MODIS series has been adjusted to fit the AVHRR series, thus some gaps can be seen.

The goal was to use four or five images, but because of the low number of images in the 1990s and the highly variable vegetation cover only three images were found suitable. By using the MODIS maximum value of the best image from July 2013 as a reference, two images with similar AVHRR NDVI taken at roughly the same time of the year were selected, one in 1986 and one in 1999 (Table 3). The final three Landsat images were shot between 7:17-7:51 a.m. and the solar elevation angle varied between 49.4-61.4º. All images had an image quality score of 9 which means that no errors were detected ("a perfect scene"; NASA 2011). The cloud cover was 0% for all images and none of the images had any visible haze or clouds in the study area (Figure 21). For the 2013 image the SLC was off and there are some stripes in the mid-eastern and south-western parts of the study area, these stripes were removed from all images before area calculations (Figure 21).

Table 3. Acquiring date and time of the Landsat images and the NDVI values of the central pixel(s) of the study area. SLC status states if the Scan Line Corrector was on or off at the time of image capture.

Date	Time	Landsat sensor	SLC status	NDVI	NDVI data source
15/08/1986	07:17 a.m.	Landsat 5	SLC on	0.467	AVHRR
12/09/1999	07:48 a.m.	Landsat 7	SLC on	0.486	AVHRR
16/07/2013	07:51 a.m.	Landsat 7	SLC off	0.487	MODIS max

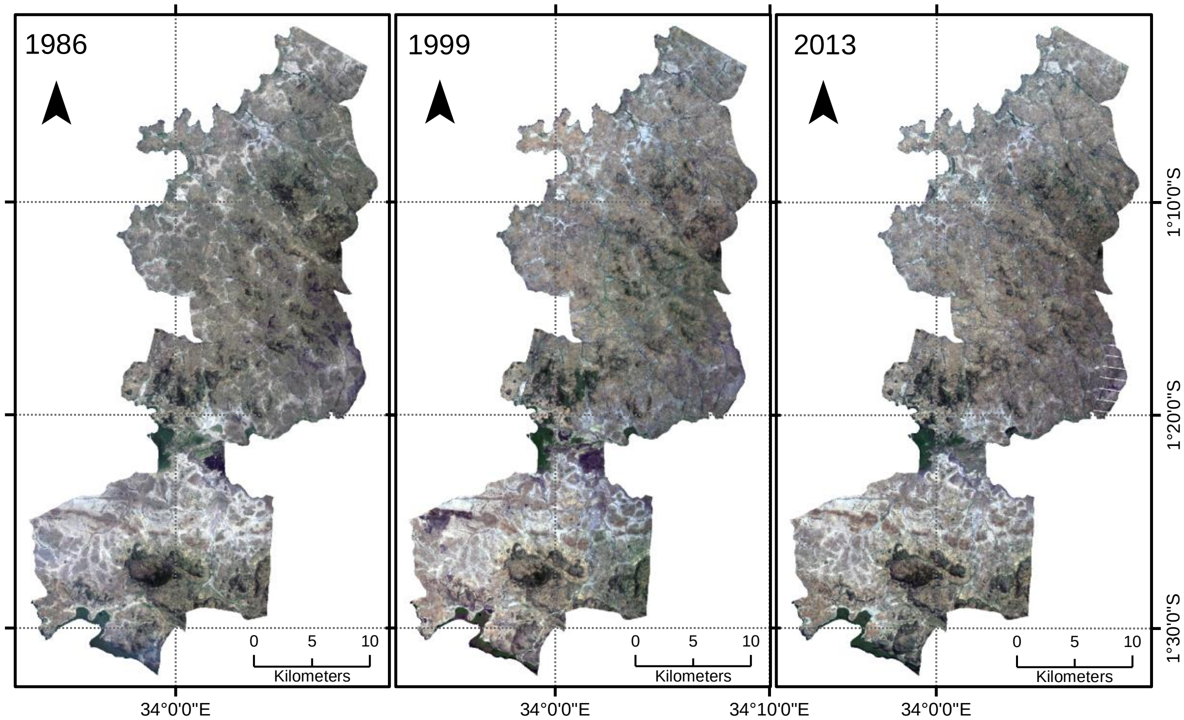


Figure 21. Landsat images showing the study area in Aug 1986, Sep 1999 and Jul 2013. In the easternmost part of the 2013 image a few stripes caused by the non-functioning SLC are visible. Source: glovis.usgs.gov.

The satellite images were Landsat Level 1G products (processed through the Level 1 Product Generation System, LPGS) which means they were both radiometrically and geometrically corrected. But since the images originate from two different sensors, Landsat 5 TM and Landsat 7 ETM+, which are originally quite different from each other (Vogelmann et al. 2001) the images had to be made compatible for further calculations. In order to do so a cross calibration was performed. Furthermore, to be able to calculate NDVI the pixel values have to be converted from digital numbers (DN) to top of the atmosphere (TOA) reflectance. The pre-processing procedures applied to the satellite images are shown in Figure 22.

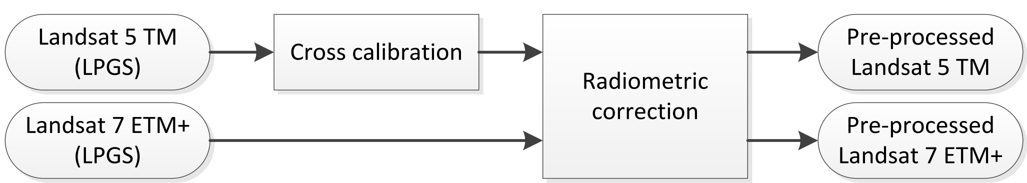


Figure 22. Pre-processing procedures applied to the satellite imagery. Landsat 5 images underwent two pre-processing procedures while Landsat 7 images were radiometrically corrected only.

Cross calibration

The method of Vogelmann et al. (2001) was chosen for cross calibration between the TM and the ETM+ images. By applying Equation 3 the Landsat TM image was converted to the radiometric responses of the Landsat ETM+ spectral bands. This should produce a spectral consistency of 98% or higher (depending on the band) and enables further radiometric calibration where all satellite images are treated as Landsat ETM+ (Teillet et al. 2001, Paolini et al. 2006).

$$L5_{DN7} = L5_{DN5} slope + intercept$$ **Equation 3.**

where $L5_{DN5}$ are the DN values of the Landsat TM band and *slope* and *intercept* are values for cross calibration obtained from Vogelmann et al. (2001).

The parameters slope and intercept (Table 4) were derived from relationships between two temporary tandem scenes of the TM and ETM+ sensors, shortly after the launch of Landsat ETM+ (Vogelmann et al. 2001, Teillet et al. 2001).

Table 4. Slope and intercept values.

Band	Slope	Intercept
1	0.9398	4.2934
2	1.7731	4.7289
3	1.5348	3.9796
4	1.4239	7.0320
5	0.9828	7.0185
7	1.3017	7.6268

Radiometric correction

The DOS (Dark Object Subtraction) absolute correction approach was employed for the radiometric correction. This method has been widely used owing to both its simplicity and its accuracy that is often equal to more complicated algorithms (Song et al. 2001, Paolini et al. 2006). Even if the Landsat images are level 1 many studies have used DOS in order to avoid problems with haze and false minimum values resulting from sensor errors (Pons et al. 2014). Furthermore, Paolini et al. (2006) concluded that land cover change estimations performed on Landsat satellite images that have not been corrected give unrealistic values.

The principle of the DOS method is based on the assumption that a scene contains dark objects (with zero or low surface reflectance) and a horizontally homogenous atmosphere. In this way the lowest DN value of a scene is attributed to the atmospheric effects (path radiance and scattering) and is therefore subtracted from the scene pixels. The first step is to convert the DN-values to at-satellite radiance (Paolini et al. 2006):

$$L_{sat} = DN gain + offset$$ **Equation 4.**

where L_{sat} is the at-satellite radiance for a specific band (W m^{-2} $sr^{-1}$$\mu m^{-1}$) and DN represents the scene pixels in digital numbers. *Gain* and *offset* are band specific image calibration values for the Landsat 7 ETM+ sensor (for values see Table 5).

In order to be able to convert the at-satellite reflectance to top of atmosphere reflectance two calculations needed to be performed (Paolini et al. 2006). First, the atmospheric transmittance along the incident direction (T_z) has to be computed as follows:

$$T_Z = exp\left(-\frac{tau_r}{cos\theta_Z}\right)$$ **Equation 5.**

where θ_z is the sun zenith angle and tau_r is the optical thickness of Rayleigh scattering. Tau_r can be estimated following Kaufman (1989):

$$tau_r = 0.008569\lambda^{-2} + 0.00013\lambda^{-4}$$ **Equation 6.**

where λ is the band specific centre wavelength in µm (Table 5). Equation 7 shows how to calculate the top of atmosphere reflectance:

$$\rho = \frac{(L_{sat} - L_{haze})\pi d^2}{E_0 cos\theta_Z T_Z}$$ **Equation 7.**

where ρ is the top of atmosphere/earth surface reflectance and *d* (astronomical unit) is the distance from sun to earth on the day of scene capture. E_0 is the exoatmospheric solar irradiance in W m^{-2} μm^{-1} obtained from Chander et al. (2009) (Table 5) and q_z is the solar zenith angle (Paolini et al. 2006). L_{haze} (W m^{-2} $sr^{-1}\mu m^{-1}$) represents the path radiance, which was estimated according to the following equation (Song et al. 2001):

$$L_{haze} = DN_{dark} gain + offset - \frac{(0.01 E_0 cos\theta_Z T_Z)}{\pi d^2}$$ **Equation 8.**

where DN_{dark} stands for the pixel of each band that contains the lowest reflectance value (i.e. the darkest pixel of the scene, which in this study normally was found in Lake Victoria).

Table 5. Values used for the radiometric correction

Band	Gain*	Offset*	Centre wavelength (λ)†	Exo-atmospheric solar irradiance (E_0)‡
1	0.775	-6.2	0.4825	1997
2	0.795	-6.4	0.565	1812
3	0.619	-5	0.66	1533
4	0.637	-5.1	0.825	1039
5	0.125	-1	1.65	230.8
7	0.043	-0.35	2.215	84.9

* Paolini et al. 2006
† http://opticks.org/confluence/display/opticksDev/Sensor+Wavelength+Definitions
‡ Chander et al. 2009

4.3 Data analysis

4.3.1 Land cover classification

Supervised land cover classification is the process of using samples of known identity (“training samples”) to classify pixels of unknown identity (Campbell 1996). Before the execution of supervised classification the land cover classes used for the classification have to be determined. After determining the classes to be used, the following procedures were completed: 1) creation of training samples, 2) evaluation of training samples, 3) creation of a signature file from the training samples, 4) evaluation of the signature file, 5) application of the classification algorithm, and lastly 6) application of post-classification procedures (e.g. filters). When these six steps had been completed the accuracy of the classification was assessed. The supervised classification was done using the maximum likelihood method in ArcGIS 10.0. Map accuracy assessment was performed in MATLAB R2012a.

Maximum likelihood classification

Land cover classes normally show some variability within their spectral reflectance pattern, both due to natural variations and because of shadows, haze, mixed pixels etc. When classifying land cover it can therefore be problematic to determine which land cover class some pixels should belong to (Campbell 1996). In a varying landscape it is important that the classification method considers the variations in reflectance of each class. This is done in the maximum likelihood classification. The method is one of the most widely used supervised classification methods and has shown to be one of the best techniques for classification and land cover mapping purposes in remote sensing (Al-Ahmadi & Hames 2009, Shafri et al. 2007, Jia & Richards 1995). For these reasons maximum likelihood classification was used in this study.

The maximum likelihood classification method uses a predefined probability of a pixel belonging to a specific class based on its spectral signature (ESRI 2012, Campbell 1996). The probability function algorithm is based on Bayes' theorem (Bayesian probability) which takes advantage of the spectral data in the training samples to estimate means and variances of the different land cover classes. These statistics are then used to estimate the probability that a certain pixel value belong to a land cover class. Bayesian (or conditional) probabilities indicate the probability of an event assuming that another one has occurred (Campbell 1996). In the case of image classification, it gives the probability of encountering a certain land cover class in a pixel providing that the pixel value already is known. In a simple example with only one spectral band and two classes, e.g. cropland and woodland, the maximum likelihood classification will estimate the mean and variance/covariance of the training data for cropland and woodland respectively. By using the relationship of Bayes' law the mean and variance/covariance can be used to calculate which one of either cropland or woodland that is most likely to be assigned to a pixel of a certain value (Figure 23). In reality several classes and spectral bands are treated in the calculations (Campbell 1996).

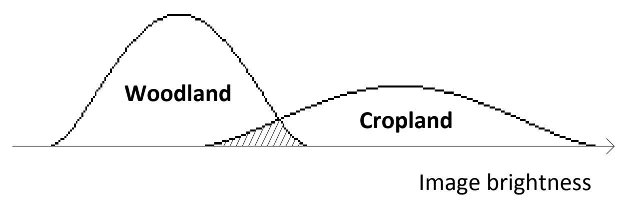


Figure 23. Maximum likelihood classification. The frequency distribution curves represent pixel values for woodland and cropland respectively. Pixel values in the overlapped zone are common in both classes. Which class these pixels will belong to depend on the relation between their pixel value and the overall frequency distribution. Source: Campbell 1996.

The maximum likelihood algorithms assume a normal frequency distribution for each training area and land cover class in each spectral band (Al-Ahmadi & Hames 2009). Therefore the training areas have to be selected carefully to avoid varying quality in the training data and introduction of errors such as over-classification of classes with wide spectral ranges (Campbell 1996). Compared to other supervised classification methods Bayes' approach is particularly sensitive to such errors. But if the assumptions are fulfilled this kind of supervised classification method is very effective. Bayes' theorem is especially effective for remote sensing of overlapping spectral classes (Campbell 1996), which is another reason why the maximum likelihood method was chosen.

It is possible to assign different weights to classes depending on whether their probability of belonging to cells of a specific value is higher or lower than the average (ESRI 2012). By default, all the classes are assigned weights with equal "membership" probability for the cells of the output raster. If there are classes with special probabilities they can be assigned higher or lower weights (weighted probability) depending on the likelihood of occurrence for those particular classes. In this project equal probabilities were used since there was no reason to expect higher probabilities for any class.

Supervised classification was done using all bands except the TIR band (Band 6). For Landsat 7 the panchromatic band (Band 8) was also excluded. Using the DEM as a complementing band, and exclusion of the blue band (Band 1) was also tried and evaluated. Two post-classification filters (3×3 pixels) were used to exclude very small areas, and the results were compared. Lastly some classes which were difficult to separate were merged.

Land cover classes

The land cover classes, with subclasses, used for classification are presented in Table 6. Several other classes and subclasses were evaluated but not used in the final classification. Built-up areas were, for example, not classified because their spectral characteristics were too similar to those of e.g. grassland, shrubland and scattered trees. The reason for the similarities is that settlements in the study area generally are very small with dirt roads, many trees and small houses which have roofs made of either grass or metal. The only larger settlement in the study area is a town called Shirati, and even there most houses are small and the main road is a dirt road. The central part of Shirati was manually classified and excluded from the study.

Because of the variations in soil colour and moisture over the study area some of the classes had to be divided into subclasses based on their appearance. For example cropland located on red soils was not possible to classify together with cropland located on light yellowish soils.

Table 6. Classification scheme showing the seven main land cover classes with subclasses and descriptions.

Land cover class	Land cover subclass	No of GCPs	Description
1. Closed woodland		40	Closed stands of trees. Tree cover >60%. Older trees appear darker and younger trees are more bright green.
2. Open woodland/thicket		58	Open stands of trees or bushes (3-7 m tall). Tree cover <60%. Often densely interlaced bushes or trees except along animal tracks.
3. Shrubland	3.1 On dark soil 3.2 On intermediate soil 3.3 On light soil	51	Open stands of shrubs (<2 m tall). Shrub cover >10%. Often traversed by animal tracks.
4. Grassland/bare soil	4.1 On dark soil 4.2 On intermediate soil 4.3 On light soil	39	Open areas with grass or bare soil and a shrub cover <10%. Often traversed by animal tracks.
5. Cropland	5.1 On dark soil 5.2 On intermediate soil 5.3 On light soil 5.4 On red soil	103	All land with different types of crops. The most common crops are maize, cassava and sorghum.
6. Seasonally inundated land		11	Lowland regions with wet clay soils, seasonally inundated. Covered with paddy rice plantations or shrubs.
7. Wetland	7.1 With vegetation	9	Wet swampy areas covered with mainly *Cyperus papyrus.*
	7.2 Disturbed wetland	2	Areas where the vegetation is disturbed
8. Water	8.1 Lake Victoria 8.2 Ponds	7	Smaller and larger water bodies. Lake Victoria and rivers appear dark, smaller lakes and ponds appear bright.
9. Flooded area		3	Recently or currently flooded areas.

Since agroforestry was implemented in many different ways, e.g. homestead tree plantings, boundary planting, rotational fallows etc. (see Appendix II), and the fields in general were very small and scattered, the agroforestry areas could not be classified separately.

Training areas

Training areas are polygons containing pixels of known identity. When performing supervised classification the training samples for a specific land cover class are used to identify pixels in the digital image that have a reflectance which corresponds to the reflectance of the training samples (Campbell 1996). It is of high importance that the selected training samples are representative for the land cover class. When creating training samples the spectral variation within the class, the position and the size need to be considered. Training samples should be placed at several locations in different parts of the image but they should not be placed on the border between two more or less distinct classes. The different training areas within a class have to be homogenous for all spectral bands used but still account for the spectral variation. Also, the total number of pixels of training samples for a class needs to be sufficiently high, but not too high. Campbell (1996) recommends the number of pixels for a class to be at least 100. This was fulfilled for all classes apart from those covering very small areas, e.g. water and disturbed wetland.

Since the maximum likelihood classification method is based on the assumption that the band data follow normal distribution, all bands were investigated before the creation of training samples. Training samples were first created for the most recent image, from 2013. The same samples were then modified to fit the earlier images, i.e. slightly extended if the area used to be larger, removed if the land cover was not there previously etc. After and during the creation of the training samples, each training sample was examined for homogeneity. Training samples were created for each of the subclasses in Table 6. When comparing the spectral signatures of each class (as an average of all subclasses) it is clear that the smallest difference is found in Band 1, the blue band (Figure 24). The classes are most distinguishable from each other in the last three bands.

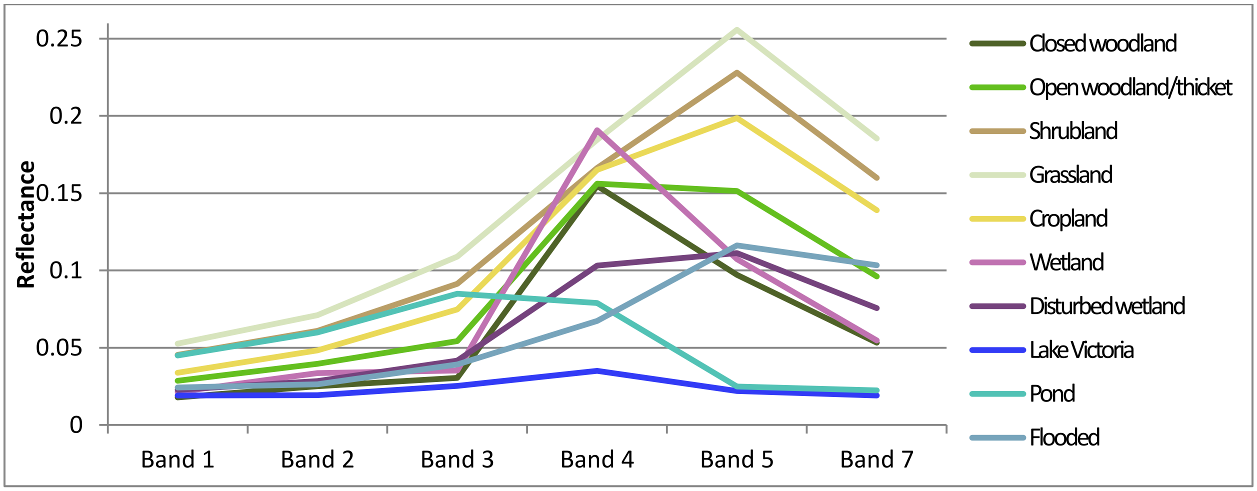


Figure 24. Signature comparison chart for the training samples. The largest spectral reflectance differences are found in Band 4 (NIR) and Band 5 and 7 (SWIR).

Figure 25 shows the relationship of the training pixels between the NIR band and the green band. Some classes are distinct in their spectral characteristics (e.g. water, flooded areas in 1986 and 2013) whereas others overlap. The biggest overlap is between seasonally inundated land and cropland. These two classes, therefore, had to be separated by other means than just their spectral differences.

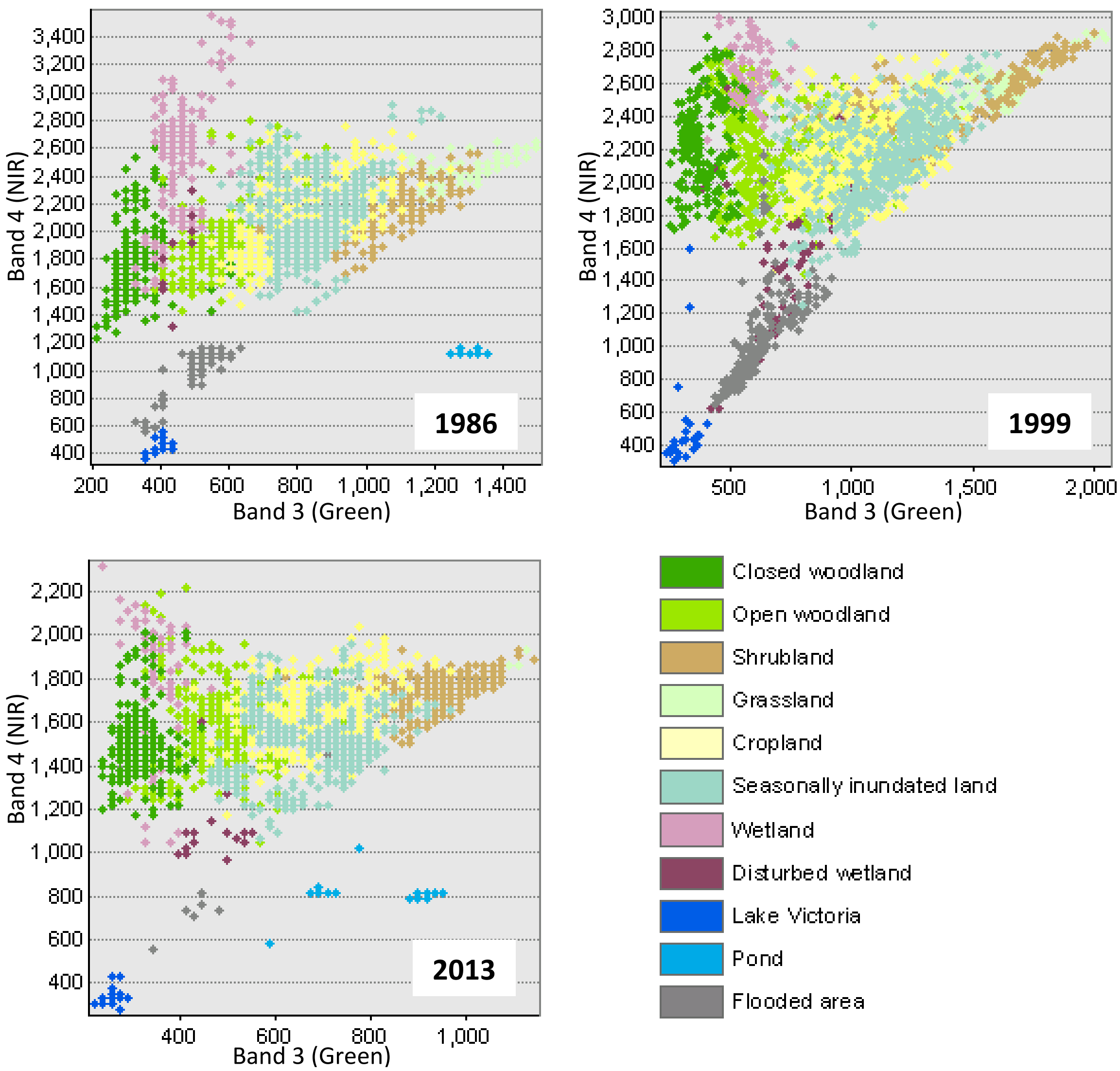


Figure 25. Scatter plots displaying the spectral signatures of the training areas. It is clear that wetland overlaps woodlands and that seasonally inundated land overlaps e.g. cropland. These areas had to be treated separately, which will be discussed later.

Accuracy assessment

The most widely accepted way of representing thematic accuracy is the error matrix (Congalton & Green 2009). An error matrix, or confusion matrix, consists of ground control data and classified data arranged in rows and columns which facilitates the assessment of the relationship between them. Since control data only exists from 2014, the accuracy was only estimated for the 2013 classification. Four measures of accuracy were calculated, namely total accuracy, the Kappa value, and the producer's and user's accuracy. Total accuracy is calculated by dividing the total number of correctly classified points by the total number of points (Equation 9). It is a measure of the overall correctness of the map.

$$Total\ accuracy = \frac{\sum_{i=1}^{n} A_i}{N} \qquad \textbf{Equation 9.}$$

where A is the number of correctly mapped points and N is the total number of points. The value is normally given as a percentage.

Kappa gives information about the map quality. The kappa values ranges from -1 to 1. Perfect agreement between the ground control points and the map gives a kappa value of 1 whereas no agreement results in a value of -1. If the value is zero it means that the quality is the same as could be expected from chance, it is called random agreement. Kappa is calculated as follows:

$$\kappa = \frac{Nd - q}{N^2 - q} \qquad \textbf{Equation 10.}$$

where N is the total number of points, *d* is the sum of the correctly mapped points and *q* is the sum of the products between the number of ground control points and the number of map data points.

For the producer's accuracy the total number of correctly classified points from each category is divided with the total number of GCPs (Equation 11). This represents the probability that a land cover in reality has been classified correctly (Congalton 1991). The user's accuracy is calculated as the total number of correctly classified points divided by the total number of points classified as that land cover class (Equation 12). User's accuracy gives the probability that a point in the map classification is represented by the same land cover class on the ground. If the producer's accuracy is lower than the user's accuracy for one specific land cover class, that class is underestimated. If the relationship is the opposite, that class is overestimated.

$$Producer's\ accuracy = \frac{A_i}{B_i} \qquad \textbf{Equation 11.}$$

$$User's\ accuracy = \frac{A_i}{C_i} \qquad \textbf{Equation 12.}$$

where A is the number of correctly mapped points, B is the number of ground control points and C is the number of map data points.

4.3.2 RUSLE modelling

The different RUSLE factors were calculated separately and combined as shown in Equation 2. Figure 26 is a simplified flow chart of the modelling process. How the factors were calculated is described in the following sections.

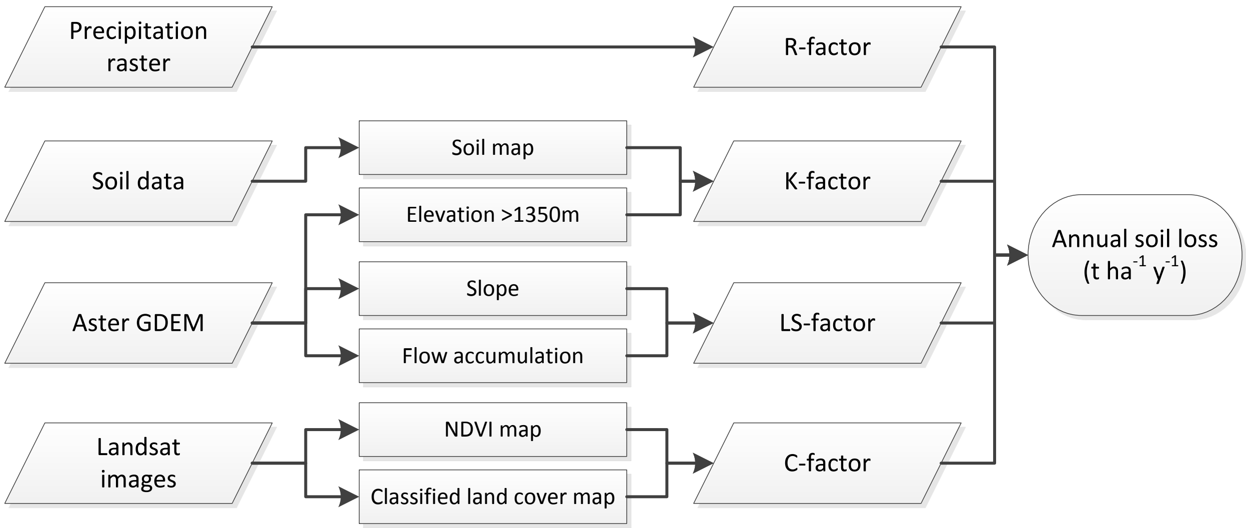


Figure 26. Flow chart showing the main products within the soil erosion modelling process. The calculations and procedures that lead to the final result have not been included.

Rainfall erosivity factor (R)

Rainfall erosivity is the potentiality of rain to erode soil particles (Wischmeier & Smith 1978). Since the development of USLE the most commonly used relationship to estimate rainfall erosivity was established by Wischmeier and Smith (1978). They based their equations on pluviograph measurements from 10 000 plot years (Wischmeier & Smith 1978, Meusburger et al. 2012). In their formula the rainfall kinetic energy and the rainfall maximum intensity of 30 minute intervals determine the transport of sediment during rainfall events (Morgan 2005, Wischmeier & Smith 1978). The transport is then averaged over a time period, usually a year, in order to get the rainfall erosivity.

However, because detailed rainfall time series rarely are available several alternative methods to estimate the rainfall erosivity have emerged (Meusburger et al. 2012). Arnoldus (1977) developed a relationship to calculate the R-factor based on Fournier's p^2/P-index (found in Fournier 1960). He chose Fournier's index because it requires only the annual and monthly precipitation. The following equation was derived from measurements in West Africa and modified to give R values for Morocco (Arnoldus 1977):

$$R = \sum_{i=1}^{12} 1.735 \times 10^{1.5\log_{10}\left(\frac{p_i^2}{P}\right)-0.08188}$$ **Equation 13.**

where *R* is the rainfall erosivity factor (unspecified metric unit), *p* is the monthly rainfall (mm) and *P* is the annual rainfall (mm). The equation has later been used by for example Khire and Agarwadkar (2014) and Dabral and Pandey (2008) in India, Essa (2004) in Jordan, and Fu et al. (2011) in China. Because of its widespread recognition and its simplicity, and because it agreed with the available data, Arnoldus' (1977) equation was used also in this study.

At the time when this equation was developed, the most commonly used metric unit was t m cm ha^{-1} h^{-1} y^{-1} and it can therefore be assumed that the resulting R-factor will be in this unit (Renard & Freimund 1994). To convert from t m cm ha^{-1} h^{-1} y^{-1} to the metric SI unit used in this study (MJ mm ha^{-1} h^{-1} y^{-1}) the result was first converted back to US customary units by dividing it with 1.735 (Arnoldus 1977) and then converted from US units to SI units by the multiplication with 17.02 as suggested in the supplement to Agriculture Handbook No. 537 (Wischmeier & Smith 1981) and in Foster et al. (1981).

In this study the focus is on variations in erosion caused by land cover changes, therefore the average rainfall data between 1950 and 2000 was used to calculate R. Thus the impact of the high interannual rainfall variability was removed. It should, however, be noted that this also removes the potential to calculate the actual soil loss of each individual year. The calculated R-factors of the study area vary between 5927 and 7902 MJ mm ha^{-1} h^{-1} y^{-1} and are shown in Figure 27. The values are in four-digit numbers which corresponds to the range suggested by Wischmeier and Smith (1981).

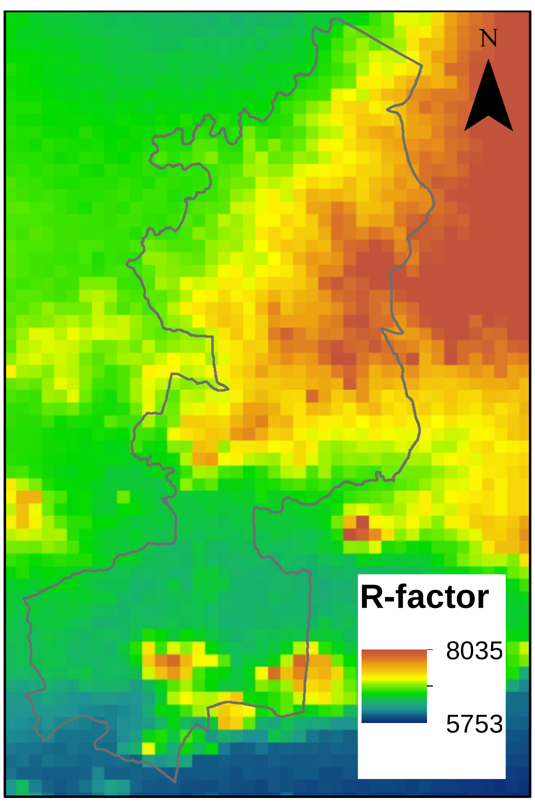


Figure 27. R-factor values. The minimum value within the study area is 5927 and the maximum value is 7902. The mean R-value within the study area is 6801.

Soil erodibility factor (K)

Due to complex interactions between a soil's physical and chemical properties soils differ in their inherent susceptibility to erosion (Stewart et al. 1976). Erodibility is a measure of this susceptibility, or resistance, to erosion when all other factors (that affect erosion) are equal (Mitchell & Bubenzer 1980). In USLE and RUSLE the erodibility is represented by the K-factor, which in this study is given in the metric SI unit t ha h ha^{-1} MJ^{-1} mm^{-1} (Römkens et al. 1997, Roose 1976). Generally, soils with high clay content have low K-values since they are resistant to detachment. Sandy soils also have low K-values even though they are easily detached, this because they produce low runoff (Kassam et al. 1992, Wischmeier & Smith 1971). Medium textured silt loam soils are moderately susceptible to detachment and produce moderate runoff and thus have intermediate K-values. The highest K-values are generally found amongst soils with high silt content since these soils are easily detached, tend to crust and produce high rates of runoff.

K-values based on direct measurements are preferable (Morgan 2005). During the early development of USLE K-values for different soils were established by measurements made for 23 major soil types in USA (Wischmeier et al. 1971). But because this process is time-, equipment- and cost demanding most studies have, since then, determined the K-values by approximations and estimations of the soil characteristics in relation to the 23 original soils (Mitchell & Bubenzer 1980). In order to simplify the determination of the K-factor for soils without prior research Wischmeier et al. (1971) developed the soil erodibility nomograph. The required inputs for this nomograph were however not available for the soil types assessed in this study. Therefore K-values were instead found in literature. This approach has been used for determination of erodibility in many studies (e.g. Gitas et al. 2009, Parveen & Kumar 2012).

For acrisols and planosols the K-values used in this study are mainly based on estimations made by Kassam et al. (1992). With slight modification of the Wischmeier and Smith's nomograph Kassam et al. (1992) estimated erodibility values for Kenyan soils and put together a table in which the average K-value can be determined from the soil texture and the soil type. The soil textures for the different soil types of the study area came from the gathered soil samples and each farmer's opinion on soil texture of his or her farmland. K-values for different soil textures were weighted depending on the occurrence of the texture.

The soil erodibility values in Kassam et al. (1992) are given in unspecified metric units and range from 0 to 0.8 which suggests that they are not in t ha h ha^{-1} MJ^{-1} mm^{-1} since R-values in t ha h ha^{-1} MJ^{-1} mm^{-1} should range downward from a maximum of about 0.09 (Wischmeier & Smith 1981). More likely the used unit is the one presented in the initial release of Agriculture Handbook No. 537 (Wischmeier & Smith 1978), where the conversion of the US customary unit ton force (tonf) was converted to metric units of metric ton (a mass unit) instead of the SI unit for force (Newton) (Foster et al. 1981). This mistake was corrected in the supplement to Agriculture Handbook No. 537 (Wischmeier & Smith 1981). To convert the metric values of Kassam et al. (1992) they were divided by Wischmeier and Smith's (1978) original conversion factor (1.292) and then multiplied by the new conversion factor (0.1317) (the same result is obtained by dividing the values by gravity, 9.81 m s^{-2}, which is suggested in APSIM 2014).

Final K-values for chromi-ferric acrisols and calci-hyposodic planosols are found in Table 7-8. The results fall within the typical range for K from about 0.007 to 0.059 t ha h ha^{-1} MJ^{-1} mm^{-1} (Foster et al. 1981, McCool et al. 1995). They furthermore agree with with FAOs generalized soil erodibility estimations which consider ferric acrisols to have relatively low erodibility whereas planosols that are not mollic or humic have higher erodibility (Young 1989).

Table 7. Soil erodibility values (K) for chromi-ferric acrisols. The table shows the percentage of different soil textures as obtained from soil samples and the farmer's opinions on their own soils. The K-value has been weighted according to the soil texture prevalence.

Chromi-Ferric Acrisols					
Texture	**Samples**	**Opinion**	**Total**	**Percent**	**K-value**
Sand	3	5	8	19%	**0.005** †
Sandy loam	7	7	14	33%	**0.029** *
Loam	0	2	2	5%	**0.043** †
Clay loam	1	0	1	2%	**0.029** *
Sandy clay loam	4	1	5	12%	**0.018** *
Sandy clay	2	2	4	9%	**0.011** *
Clay	3	6	9	21%	**0.018** *
Total:	20	23	43	**Weighted K:**	**0.0199**

* Value from Kassam et al. 1992

† Value from Mitchell and Bubenzer 1980

Table 8. Soil erodibility values (K) for calci-hyposodic planosols. The table shows the percentage of different soil textures as obtained from soil samples and the farmer's opinions on their own soils. The K-value has been weighted according to the soil texture prevalence.

Calci-Hyposodic Planosols					
Texture	**Samples**	**Opinion**	**Total**	**Percent**	**K-value**
Sand	0	6	6	13%	**0.005** †
Sandy loam	4	1	5	11%	**0.043** *
Loam	0	9	9	20%	**0.043** *
Clay loam	3	3	6	13%	**0.029** *
Sandy clay loam	2	3	5	11%	**0.029** *
Sandy clay	0	3	3	7%	**0.018** *
Clay	2	10	12	26%	**0.029** *
Total:	11	35	46	**Weighted K:**	**0.0292**

* Value from Kassam et al. 1992

† Value from Mitchell and Bubenzer 1980

Apart from clay and clay loam K-values for soil textures of the vertisols were not available in Kassam et al. (1992). The rest of the values were obtained from ARS's (1975) general K-value estimations for different soil textures, which are based on the nomograph (Mitchell & Bubenzer 1980). ARS's values are divided according to the percent organic matter content (OM). No field measurements to determine OM were made, but from field observations the OM appeared low for the dominating land cover (cropland). Most often cattle were allowed to eat all crop residues after harvest and nothing was added to the soils. Hence K-values for OM < 0.5% were chosen.

Vertisols are soil types with high clay proportion which are, unlike many other soils with high clay content, known for a relatively high susceptibility to erosion (Strahler & Strahler 2006, Deckers et al. 2001, Ahmad & Mermut 1996). These soils are prone to extensive cracking in the dry season when the clay minerals shrink (Strahler & Strahler 2006). When the rains return the cracks seal again and this often causes subsequent crusting that hinders water infiltration and thereby induces erosion (Mullins et al. 1987). The K-value for eutri-pellic vertisols should therefore be higher than for the other soils. The obtained value was 0.0314 (Table 9).

Table 9. Soil erodibility values (K) for eutri-pellic vertisols. The table shows the percentage of different soil textures as obtained from soil samples and the farmer's opinions on their own soils. The K-value has been weighted according to the soil texture prevalence.

Eutri-Pellic Vertisols					
Texture	**Samples**	**Opinion**	**Total**	**Percent**	**K-value**
Sand	0	3	3	13%	**0.005** †
Sandy loam	4	0	4	17%	**0.028** †
Loam	0	4	4	17%	**0.039** †
Clay loam	0	2	2	9%	**0.043** *
Sandy clay loam	1	0	1	4%	**0.028** †
Sandy clay	1	1	2	9%	**0.014** †
Clay	2	5	7	30%	**0.043** *
Total:	8	15	23	**Weighted K:**	**0.0314**

* Value from Kassam et al. 1992

† Value from Mitchell and Bubenzer 1980

In the study area there is also a fourth soil type, humi-umbric nitisols, which is only present in a small area. This area was never visited and there were hence no soil samples taken there. Consequently, the literature data could not be complemented with any field data on soil texture when determining the nitisol K-factor. In the work by Young (1989) generalized data is provided on erodibility classes of different soil types (divided into low, moderate or high). It is possible to determine a subsequent K-factor according to the textural class (coarse, medium and fine). With no knowledge on the actual texture the average of the three textural classes was used. The average K obtained for nitisols was 0.01. This value is consistent with values derived from the Wischmeier and Smith nomograph found in literature where the K-value for nitosols is low and varies around 0.01 (e.g. Khamsouk et al. 2002, Macharia et al. 1997).

Many of the upslope areas in the Mara region have a quite rocky surface (see Figure 15). Rocks on the surface will most likely reduce the soil detachment by rainfall, which decreases the erodibility. At the same time it might reduce the infiltration capacity which would increase the erodibility. Kassam et al. (1992) suggests that the K-value of areas with rocky surfaces should be multiplied with 0.7. Therefore the K-factor of upslope areas at an altitude of 1350 m or higher was multiplied with 0.7. Figure 28 shows the soil erodibility of the soils in the study area.

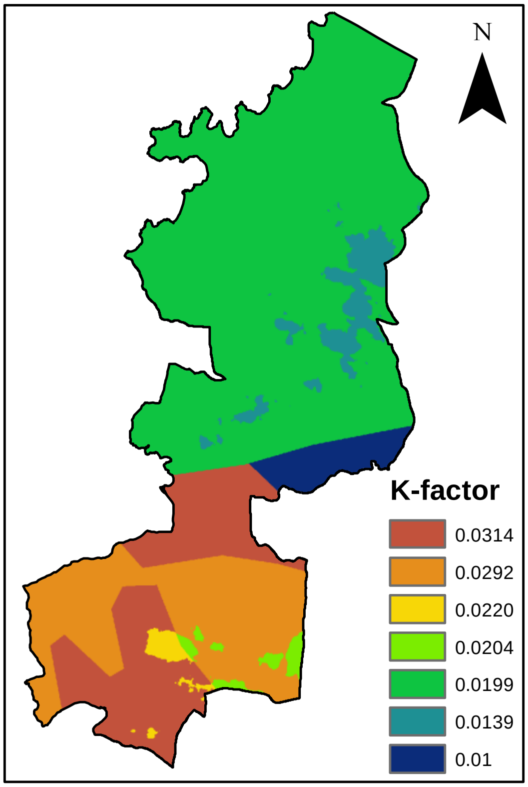


Figure 28. K-factor values for the different soils of the study area. Highland areas over 1350 m have 30% lower K-values because of the higher stone cover.

Topographic factor (LS)

When slope length and slope steepness increases it results in a higher speed of surface flow and, thus, increased soil losses (Oliveira et al. 2013). In RUSLE the erosion related to slope length is represented by the L-factor and the influence of slope gradient on erosion is reflected by the S-factor. The L- and S-factors are normally combined as one, unitless, index called the LS-factor or the topographic factor. The topographic factor is given by a purely empirical relationship and represents the soil loss ratio per unit area in a field slope compared to a default, uniform 9% slope with the length of 22.13 m under otherwise identical conditions (Renard et al. 1997, Wischmeier & Smith 1978).

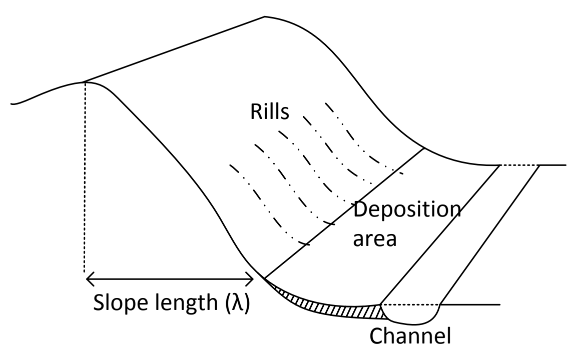


Figure 29. Schematic slope profile showing the slope length as it is defined in RUSLE calculations. Source: Modified from Renard et al. 1997.

In the original USLE and RUSLE the L-factor is derived from the slope length which is defined as the distance from the point of origin of the surface flow to the point where the slope has decreased enough for deposition to occur (Figure 29) or, alternatively, where the runoff water enters a well-defined channel (Wischmeier & Smith 1978). However, Moore and Burch (1986) argue that the original equations to calculate LS do not account for all transport mechanisms on the normally complex hillslopes geometries of the real world. They therefore developed unit stream power theory from which they derived a new equation to calculate LS. Based on the Moore and Burch's (1986) theory it is suggested that the topographic factor can be obtained by the following relationship, where the upslope drainage area is used instead of the slope length:

$$LS = \left(\frac{A_s}{22.13}\right)^m \left(\frac{sin\beta}{0.0896}\right)^n$$ **Equation 14.**

where A_s is the specific catchment area, i.e. the upslope contributing area per unit width of the contour (or rill) (m^2 m^{-1}), β is the local slope (in radians), and *m* and *n* are adjustable values depending on the soil's susceptibility to erosion. The values of these exponents vary in the literature, it appears as *m*=0.4 and *n*=1.3 are the most commonly used values. Therefore these values have been used in this study. The two denominators, 22.13 and 0.0896, come from the default slope mentioned above.

Before applying Equation 14 the specific catchment area and slope had to be calculated. The specific catchment area can be estimated by multiplying the flow accumulation with the cell size (or more specifically: flow accumulation$\times 30^2/30$ if the cell size is 30 m). The flow accumulation was derived using the triangular form-based multiple flow (TFM) algorithm developed by Pilesjö and Hasan (2014). The TFM algorithm simulates overland flow in a realistic way by dividing each raster cell from where the flow routing takes place into eight triangular facets. It allows overland flow into all surrounding cells with lower values, instead of only into the one surrounding cell with the lowest value which many other flow algorithms does. Experiments have shown advantages of the TFM over other commonly used flow algorithms such as for example the deterministic eight-node (D8) algorithm used by ArcGIS (Pilesjö & Hasan 2014).

Surface runoff normally becomes concentrated in well-defined channels in less than 120 m (occasionally up to 300 m) according to Renard et al. (1997). Since RUSLE only is suitable for rill and interrill erosion the slope lengths should be limited to about 120 m and only few slopes as long as 300 m should be used (Renard et al. 1997). An upper bound on the specific catchment area was therefore set to 150 as suggested by Engel (2003). All values above the maximum value where set to 150. The resulting LS-values ranged from 0- 27.9 and are found in Figure 30.

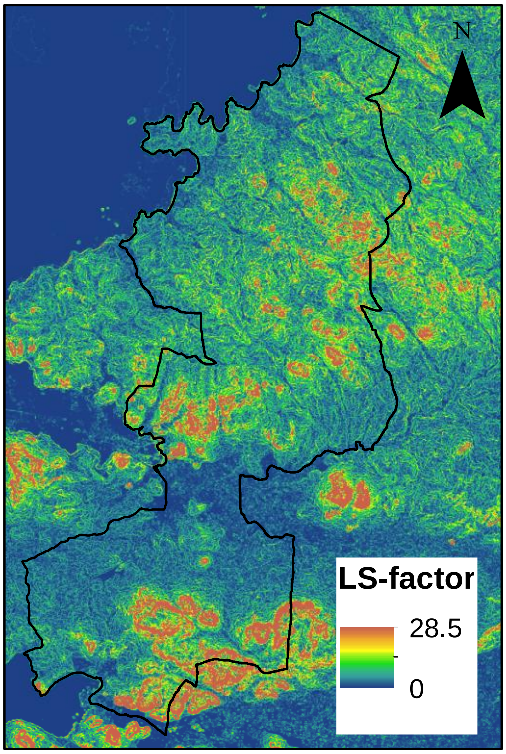


Figure 30. LS-factor values. The minimum value within the study area is 0 and the maximum value is 27.9. The mean LS-value within the study area is 1.38.

Cover management factor (C)

The cover management parameter (C-factor) depends to a high degree on human activity. It is an important factor in the RUSLE equation, especially when it comes to time series analysis (Karaburun 2010). The C-factor should denote the impact of vegetation and soil cover/type, roots, management and growth stage on rainfall energy interception and soil loss (Gitas et al. 2009, Morgan 2005). It is defined as the ratio of soil loss from a particular land area under certain conditions to the soil loss of a standard area (under tilled continuous fallow) (Wischmeier and Smith 1978, Renard et al. 1997). The scale ranges from 0 to 1, the C-factor for a plot is determined by how much it deviates from the standard plot.

In the original calculations the parameter was determined by the combined effect of a number of variables, namely the canopy cover, the ground (surface) cover, the soil surface roughness, the ridge height, the daily soil biomass, the soil consolidation and the antecedent soil moisture (Jones et al. 1996). This required inputs from field measurement data of ground cover which in turn requires a substantial amount of resources and time (Karaburun 2010). For this reason different scientifically based estimations of the C-factor have been presented by researchers. Some of them are using correlation analysis with vegetation indices such as NDVI (Van der Knijff et al. 1999) while others use k-nearest neighbour algorithms (Zhou et al. 2008) or crop coefficients to estimate canopy cover at different growing phases (Allen et al. 1998). Common for all methods is that they are developed with vegetation cover as a basis.

Since the aim of this study is to determine the effect land cover change has on erosion separate C-values for each land cover class were required. The C-factors were determined as an average of C-factors from literature and C-factors calculated from NDVI. By averaging the calculated NDVI-values with the literature values, possible local variations in vegetation dynamics are better accounted for. These could otherwise be lost when using general C-values. To solely base the C-factors on NDVI does not fully represent all features of vegetation. It does, for example, not include forest soil cover or plant residues (Suriyaprasit & Shrestha 2008).

When consulting literature, C-values should be obtained from studies in similar biogeophysical environments. In East Africa there is unfortunately not a wide selection of available studies with C-factor derivations although some exist, like for example Mati and Veihe (2001). Since Mati and Veihe's study did not contain all values needed, Morgan's (1995) comprehensive record, based on studies from different parts of the world with tedious field measurements of all the underlying variables, was consulted instead. The values were based on e.g. Wischmeier and Smith (1978), Roose (1976) from West Africa and Hurni (1987) from Ethiopia. Three land cover classes assessed in this project (seasonally inundated land, wetland and water) were not available in Morgan (1995). A couple of other studies were therefore chosen as references for wetland (Smulyan 2010, Mårtensson 2009) and water (Ligonja & Shrestha 2013). The major part of the seasonally inundated land was occupied by rice paddy agriculture. Consequently the C-value for this land cover class was based on such values from a number of studies (Morgan 2005, Shi et al. 2002, Chen et al. 2012, Kuok et al. 2013).

There are two common methods for calculating C-factors from NDVI values (Suriyaprasit & Shrestha 2008). Both of them are based on regression functions but the difference is that one of them is linear (least square) (de Jong 1994) and the other one exponential (Van der Knijff et al. 1999). A number of studies have calculated the C-factor using the linear regression (Karaburun 2010, Lin et al. 2008, de Jong 1994). Van der Knijff et al. (1999) derived an exponential equation in order to obtain a better relationship between NDVI and the C-factor. This method was employed for estimation of the C-factor in each of the three years as follows (Gitas et al. 2009, Van der Knijff et al. 1999):

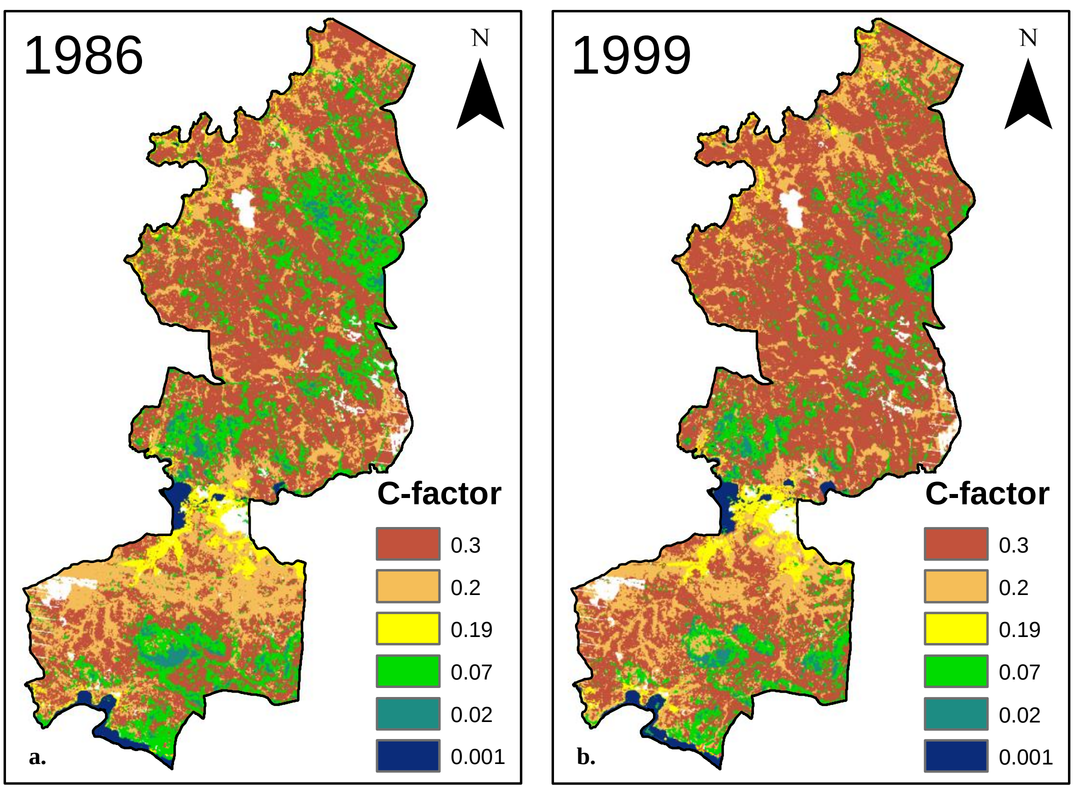
$$C = exp\left[-\alpha \times \frac{NDVI}{(\beta - NDVI)}\right]$$ **Equation 15.**

Where α and β are unitless parameters that determine the shape of the correlation curve of NDVI and the C-factor. Van der Knijff et al. (1999) recommends a scaling of 2 for the α parameter and 1 for the β parameter for Italy and Europe (Van der Knijff et al. 2000), these values has also been used in Greece by Gitas et al. (2009) and Kouli et al. (2009) as well as in Uganda by Jiang et al. (2014). There are also other exponential functions that have been used for estimating C-factors in for instance Thailand by Suriyaprasit and Shrestha (2008) but the method presented by Van der Knijff et al. (1999) was chosen because of recognition and frequent use.

The raster of NDVI-derived C-values was combined with the produced land cover classification map. This was done so that the mean C-values from the NVDI derivation could be determined for each land use class. Subsequently, the average was calculated from these mean C-factors and the corresponding values from literature. The resulting values are shown in Table 10. Flooded areas were removed from the final C-factor layer (Figure 31) since the extent and location of these areas varied greatly between the years, which would introduce misleading changes in the soil erosion modelling.

Table 10. C-factor values of the different land cover classes. The values are an average of the C-factor value calculated from Equation 15 and values from literature.

Land cover	C-factor
Closed woodland	0.02
Open woodland and thicket	0.07
Shrubland and grassland	0.2
Cropland	0.3
Seasonally inundated land	0.19
Wetland (and disturbed wetland)	0.001
Water	0.001
Flooded area	-



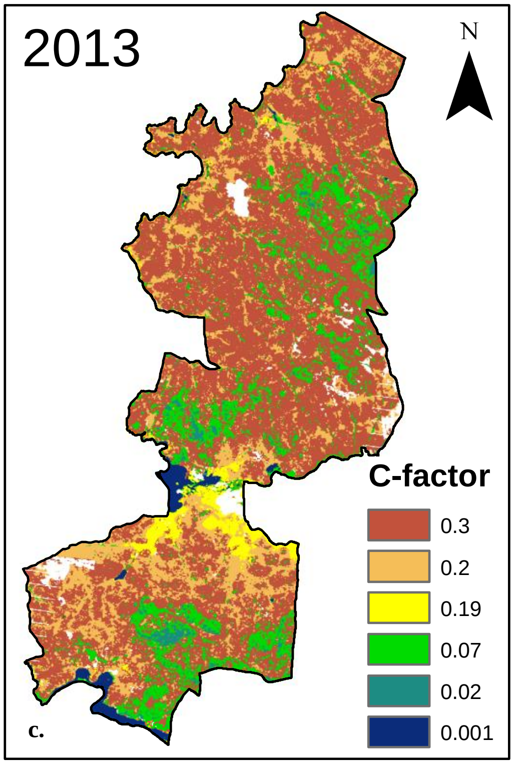


Figure 31. C-factor values of the study area in (a) 1986, (b) 1999 and (c) 2013. The average C-value for each year were 1986: 0.220, 1999: 0.235 and 2013: 0.237

Conservation practice factor (P)

The conservation (or support) practice factor (P-factor) represents the control practice that reduces soil erosion by water runoff (Gitas et al. 2009, Roose 1976). It is estimated as the soil loss ratio between a base plot with tillage up and down a slope (farm practice presumed to cause the most erosion) and another plot with a specific kind of erosion control management (Wischmeier & Smith 1978, El-Swaify et al. 1982). Examples of management for control of soil loss are terracing, contouring and contour strip cropping.

The P-factor is often claimed to be the RUSLE parameter which is most difficult to determine due to the sensitivity of runoff erosivity to changes in erosion control practice (Agassi 1996, Renard et al. 1997). It is also difficult to document small changes which may have great impact on soil loss. These facts also make the conservation practice factor the least reliable factor (Renard et al. 1997).

In the Mara region, soil protection measures for the land are rarely taken and where it occurs, for example when agroforestry has been introduced, the areas are small and fragmented. There are no clear definitions or groups of control practices and many of the traditional techniques involve planting of vegetation and management of crop residues that would be partly considered in the C-factor (Renard et al. 1997). Due to these and aforementioned circumstances along with lack of satisfactory data it was decided to set the P-factor to a value of 1 for the whole study area.

5. Results

5.1 Interview outcomes

5.1.1 Rural life in numbers

The respondents represented their households which on average consisted of 7.4 people. Totally 64 households were visited, 44 of the respondents were men and 20 were women. The majority of the respondents belonged to the Luo tribe (63%) and Kuria/Simbiti/Hacha (35%) which roughly corresponds to the proportions of the total population in Rorya. The average age of the respondents were 45.5 years old and 68% of them had finished primary school, 14% had finished secondary school, 11% had higher education and 8% had not finish primary school. On average three people from each household were involved in farming activities full time.

All except two of the farmers claimed that they owned their farmland and the median size of total farmland was 1.6 ha (mean was 1.8 ha). The majority of the interviewed farmers (84%) were practicing agroforestry, had practiced agroforestry in the past or had plans to start in the near future. The median size of agroforestry land was about 0.8 ha (mean was 1 ha). On average, the respondents had been farming their land for 22 years.

Both Luo and Kuria are traditional livestock keepers and 72% of the farmers kept cows, 55% kept goats and 36% kept sheep. The average amount of animals per farmer was 12, 8, and 15 for cows, goats and sheep respectively. 91% of the farmers also kept poultry. The majority of the livestock was grazing freely at daytime, on common land and sometimes on the private farms (Figure 32). At night the animals were tied up. In Luoimbo each household had on average nearly twice the amount of livestock compared to the households in Nyancha.

Figure 32. Livestock grazing on common land in Komuge ward. Photo: Århem 2014.

Staple foods in the villages were cassava, maize and sorghum and these were naturally the most commonly grown crops (Figure 33a-b). The traditional way of cooking was on open fires with three stones placed around to hold the pot. 60 of the respondents cooked most of their food in this way and they, thus, used mainly firewood as cooking fuel. Eight households had wood saving stoves, i.e. a more energy efficient stove made of clay or bricks (Figure 33c). Three households claimed that they mainly used charcoal as cooking fuel. The cereal crops were not irrigated in 97% of the farms but about 30% of the farmers watered vegetable crops and newly planted trees. In the whole study area 50% of the households managed to store some food for the household during 2013, although the majority of them did not have enough for more than a few weeks. In Kirogo six out of seven households did not have the possibility to store anything. In 2013 there were 28 households (29 in 2012) that could sell some farm products on the market. On average, these farms made ca 268 000 TZS (~USD 161) in 2013 and ca 189 000 TZS (~USD 113) in 2012. However, there were big gaps between the households regarding the revenues. The farm with the highest sales income made 1 600 000 TZS (~USD 963) and 1 500 000 TZS (~USD 902) in 2013 and 2012 respectively, which was more than double than the farm with the second highest income. 13 of the 28 farmers did not make more than 200 000 TZS (~USD 120) per year and rarely in two consecutive years.

Figure 33. Staple food in the study area. (a) Cassava planted in rows, a newly planted agroforestry tree can be seen in the foreground. (b) Woman preparing maize. (c) Wood saving stove, a more efficient stove which both decreases the amount of time and firewood needed for cooking. It also has health benefits since it reduces the indoor smoke by redirecting the emissions outside through a chimney. Photos: Århem 2014.

5.1.2 Farmers' experiences

After having visited 64 households in Rorya some general conclusions about the farmers' perceptions could be made. When asking about deforestation, 73% of the farmers explained that deforestation was going on in the area where they live. Several respondents had observed that almost all the big trees on hills were now gone. The majority of them said that the deforestation started in the early 1990's but various respondents also felt that it started more recently. Many of those who replied that there was no deforestation in their area were living in the north-western part of Nyancha where there has never been woodland (at least not recently). A few farmers said that the deforestation had stopped in their area because there are no trees left to cut down.

Several farmers explained that the increased rates of deforestation are caused by the lucrative charcoal business (Appendix I). Many people are involved in the business because of the relatively fast money (as compared to farming) thanks to the high demand and high prices. For many farmers the making of charcoal was a way to ensure their food supply in drier years or to pay the secondary school fees for their children. The households in Luoimbo which were located close to the tarmac road that goes northwards to Tarime claimed that deforestation accelerated after this road had been constructed in 1996.

According to many respondents the land cover changes do not only include the changes in woodland extent. The main change is the increased extent of agricultural land. Open woodland, thicket, grass- and shrubland (grazing land) have been cleared to make way for new farms as the population density has gotten higher. Quite a few respondents feared that the land scarcity will get worse in the future. Some farmers complained about conflicts with other farmers that let their cattle graze everywhere, even on other people’s farmland. Generally, people can have their cattle grazing on land that belong to others but not when there are crops on the fields. About 70% of the farmers explained that they had seen signs of overgrazing such as erosion (rills and gullies) and decrease in productivity of the grazing lands.

Among the farmers living by the coast, quite a few explained that there used to be many fishermen, including themselves. But due to large fishing companies’ exploitation of Lake Victoria there is not enough big fish left to make a living for many small-scale fishermen. The breeding grounds have also been destructed by cyanide fishing. Consequently a lot of people stopped fishing and had to start farming and/or solely rely on agriculture, which, in turn, further increased the pressure on the land.

Another recognizable concern for many households was the climate change. All households but one, 63 households, claimed that the climate today was different compared to ten years ago. The most commonly believed reason for the climate changes was the deforestation of the woodlands (a belief held by 79% of the respondents). Only 6 farmers recognized the potential influence of emissions from industrialized countries. The changes in climate had led to additional fear and worries about the future for as many as 80% of the respondents. Since irrigation is uncommon farmers are highly dependent on the timing and amount of rainfall every season. As can be seen in Figure 34, 73% of the farmers felt the rainfall was more unpredictable today compared to before. This increased unpredictability was especially worrying as it led to miscalculations of when to plant the crops which sometimes resulted in a complete crop failure. The majority (86%) of the respondents felt that the total rainfall and the length of the rain seasons had decreased. The northern ward Tai was the only ward where people had different perceptions, i.e. that the rainfall had either not changed or increased.

The temperature and windiness were also, like the unpredictable rainfalls, in general perceived as increasing (Figure 34). Increased temperatures and decreased total rainfall means a drier climate in general. Increased wind speeds and unpredictable, heavy rainfalls in a drier climate can lead to more erosion. With the changing climate the farmers have observed a resulting change in the landscape towards more erosion and less green pastures. 64% felt that the droughts had increased, only 6% of these were living in the northern wards of the study area, the remainder lived in the wards Kirogo, Komuge and Rabour. Problems related to climate change and droughts were in general much more apparent in Luoimbo than in Nyancha.

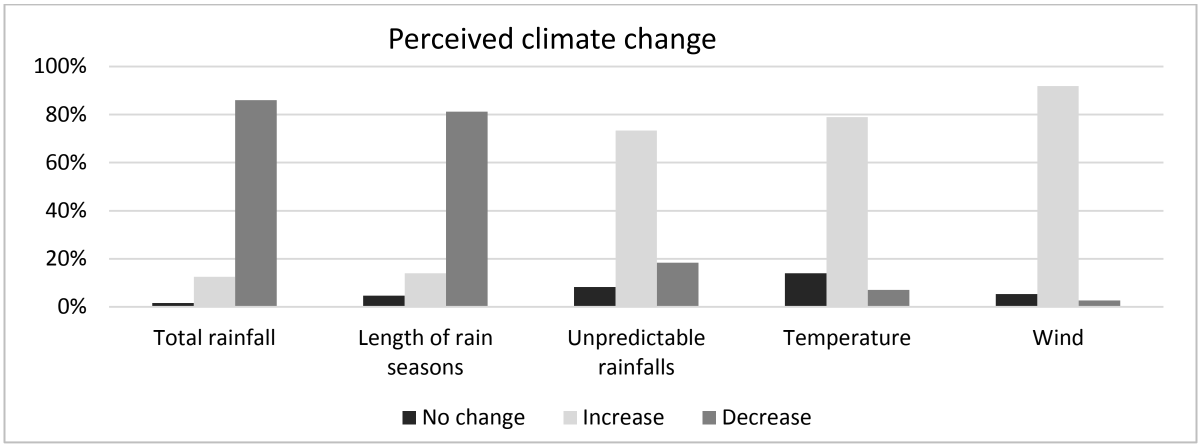


Figure 34. Climatic changes over the past ten years, as perceived by the 64 interviewed farmers.

The majority of the farmers interviewed were or had been in contact with Vi Agroforestry or MVIWANYA. Thus, most of the farmers were or had been practicing some kind of agroforestry. Only 13 households had never practiced agroforestry. When asking about erosion on the farmers' cropland the majority of both the agroforestry and non-agroforestry farmers, 58% and 55% respectively, explained that they used to have erosion ten years ago (Figure 35). Over the past ten years this had changed and the proportion of agroforestry farmers with erosion problems has decreased to 38% whereas the non-agroforestry farmers with problems have increased to 64%. The agroforestry farmers saw the introduction of agroforestry as the main reason for reducing erosion in their farmland. Most of them made a clear distinction between their own land and common land. When questioned about the situation on common land the general perception was that the erosion problems were still prevalent or had become worse. Many had borne witness to "growing stones" a phenomenon seen when the soil around the stones dissapear due to erosion.

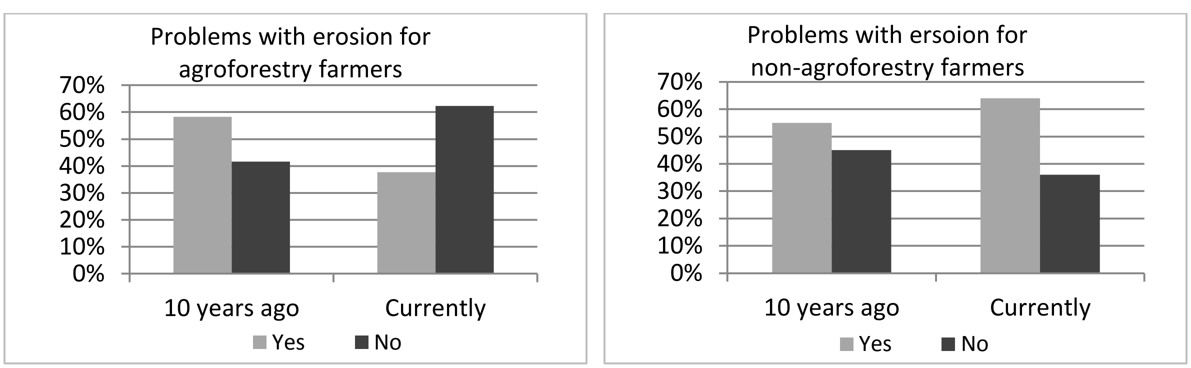


Figure 35. Changes in farmland erosion over the past ten years, as perceived by the 64 interviewed farmers. There were 51 agroforestry farmers when including farmers who had only a few trees, farmers who started with agroforestry less than two years ago etc. The number of non-agroforestry farmers was 13.

Out of the 64 households asked 37 (58%) either bought or collected fuel wood from nearby woodlands. Naturally, all of the non-agroforestry farmers belong to this group but there were also many who practiced agroforestry but still acquired fuel wood from outside of their own farmland. 70% of them had not been practicing agroforestry for more than 10 years and the majority of them explained that they were planning to get self-sufficient as soon as more trees were mature or planted. More than half of the farmers that did not practice agroforestry had plans to start within the near future.

5.1.3 Regulations and officials' perceptions

The employees at the Ministry of Natural Resources stressed the importance of conserving the woodlands of the Mara region. Two of the reasons are the soil conservation provided by trees and the improvement in local climate that trees give. They explained that soil erosion is high in the Mara region and that it causes pollution and siltation of the lake. This leads to destroyed fish breeding grounds and eutrophication. Another adverse consequence which they mentioned was the lowered productivity of cropland when top soils are removed.

They confirmed that soil erosion and deforestation in the Mara region have been steadily increasing. Climate change is seen as one contributing factor to the decrease in woodlands since, according to their observations, the trees use to grow vigorously before but now they grow more slowly. Deforestation, they said, is more prevalent close to the lakeshore where the population density is high and since fisheries require a lot of wood. Just like the farmers they recognised the area along the tarmac road that was completed in 1996 (which improved accessibility especially in Kirogo) as another area with increasing rates of deforestation.

According to national forest laws it is prohibited to cut down trees in woodlands without a permit. A person with no permit is only allowed to collect dead branches and roots. Still, illegal logging, which is also increasing, makes up the major part of the deforestation. The interviewees say that around 80% of the tree cutting is going on without a permit. Currently there are local committees in every ward that are responsible for permit regulations concerning forest protection. These committees have been appointed by the local community in order to ensure that people are aware of the rules. There are also forest officers that guide the committees in their work and hand in status reports to the local government. However, each community are to a large extent able to establish their own rules on forest protection, the rules are hence more or less different for each forest.

The respondents from the Ministry of Natural Resources claimed that most laws and regulations are not known to ordinary people. The problem is not that the laws are weak but that they are not implemented. It lies within the responsibility of the Ministry of Natural Resources to control violation of the forest laws and there is a forest police force since 1988. Controls are made twice a week (when they manage to get transportation) but they realize that it is far from enough. Governmental funds are low and therefore they cannot afford to allocate more time or money to hire more staff. One major dilemma is that the authorities cannot offer any sustainable alternatives to woodfuel. The population is not able to stop cutting trees or buying charcoal since most of them cannot afford any of the alternative energy sources available such as kerosene or gas. In order to solve the issues the employees emphasize that the government needs to make more efforts for education about forest conservation, subsidise alternative fuels and invest in environmental protection. They think that the government has to allocate more money for this so that villagers can be compensated when reserves are established. At the moment there are only two forest reserves in Mara and both are located outside of the study area of this project.

5.2 Classified land cover: 1986, 1999, 2013

The final maps produced by the land cover classification show a landscape dominated by agricultural land, shrubs and grassland (full cover maps are presented in Appendix IV). The northern part of the study area, which has a higher population density also has more cropland, whereas the southern part has higher shrub- and grassland cover (Figure 36).

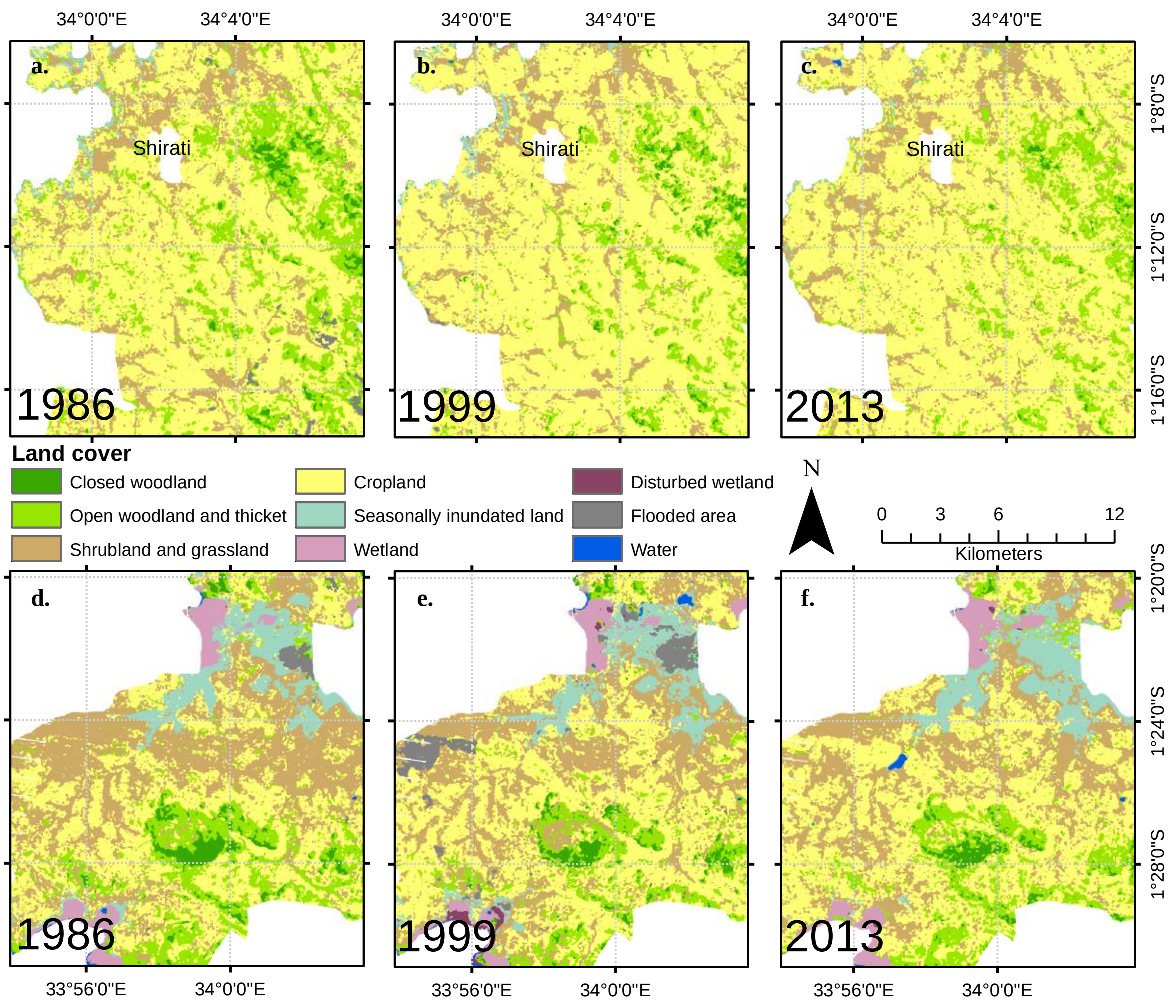


Figure 36. Cut outs from the produced land cover maps. (a-c) The northern part of the study area which has a high proportion of cropland. (d-f) The southern part of the study area where shrub-and grassland is common.

Seasonally inundated land, where paddy rice plantations are common, is dominating the area around the Mori River in the central part of the study area (Figure 36d-f).

There were some flooded areas in all the three years, in 1986 the flooded areas were mainly located in the mid-eastern part of the study area (Figure 36a) and in 1999 they were located in the south western part (Figure 36e). For full extent see Appendix IV.

The majority of woodland areas are confined to higher altitudes, often on hilltops. Some tree covered areas are also found along some of the many streams. Three areas with continuous woodland can be distinguished, one in the north-eastern part of the study area, one in the central part and one in the southern part (Figure 37). The names of the hills in the map come from old maps and conversations with locals.

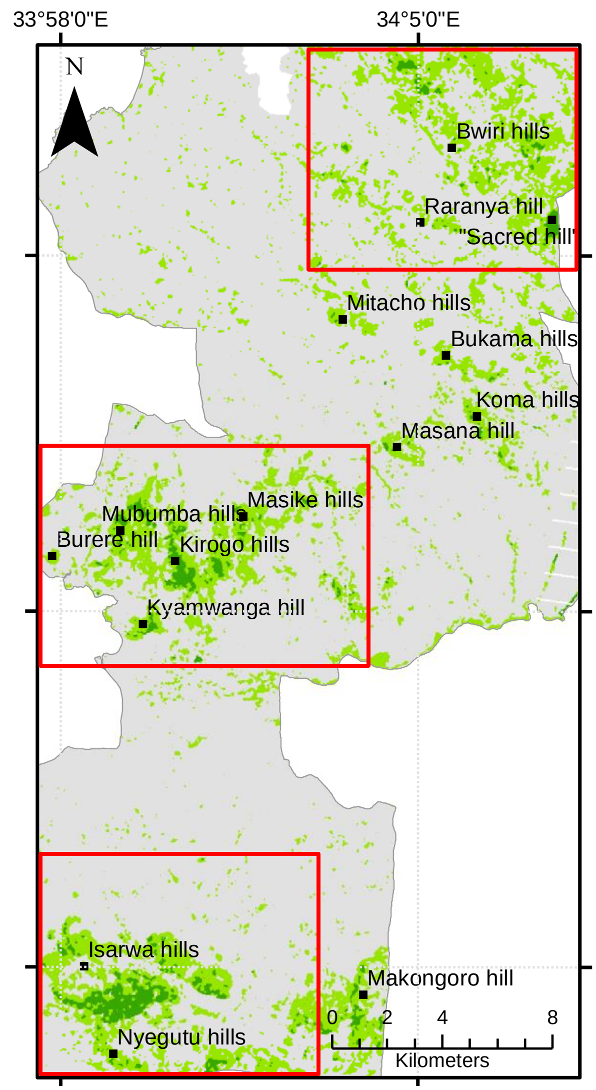


Figure 37. The three woodland areas within the study area. The map shows the estimated extent of closed woodlands (dark green) and open woodlands (light green) as of 2013.

5.2.1 Accuracy of the maps

Total accuracy and the Kappa values of the produced land cover maps for 2013 are found in Table 11. In total seven different maps were produced and evaluated but only the map with the highest accuracy has been presented. The highest accuracy obtained was 87.3% and the highest Kappa value was 0.84. These values were obtained after combining two maps, using two post-classification filters and after merging shrubland and grassland into one class. The combination of the two classified maps was done by adding the classes confined to lowland regions (i.e. seasonally inundated land, wetland, water and flooded areas) from the classification when the DEM was included, to the map classified without using the DEM. This was done since seasonally inundated land, wetland, water and flooded areas got the highest user's and producer's accuracy when all Landsat bands were used together with the DEM (Table 12), but for all other classes the results looked better without using the DEM. Another classification was performed without the blue band (Band 1; because the spectral differences between the classes was very small in this band). However, the resulting total accuracy and kappa value without the blue band were low (70.6% and 0.64, respectively).

Table 11. Type of post classification correction, total accuracy and Kappa values for the different classifications of the 2013 satellite image. In total seven maps were produced and evaluated.

	Post classification correction	Total Accuracy	Kappa value
Combination*	2 3x3 filter + class merging	87.3%	0.835
Combination*	2 3x3 filter	83.0%	0.789
Combination*	1 3x3 filter	82.4%	0.782
Combination*	-	81.4%	0.770
Bands 1-5, 7 and DEM	-	79.6%	0.748
Bands 1-5, and 7	-	72.8%	0.667
Bands 2-5, and 7	-	70.6%	0.639

*Combination of the two classifications with all bands+DEM and all band but no DEM

The method with lowest overall user's and producer's accuracy is the classification without the blue band (Table 12). The average user's and producer's accuracies neither increased nor decreased considerably after post-classification filtering. However, when considering the user's and producer's accuracies together with the total accuracy and kappa value, the combination plus two 3×3 filters was chosen as the best produced land cover map. For this combined map with two post-classification filters the lowest user's accuracies were obtained for shrubland and for grassland. Shrubland also had very low producer's accuracy. Since these two classes were easily mixed up in the classification, which can be seen in the error matrix (Figure 38), they were merged together into "shrubland and grassland". The user's accuracy of shrub- and grassland was then increased to 88.8% and the producer's accuracy became 87.8%.

Table 12. User's accuracy (U.A.) and producer's accuracy (P.A.) for each land cover class of the different 2013 satellite image classifications. The classification in which shrubland and grassland were merged together is not included.

	No blue, no filter		All bands, no filter		All bands + DEM, no filter		Combination, no filter		Combination, 1 3x3 filter		Combination, 2 3x3 filter	
	U.A.	P.A.	U.A.	P.A.	U.A.	P.A.	U.A.	P.A.	U.A.	P.A.	U.A.	P.A.
Closed woodland	87.5%	52.5%	88.0%	55.0%	96.6%	70.0%	89.7%	87.5%	84.2%	80.0%	86.1%	77.5%
Open woodl./thicket	88.4%	65.5%	89.8%	75.9%	75.3%	94.8%	88.7%	81.0%	84.5%	84.5%	84.2%	82.8%
Shrubland	59.5%	49.0%	59.5%	49.0%	59.3%	62.7%	64.6%	60.8%	68.1%	62.7%	71.1%	62.7%
Grassland	68.9%	79.5%	71.7%	84.6%	72.5%	74.4%	71.1%	82.1%	72.7%	82.1%	75.0%	84.6%
Cropland	76.8%	83.5%	80.0%	81.6%	86.2%	78.6%	81.9%	83.5%	87.3%	86.4%	86.0%	89.3%
Seas. inundated land	46.2%	54.5%	50.0%	72.7%	91.7%	100%	91.7%	100%	91.7%	100%	91.7%	100%
Wetland	33.3%	100%	32.1%	100%	100%	100%	100%	100%	90.0%	100%	90.0%	100%
Water	100%	100%	100%	71.4%	100%	100%	100%	100%	100%	100%	100%	100%
Disturbed wetland	28.6%	100%	50.0%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Flooded area	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Average	**68.9%**	**78.5%**	**72.1%**	**79.0%**	**88.2%**	**88.1%**	**88.8%**	**89.5%**	**87.8%**	**89.6%**	**88.4%**	**89.7%**

The generated error matrix for the filtered combination classification (Figure 38) shows that, like for shrubland and grassland, the open and closed woodland were often mixed up. It can be seen that nine of the ground truth points that should have been mapped as closed woodland instead were classified as open woodland and five points that should have been classified as open woodland ended up as closed woodland. The two woodland classes still got higher user's and producer's accuracy than shrub- and grassland, and since they were more interesting for the study in general they were left as two separate classes. The error matrix furthermore shows that there are several areas of open woodland/thicket, shrubland and grassland that have been classified as cropland, and ten cropland points have been classified as shrubland and grassland.

		Reference data (GCP class)										
		Closed woodland	Open woodl./thicket	Shrubland	Grassland	Cropland	Seas. inundated land	Wetland	Water	Disturbed wetland	Flooded area	**Total**
Classified data	Closed woodland	31	5	0	0	0	0	0	0	0	0	36
	Open woodl./thicket	9	48	0	0	0	0	0	0	0	0	57
	Shrubland	0	0	32	4	9	0	0	0	0	0	45
	Grassland	0	0	10	33	1	0	0	0	0	0	44
	Cropland	0	4	9	2	92	0	0	0	0	0	107
	Seas. inundated land	0	0	0	0	1	11	0	0	0	0	12
	Wetland	0	1	0	0	0	0	9	0	0	0	10
	Water	0	0	0	0	0	0	0	7	0	0	7
	Disturbed wetland	0	0	0	0	0	0	0	0	2	0	2
	Flooded area	0	0	0	0	0	0	0	0	0	3	3
	Total	40	58	51	39	103	11	9	7	2	3	

Figure 38. Error matrix for the final classification, before class merging of shrubland and grassland. The numbers in the grey diagonal show the number of correctly classified points for each land cover class.

5.2.1 Land cover change

Between 1986 and 2013 it seems as the extent of cropland has increased whereas open woodland and thicket, shrubland and grassland has decreased (Figure 39-40). Cropland increased with 75.5 km^2 between 1986 and 2013 (Figure 39b). Water, wetland and seasonally inundated land have remained fairly similar in size. The total change for closed woodland was 9.2 km^2 which means the extent nearly halved during the study period, the area decreased from 20.0 km^2 in 1986 to 17.9 km^2 in 1999, and finally to 10.7 km^2 in 2013.

Figure 40 clarifies the proportions of each land cover class. Overall the proportions remained fairly the same but there are some clear differences. Cropland constituted 51.6% of the study area in 1986 and 61.2% in 2013. Shrub- and grassland decreased from covering 18.2% of the study area to covering 13.4%, and closed woodland decreased from 2.5% to 1.4%.

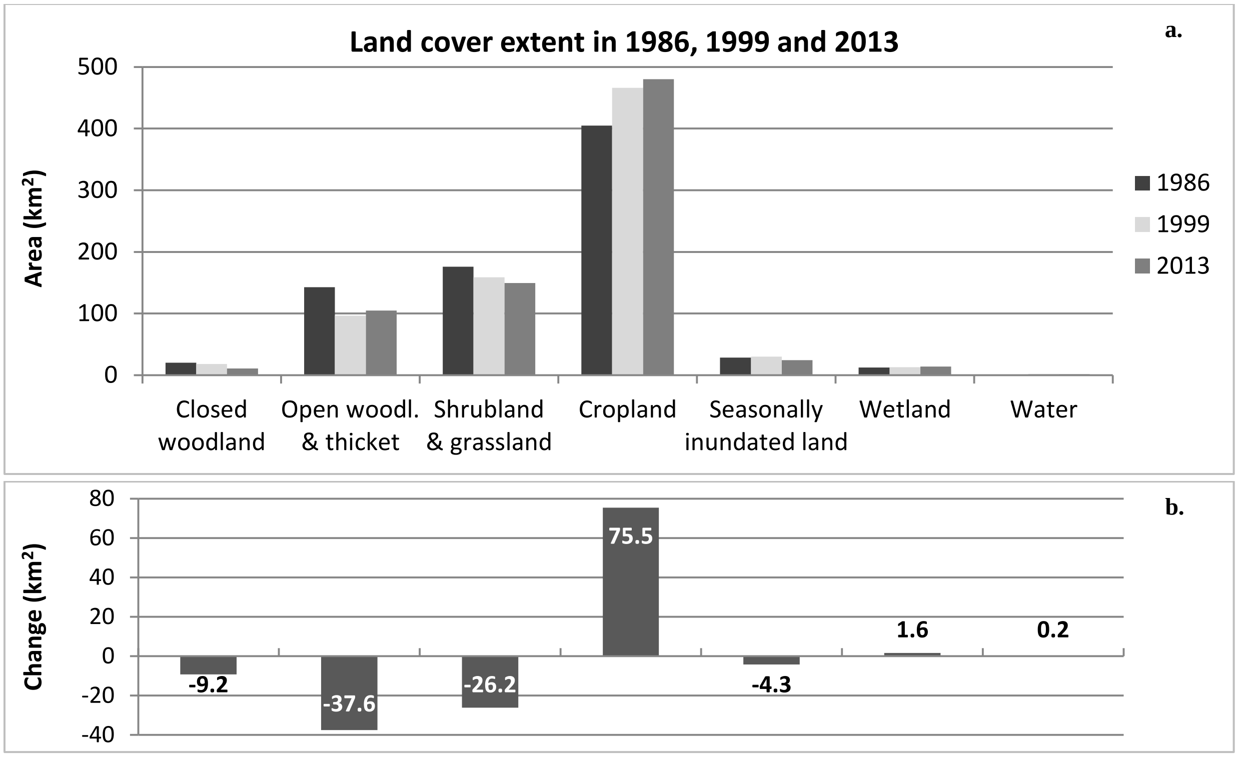


Figure 39. Land cover extent and changes. (a) Extent of the different land cover classes in 1986, 1999 and 2013. (b) The total change per land cover class between 1986 and 2013 (in km^2).

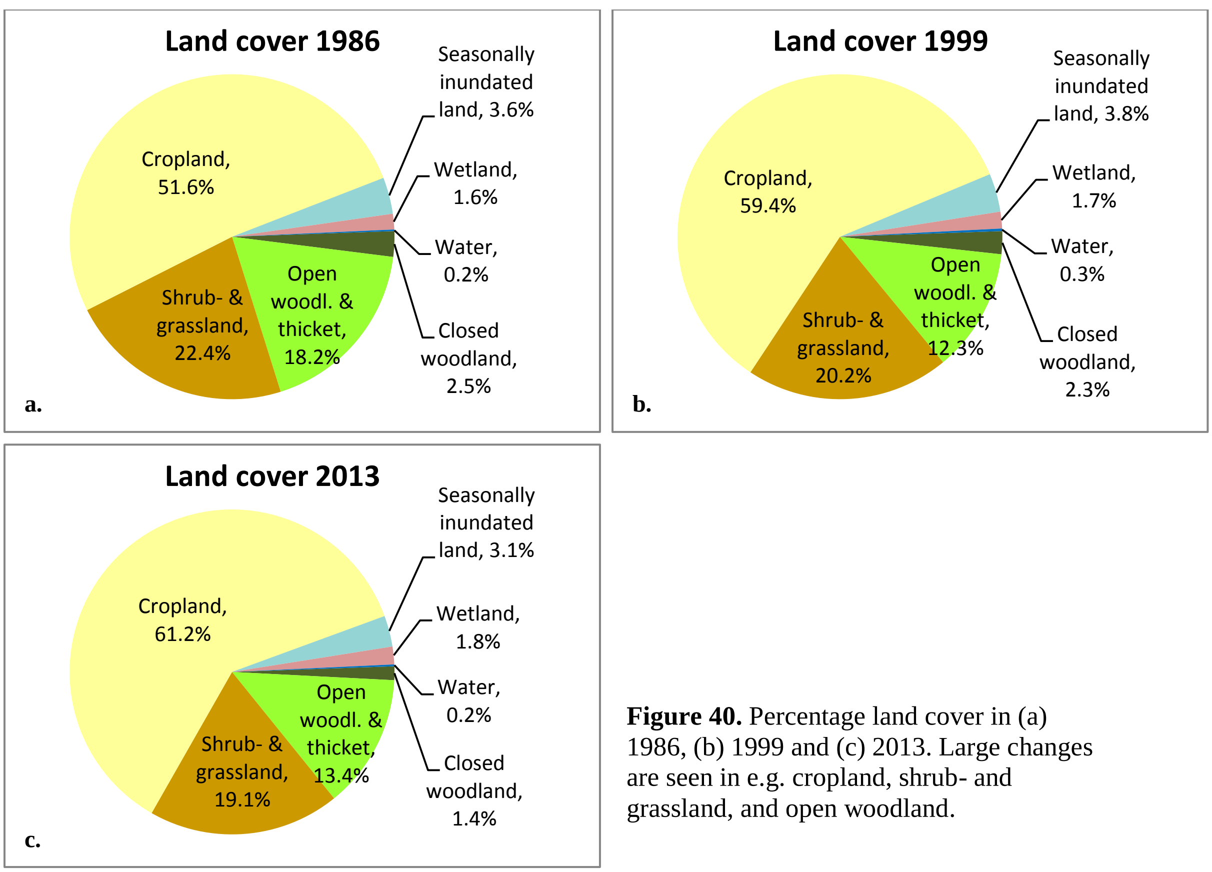


Figure 40. Percentage land cover in (a) 1986, (b) 1999 and (c) 2013. Large changes are seen in e.g. cropland, shrub- and grassland, and open woodland.

When studying each ward separately, closed woodland is constantly decreasing in all wards except Mkoma, Nyahongo and Rabour where closed woodland had a larger extent in 1999 than in 1986 (Figure 41a). The biggest change in closed woodland is found in Kirogo where the area is 2.2 km^2 smaller in 2013 than in 1986. In terms of percentage the largest differences are found in Bukura and Tai where only 24.6% and 28.0% of the 1986's closed woodland extent remains respectively (Table 13). Overall the decrease, in terms of percentage, is larger in the four northernmost wards (Bukura, Tai, Mkoma and Nyahongo) where the population density also is the highest. Overall 32.3% of the 1986 extent remains in the northern wards, compared to 61.9% in the four southernmost wards (Kigunga, Kirogo, Rabour and Komouge). This corresponds to a decrease in extent of about 3.7 km^2 in the north and 5.5 km^2 in the south.

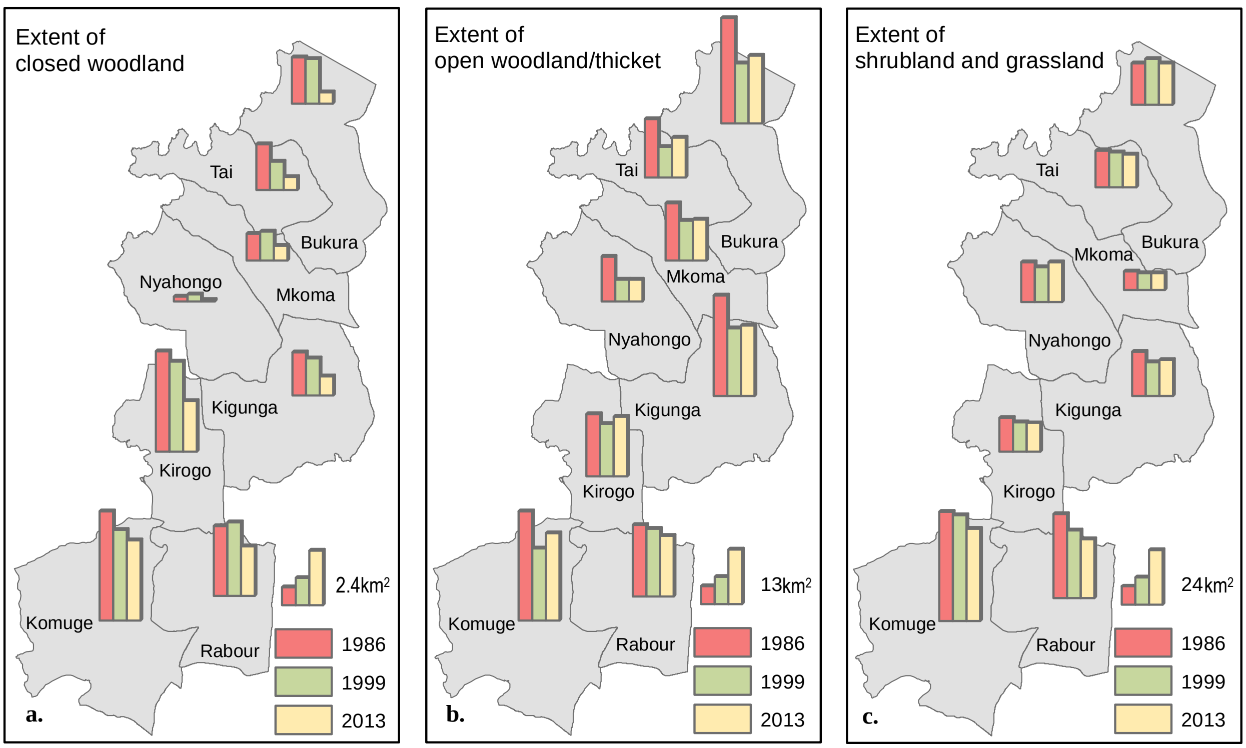


Figure 41. Extent of different land covers per ward. (a) Closed woodland, (b) open woodland and thicket, and (c) shrubland and grassland. The small bar charts in the legend show the scale.

For open woodland and thicket there is a total decrease in extent from 1986 to 2013, but the extent is generally smaller in 1999 than in 2013 (Figure 41b). The largest change occurred in Bukura where the decrease was 8.8 km^2 between 1986 and 2013. The smallest change is found in Kirogo where 95.3% remained (0.7 km^2 decrease). The open woodland of the four northernmost wards decreased with 22.2 km^2 compared to 15.4 km^2 in the southern wards.

Shrubland and grassland decreased from 1986 to 2013 in all wards (Figure 41c). In Mkoma, Nyahongo and Kigunga the area of shrub- and grassland was slightly smaller in 1999 than in 2013. The largest total decrease of shrub- and grassland is found in Rabour.

Table 13. The extent of 2013 compared to 1986 for some of the land covers, i.e. how much of the 1986 area remained in 2013. The changes in km^2 are shown within brackets. The four northernmost wards are above the line and the southernmost wards are below.

	Closed woodland		Open woodland/thicket		Shrubland and grassland		Cropland	
Bukura	24.6%	(-1.57)	64.3%	(-8.78)	99.2%	(-0.14)	117.9%	(11.48)
Tai	28.0%	(-1.47)	68.7%	(-4.28)	89.4%	(-1.66)	124.0%	(8.94)
Mkoma	54.0%	(-0.54)	71.3%	(-3.87)	92.8%	(-0.57)	113.3%	(5.40)
Nyahongo	29.0%	(-0.15)	49.6%	(-5.26)	99.6%	(-0.07)	108.5%	(6.28)
Kigunga	44.2%	(-1.08)	69.9%	(-7.08)	82.2%	(-3.41)	116.2%	(11.68)
Kirogo	50.5%	(-2.22)	95.3%	(-0.69)	84.8%	(-2.20)	118.0%	(4.58)
Komuge	73.5%	(-1.29)	80.1%	(-5.09)	84.6%	(-7.27)	125.7%	(14.60)
Rabour	71.1%	(-0.91)	84.6%	(-2.56)	70.1%	(-10.84)	136.2%	(12.50)

Figure 42 shows the changes in extent of closed woodland in the study areas' three largest woodlands. The red colour represent areas where woodland has disappeared, green represent newly established closed woodland areas and the grey areas have not changed during the study period. The figure suggests that the biggest change is the disappearance of closed woodland, but there are also some new woodland areas that have appeared. About Bwiri hills one middle-aged woman explained that when she was young the hills were completely covered with forest and no stones could be seen. At the time of fieldwork these hills were highly degraded and several columns of smoke from charcoal burning could be seen. Similar observations had been made by farmers living close to Kirogo hills and Kuruya hills. The hill referred to as the "sacred hill" was at the time of fieldwork still covered with closed woodland. One man explained that this hill was considered sacred by the ancestors and no one dared to cut down the trees. However, he explained, this seemed to be about to change as he had seen recent cuttings there.

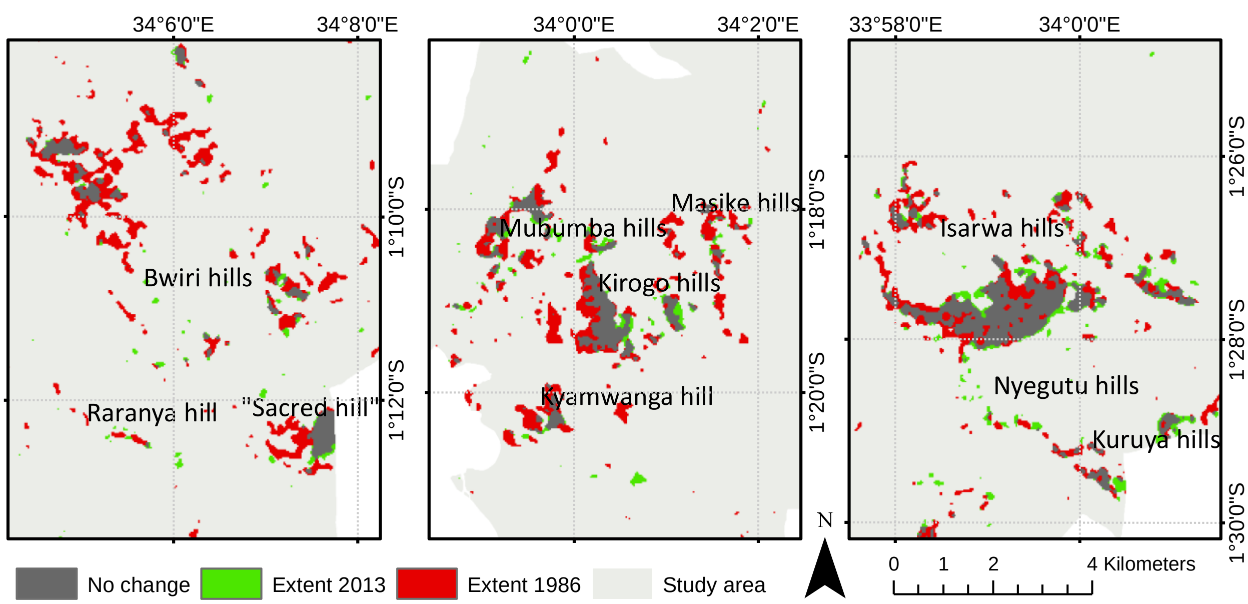


Figure 42. Change in extent of closed woodland between 1986 and 2013. The red colour represents areas where closed woodland has disappeared and the green shows new areas of closed woodland.

Changes in NDVI

Even though the images were selected based on NDVI data there are some differences in the NDVI calculated from the Landsat images. The 1986 and 2013 images have fairly similar NDVI values when it comes to closed and open woodland, shrubland, wetland and water (Figure 43). The 1999 image generally has lower NDVI values. When looking at the NDVI for the whole study area the result shows the lowest mean value in 1999 and the highest in 1986 (Table 14).

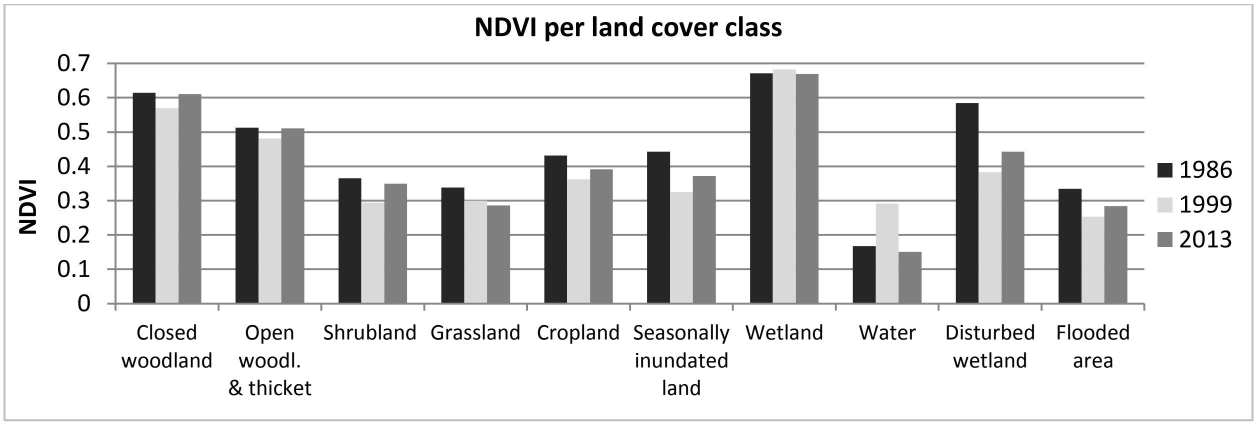


Figure 43. NDVI per land cover class as calculated from the Landsat satellite images.

Table 14. NDVI statistics for the whole study area, calculated from the Landsat satellite images.

	1986	1999	2013
Minimum	-0.312	-0.259	-0.186
Maximum	0.828	0.829	0.815
Mean	0.437	0.370	0.403

Potential to detect agroforestry

Agroforestry was, as mentioned earlier, not classified separately since the agroforestry areas generally were too small to be distinguished in the Landsat images. To see whether any land cover change could be seen in agroforestry areas the 81 agroforestry control points were compared to the mapped land cover. The results show that the majority of the points have been classified as cropland all three years (Figure 44). However, 18 of the points were classified as open woodland in 2013. Out of these was one point classified as open woodland all three years, and two of the points were classified as open woodland in 1986 but not in 1999.

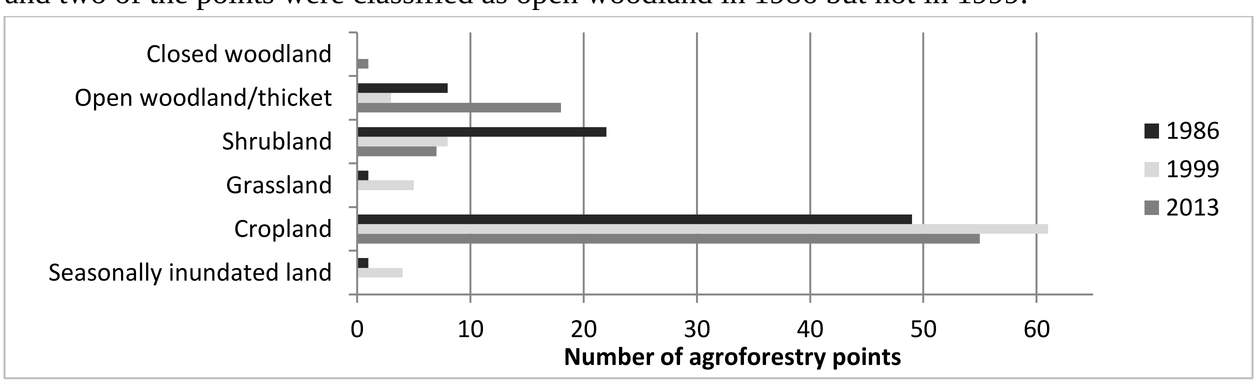


Figure 44. Comparison of what the agroforestry control points were classified as in the three years.

5.3 Erosion susceptibility

The RUSLE calculations suggest that the average soil loss increased from 1986 to 1999 and from 1999 to 2013. The maximum rate and potential total soil loss also increased over the study period (Table 15). It should be noted that, since variations in annual rainfall, soil moisture and seasonal differences in vegetation cover are not accounted for, the results from the RUSLE calculations cannot be seen as the actual soil loss of each specific year. The calculated changes in soil loss result from the changing land cover only.

Table 15. Soil loss statistics for the whole study area in the three different years, estimated with RUSLE. The figures are not to be seen as the actual erosion of each year since land cover is the only variable parameter.

	1986	1999	2013
Average soil loss (t ha^{-1} y^{-1})	43	47	48
Maximum soil loss (t ha^{-1} y^{-1})	1454	1516	1613
Minimum soil loss (t ha^{-1} y^{-1})	0	0	0
Total soil loss (t y^{-1})	3.4×10^6	3.7×10^6	3.8×10^6

The spatial distribution of the erosion changes are shown in Figure 45. The most extensive changes, both increases and decreases, occur in the highland areas. The maps suggest that the increases in soil loss in the 1986-1999 period were more widespread than between 1999-2013.

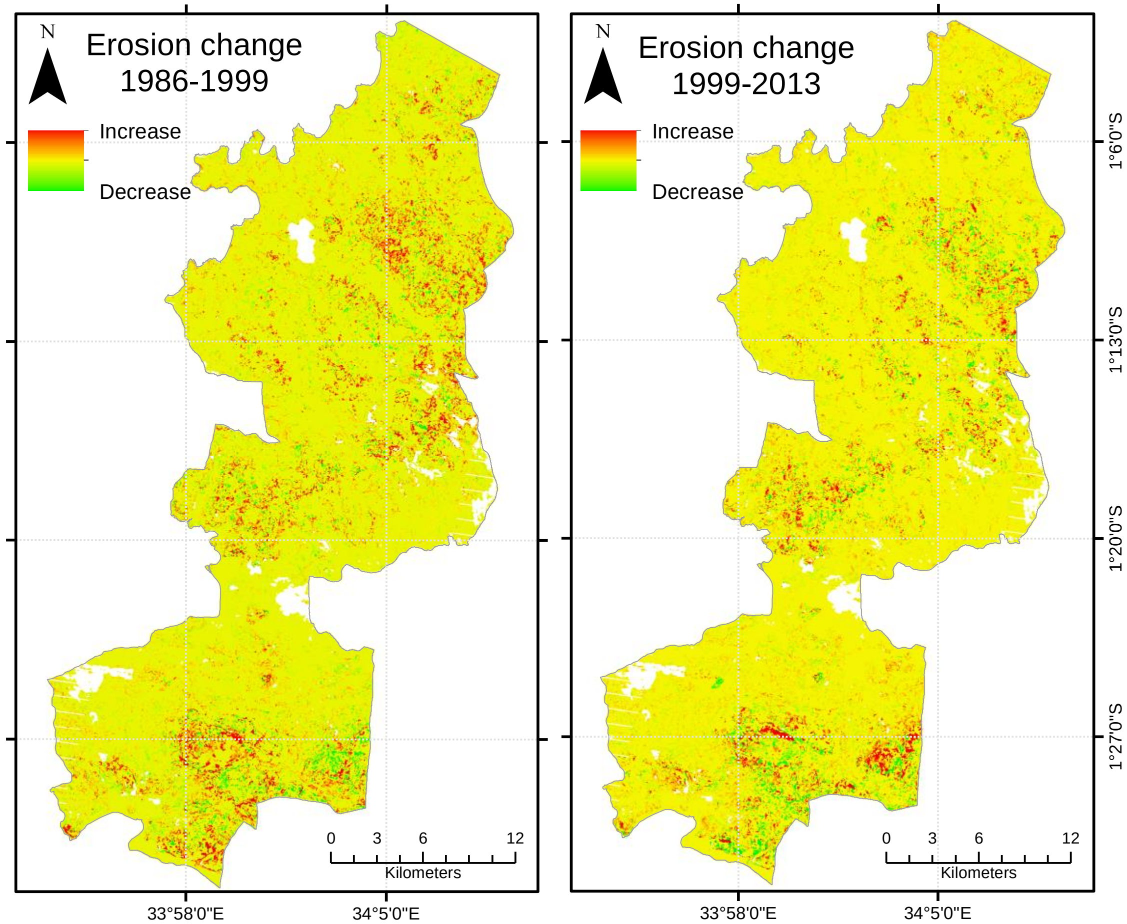


Figure 45. Maps showing the areas with increases and decreases in erosion from 1986-1999 and from 1999-2013. The changes in soil loss represent the changes in land cover only, all other factors being constant.

The average soil loss rates are quite similar in all wards, slightly higher values can be found in Komuge and Rabour whereas the values are slightly lower in Tai (Figure 46). Komuge is the only ward where the average soil loss rate has decreased from 1999 to 2013.

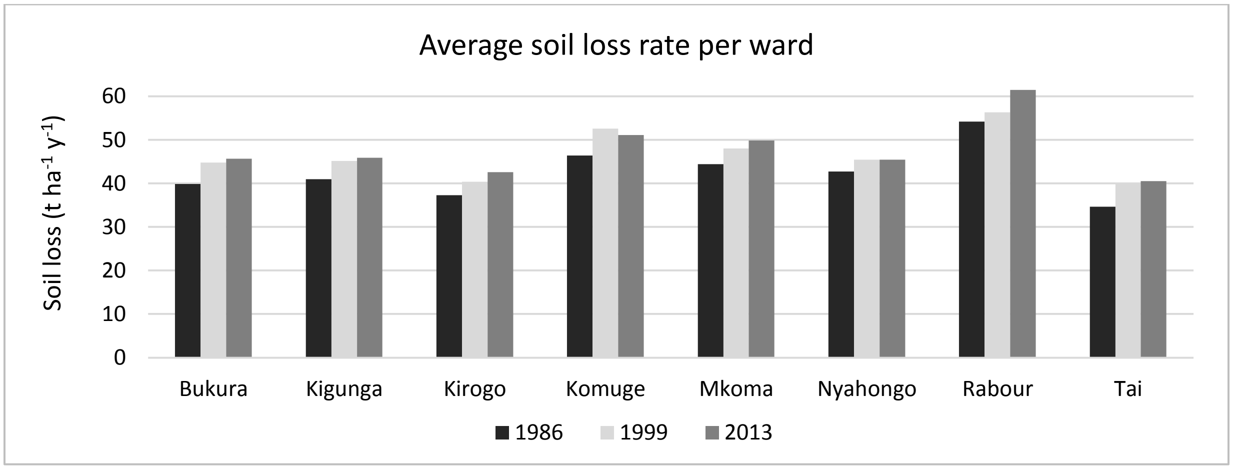


Figure 46. Average soil loss rate per ward and year. The figures are not to be seen as the actual erosion of each year since land cover is the only variable parameter.

When looking at the average soil loss rate per land cover class it is clear that the most vulnerable land cover is cropland, followed by open woodland/thicket (Figure 47). Both of these classes have increased between all of the study years. Shrubland and grassland, and seasonally inundated land slightly decreased 1986-2013 but had the highest value in 1999.

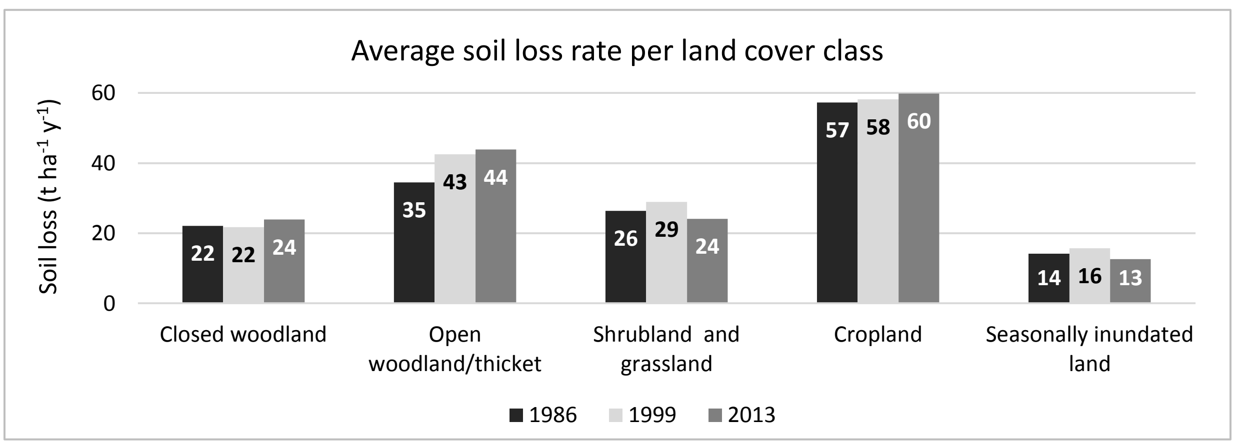


Figure 47. Average soil loss rate per land cover class and year. The figures are not to be seen as the actual erosion of each year since land cover is the only variable parameter.

To get a better overview of the results the soil loss rates were classified into soil loss intervals ranging from very low to extremely high. The largest proportion of the study area belongs to the moderately high interval in all three years (Table 16 and Figure 48). Very low, low and moderate areas decreased with time whereas areas with moderate/high, high and very high soil loss increased. Only 0.1-0.2% of the area belongs to the extremely high interval.

Table 16. Soil loss intervals and the area (km^2) each interval covers in the three years.

Soil loss intervals (t ha^{-1} y^{-1})		1986 (km^2)	1999 (km^2)	2013 (km^2)
Very low	0-2	47.9	45.9	46.6
Low	2-10	118.5	106.1	103.0
Moderate	10-30	239.7	223.4	219.8
Moderate/high	30-50	143.1	145.6	146.6
High	50-100	163.1	177.6	180.9
Very high	100-500	71.3	84.5	86.0
Extremely high	>500	0.9	1.3	1.6

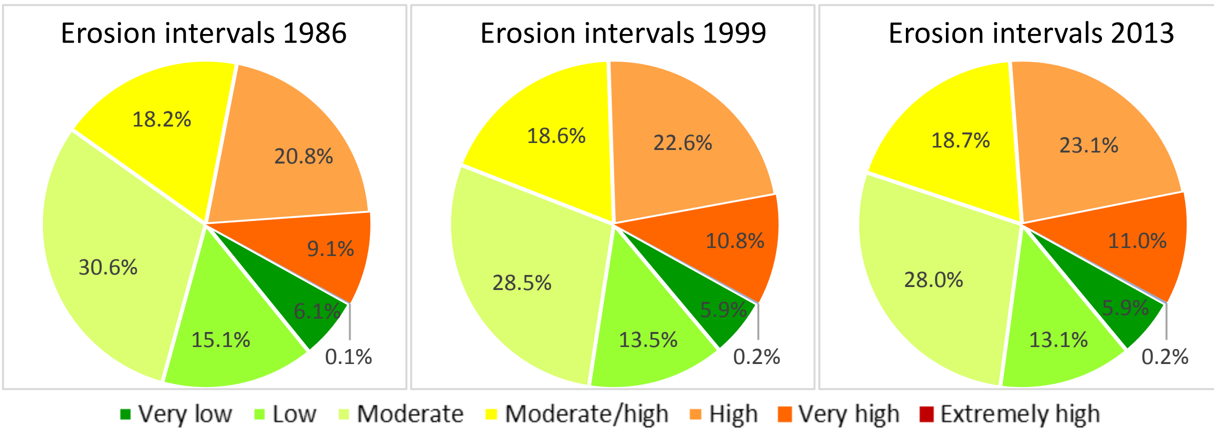


Figure 48. Proportional cover of each soil loss interval in the study area.

The soil loss interval maps are presented in full format in Appendix V. Figure 49 shows cut-outs from the northern part of the study area. A small area with extremely high erosion has appeared northeast of Shirati and a trend towards higher erosion can be seen.

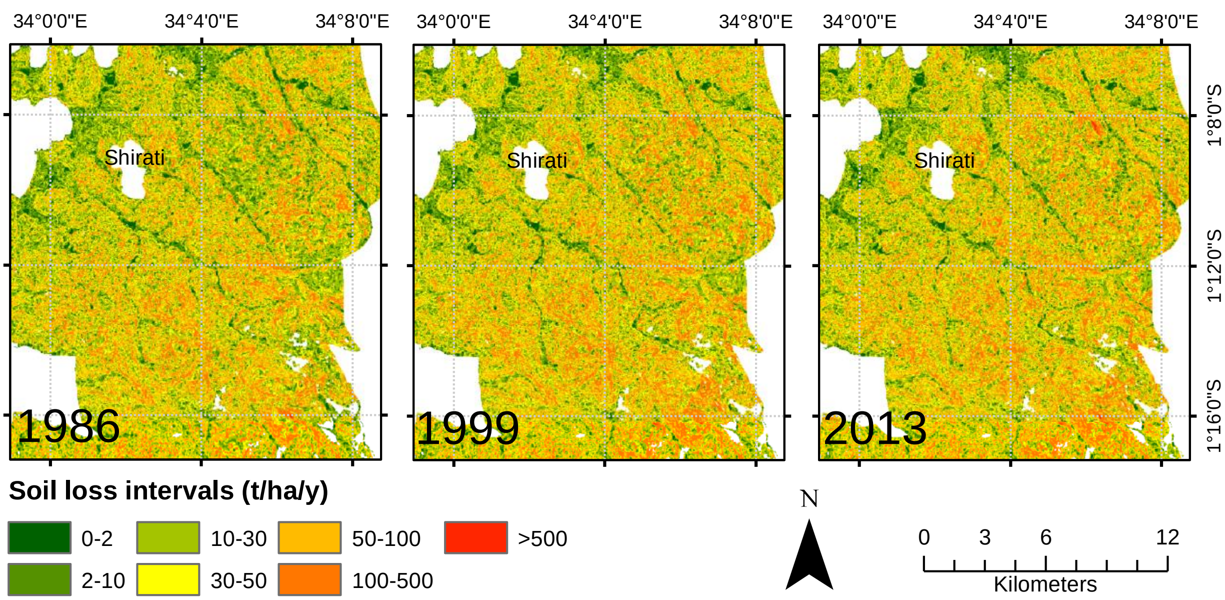


Figure 49. Soil loss in the northern part of the study area. Some changes can be seen, especially in the highland area east of Shirati.

6. Synthesis and discussion

6.1 The estimated values

6.1.1 Land cover change

The results show increasing cropland and decreasing woodlands, shrublands and grasslands. This could be explained by an increasing population which demands more farmland to provide food for more households. Thus, natural land is cleared to make room for agriculture. Consequently woodlands, shrublands and grasslands get scarcer as the population grows. The decreases in woodland are further triggered by higher demands on wood, especially woodfuel. The overall pattern of land cover changes were confirmed by the interviewed farmers as well as the respondents from the Ministry of Natural Resources. Similar results, with intensified pressure on the land resulting in loss of forests, woodlands and/or shrubland since the 1980s, have been obtained in several other land cover studies from East Africa (e.g. Kiunsi & Meadows 2006 in Tanzania, and Imbernon 1999 and Baldyga et al. 2008 in Kenya).

The northernmost wards had the smallest extent of closed woodland in 1986 and this study suggests that less than 30% is left today. It is possible that the deforestation started earlier in these northern, more densely populated areas. The biggest area decrease of closed woodland was found in Kirogo which is the least densely populated ward. Kirogo is a ward which is situated far from any major roads, and where agroforestry has just recently been advocated. This means that the inhabitants are dependent on the local hills for fuel supply. Six out of seven of the farmers interviewed in Kirogo explained they got their fuel from the woodlands. The one exception was the only farmer who practiced agroforestry. The reason for the high deforestation rate in Kirogo could also be an effect of the decreased woodlands in the northern wards resulting in an increased number of people coming all the way down to Kirogo to acquire woodfuel. Appendix I shows how the hawkers that are supporting the cooking-fuel market in Musoma come from a wide surrounding area. It can be assumed that this is the case of Shirati as well.

Even though the Landsat images were chosen from time periods which had similar NDVI in the AVHRR and MODIS satellites, there were some differences in NDVI in the three chosen Landsat images. For most land cover classes the changes showed a steady trend, either decreasing or increasing. However, for open woodland and thicket the extent decreased from 1986 to 1999 but then increased to 2013. The generally lower NDVI values of the 1999 image compared to 1986 and 2013 might explain the disrupted trend of change in open woodland and thicket extent. For example the wards Bukura (e.g. Bwiri hills) and Komuge (e.g. Isarwa hills) looked much greener in the Landsat images of both 1986 and 2013 than they did in 1999. Only one area was considerably greener in 1999, namely eastern Rabour. The reason for the differences are most likely related to local rainfall and the fact that the 1999 image was acquired in September whereas the other two were from July and August. The first rain season normally ends in May which means the study area must have been relatively dry during three months prior to the image acquisition in 1999. The differences in pixel values could also have been affected by different atmospheric conditions and the use of different satellite sensors, although the radiometric and cross-calibrations should have minimised such differences. Another explanation for the disrupted trend could be that there was an overestimated extent of open woodlands in the overall greener images of 1986 and 2013 or alternatively an underestimation of open woodlands in the drier 1999 image. Small trees and bushes are more likely to be classified as open woodland if the surrounding vegetation also is green.

The disrupted trend of open woodland could also be due to an actual increase from 1999 to 2013. Trees are growing very fast in the sub-tropics and a few years with less cutting would probably mean extensive regrowth. The introduction of agroforestry could also be part of the explanation. Even though the satellite image resolution generally was too low to detect agroforestry, and the areas known to be agroforestry most often ended up being classified as cropland, agroforestry was sometimes classified as open woodland (which was shown in Figure 44). Figure 50 shows how an area in Komuge, where planted trees in and around homesteads and fields clearly have affected the classification. Figure 50a is a Google Earth image from 2005, some planted trees can be seen but they are still small. In Figure 50b, from 2013, there are more trees and the old ones have grown bigger. Figure 50c-d show the Landsat images from 1999 and 2013, and it is clear that the plantations have had an effect on the overall greenness. Finally Figure 50e-f show the corresponding classification where the agroforestry has been classified as open woodland.

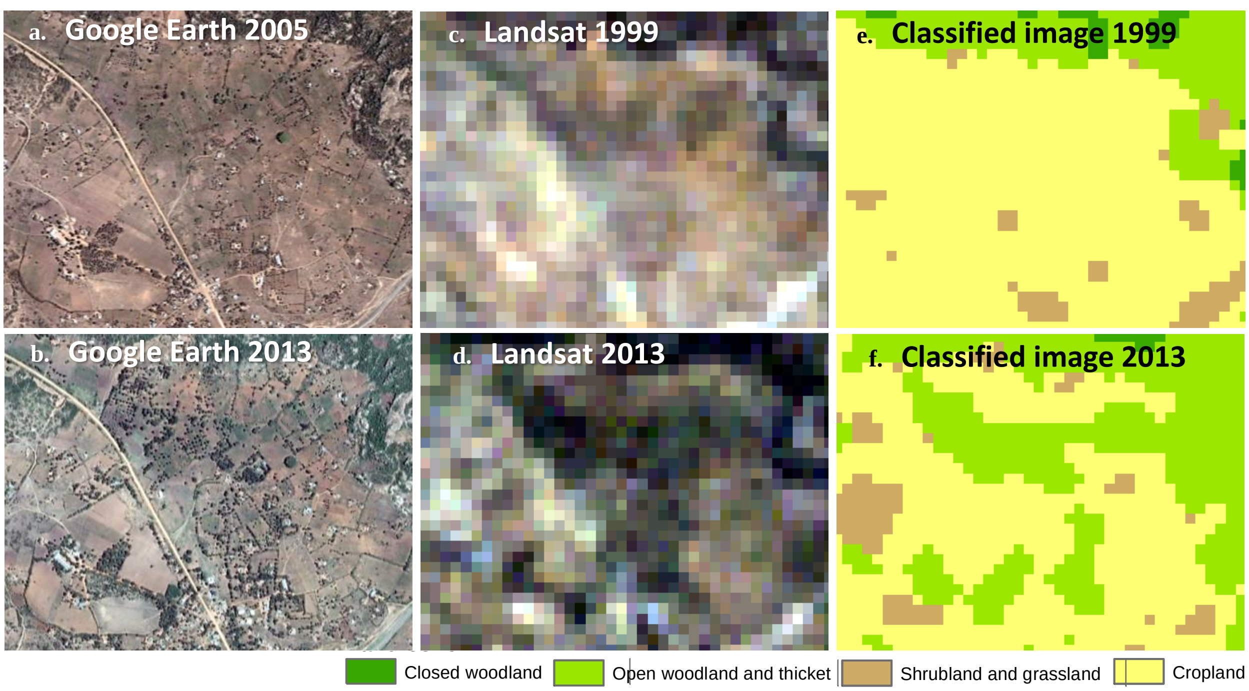


Figure 50. Cut-outs from (a-b) Google Earth images, (c-d) Landsat images and (e-f) the classified maps.

It is likely that several of the abovementioned factors together have had an impact on the differences between the 1999 map and the two other maps. There would probably have been more open woodland in the 1999 image if the climatic/seasonal conditions were more similar to those of 1986 and 2013. But some of the increase between 1999 and 2013 can probably be attributed to woodland regrowth and the introduction of agroforestry. Whether it is the 1999 image or the others that are most correctly reflecting the actual extent is impossible to tell since accuracy was only calculated for the 2013 classification. The producer's accuracy of open woodland was however slightly lower than the user's accuracy which indicates a slight underestimation in 2013. Thus it can be assumed that the 1999 image also is underestimating the extent of open woodland.

Some of the farmers in Luoimbo mention the tarmac road built in 1996 as an accelerating factor of deforestation. Overall the biggest land cover changes occurred from 1986 to 1999, but the decrease in closed woodland seem to speed up between 1999 and 2013. In for example Rabour, the ward which is intersected by the tarmac road, the extent of closed woodland decreased slightly from 1999-2013, compared to a slight increase 1986-1999. This could be interpreted as supporting the theory of the tarmac road. It could also be related to the difference of the 1999 image compared to 1986 and 2013. The dissimilarities between the images highlight the fact that environmental circumstances can have big influences on classifications. To get more certain results more detailed and comprehensive satellite image time series should be consulted.

It is impossible to create a map from remote sensing which is completely without errors (Steele et al. 1998). Spectral overlapping and scale reduction from ground truth to map are some of the many challenges. The scatter plots in Figure 25 show clearly how some of the classes have partly overlapping spectral reflectance. For seasonally inundated land and cropland this could be solved by including a DEM in the classification since they were, to a high degree, located at different altitudes. For shrubland and grassland it was solved by merging the classes together after the classification. For some of the other classes, however, the problem could not be solved and thus errors emerged in the final product.

The inclusion of a DEM in the classification resulted in high accuracy for most lowland classes. It also removed a few errors of woodland areas classified as wetland. The use of the DEM, however, classified most of the highland areas as woodland. In reality large parts of the highlands were covered with cropland. Nearly all land covers in the study area were affected by human activities. It might be that the use of a DEM better reflects the original, primary vegetation without human interference.

The selection, rejection and grouping of different land cover classes are important parts of the classification. Many classes were tested before the final classification scheme was decided upon. Still there were classes which were easily mixed up. For example open woodland was difficult to differentiate from closed woodland when it was located on a shaded hillside. Some of the final classes, e.g. shrubland and cropland, were sometimes difficult to separate even in field. In reality there were not always clear distinctions between shrubland and cropland since part of the land is sometimes cultivated and sometimes not. If the land is left for fallow the shrubs will grow high, but it can easily be shifted back to agriculture any time. The error matrix, however, suggests that the mix-up between cropland and shrubland and grassland is equal, i.e. nearly the same amount of cropland GCPs have been classified as shrubland and grassland as the opposite. There might be some errors because of the several months between the acquisition date of the 2013 image and the fieldwork.

The total accuracy of the final 2013 classification was 87.3% and the Kappa value was 0.84. There are no standard requirements of what accuracy should be obtained but several studies agree on 85% as a reasonable threshold for the total accuracy (Foody 2002, Avery & Berlin 1985, Thomlinson et al. 1999). Further Thomlinson et al. (1999) set the target of having no classes with less than 70% accuracy. After the class merging the lowest producer's accuracy obtained in this study was 77.5%. The low producer's accuracy was obtained for closed woodland and it suggests the class is slightly underestimated. While the accuracy of several of the other classes increased after the post-classification filtering, the producer's accuracy of closed woodland decreased from 87.5% without any filter to 80.0% after one filter and finally to 77.5% after two filters. Many closed woodlands were located on top of hills and covered only a few pixels which is why they were removed during the filtering process. In both of the earlier years the closed woodland areas were generally larger and not as often removed by the 3×3 pixels filter. Thus, the estimated decrease in closed woodland can be slightly overestimated.

6.1.2 Soil loss estimations

Cropland has the highest C-factor value. Hence the calculated erosion rate will increase when a land cover type is converted to cropland since all other factors are constant. The biggest changes in erosion were confined to the highland areas. This was expected since high altitudes generally have more rainfall and steeper slopes, features which increase erosion and thus the RUSLE factor values. Even though the K-factors were 30% lower at elevations above 1350 m.a.s.l. (because of the higher proportion of rocks in the ground) this does not compensate for the normally much higher LS- and R-factors found in highland areas. Land cover changes in the highlands therefore have a much bigger impact on the soil loss rate, than changes in the lowlands. The fact that the most extensive loss of woodlands, which have the lowest C-factor values, occurred in the highlands has further accelerated highland erosion. When looking at the calculated annual increase in soil loss rates the change between 1986 and 1999 is greater than the change between 1999 and 2013. This can probably be partly explained by the aforementioned differences between the satellite images and their effect on the land cover classification. Since the change in open woodland and thicket (decrease) and in cropland (increase) were of a higher magnitude 1986-1999 a bigger change in erosion rate was expected.

Soil losses were quite similar in the different wards throughout the study area. The two wards in Luoimbo, Komuge and especially Rabour, got higher soil loss rates. The reason for this can be explained by the fact that these two wards had the highest conversion into cropland and the highest decrease of shrubland and grassland (both in terms of percentage and in km^2) together with a decrease in woodlands similar to other wards. Another contributing factor is the higher K-values in Luoimbo. Regarding the average soil loss per land cover class there are no big differences between the three years for most classes. The erosion rate in croplands increased slightly which can be explained by the land scarcity that forces people to convert steeper lands into fields. For open woodland the increase is bigger. This is related to the disappearance of the class in flat lowland areas, and the uphill advancement as closed woodlands are degraded enough to become open woodlands.

The calculated soil loss maximums in all three years vary around 1500 t ha^{-1} y^{-1} which is not realistic. When looking at these high values it is important to take into account that they are extremes which only have been obtained in a few pixels where all the RUSLE factors happened to be very high. Values over 500 t ha^{-1} y^{-1} never occurred in more than 0.1-0.2% of the study area. The average soil loss rates seem more realistic but to determine the accuracy of the values would require actual measurements to compare with. Since this was not available for the study area other studies have been consulted for comparison. There are a number of studies that have modelled and measured soil loss in East Africa. In Table 17 some results from different studies have been summarised.

Table 17. Comparison of different soil loss estimations in East Africa from 1938-2014.

Location	Main land cover	Year	Model	Soil loss (t ha^{-1} y^{-1})	Precipitation (mm)	Elevation (m.a.s.l.)	Source
Tanzania, Mara	*Agriculture*	*1986 1999 2013*	*RUSLE*	*43 47 48*	*900-1500*	*1130-1600*	*This study*
Tanzania	-	1938	Plot data	146	Avg. 620	-	Staples 1938
Ethiopia	-	1978	-	165	500-800	-	Virgo & Munro 1978
Kenya, Machakos	Degraded grazing land	1982	-	5.4	-	-	Barber 1982
Tanzania, Shinyanga	Rangeland	1984	USLE	20-61	-	-	Stocking 1984
Kenya, Ewaso Ng'iro Basin	Agriculture Shrubland Forest	1999	USLE	5.2-35.4 38.2 0.4-0.9	365-2000	1700-1800	Mati et al. 2000
Kenya, central		2003	RUSLE	134-549	Avg. 1500	Avg. 1480	Angima et al. 2003
Uganda	Cropland Rangeland Banana-Coffee Banana	2003	USLE	93 52 47 32	Avg. 1218	1150-1400	Lufafa et al. 2003
Kenya, Eastern	Cropland	2008	RUSLE	22.3	600-1200	Avg. 1500	Omuto 2008
Kenya	Cropland	2011	USLE	>30	700-2000	500/1000-1300/1800	Erdogan et al. 2011
Kenya, Mara River Basin	Forest Grassland Bushland Agriculture Woodland	2012	WEPP, Erosion 3D	11 3 7 120 11	Avg. 600	-	Defersha et al. 2012
Uganda, Mt. Elgon		2000 2006 2012	RUSLE	103 67 101	Avg. 1500	1084-2455	Jiang et al. 2014
Tanzania, Kondoa	Grassland and wooded savannah	1973 1986 2008	USLE	14.7 23 15.7	400-1000	900-2190	Ligonja & Shrestha 2013

It can be seen that the modelled or measured soil loss varies a lot in different studies. Naturally the model output depends on the physical environment. Therefore studies with similar conditions were chosen. The study with the most similar precipitation and elevation conditions to the study at hand is Lufafa et al. (2003) who overall got higher values. In the upper Mara river basin, Defersha et al. (2012) obtained cropland soil loss rates that were twice as high as those obtained in this study. On the other hand there are several studies that got considerably lower soil loss rates. It is important to bear in mind that this study's calculated soil loss of each year does not represent the actual soil losses, since all factors but the C-factor were kept constant. In reality, rainfall has a large effect on the soil loss rate and since the rainfall of the region varies a lot from year to year it can be expected that the soil erosion also varies a lot. From the comparison it can be concluded that the results found in this study lies within the range of estimated soil loss values in East Africa.

Factor uncertainties

Even though the final result lies within the range of other studies, it is important to acknowledge that a model is always a simplification of reality. Many different ways of estimating the RUSLE factors have been developed over the years and all the different methods make assumptions and generalisations. Combined with input data which is not completely perfect there is room for propagation of errors. The following section describes some factor uncertainties which could be modified for an improved result of the RUSLE modelling.

The rainfall data used to calculate the R-factors came from a global dataset with low resolution. And since an average was used the interannual variations were not reflected which means that the actual erosion of 1986, 1999 and 2013 has not been calculated. To get a more accurate result the R-factors could have been adjusted by the measured rainfall from Musoma in the three years. This was, however, not done since it would have made it more difficult to distinguish the changes in erosion rates caused by land cover change. The R-factor values ranged from 5900-7900 MJ mm ha^{-1} h^{-1} y^{-1} which compared to some studies is high. Nevertheless, similar results have been obtained in Kenya by for example Angima et al. (2003) who got an average R-value of 8527 MJ mm ha^{-1} h^{-1} y^{-1}, and by Maeda et al. (2010) who got a R-factor of about 6000 MJ mm ha^{-1} h^{-1} y^{-1} in areas with an annual precipitation of about 900 mm.

As for the K-factor, the used soil map lacked details and during fieldwork it became clear that there were large local variations in the soils. For example one farmer described erosion and emerging cracks on one part of his land, whereas the other part which was located next to it was completely different. Other simplifications were that the K-values did not reflect seasonal variations which in reality influences erosion, and that the textures were based on only a few soil samples per soil type. Furthermore, the original factor values were based on measurements in similar environments but not from the particular study area.

The LS-factor is one of the most problematic of the RUSLE factors to calculate. The equation utilised in this study to calculate the LS-factor has been widely employed. But it has also been criticised for not representing the LS-factor accurately by for example Foster and McCool

(1994). Moreover, it has been suggested that a DEM with 30 m resolution is too coarse to give correct results (Mitasova et al. 1996).

The C-values were based on the land cover classification. Thus all potential inaccuracies in the classification are C-factor errors. Since the land cover classification did not represent agroforestry very well, which according to the farmers helped reduce erosion, agroforestry was not well represented in the RUSLE calculations. Neither did the classification distinguish small settlements, roads, different degrees of open woodland etc. The C-factors were also the same for each land cover class in all three years. Hence they do not reflect the fact that the NDVI values varied between the years and that the agriculture has been intensified with reduced fallow periods. Furthermore, the C-factor values did not account for local variations in e.g. farming intensity or the fact that some of the farmers practiced mulching or had terraces etc.

6.2 Fieldwork difficulties

It should be taken into account that the reliability of the interview answers may vary for a number of reasons. In a situation with one or sometimes two interpreters there is a risk that questions and answers can get confused or shortened. This could happen if any of the persons present at the interview does not understand the question and alternatively if the answer is not fully interpreted or understood. Since the interviews were conducted with assistance from Vi Agroforestry and MVIWANYA there is also a risk that the respondents exaggerated about e.g. their yields in order to impress or show gratitude to the organisations. On the other hand, some farmers might have understated their situation thinking that they could get benefits from the organisation. These risks were considered when conducting interviews, especially regarding the qualitative questions, and the interpreters were well-informed about the questions and the approach of the study. Furthermore the majority of the questions were closed-ended. When open-ended questions were asked they were supplemented with follow-up questions in order to minimize confusion. Still, it is hard to fully estimate the extent of misleading data gathered from the interviews.

During the implementation of fieldwork and interviews the aim was to get a representative data collection for all regions, environments, cultural aspects etc. This was fulfilled to a large extent since the major part of the study area was covered with field surveys and control points. Furthermore, it was made sure that the interviewees varied in terms of for example sex, age, education and income. Hence, the possibility of a biased data was reduced. One bias in the data collection is the fact that most farmers interviewed had heard of, had been or was in contact with Vi Agroforestry or MVIWANYA. This could have meant that they had gotten to know about problems and/or opportunities that they otherwise not would have considered.

6.3 General comments and future predictions

Most farmers felt that the climate is getting drier and the rainfalls more unpredictable. The climate trends (Appendix III) support their experiences. The climate changes have already caused decreases in yields and productivity. If the climate trend continues it can become a major cause of increased poverty in Mara since the households depend on the quantity and quality of farm output. The pastures will get scarcer in a dry climate which could cause higher risks of cattle malnutrition or death resulting in further increases in poverty. Also, in a drier climate with less rainfall pests and diseases may spread. One of the staple crops, cassava, has been affected by a mosaic disease that spreads during the dry season. If the dry season is prolonged this disease will pose a bigger threat to farm yields (Hill 2008). Several farmers have already been forced to stop planting cassava. The surplus is often the only source of income for the household and when yields fail they are forced to look for other sources of income. There are not many alternatives in order to get extra money since the fish stocks have been depleted and there are no big employers in the region anymore. Some of the few alternatives that remain are to either to sell off cattle or, as more and more choose, to sell firewood or charcoal.

The deforestation and the subsequent land degradation is a further step in the negative spiral. When acquiring firewood and charcoal trees are cut down and the large roots are often dug up which exposes the soil to erosion. Under natural conditions the vegetation recovers relatively fast in subtropical Africa. But if the soil is swept away by a burst of rain or strong winds, which are getting more prevalent according to the farmers, leaving a stony surface there is no possibility that the same amount of vegetation can regenerate. Also, the demand for firewood/charcoal could cause further cuttings of the area before it has had time to recuperate.

One problem is that all households with few exceptions depend on firewood or charcoal for their cooking and, as discussed, most of them do not have enough trees for supporting this necessity or money to buy alternative cooking fuels. The demand for wood will continue to increase as the rural and urban populations grow. This will accelerate the deforestation and eventually the demand might get greater than the supply. Further issues would be depleted woodlands and extensive land degradation. In addition, a considerable part of the soil that is eroded end ups in the lake that gets siltated and polluted. Pollution of the lake is a major health threat since this is where many people get water for the household.

One solution to halt the deforestation would be to call for government action so that resources are allocated to ensure law obedience. But that will not solve the problem as long as the prices on e.g. kerosene are too high. A major intervention to stop the logging would therefore cause severe economic issues and starvation for a large part of the Mara population. Subsidies on other cooking fuels could be the answer but the question is if it is not only a short term solution. The government claim that they encourage the use of e.g. biogas and briquettes for domestic and industrial use (NEAP 2013). These actions were however not apparent during the fieldwork. In the light of these circumstances agroforestry is probably one of the better options to stop the deforestation by securing a self-supply of fuel wood, timber etc. Agroforestry can also ease climate change adaption and it is also, according to many agroforestry farmers, a way to reduce the erosion rates.

The woodlands of Rorya are small and might seem insignificant. This study, however, suggests that their degradation has a considerable impact on the erosion rates which in turn affects soil fertility and the pollution, siltation and eutrophication of Lake Victoria. This could be argued as one reason to preserve them. Other reasons to preserve the woodlands could be to inhibit the loss of biodiversity (although no studies on biodiversity have been carried out in the study area, there is no reason to believe that the woodlands lack diversity), or to halt local climate change. Most farmers thought the greatest reason for climate change was the depletion of woodlands. Even though the major reason for climate change in the region probably is pollution from the industrialized world, studies like for example Otieno and Anyah (2012) show significant local reductions in precipitation due to conversion of forests into cropland in the Kenyan Lake Victoria region.

7. Concluding remarks

In this thesis the land cover changes and soil erosion rates have been estimated by performing supervised classification on Landsat data from three years, 1986, 1999 and 2013, and then employing RUSLE in the same three years. The results suggest that the extent of cropland has increased at the expense of open woodland, shrubland and grassland. This is in line with the experiences of the farmers living in the study area. According to the produced classification maps, the extent of cropland has increased by about 76 km^2 whereas the extent of woodland, shrubland and grassland together has decreased by 73 km^2.

The results furthermore indicate that the land cover changes have caused higher rates of soil erosion in the study area as a whole, especially in the highland regions, given that the rainfall is kept on an average. The modelled soil loss rates are within the range of other studies in the region but more detailed parameters would optimize the result. To obtain soil loss values that better represent each year the rainfall erosivity factor should be adjusted to that specific year. Features such as agroforestry were not properly accounted for since the small fields could not be classified when using such low resolution satellite images.

It can be concluded that the alterations in the study area are similar to those observed in other parts of East Africa. The major reason for the land cover changes seems to be an interrelationship between an increasing population, a higher demand for wood products and fuel in combination with high poverty rates and lack of alternative incomes. To control the erosion rates it is important to protect the woodlands of the study area. The farmers have experienced progressively drier climate which would, if the trend continues, exacerbate the consequent land degradation and yield declines. And thereby worsen poverty and food insecurity. In order to improve living conditions and climate adaption agroforestry seem to be one of the better options.

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Appendix I: Cooking-fuel investigation

In the Mara region there are very few alternatives for cooking fuel other than firewood and charcoal. For this reason the demand for these two products is very high and thousands of men travel long distances on their bicycles every day to sell their produce along the road or in the bigger towns. To get a grasp of the extent of this business the charcoal and firewood hawkers bicycling towards Musoma town in the morning were counted. This was done at seven occasions from a car driving along a certain road segment of about 27 km from Musoma town to the Mara River. The starting time ranged between 8.00 and 11.00 a.m. and the trip took around 25 min.

Furthermore, 28 hawkers were asked about details on where they were travelling from, from where they got their goods, how often they were working etc. The questioning took place on the road between Musoma town and Bweri (~6.3 km E of Musoma). It was done at several occasions together with an interpreter. Since cutting down and selling trees requires certain certificates which most people do not have, it is an illegal business and personal questions were avoided.

Results

Counting of cooking-fuel hawkers

The sample size of only 7 days is much too small to conclude anything certain, but it gives a hint on how many people who are involved in the cooking-fuel business.[2] The results suggest that charcoal is the most commonly sold fuel in Musoma town. On average 71 hawkers were counted each day (of which 90% were counted on the first 18 km of the road) and 77% of the counted fuel hawkers were carrying only charcoal on their bikes, an additional 6% were carrying charcoal and firewood, and the rest were carrying only firewood (Figure I:1). The busiest time, with an average of 88 hawkers, occurred between 9:00 and 9:30 a.m. On day number seven the counting did not begin until 11:00 a.m. when the flow of hawkers had started to decrease and on day number four the weather was very bad. If assuming that the numbers are fairly representative for the daily transport of cooking fuel to Musoma, with approximately 70 hawkers per half an hour between 8:30 to 11:30 (with slightly more in the earlier hours and slightly less after eleven), about 420 large loads of fuel are transported to Musoma every day. This number is most certainly under-estimated since many hawkers were seen throughout the whole day, up to late evening, and the counting did only take place on the major road leading to town.

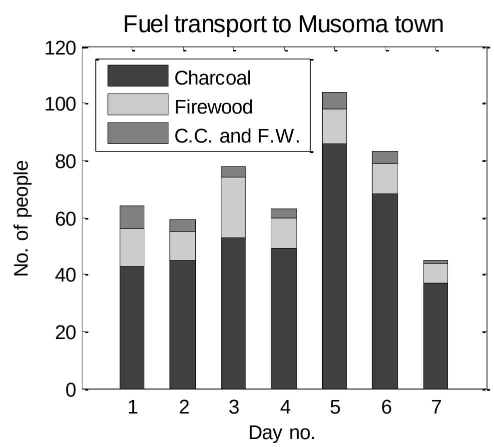


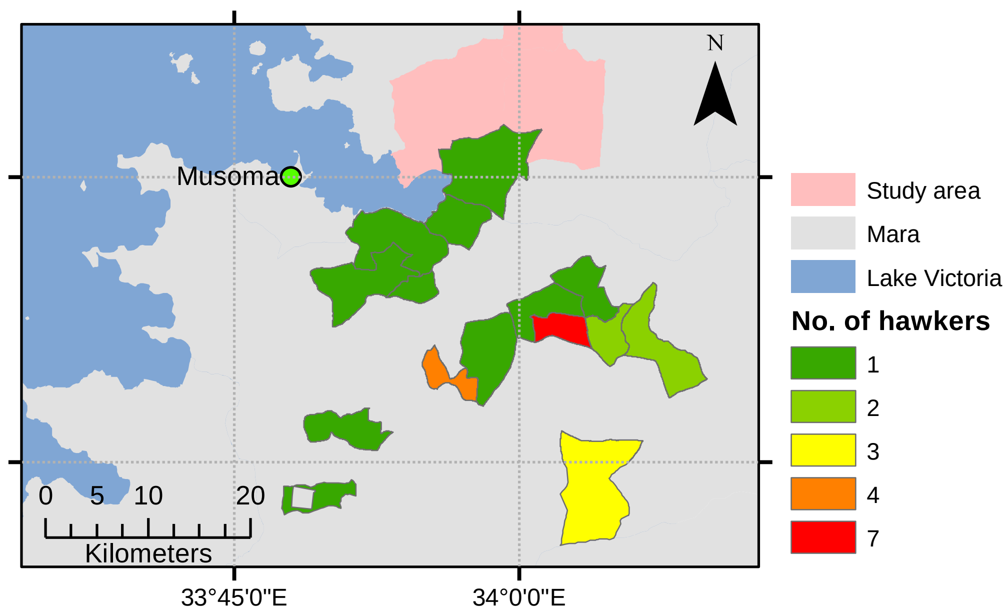
Figure I:1. The ratio of goods carried by the cooking-fuel hawkers traveling to Musoma during the seven days of counting.

[2] It could be mentioned that the counting was carried out at five other occasions as well, but only on part of the road segment and with other means of transport (by foot or by bus) which makes these data not fully comparable. The overall highest number of hawkers per km obtained was on a Saturday when 56 people carrying charcoal and 22 carrying firewood were counted on a 10 min travel of 6.3 km between Musoma town and Bweri bus station.

Questioning of cooking-fuel hawkers

20 of the 28 hawkers questioned were transporting charcoal and eight were transporting firewood. The average age of the hawkers was 29 years, and the average time they had been doing this particular job was 5.6 years. Very few were producing/gathering their own goods, they instead bought the processed charcoal or bundles of firewood from villagers who lived nearby woodlands. All of the asked hawkers reported that the goods mostly came from common woodlands. When comparing Figure I:2, which shows the home villages of the hawkers, with a land cover map it is clear that the hawkers come from the villages where common woodlands are located. The approximate distances travelled can be seen in Figure I:2, to travel more than 60 km back and forth was common. Most of the hawkers reported that they started very early in the morning, returned to their villages around mid-day and bought a new load of their goods on the way back home. A few explained that they sometimes made it back to Musoma one more time in the afternoon.

The average profit for selling charcoal was 12 500 TZS per bag and for selling firewood it was 9000 TZS per bundle (approximately USD 7.7 and USD 5.5 respectively). About 70% of the hawkers were coming to town every day (including weekends) which gives a monthly salary of 350 000 TZS and 252 000 TZS respectively. This can be compared to the average salary for a regular Tanzanian employee (within the public or private sector) which was 375 781 TZS per month in 2012. It can also be compared with the income of the farmers interviewed in this study which in many cases was close to nothing. For those who sold farm products the average income was 200 000 TZS.



Appendix II: Farmer Questionnaire

Some of the questions in this questionnaire were not used in the final study. A wide variety of questions were asked in order to obtain a comprehensive overview of the farmers' living situations, thoughts and experiences.

For questions marked with asterisk (*) all suitable answers should be marked.

Name of interviewer:	**Date of interview:**
Interview time Start: End:	**Name of interpreter:**

A. Identification details

A1. Form no:					**A2. Name of respondent:**					
A3. Age of respondent:	**A5. Age of HH head:**				**A4. Name of HH head:**					
A5. Sex of respondent:	M		F		**A6. Sex of HH head**	M			F	
A7. Respondent's level of education:					**A8. Tribe:**					
A9. HH head's level of education:					**A10. Relationship of respondent to HH head** 1=HH head 2=Spouse 3=Son/daughter 4=Father/mother 5=Other relative 6=Other (friend, employee etc.)	1	2	3	4	5	6
A11. Marital status of HH head 1=Married 2=Divorced 3=Widow/widower 4=Single	1	2	3	4						
A12. Village:					**A14. GPS coordinates:**					
A13. Ward:										

B. The household (HH)

B1. Total no of people in this HH? How many are women and how many are men?	Total:		Men:		Women:
B2. In this HH, how many are					
Males by age-group	<6:	7-18:	19-35:	36-55:	>56:
Females by age group	<6:	7-18:	19-35:	36-55:	>56:
Attending/have finished school, and what level of education do they have?	***Attended school*** Pri:	Sec:	Uni:	***Never attended school:***	
Involved in farming and to what extent	Full time:	Quite often:	Seldom:	Never:	

C. Farm details and livelihood activities

C1. What is the approximate size of the land used for agricultural activities? 1=Less than 1 acre (<0.4 ha, 0.004 km^2) 2=Between 1-2.5 acres (0.4-1 ha, 0.004-0.01 km^2) 3=Between 2.5-4 acres (1-1.6 ha, 0.01-0.016 km^2) 4=Between 4-6 acres (1.6-2.4 ha, 0.016-0.024 km^2) 5=More than 6 acres (>2.4 ha, >0.024 km^2)	Actual size, if known:	1	2	3	4	5
C2. How much of the farmland is used for agroforestry, i.e. trees together with other crops?						

C3. Is the farmland owned or leased?				
C4. For how long have you farmed the land you are farming now? 1=Less than 5 years 2=Between 5-10 years 3=More than 10 years	Since year, if known:	1	2	3
C5. Has this farmland been inherited in your family?				

C6. Do you know what was on this land 20-30 years ago? *						
1=Do not know 2=Similar farm (agroforestry) 3=Monocrop farm 4=Woodland 5=Grassland 6=Bushland 7=Other, specify	1	2	3	4	5	6
	7					

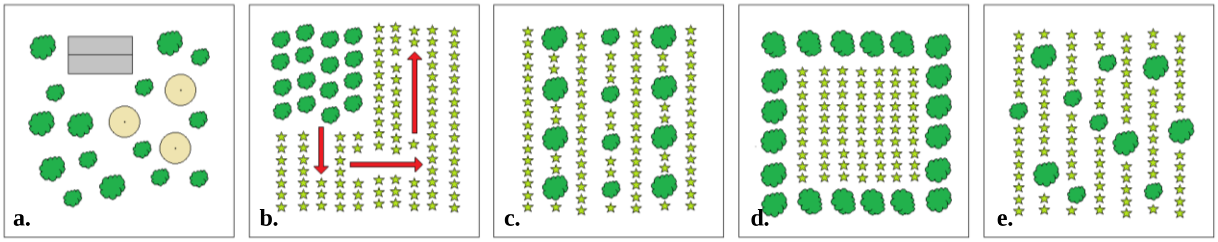
C7. Does the HH keep livestock? *If so:* what animals and how many? *			
Poultry	Yes	No	
Cows	Yes	No	
Sheep	Yes	No	
Goats	Yes	No	
Donkeys	Yes	No	
Other, specify			

C8. Is the livestock walking freely/grazing on your farmland or on common land?	No	Always	Some-times
C9. *If always/sometimes:* Have you seen signs of overgrazing (e.g. erosion, decreased productivity)?			
C10. Is the land prepared using an ox-plough or a hand-held hoe? (Or anything else?)			

D. Agroforestry – history, practices, species and productivity

D1. For how long have you practiced agroforestry? (Trees together with crops)	Since year, if known:	1	2	3	4
1=Less than 2 years 2=Between 2-5 years 3=Between 5-10 years 4=More than 10 years					
D2. Who introduced agroforestry to this HH? And in which year was this? 1=Vi Agroforestry 2=Friends or family 3=Already practiced agroforestry 4=Other, specify	Year, if known:	1	2	3	
		4			
D3. How was the land utilized before you started with agroforestry? 1=Multiple crop agriculture, but without trees 2=Monocrop agriculture 3=Natural land 4=Other, specify		1	2	3	
		4			
D4. How many trees are planted on this farm in total? And how many of them are in the homestead? Were all trees planted at the same time?					
D5. Have you continued planting trees? How do you get seedlings now? When was the last tree planted?					

D6. What agroforestry techniques are practiced on this farm? * (see figure below)					
1=Homestead tree planting 2=Rotational fallow with short-term trees 3=Alley cropping with short- and/or long-term trees between crops 4=Boundary planting with short- and/or long-term trees around crops (hedgerows?) 5=Dispersed intercropping with short- and/or long-term trees mixed with crops 6=Other, specify	1	2	3	4	5
	6				



Different types of agroforestry systems. The larger dark green symbols represent trees and the smaller light green symbols represent other crops. (a) Homestead tree planting: various trees scattered in the homestead. The yellow circles symbolises traditional round houses. (b) Rotational/Improved fallow: with short-term trees (often soil improving trees) that are harvested after some years to give way for crops. (c) Alley cropping: short- and/or long-term trees in rows together with crops. (d) Boundary planting: short- and/or long-term trees around field of crops. (e) Dispersed intercropping: Short- and/or long-term trees scattered in the field of crops.

D7. What tree/large bush species have been planted In your homestead (HS) and fields (F)?

HS	F	Latin	English	Swahili
		***Acacia* spp.**	--	--
		Acrocarpus fraxinifolius	Indian ash	--
		Albizia lebbeck	Women's tongue tree, siris tree	Mkingu
		***Annona* spp.**	--	--
		Azadirachta indica	Neem tree, margosa tree	Mkilifi, Mwarubaini, Kamili
		Balanites aegyptiaca	Desert date	Mjunju
		Bauhinia variegata	Camel's foot	--
		Cajanus cajan	Pigeon peas	Mbaazi
		Calliandra calothyrsus	Calliandra	Mkaliandra
		Carica papaya	Papaya, pawpaw	Mpapai
		Carissa edulis	Simple-spined carissa	--
		Casimiroa edulis	White sapote	Mtanda-mboo
		Casuarina equisetifolia	Casuarina, Whistling pine	Mvinje, Moinga
		Cedrela odorata	Spanish cedar, Mexican cedar	Mwerezi
		***Citrus* spp.**	--	--
		***Eucalyptus* spp.**	--	--
		Gliricidia sepium	Mexican lilac, mother of cocoa	--
		Grevillea robusta	Silky oak, Grevillea	Mgrivea, Mukima
		***Leucaena* spp.**	--	--
		Maesopsis eminii	Umbrella tree	Musizi, Mutere
		Magnifera indica	Mango	Mwembe
		Markhamia lutea	Markhamia	Mgambo, Mtalawanda
		***Melia* spp.**	--	--
		Moringa oleifera	Drumstick tree, Horseradish tree	Mlonge, Mzunze
		***Musa* spp.**	Banana	Ndizi
		Persea americana	Avocado	Mparachichi
		Podocarpus falcatus	Podo, East African Yellowwood	--
		Psidium guajava	Guava	Mpera
		Sclerocarya birrea	Marula tree	Mng'ongo
		***Senna* spp.**	--	--
		Sesbania sesban	Sesbania, River bean	--
		***Terminalia* spp.**	--	--
		Tamarindus Indica	Indian date	Mkwaju, Msisi
		Vangueria infausta	Wild medlar	Mviru
		Vitex keniensis	Meru oak	Mfuu

D8. Of these species, which are dominating on your fields?

D9. What is the reason for your choice of tree species? (For ex. would you say that they are well adapted to the land?)
D10. How did you choose which tree species to plant? (Were they suggested by Vi Agroforestry or someone else?)
D11. Are there any tree species you will not plant again? Why? When did you stop planting this/these species?

D12. What crops are planted on this farm?		
	English	**Swahili**
	Maize	Mahindi
	Cassava	Mihogo
	Sorghum	Mtama
	Millet	Ulezi
	Beans (various types)	Maharage
	Potato/sweet potato	Viazi
	Groundnuts	Karanga
	Cotton	Pamba
	Paddy rice	Mpunga
	Sugarcane	Miwa
	Vegetables (various types)	
D13. What is the staple food in this village?		

D14. What tree species do you plant together with which crops? Are there any combinations you find better/worse?

D15. For *own use* – what are the main products obtained from the *trees* on the farm? *						
1=Building material (planks/timber/poles) 2=Fruit/food 3=Firewood 4=Charcoal 5=Animal fodder 6=Medicinal products 7=Other products, specify	1	2	3	4	5	6
	7					
D16. For *sale* – what are the main products obtained from the *trees* on the farm? *						
1=Building material (planks/timber/poles) 2=Fruit/food 3=Firewood 4=Charcoal 5=Animal fodder 6=Medicinal products 7=Other products, specify	1	2	3	4	5	6
	7					
D17. Have you experienced any other benefits of the *trees* on the farm? For example: a. Provides shade b. Provides wind shelter c. Keeps the soil moist d. Increases soil fertility/nutrients e. Inhibits erosion f. Other, specify						
D18. Since you started planting trees, can you see any changes such as for example: a. less/higher mud in the water b. less/higher need of fertilizers c. less/higher labour requirements						

D19. What was the <u>main reason</u> for starting with agroforestry? Specify:			
D20. Did you get the results/products you expected?	Yes	No	Partly
D21. Would you have started with agroforestry without guidance from Vi Agroforestry?	Yes	No	Maybe
D22. Are you satisfied with the introduction of agroforestry?	Yes	No	Partly
D23. ***If no:*** **Why not?**			
D24. Are you happy? (In general)	Yes	No	
D25. ***If no:*** **Why not?**			

D26. Can you see any <u>damage</u> in your farming since the introduction of agroforestry?

D27. How important are the following activities/products for your livelihood? (Both for HH consumption and for income)				
1=High importance 2=Moderate importance 3=Low importance 4=No importance				
Farming products from **annual crops** (e.g. cassava, maize, rice, vegetables)	1	2	3	4
Farming products from **non-woody perennial crops** (e.g. sugarcane, cotton, sisal)	1	2	3	4
Farming products from **trees and bushes** (e.g. firewood, timber, fruit, honey)	1	2	3	4
Livestock products (e.g. eggs, milk, meat)	1	2	3	4
Off-farm income (e.g. small business, wage labour)	1	2	3	4
Remittances (e.g. money sent by relatives)	1	2	3	4
Fishing or hunting	1	2	3	4

E. Productivity and market availability

E1. Have the yields of the planted <u>crops</u> increased since you started with agroforestry?	Yes	No		
E2. Compared to 10 years ago, what is the agricultural productivity of the land today? 1=The same productivity 2=Lower productivity 3=Slightly higher productivity 4=Much higher productivity	1	2	3	4
E3. Compared to 3 years ago, what is the agricultural productivity of the land today? 1=The same productivity 2=Lower productivity 3=Slightly higher productivity 4=Much higher productivity	1	2	3	4
E4. ***If there has been any change:*** **Do you think it is because you have planted trees?**	Yes	No		

E5. Did the HH store any crops in 2013?	Yes	No	
E6. ***If yes:*** **What was the main purpose of storage?** 1=Food for the HH 2=To sell for higher price 3=Seeds for planting 4=Other purpose, specify	1	2	3
	4		
E7. Do you or someone else in the HH sell products from the farm on the market?	No	Often	Some-times
E8. ***If often or sometimes:*** **Approx. how much cash income did the HH earn from selling crops last year (2013)?**			

E9. ***If often or sometimes:*** **Approx. how much cash income did the HH earn from selling crops the year before (2012)?**				
E10. What is the name of the closest market and in which village is it located?				
E11. What is the means of transport to the market place? 1=Walk 2=Bicycle 3=Motorbike (pikipiki) 4=Bus or daladala 5=Other, specify	1	2	3	4
	5			
E12. What is the approximate distance to the market? And/or how long time does it take to go there (one-way)? (Specify for different means of transport)				
E13. How would you describe the roads leading to the market? 1=In very good condition 2=In fairly good condition 3=In poor condition 4=In very poor condition	1	2	3	4

F. Farm management and environmental setting

F1. Do you use farmyard manure/compost on your fields?	Yes	No		
F2. What type of other farm inputs, if any, have been applied on the land this year? * 1=No other inputs 2=Chemical fertilizer 3=Herbicide 4=Pesticide/fungicide	1	2	3	4
F3. ***If 2-4:*** **Have you used similar products earlier years? Approx. for how many years?**				
F4. Do you use improved seeds?	Yes	No		
F5. Do you use any cover-crops? Which crops? Approx. for how many years have you done this?				

F6. Do you have any slopes on your farmland?	Yes	No	
F7. Compared to other farms, would you describe this farm as located in a ***more*** **hilly area, a** ***less*** **hilly area or about the** ***same*****?**	More	Less	Same
F8. Have you planted any trees in slopes?	Yes	No	
F9. ***If yes:*** **Did you choose tree species specially adapted to slopes (e.g. with deep roots)?**	Yes	No	
F10. 10 years ago, did you have any problems with soil erosion/soil degradation?	Yes	No	
F11. Do you have any problems with soil erosion/soil degradation at the moment?	Yes	No	
F12. Are any practices employed for soil conservation/erosion control?			
F13. Have you noticed any difference in erosion since you started planting trees?	Yes	No	Maybe
F14. Can you describe the soils of your farm? What soil type(s) do you have?			
F15. Compared to other farms in the area, would you describe the soil as 1=The same 2=More degraded/unproductive/difficult to farm 3=More fertile/productive	1	2	3

F16. Have you had any problems with crop diseases/pests in the past 10 years?	Yes	No

F17. *If yes:* Since you started with agroforestry would you say the occurrence of pests have 1=Stayed the same 2=Increased 3=Decreased	1	2	3

F18. Do you irrigate your crops?	Yes	No
F19. *If yes:* What irrigation practices are employed? And which type of crops are irrigated?		

F14. From where does the HH get water? (Does it differ between dry and rain season?) 1=Nearby river/stream 2=Spring 3=Lake 4=Well 5=Water pipe 6=Other, specify	1	2	3	4	5
	6				
F15. How far away is the place from where the HH get water? How long time does it take to go there (one-way)?					
F16. How often do you or someone in the HH get water?					

F17. Do you employ any rainwater harvesting (RWH) techniques?	Yes	No
F18. *If yes:* Do you harvest rainwater from your roof? Is it working well? How much water do you get?		

F19. *If yes:* Are any RWH practices employed on the fields? * 1=Ridges 2=Mulching 3=Microcatchments (circular or "half-moons") 4=Other, specify	1	2	3
	4		
F20. *If no:* Why not? * 1=Do not need it 2=Have no knowledge and need help 3=Too expensive to buy water containers and/or gutters 4=Other, specify	1	2	3
	4		

F21. Are there many agroforestry farms in this area? Are any of your neighbours practicing agroforestry?
F22. Has the landscape changed a lot in the past 10 to 20 years?
F23. What is the main land use of this area now? What did it use to be?

G. Use of trees as energy

G1. How is food prepared in this HH? * 1=Traditional stove ("three-stone-stove") 2=Charcoal stove 3=Wood-saving stove 4=Other, specify	1	2	3
	4		
G2. What type of fuel is used for the stove? * 1=Charcoal 2=Fire wood 5=Other, specify	1	2	
	3		

G3. How is the fuel obtained? * 1=Own farm 2=Bought 3=Collected from woodland 4=Collected from single trees in the landscape 5=Other specify	1	2	3	4
	5			
G4. *If 2:* Is it bought on the market or from charcoal/fire-wood hawkers?				
G5. *If 2-5:* How often is fuel obtained? And how much is needed in a week?				
G6. Before you started with agroforestry, how was the fuel obtained?				

G7. Is there a lot of deforestation going on in this area? When did it start?		
G8. Have people ever cut down trees from your land without permission? (When was this?)	Yes	No

H. Climate and climate change

H1. Compared to 10 years ago, do you feel the weather is different today?	Yes	No
H2. *If yes:* would you describe these changes as 1=No change 2=Increase 3=Decrease		
Total rainfall	1	2	3
Length of rain seasons	1	2	3
Unpredictable rainfalls	1	2	3
Temperature	1	2	3
Wind	1	2	3
H3. 10 years ago, in which months did the <u>long rains</u> use to start and end?			
H4. In which months do the <u>long rains</u> start and end nowadays?			
H5. 10 years ago, in which months did the <u>short rains</u> use to start and end?			
H6. In which months do the <u>short rains</u> start and end nowadays?			
H7. Have you ever had a <u>flood</u> in this area? When was the last time? Has the frequency of floods increased/decreased?			
H8. Have you ever had a <u>drought</u> in this area? When was the last time? Has the frequency of droughts increased/decreased?			

H9. *If yes on H1:* Why do you think the weather has changed?
H10. *If yes on H1:* Are you worried about the future? Do you think farms that are practicing agroforestry are better adapted to these changes?

Appendix III: Climate change in the study area

Africa as a whole is, according to the fifth IPCC report (2014), very sensitive to climate change and is considered "one of the most vulnerable continents due to its high exposure and low adaptive capacity". It is predicted, with a high confidence, that heavy precipitation will increase in East Africa overall (Seneviratne et al. 2012 in IPCC 2014). It is also predicted, with a medium confidence, that droughts will intensify (in the dry seasons) due to reduced precipitation and/or increased evapotranspiration.

63 out of 64 respondents interviewed for this study claimed they had felt changes in the climate over the past ten years and many of them expressed deep concern and worries about their future. This Appendix will therefore treat the climate trends in the study area over the past three decades. The trends were assessed from rainfall and temperature data measured at a climate station in Musoma, and by a brief analysis of NDVI data (GIMMS) using TIMESAT 3.1 and SPSS Statistics 17.0. The GIMMS data set covers the time period 1986-2011, and the measured climate data covers the time period 1980-2013.

TIMESAT is a software programmed for studies of satellite data time series (Eklundh & Jönsson 2012). The software uses a number of methods to extract seasonality parameters such as the beginning and end of the growing season, and the seasonal amplitude. Further TIMESAT uses an adaptive Savitzky-Golay filtering method to smooth the fitted data.

Measured climate data

The climate of Musoma has always varied from month to month and year to year and thus the period 1980-2013 is too short to draw any certain conclusions. The rainfall and temperature data presented here merely shows the measured values together with linear trends which not have been tested for significance.

Figure II:1 shows five-year monthly rainfall averages between 1980 and 2013. A slight shift in the long rains (March-May) is seen. In earlier years the highest rainfall was obtained in April but in the periods 2005-2009 and 2010-2013 most rain fell in March. This is consistent with the trend of increasing rainfall in March and decreasing rainfall in May and June (Figure II:2).

From the monthly rainfall and monthly minimum and maximum temperatures, which are found in Figures II:2-4, the main trends can be summarised as:

Long rains (March to May)

The trends show an increase of rainfall in March but decreases in April and May. Traditionally April has been the month with the highest rainfall but since 2006 the rainfall of April has been less than 100 mm three times. Nearly all farmers (apart from in Shirati) were complaining about the decrease of rain in April and May, and the measured data supports the farmers views. The increasing trend of March would maybe have been flatter if it were not for the two rainfall peaks in 2010-2011. However, it looks like the March rainfall is getting more variable.

Short rains (Oct to Dec)

No big changes can be seen. There are slight increases in November and December and a very small decrease in October.

Dry periods

The rainfall of the dry period between June and September has not changed very much. In September the rainfall seems to have increased slightly in the past ten years. In January and February the rainfall shows a very small decreasing trend.

Minimum and maximum temperatures

Both minimum and maximum temperatures show slightly increasing trends nearly every month (except from the maximum temperatures of September, November and December). The trend of temperature increase from 1980 to 2013 rarely exceeds 0.5°C. But the trends of maximum temperature of February and the minimum temperature of August show an increase of about 1°C.

Overall change

The observed rainfall in Musoma suggests slightly decreasing rainfall in the first six months of the year except for in March, which is the beginning of the rainy season. For the rest of the months the only notable change is the rainfall in November which has increased. Both minimum and maximum trends for temperature have had a general increase throughout the year.

Considering the measured climate data it seems as it supports the farmers' experiences. Opinions on whether the total rainfall had increased or not varied between the farmers, but nearly all claimed that the unpredictability had increased and that periods of drought were more severe now than they used to be. Furthermore, the increases of temperature in especially the dry months of July and August combined with no changes in rainfall indicate more severe dry periods.

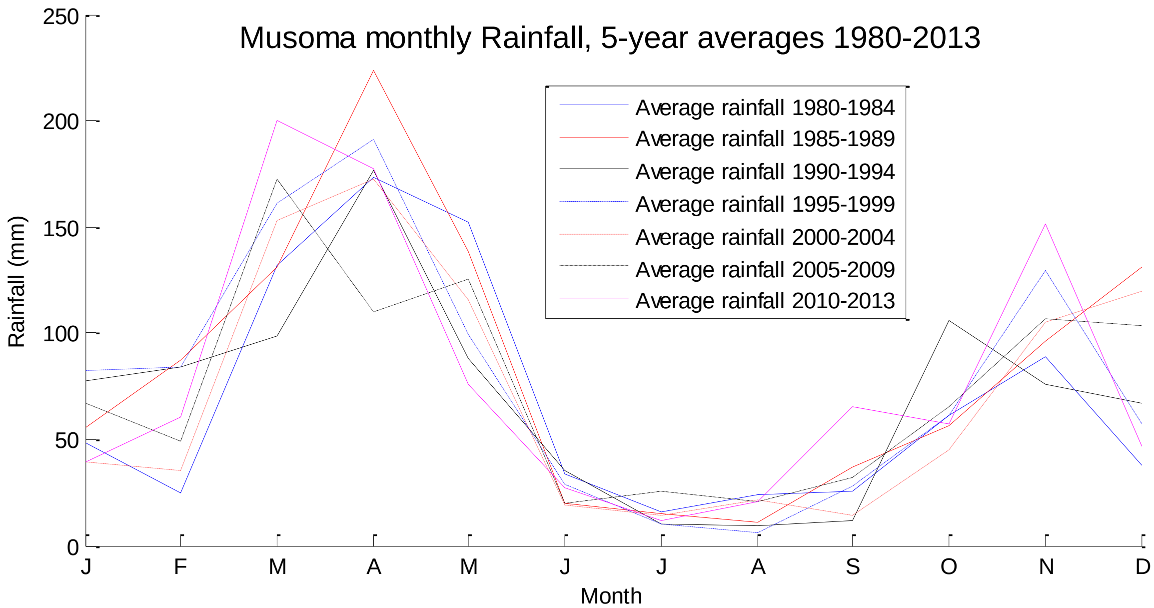


Figure II:1. Montly rainfall in Musoma, divided into five-year-averages. Source: TMA 2014.

Figure II:2.

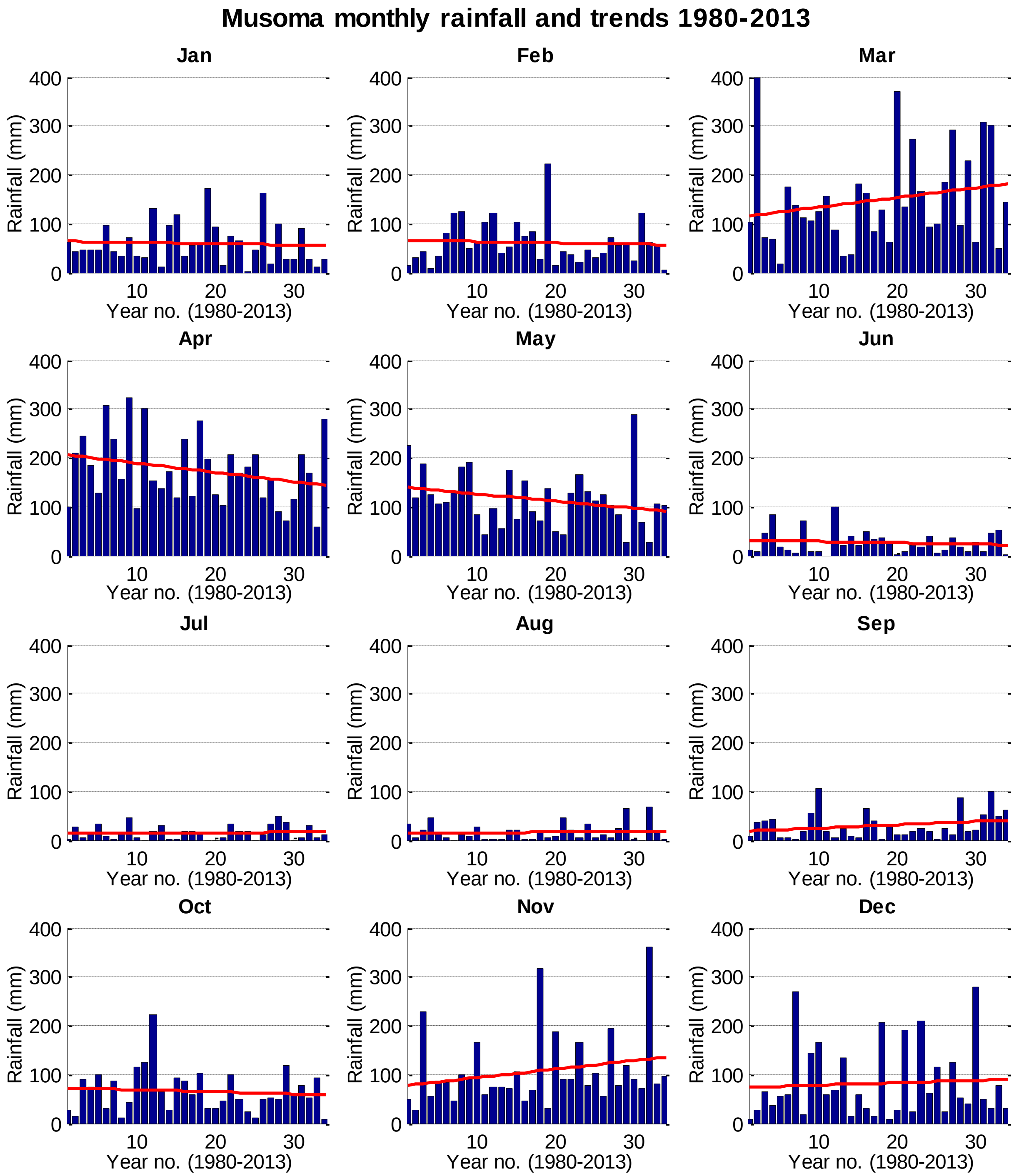

Musoma monthly rainfall and trends 1980-2013
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Rainfall (mm)
Year no. (1980-2013)
400
300
200
100
0
10
20
30

Figure II:3.

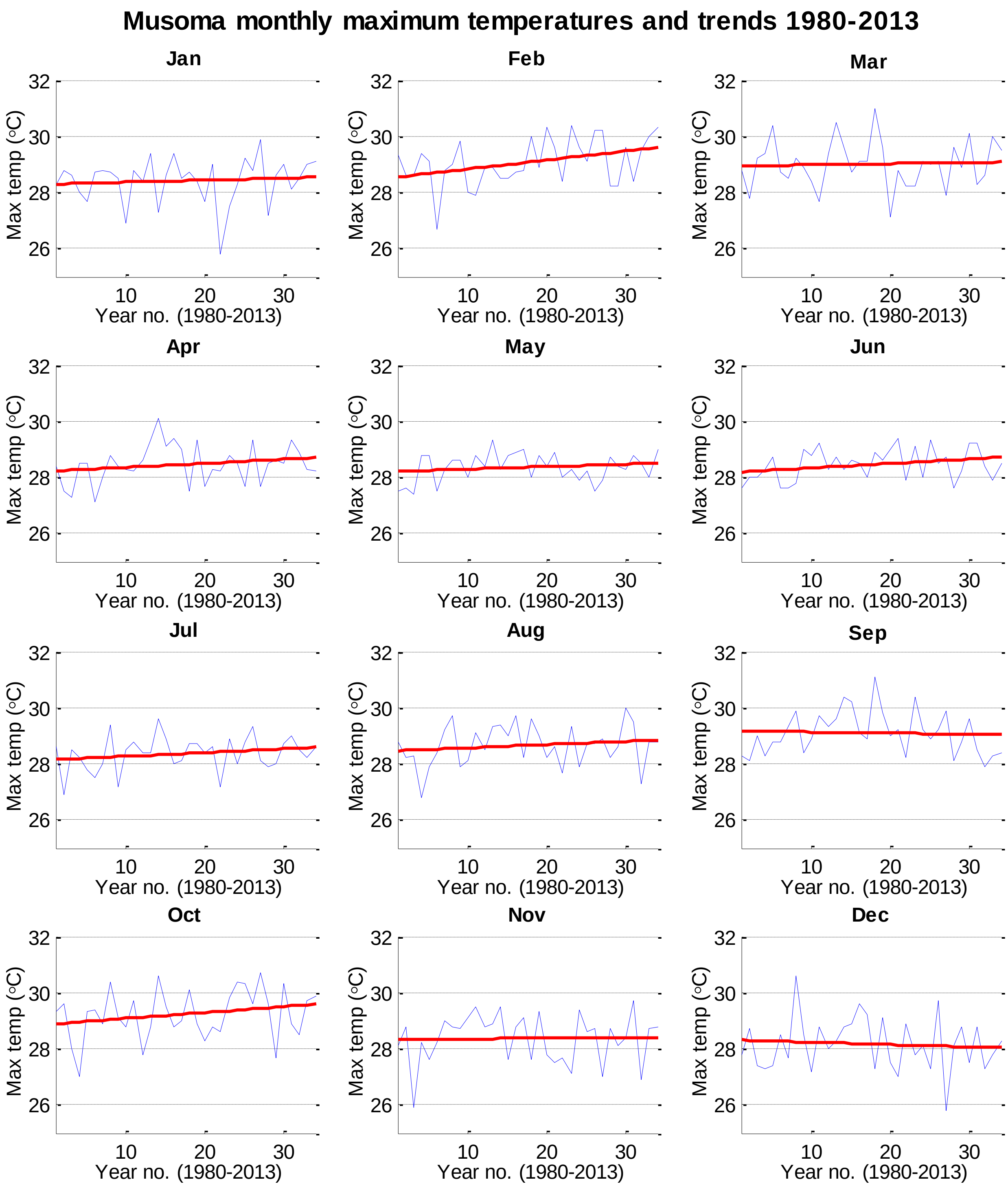
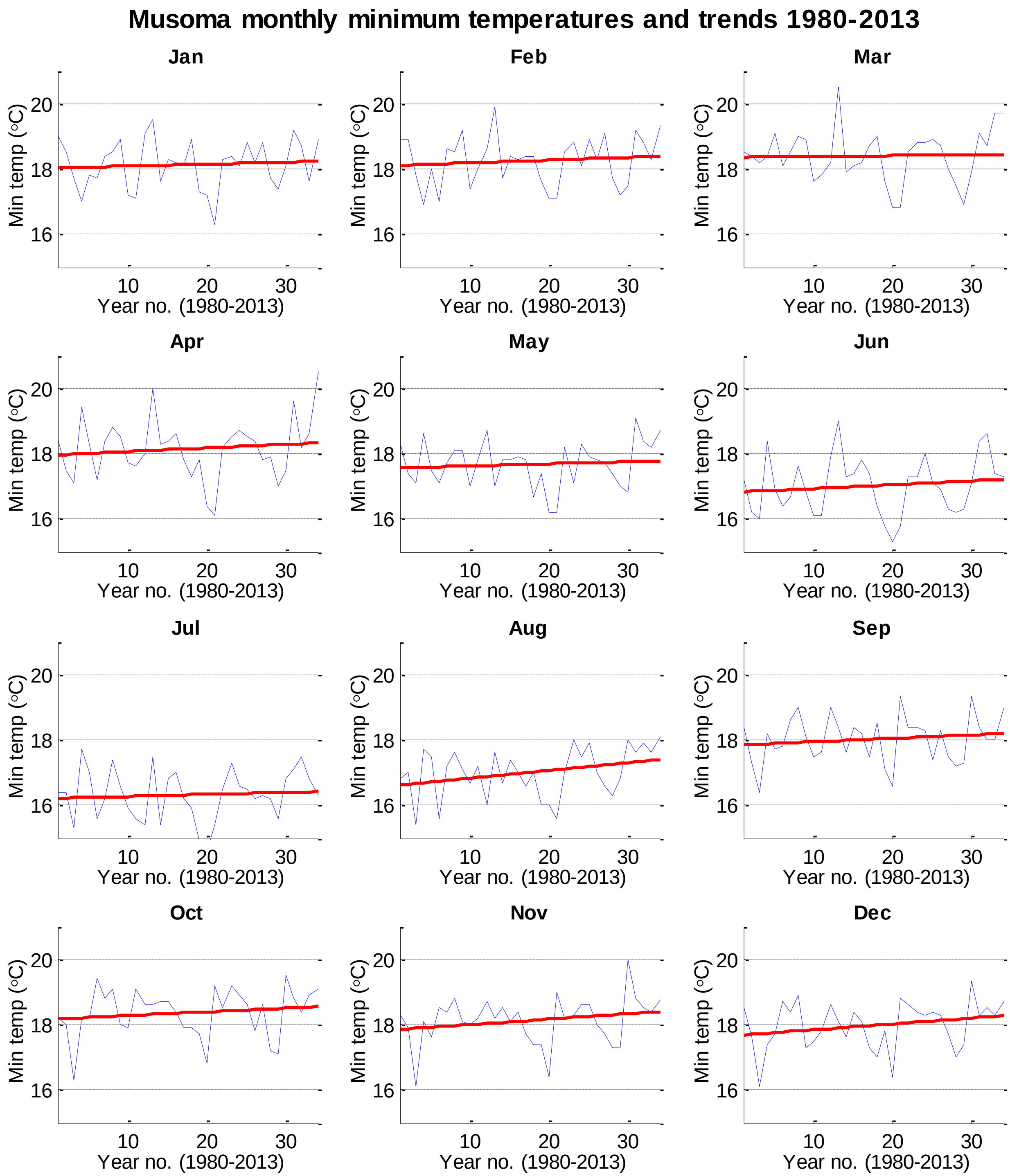

Musoma monthly maximum temperatures and trends 1980-2013
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Max temp (ºC)
32
30
28
26
10
20
30
Year no. (1980-2013)

Figure II:4.



Musoma monthly minimum temperatures and trends 1980-2013
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Min temp (oC)
Year no. (1980-2013)
20
18
16
10
20
30

NDVI trends

Seasonal parameters were extracted from NDVI data of one 8×8 km pixel located in the middle of the study area. To be sure of the trends a much larger area would have to be investigated. Still the results can be used as an indicator of possible changes since 1986.

Figure II:5 shows the NDVI time series. Each year has two seasons so two peaks can be seen, the first peak each year represents the long rains and the second represents the short rains. It looks like the NDVI values varies between about 0.45-0.70 in the 1980s and early 1990s, but sometime in the mid-1990s the peaks start to increase whereas the dips seem to become more irregular. For the first time in the time series none of the seasons could be detected in 1998. In 2006, 2007 and 2009 the second season was undetected. Many farmers mentioned absent rain seasons as an increasing problem and this result indicates they were right.

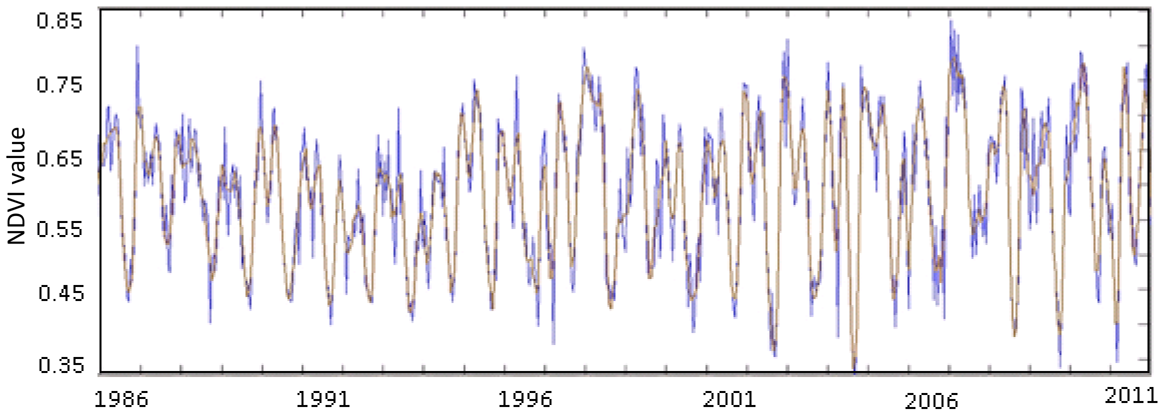


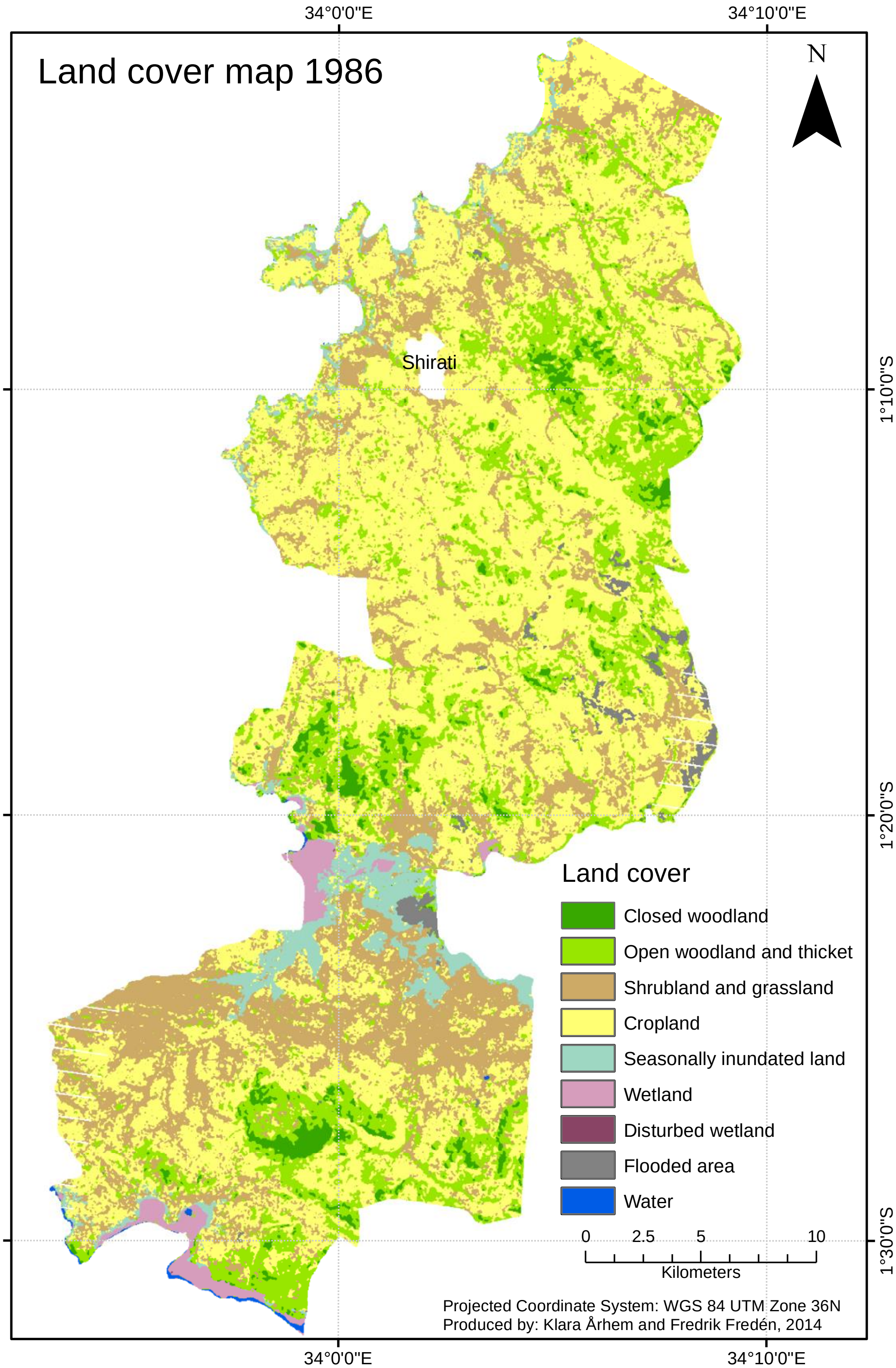
Figure II:5. NDVI values (blue) together with the Savitzky-Golay smoothing curve (brown).

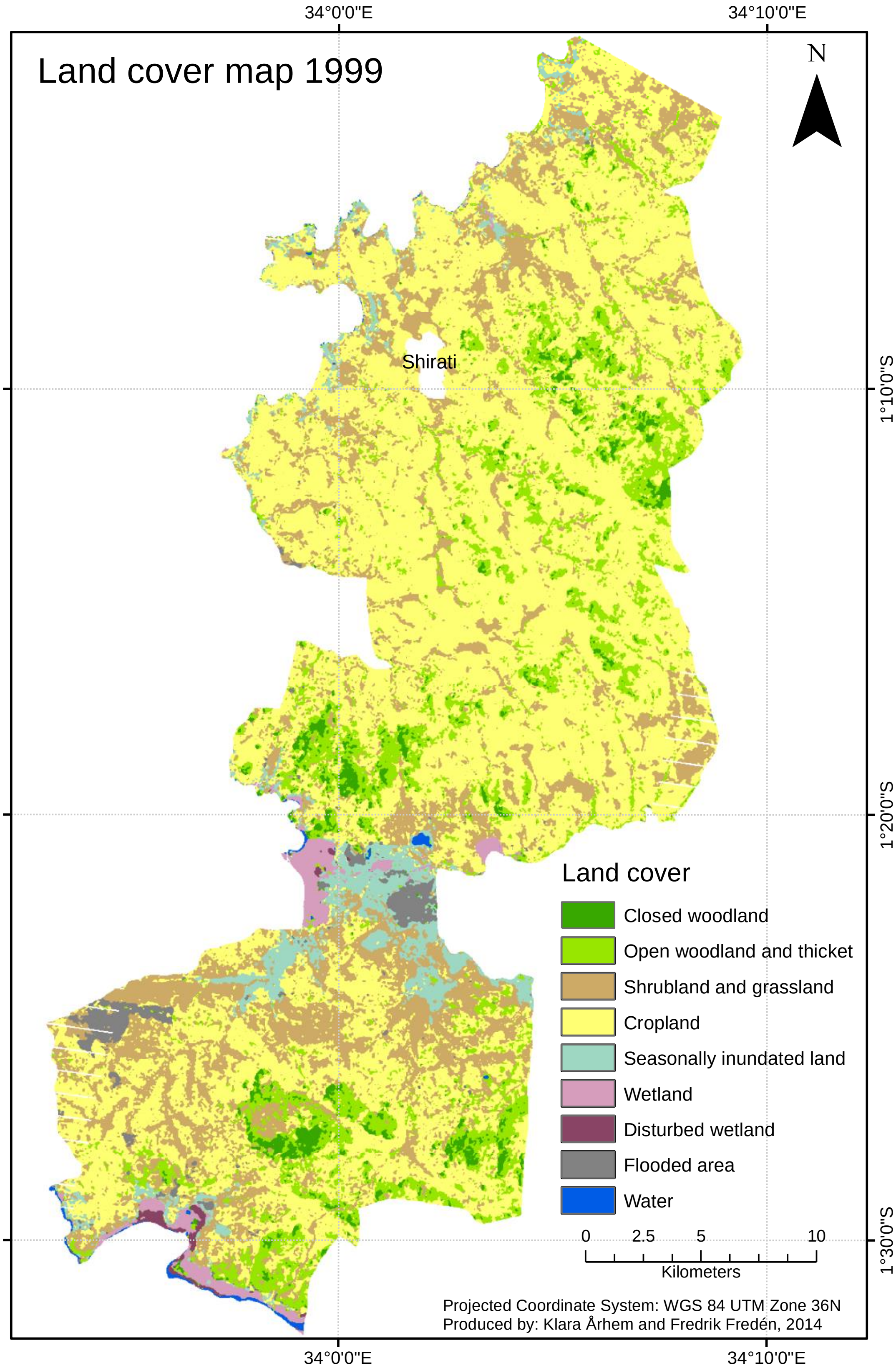
To investigate whether there were any significant trends in the data the peak values (the highest value per season), the base value (the average of the left and right minimum values) and the seasonal amplitude (the difference between the peak value and the base level) were analysed using linear regression in SPSS. The linear regression shows significant increasing trends of the amplitudes ($p<0.001$). For the first season the amplitude increases with an average of 0.00548 per season during the study period, and the second season the average increase is 0.00515 per season (Table II:1). The peak values also increase, although the peak values of the second season could not be proven significantly (probably because of the missing years). The base values show a small and insignificant decreasing trend the first season and in the second season there is an average decrease of 0.0026 per year ($p<0.05$). The trends support the farmers' experiences of larger variations in the climate.

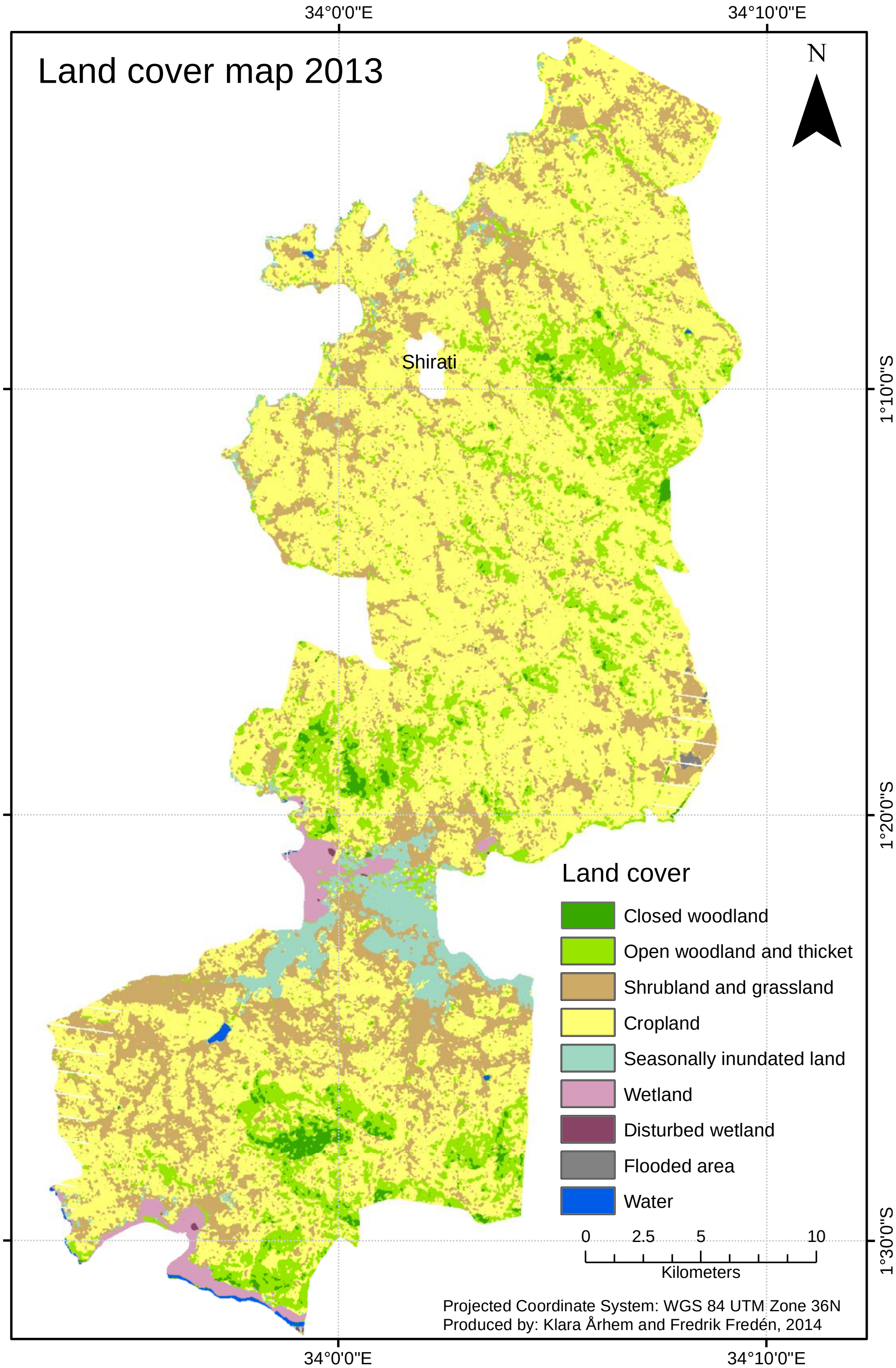
Table II:1. Changes in NDVI peak value, base value and amplitude between 1986 and 2011. For the full series the number denotes the change in NDVI per season, and for the two seasons it shows the change in NDVI per year. The significance value is shown within brackets.

	Peak value		Base value		Amplitude	
Full NDVI series	0.00189	(p=0.000)	-0.00077	(p=0.039)	0.00267	(p=0.000)
Season 1	0.00475	(p=0.000)	-0.00073	(p=0.488)	0.00548	(p=0.000)
Season 2	0.00254	(p=0.108)	-0.00260	(p=0.018)	0.00515	(p=0.000)

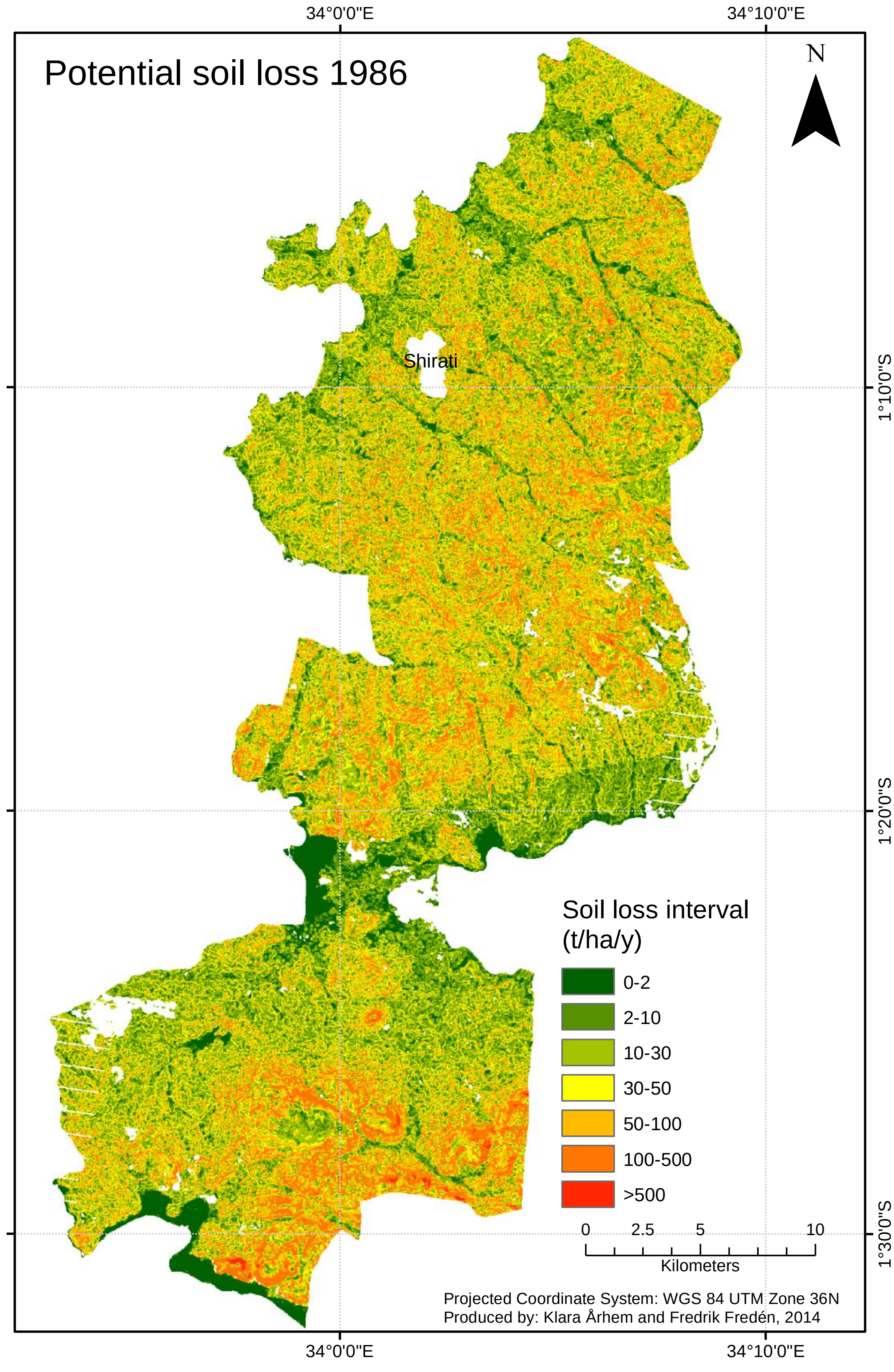
Appendix IV: Land cover maps 1986-2013

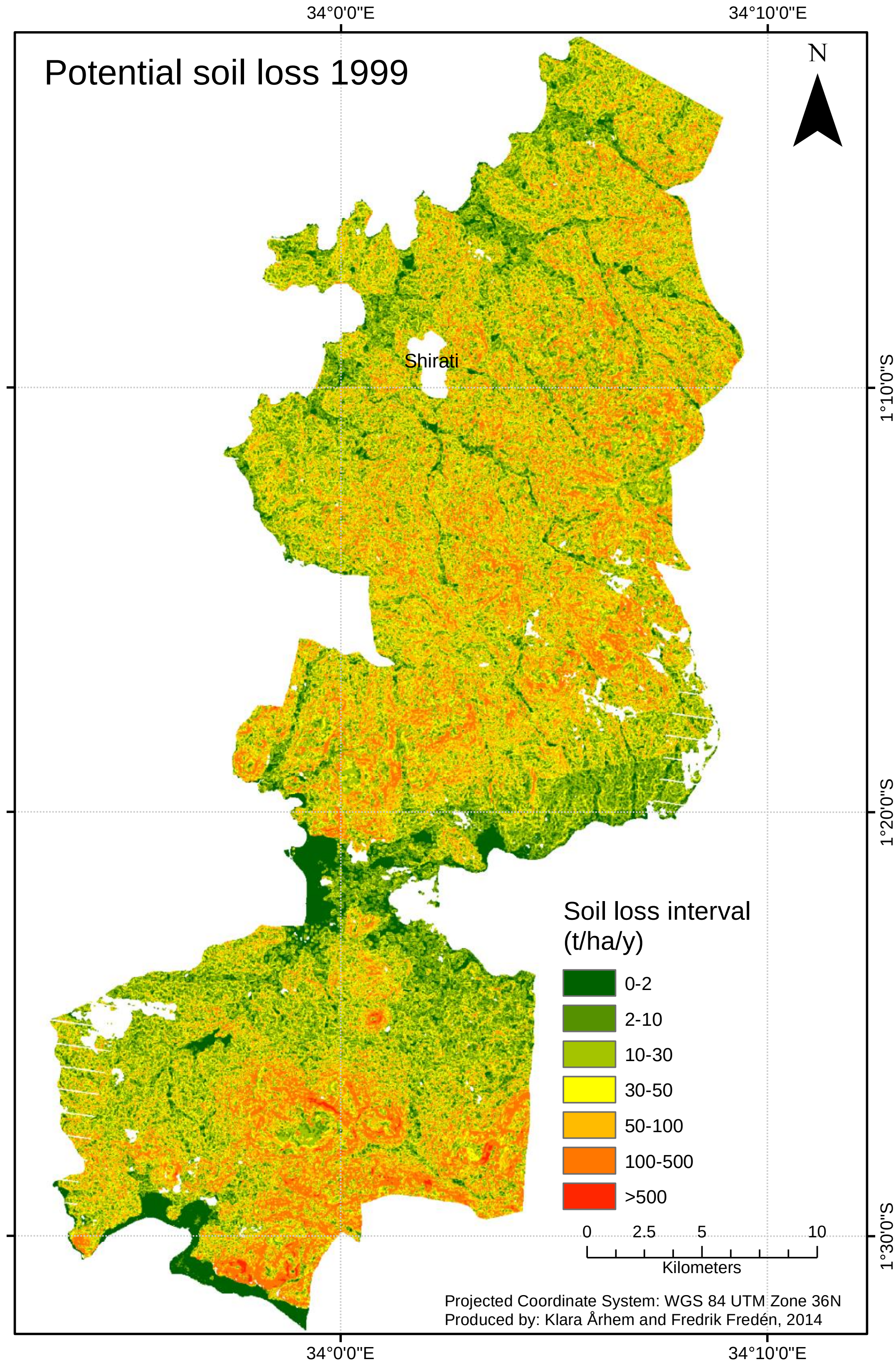


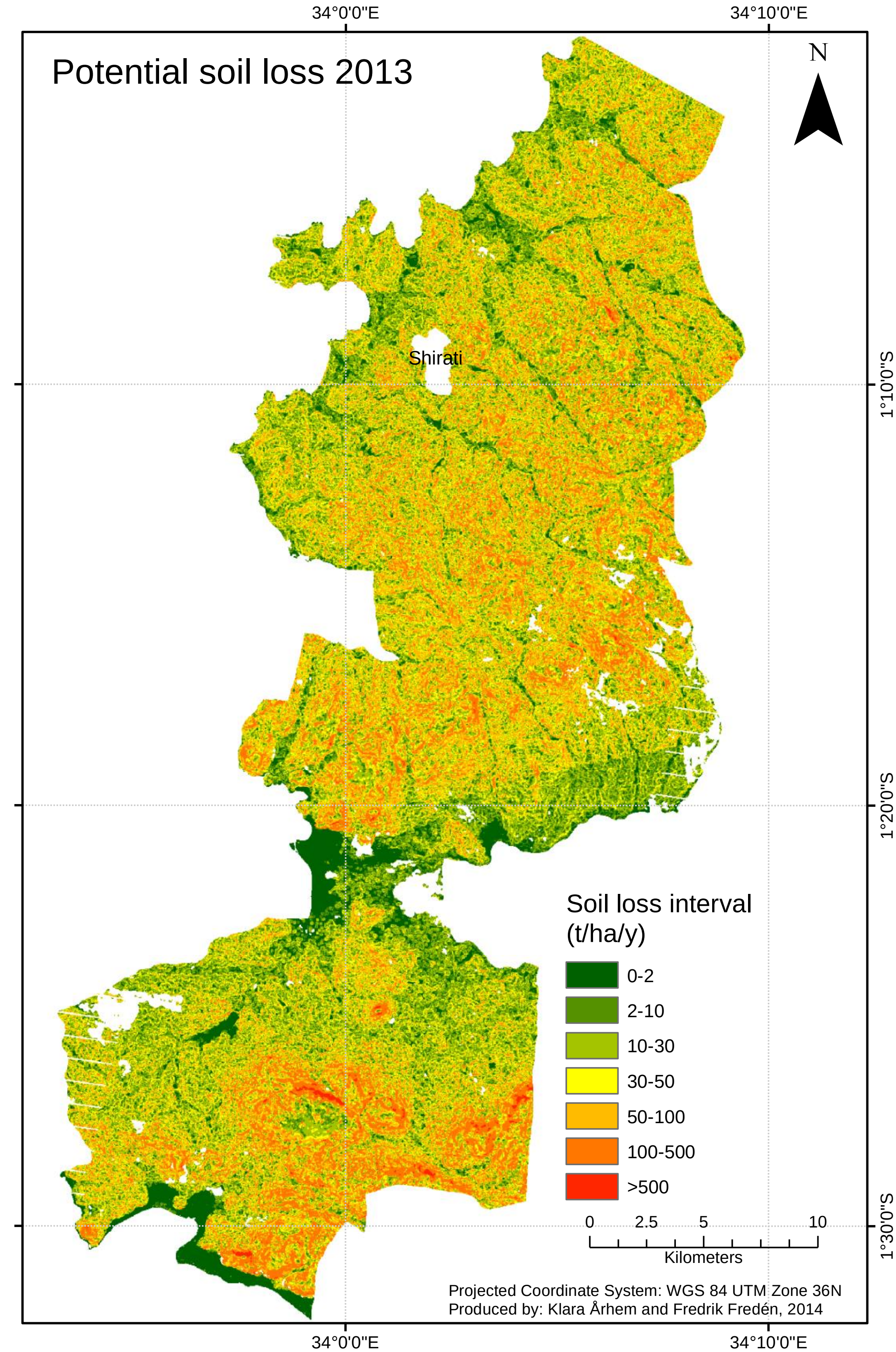

34°0'0"E
34°10'0"E
Land cover map 1999
N
Shirati
1°10'0"S
1°20'0"S
1°30'0"S
Land cover
Closed woodland
Open woodland and thicket
Shrubland and grassland
Cropland
Seasonally inundated land
Wetland
Disturbed wetland
Flooded area
Water
0
2.5
5
10
Kilometers
Projected Coordinate System: WGS 84 UTM Zone 36N
Produced by: Klara Århem and Fredrik Fredén, 2014
34°0'0"E
34°10'0"E


Land cover map 2013
34°0'0"E
34°10'0"E
N
Shirati
1°10'0"S
1°20'0"S
1°30'0"S
Land cover
Closed woodland
Open woodland and thicket
Shrubland and grassland
Cropland
Seasonally inundated land
Wetland
Disturbed wetland
Flooded area
Water
0 2.5 5 10
Kilometers
Projected Coordinate System: WGS 84 UTM Zone 36N
Produced by: Klara Århem and Fredrik Fredén, 2014

Appendix V: Soil loss maps 1986-2013




Potential soil loss 1999
34°0'0"E
34°10'0"E
N
Shirati
1°10'0"S
1°20'0"S
1°30'0"S
Soil loss interval
(t/ha/y)
0-2
2-10
10-30
30-50
50-100
100-500
>500
0
2.5
5
10
Kilometers
Projected Coordinate System: WGS 84 UTM Zone 36N
Produced by: Klara Århem and Fredrik Fredén, 2014



34°0'0"E
34°10'0"E
Potential soil loss 2013
N
Shirati
1°10'0"S
1°20'0"S
1°30'0"S
Soil loss interval (t/ha/y)
0-2
2-10
10-30
30-50
50-100
100-500
>500
0 2.5 5 10
Kilometers
Projected Coordinate System: WGS 84 UTM Zone 36N
Produced by: Klara Århem and Fredrik Fredén, 2014
34°0'0"E
34°10'0"E

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