The impacts of Maasai settlement on land cover, meteorological conditions and wind erosion risk in northern Tanzania




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Abstract

Many land cover changes took place in northern Tanzania in the last decades. These land cover changes were determined using satellite images. The causes and consequences of the land cover changes were determined using literature and field data from interviews. It turned out that the Maasai, an ethnic group of pastoralists living in northern Tanzania, started to settle in the 1970s, because of governmental policies, population growth, climate change, cultural shift or a combination of these factors. When settled the Maasai started to adopt crop cultivation next to their traditional pastoralism. In order to do this, they had to clear the traditional vegetation. This land clearance has consequences for the wind speed and wind erosion risk. The latter two were estimated using a model with input data from both field plots and scenarios. It turned out that the erosion risk becomes high after clearance, since trees are very important in wind reduction and shrubs are very important in covering the soil surface and preventing particle entrainment.

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1. Introduction

The Maasai is an ethnic group of semi-nomadic pastoralists and agro-pastoralists, who have been living on the rangelands of southern Kenya and northern Tanzania since approximately 1850 (Homewood and Rodgers, 1989). This area covers about 150,000 km^2 (Homewood et al., 2009), which is approximately half the size of Germany. Based on the number of Maa speakers, which is the native language of the Maasai, total Maasai population is estimated to be 1,297,000, and the Tanzanian Maasai population is estimated to be 455,000 (Ethnologue, 2015). Their current economy is mainly based on subsistence agro-pastoralism (MDC, 2014). However, the Maasai used to live as pastoralists only, who raise animals like cows, goats, donkeys and sheep for their livelihood (Homewood et al., 2009). The pastoralists moved a few times a year in order to find new pastures for their livestock (Butt et al., 2009). The pastures are not covered with enough grass for grazing throughout the whole year, because of seasonal productivity. The semi-arid savanna climate with dry and wet seasons is responsible for the seasonality, which results in lack of water availability for vegetation growth in the dry seasons (Pratt and Gwynne, 1977).

The Maasai are not only restricted in their movements by environmental factors, but also by governmental factors like the villagization campaign (Ruppert and Schrüfer, 1995). The Tanzanian government started this campaign in the 1970s in order to settle down Maasai nomads in permanent villages. The government sees settlement as prerequisite for the abilities to improve infrastructure, increase agricultural production for export, collect taxes from registered residents more easily and to introduce formal education (Kjekshus, 1977; Homewood et al., 2009). Before the 1970s, Maasai children rarely went to a secondary school (Coast, 2002). The villagization policy is seen as one of the major factors driving land use and land cover changes in northern Tanzania (Sandström, 1995; Homewood et al., 2009; John et al., 2014).

Maasai households, who got settled, started to diversify their livelihood in the past decades (McCabe et al., 2014). Some households started to adopt crop cultivation next to their traditional pastoralism, most of the times by choice and not out of necessity (McCabe et al., 2010), despite the fact that the Maasai have had no experience with farming in the beginning (Ruppert and Schrüfer, 1995). In order to make the land suitable for agriculture, the settled Maasai needed to clear parts of the savanna. One of the consequences of the land clearance because of adoption of agriculture is land degradation (Schmidt, 1997). Due to the lack of vegetation cover and the semi-arid environment, the risk of wind and water erosion may increase. For example, large areas around Lake Babati, north Tanzania, were converted to farmland since the mid-1970s. This accelerated land degradation and in the end induced flooding of the lake in 1964, 1979 and 1990 (Sandström, 1995). The rainfall record does not show a trend which can explain these floods (Sandström, 1995). In general, ‘anthropogenic soil erosion and not external climate drivers shaped landscape development in northeast Tanzania,’ according to Heckmann (2014).

In addition to agro-pastoralism, the Maasai people started to produce and sell fuelwood (Butz, 2013). However, the rate of production is presumably higher than the regeneration of savanna woodland (Butz, 2013), hence land degradation could be a consequence. Besides fuelwood, Maasai started to sell livestock and products like milk, tobacco and beadwork and they started to migrate to urban areas for employment, as new ways of gaining income (McCabe et al., 2014). Nowadays, migration is playing an important role in the Maasai society (McCabe et al., 2014).

Besides some Maasai lifestyle changes, the landscape of northern Tanzania has also been altered by the expansion of national parks and conservation areas and the advent of large commercial farms (Homewood and Brockington, 1999; Igoe and Brockington, 1999; Miller, 2015). Hence, the traditional landscape of northern Tanzania is being fragmented (Grimm et al., 2008). This fragmentation has negative consequences for both the livelihoods of the Maasai and the wildlife of the savanna (FAO, 2009). For example, conversion of savanna into new residential and agricultural areas around national parks and conservation areas causes decreasing wildlife populations, since large mammals can only survive on extended lands, which are larger than the parks themselves (Ogutu et al., 2008). For the Maasai fewer pastures are available because of the fragmentation.

This study focused on the above mentioned land use and land cover (LULC) changes in northern Tanzania, since the introduction of the villagization policy in the mid-1970s, and the subsequent consequences regarding meteorological conditions and wind erosion risk.

Therefore, the objectives of this research project were:

- To determine land use and land cover changes since the mid-1980s in the study area in northern Tanzania;
- To determine the causes and consequences of the land use and land cover changes;
- To estimate the change in wind speed due to land clearance in the areas where Maasai people have settled;
- To estimate the associated wind erosion risk.

2. Study area

2.1 General

The study area is the Monduli District, which is located in Arusha Region in northern Tanzania (Figure 2.1). The district is further divided into several wards. This district is situated between latitudes 3.00 and 4.50°S and between longitudes 36.45 and 36.50°E. It is enclosed by Karatu and Ngorongoro District in the west, Mbulu and Babati District in the south, Simanjiro District in the southeast, Arumeru District in the east and the border with Kenya in the north. The area covers 15,955 km^2, which is about half the size of The Netherlands. Monduli District has got a population of 158,929 (NBS, 2012). 40% of the population is Maasai, 20% is another ethnic group called Waarusha and 40% is not indigenous (MDC, 2014). Since most of the data needed for this thesis research was obtained in the southern part of the study area during a three-month field trip (January – March 2016), the analysis were applied to both the entire district and only the southern part. The analysis of the latter is more extensive. The southern part of Monduli District covers all the area located to the south of the imaginary line between Selela and Monduli (Figure 2.3).

In terms of land use, the study area consists mostly of pastures and rain-fed agricultural areas (Maerker et al., 2015), with large-scale farming mainly present in the southeastern part (MDC, 2014). According to MDC (2014) approximately 14% of the semi-arid grazing land is identified as agricultural land. To the north and northeast of Lake Manyara, alkaline grasslands occur next to banana plantations (Loth and Prins, 1986). Several roads are present in the area (depicted as black lines on Figure 2.1), however it should be noted that only two of them are paved: road A104 and road B144. The many roads in the southern part are dirt roads in the Tarangire National Park and the other roads, mainly in the northern part of the district, are dirt roads as well.

Currently, socio-economic as well as environmental changes are taking place in Monduli District, such as land use and land cover (LULC) changes and population increase (Kiunsi and Meadows, 2006). Kiunsi and Meadows (2006) state that between 1960 and 1999 the increase is agricultural areas, both small scale (subsistence) and large scale (commercial) farms, is the most significant LULC change, accompanied by a decrease in natural and semi-natural vegetation and an increase in bare soil and gullies. This gully erosion is the dominant erosion process and forms a major threat regarding land degradation (Maerker et al., 2015). According to MDC (1997), overgrazing is a serious cause of land degradation in the study area. Other possible causes of land degradation are the removal of natural vegetation for agricultural purposes, heavy machinery usage on farms resulting in soil compaction, high erodibility of volcanic soils, population increase and certain governmental policies (Kiunsi and Meadows, 2006).

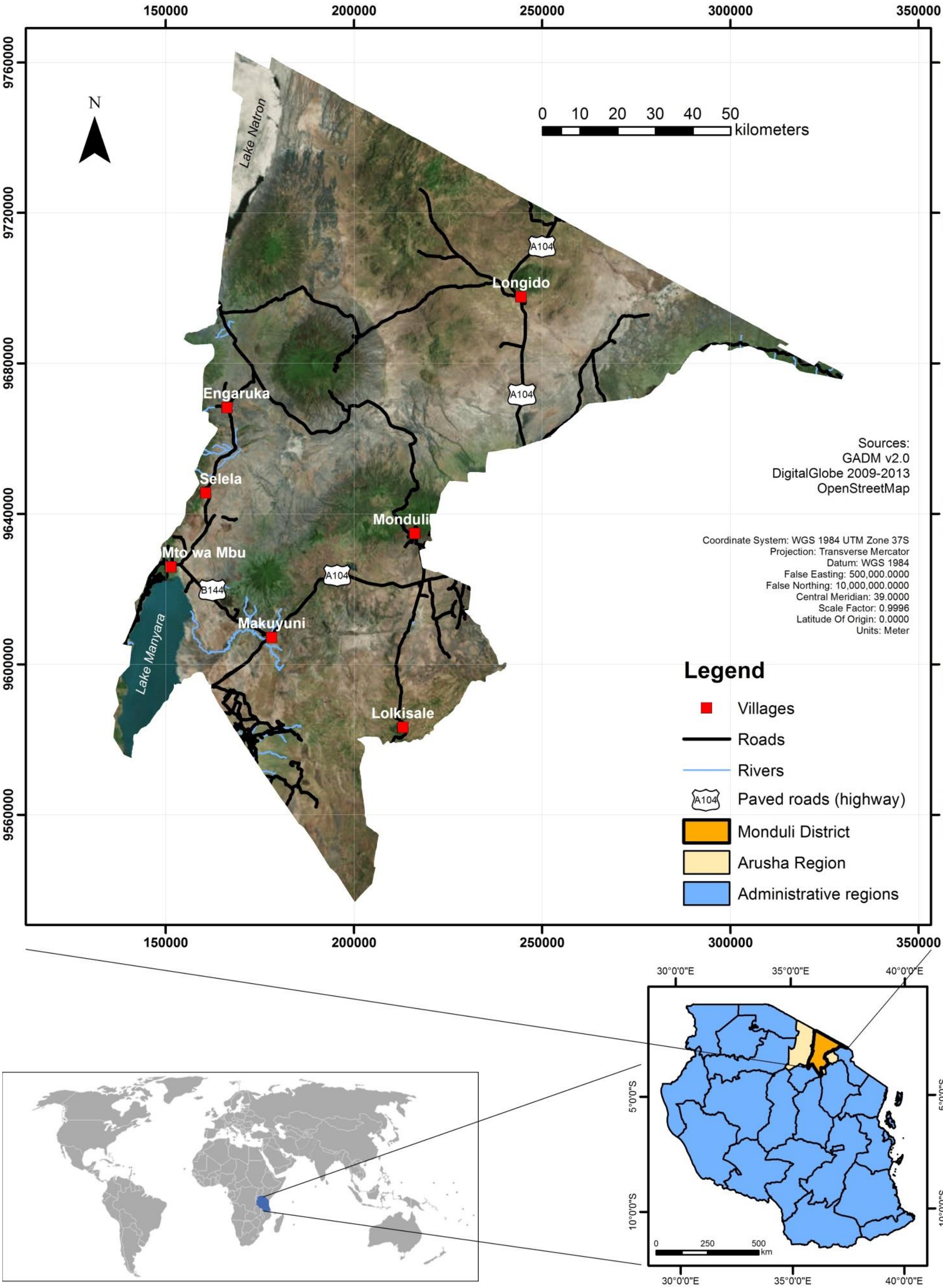


Figure 2.1: Study area: Monduli District in Arusha Region, northern Tanzania.

2.2 Climate

The study area is characterized by a tropical wet and dry, or savanna, climate ('Aw' in the Köppen climate classification system) (Hudak, 1999; Bachofer et al., 2014). This means that the average temperature is approximately 18 °C or higher during the whole year (Figure 2.2). Over the last 50 to 100 years, the IPCC (2011) observed an increase in temperature in Tanzania, and this warming will likely continue with 2-4 °C by the end of this century. Currently, mean annual temperature is approximately 22 °C around Lake Manyara, in the center of the fieldwork area (Loth and Prins, 1986). The mean annual rainfall is ranging between 200 and 1,200 mm (Gichohi et al., 1996; Kiunsi and Meadows, 2006; Bachofer et al., 2014). The lower lying areas, or lowland zone, receive a mean annual rainfall of 700 mm (Maerker et al., 2015), whereas in the mountainous areas, or highland zone, 1,000-1,200 mm rain is the annual average (Gichohi et al., 1996; Kiunsi and Meadows, 2006; Bachofer et al., 2014). In the Arusha region, a bimodal rainfall distribution is present (Loth and Prins, 1986; Butz, 2013; Bachofer et al., 2014). This means that two rainy seasons and two dry seasons can be distinguished (Figure 2.2). The short dry season is from January until February. After that, a three-month period of rain occurs from March until May ('long rains'). The long dry period lasts from June until October. In November and December is the second rainy season ('short rains'). The latter period has got unreliable rains, which are poorly distributed and a cause of local droughts (Ngailo et al., 2001). The study area was hit by severe droughts in 1997 and 2009 (Miller et al., 2014). These prolonged periods of drought occur more frequently in recent years and result in lack of water, scarcity of pastures, deaths of large numbers of livestock and subsequent food insecurity (URT, 2007; Oxfam International, 2008; Shemsanga et al., 2010).

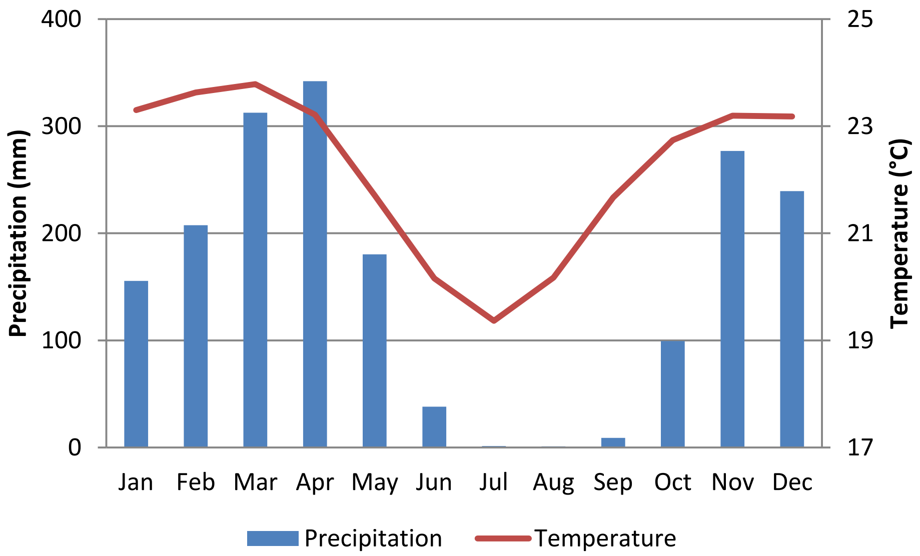


Figure 2.2: Climate graph of Makuyuni in northern Tanzania. Modified from FAO (2005).

2.3 Geology, geomorphology and soils

The geology, geomorphology and soil types of the study area are strongly influenced by Quaternary volcanism and tectonic activity, which are ongoing processes (Iranga, 1991; Marghany, 2002). From north to south, the eastern branch of the East African Rift System (EARS), or Rift Valley, runs through the study area. The EARS was formed in the Late Tertiary (Loth and Prins, 1986). The EARS is an active continental rift zone with corresponding volcanic and seismic activity (Loth and Prins, 1986; Chorowicz, 2005). This system is responsible for some characteristic landscape phenomena originated from the Pleistocene, like the Ngorongoro crater (2,960 m) to the west of the study area, the active Ol Doinyo Lengai volcano in the northwest, the Essimingor volcano (2,154 m) east of Lake Manyara and the Monduli Mountains in the east (Berry, 1972). During the Holocene, the Rift Valley got its present form after been filled up with sediments (Berry, 1972).

The EARS also created the Manyara Basin in the southern part of the study area, with a 200-600 m high escarpment in the west, which runs from Lake Manyara to Lake Natron (Bachofer et al., 2014). This escarpment forms the western border of the study area. In the western and northwestern part of the basin, just outside the study area, a higher plateau with sequences of mainly lavas and layers of volcanic ash exists (Bachofer et al., 2014). The lavas and volcanic ash are rich in sodium and easily weathered, so a high amount of sodium is being released into the lower lying areas, like Lake Manyara, and therefore the alkalinity of the study area is high (Loth and Prins, 1986). When evaporation occurs in the dry periods, some parts of the lake bed of Lake Manyara are exposed and the alkalinity of the water reaches a level at which the sodium crystallizes into large soda crystals (Beadle, 1974). Besides seasonal variability on the short term, variations in annual rainfall amount are responsible for lake level fluctuations on the long term (Loth and Prins, 1986).

The elevation of the study area ranges between approximately 600 m and 2,900 m (MDC, 2014). Figure 2.3 provides a Digital Elevation Model (DEM) of the southern part of the study area. Lake Manyara (954 m), Essimingor volcano (2,154 m, also known as Losimingori), Monduli Mountains and Lolkisale Mountain can easily be recognized. Based on altitude, MDC (2014) distinguishes two major agro-ecological zones in Monduli District. The highland zone (1,200 – 2,200 m) is characterized by isolated mountains, with a mean altitude of 2,000 m a.s.l. (MDC, 2014). In this zone, forests are present with mainly deep, loamy soils rich in organic matter content (MDC, 2014). Because of the long dry periods, not enough water is available in the lowland zone of the study area (600 – 1,200 m) for the development of forests. Here, bushed wooded grasslands and grasslands on flat and rolling plains dominate with mainly deep clay soils, which occupy approximately 32% of the Monduli District (MDC, 2014). Agriculture and extensive livestock farming activities take mainly place in the lowland zone (MDC, 2014). MARI (2006) has described agro-ecological zones as well (Figure 2.4), but these zones are not only based on altitude, but also on amount of rainfall and physiography.

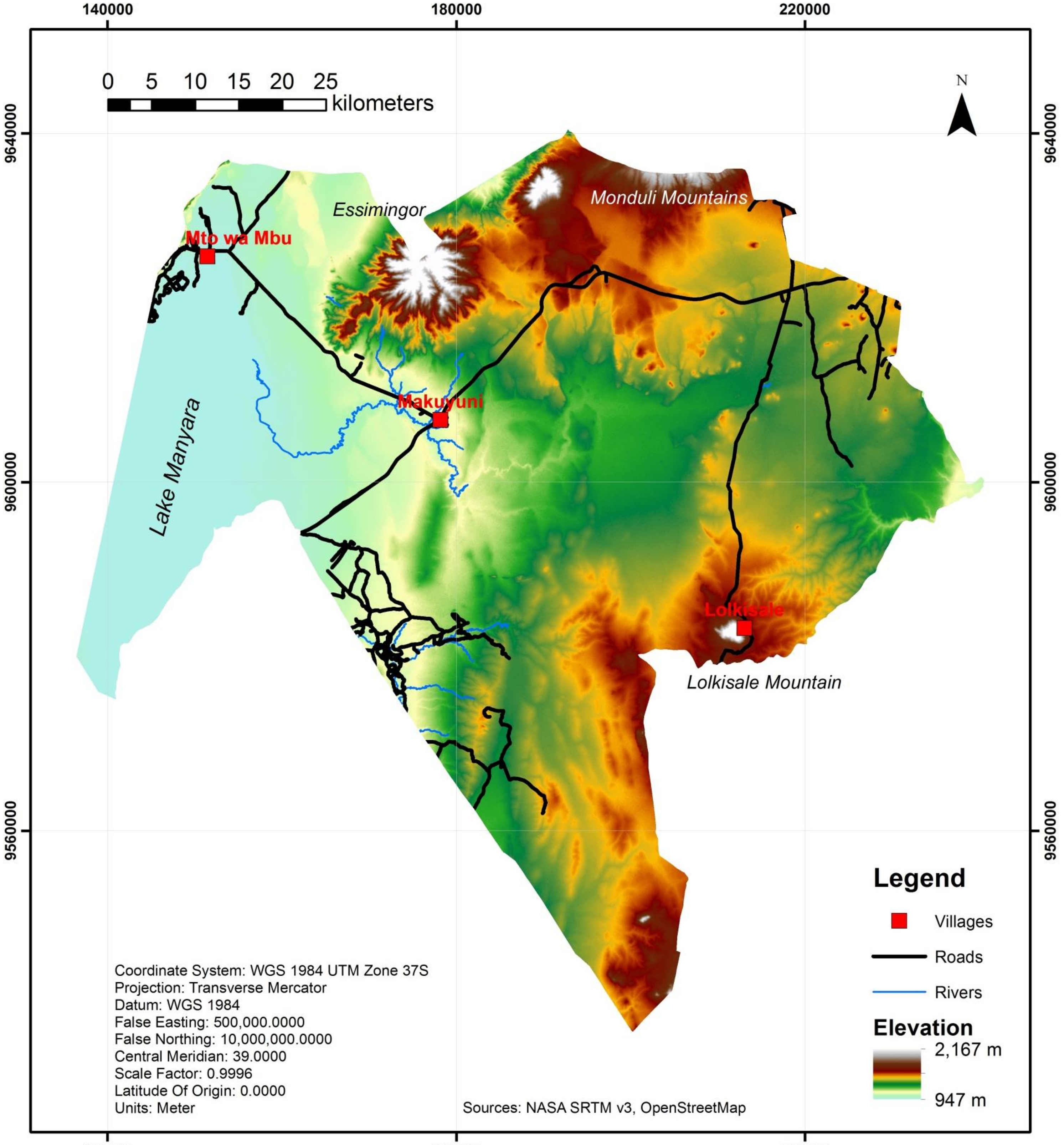
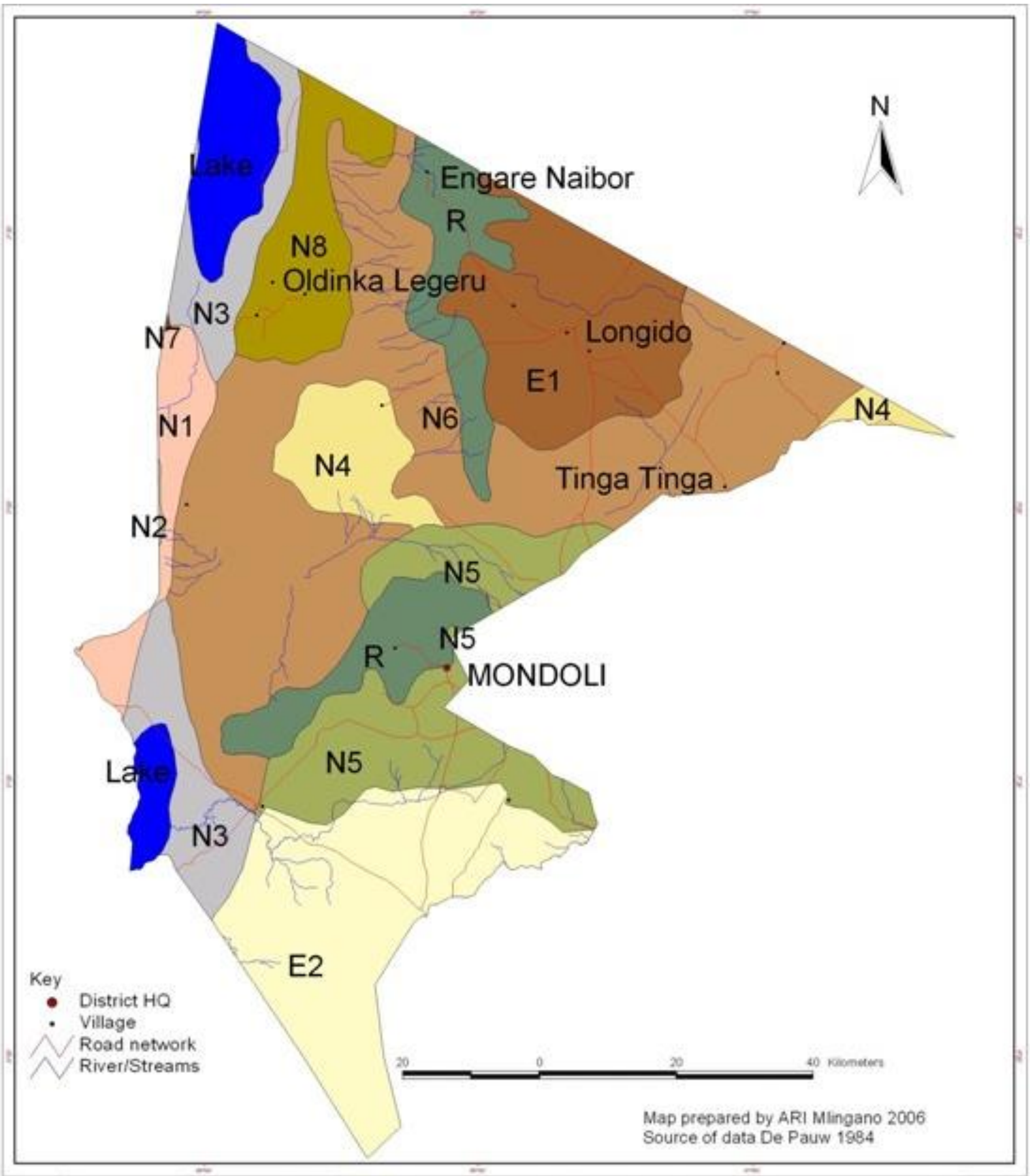


Figure 2.3: DEM of southern part of Monduli District, northern Tanzania.



Aez_code	Altitude(masl)	Rainfall (mm/year)	Physiography
E1	500-1200	400 - 500	Gently undulating to rolling plains and plateaux developed on gneisses
E2	500-1200	< 500	Undulating to rolling plains and plateaux alti 500-1200 m developed on gneiss
Lake		1200 - 1400	
N1	1500-2500	600 - 700	Rolling to hilly, dissected plateaux developed on volcanic ash and lava
N2	2000-2500	800 - 1000	Rolling to hilly plateau with calderas and volcanic cones
N3	900-1100	400 - 500	Flat lacustrine plains with extensive salt and soda flats, inundated
N4	900-3500	500 - 600	Volcanic mountains with gentle to steep slopes developed on ash and lava
N5	1300-1700	1000 - 1200	Flat to rolling plains developed on volcanic ash and sediments
N6	1300-1700	200 - 400	Flat to rolling plains developed on volcanic ash, lava and lahars
N7	1300- 1800	600- 700	Low to rolling plains meium to high altitude developed on slightly weathered volcanic ash
N8	1300 - 2300	800 - 1000	Level to undulating or rolling plains at medium to high altitude developed on volcnic ash
R			Rocky terrain

Figure 2.4: Agro-ecological zones of Monduli District, northern Tanzania (MARI, 2006).

Figure 2.5 shows a different view on the elevation, whereby different elevation classes are distinguished based on the agro-ecological zones of MDC (2014) and MARI (2006). The lowest zone (947 – 1,200 m) corresponds to the 'lowland zone' and the two other zones correspond to the 'highland zone' of MDC (2014). Furthermore, the lowest zone corresponds to zone 'N3', the middle zone (1,200 – 1,700 m) corresponds to zone 'N5' and 'N6' and the highest zone (1,700 – 2,167 m) corresponds to zone 'R' of MARI (2006). A description of the elevation zones of Figure 2.5 is shown in Table 2.1. The elevation classes are used for land cover analysis (Chapter 3.2 and 4.2) of the southern part of Monduli District.

Table 2.1: Elevation classes of Figure 2.5 in northern Tanzania.

Elevation class (m)	**Corresponds with MDC (2014) zone**	**Corresponds with MARI (2006) zone**	**Description**
1,700 – 2,167	Highland	R	Tops of mountains with forests.
1,200 – 1,700	Highland	N5 and N6	Flat to rolling plains on volcanic ash.
947 – 1,200	Lowland	N3	Flat (lacustrine) plains with soda flats and grasslands.

The soil types of the study area are strongly influenced by Quaternary volcanism and tectonic activity, which are ongoing processes (Iranga, 1991; Marghany, 2002). The soil types were used for land cover analysis (Chapter 3.2 and 4.2) of the southern part of Monduli District. The most common soil types found in the southern part of Monduli District are shown in Table 2.2 (FAO, 2012; Jones et al., 2013) and on the soil map in Figure 2.6. Luvisols cover most of the area (44%), followed by chernozems (23%). Andosols (soil on volcanic material) and leptosols (shallow soil over hard rock) are situated on the slopes of the Essimingor volcano and Monduli Mountains and cover respectively 3% and 14% of the area. Leptosols are subject to drought, runoff and hence erosion due to their shallow depth (FAO, 1993). Andosols, chernozems and luvisols are both fertile and suitable for agriculture, whereas vertisols are fertile as well, but less suited for subsistence agriculture (FAO, 1993). Soils with a high sodium content (solonetz) and high clay content (vertisols) are found in the depositional area of the Manyara Basin. Due to the high sodicity of solonetz, this type of soil is toxic for crops (FAO, 1993).

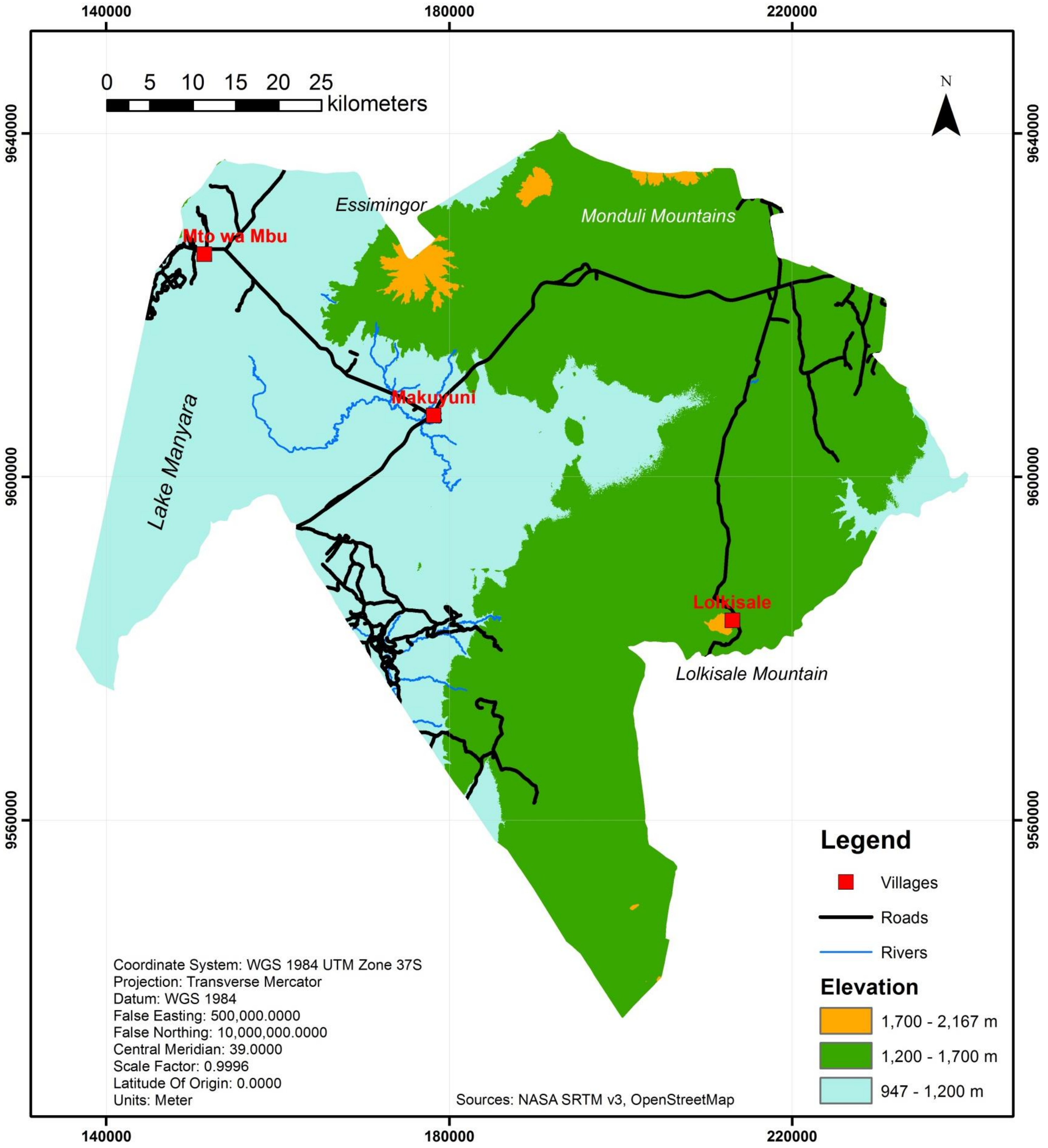


Figure 2.5: DEM with elevation classes of southern part of Monduli District, northern Tanzania.

Table 2.2: Most common soil types in southern part of Monduli District, northern Tanzania.

Soil type	Code	Percentage	Color on fig. 2.6	Description
Andosols	ANsm	2.88	Red	Young soil formed from volcanic deposits.
Chernozems	CHlv	22.78	Green	Soil with a thick, dark topsoil, rich in organic matter with a calcareous subsoil.
Leptosols	LPeu	13.72	Orange	Very shallow soil over hard rock.
Luvisols	LVcr	44.17	Dark green	Soil with subsurface accumulation of high activity clays and high base saturation.
Solonetz	SN	1.16	Purple	Soil with subsurface clay accumulation, rich in sodium.
Vertisols	VRha	8.81	Grey	Soil with dark colored cracking and swelling clays.
Water bodies	-	6.47	Blue	Water.

2.4 Vegetation

The savanna landscape of the study area is characterized by grassland, bushed wooded grassland (grasses with shrubs and trees of varying densities) and forest, and is inhabited by lots of wildlife, like elephants, zebras, lions, giraffes, buffalos and antelopes (Butz, 2009). Most common tree species on the east African savanna are members of the Acacia genus and members of the Baobab genus (Hudak, 1999; Homewood et al., 2009). The vegetation provides multiple products for the inhabitants and their livestock as well as for the wildlife, like forage, fuelwood, building materials and medicinal plants (Ibrahim, 1997; Kiunsi and Meadows, 2006). The vegetated areas have also been cleared in order to make the land suitable for agriculture for both small-scale (subsistence fields) and large-scale (commercial farms) farm holders (Kiunsi and Meadows, 2006). Besides, fires used by Maasai as land management tool have altered the vegetation in some parts of the study area as well (Greenway and Vesey-FitzGerald, 1969; Butz, 2009).

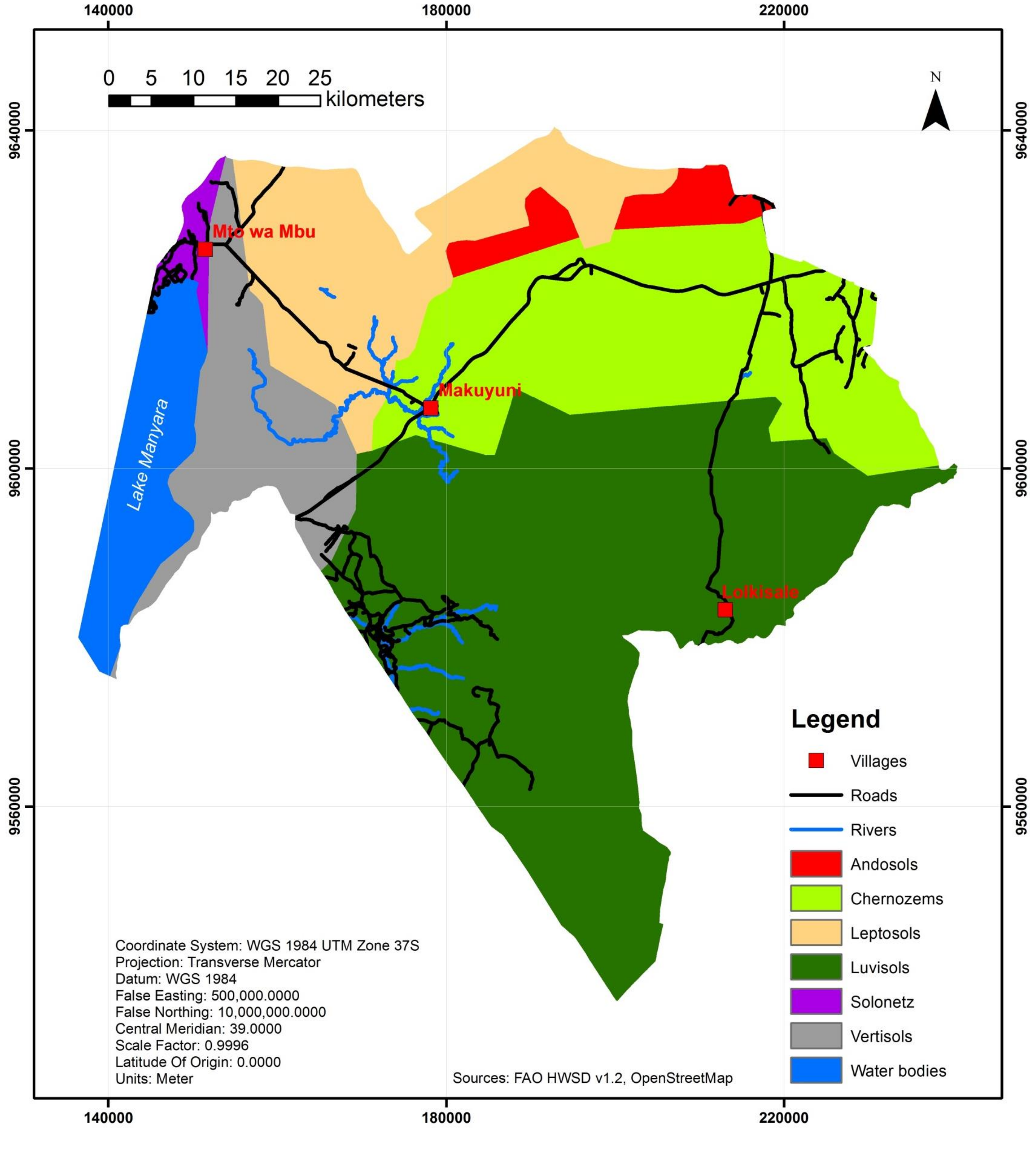


Figure 2.6: Soil map of southern part of Monduli District, northern Tanzania.

2.5 Maasai inhabitation

The Maasai residents live together with their families and livestock in huts made of mud, manure and timber, which is called a ‘boma’. Bomas range in size from 20 to 200 people, depending on the number of families, and several bomas make up a village (Butz, 2009). Sometimes, temporary bomas are built in so called ‘drought resource areas’ (DRAs), areas like rivers and swamps which provide resources (forage and water) for the livestock of the Maasai in the dry season (Miller et al., 2014). Within a Maasai family, the men take care of the cattle and the women raise the children and run the household (Homewood et al., 2009). The Maasai use almost the entire body of an animal for their livelihood. For instance, meat is eaten, milk and blood is drunk, skin is used as floor mat to sleep on and manure is used to build huts (Homewood et al., 2009). Main source of energy used by Maasai is fuelwood (i.e. charcoal and firewood) (Arnold et al. 2006).

The area which is inhabited by the Maasai is characterized by a semi-arid savanna climate (Hudak, 1999; Bachofer et al., 2014), which has a long dry period and periods of (unreliable) rains (Ngailo et al., 2001). Furthermore, over the last 50 to 100 years, the IPCC (2011) observed an increase in temperature in Tanzania, and this warming will likely continue with 2-4 °C by the end of this century. The Maasai have been dealing with success with this highly variable climate for centuries (Nassef et al., 2009). However, the current rapid climate change is increasingly compromising their adaptive capacities and hence putting more pressure on the traditional livelihood of the Maasai (Galvin et al., 2004; Oxfam International, 2008).

During the dry period, vast areas of dried grass, or poor grasses, are present. The Maasai pastoralists use small fires to eliminate those poor grasses and to prevent larger catastrophic fires in the late season (Butz, 2009). Therefore, the vegetation in some parts of Maasai land is modified (Greenway and Vesey-FitzGerald, 1969). The burning practices are reasons of conflicts between wildlife managers, or the government, and the Maasai (Butz, 2002). However, the frequency of burning practices by Maasai is currently declining, because possible conflicts with the government, unreliable rainfall amounts, accidental fires increase, population increase and livestock increase make burning too risky (Butz, 2009).

According to the Maasai, land ownership rights do not exist, whereas the Tanzanian government considers all areas with no registered owner as national property (Kuney, 1994; Ruppert and Schrüfer, 1995). Hence, their legal systems contradict each other, resulting in restrictions on movement possibilities for the Maasai (Ruppert and Schrüfer, 1995). The government threatens Maasai movements by the villagization policy and by allocation of conservation areas and expansion of existing national parks, where housing is prohibited (Ruppert and Schrüfer, 1995; Homewood and Brockington, 1999; Miller, 2015). These expansions of parks are also reasons of conflict between wildlife agencies and Maasai (Coast, 2002). Another restriction on Maasai movements and hence on access to spatially divided resources, is the advent of commercial farms on the rangelands of Tanzania (Igoe and Brockington, 1999). Large scale fields of e.g. wheat, barley and flowers reduce the availability of pastures, water and other resources for the Maasai (Fratkin, 2001). Because of all those restrictions and because of a cultural shift, many Maasai changed their economy from pastoralism to agro-pastoralism (McCabe et al., 2010).

3. Methods

3.1 Interviews

To obtain a first indication of land use changes, meteorological conditions and wind erosion risk in the study area, people who inhabit the area have been interviewed. In total fifteen semi-nomadic Maasai and fifteen settled people have been interviewed. They were asked about their experiences and opinions regarding land use changes and its consequences for the last decades. An interpreter was used for translation during the interviews. A first interview was conducted to test if the questions are suitable. Based on this test, the questionnaire has been changed before doing the rest of the interviews. The questionnaire is attached to this document in Appendix I and is divided into three sections:

1) General questions;
2) Questions regarding livestock and agriculture;
3) Questions regarding experiences and opinions about land use changes.

Firstly, the interviewee was asked general questions (section 1) about how long and why they live there, what type of farming they carry out, what they changed to the landscape and about any other activities to gain income. Secondly, questions about farming (section 2) were asked, like what is the herd size, what is the area and quality of grazing lands and what is the area and quality of agricultural lands. Thirdly, section 3 consists of more open questions regarding the experiences and opinions of the interviewed inhabitant about land use and land cover changes. These questions are about differences in quality of grazing lands and agricultural fields, meteorological differences, amount of wind, amount of dust and consequences for the land cover and for the interviewee due to external factors like commercial farms and national parks. The outcome of the interviews was used to put the results of the land use and land cover changes analysis and the results of the meteorological conditions and wind erosion risk analysis in perspective.

3.2 Land use and land cover

The study area has been investigated through time with remote sensing (RS) images. These images are classified in order to make land cover maps for different years, to detect areas of land cover change and to calculate the amount and rate of land cover change. To be able to make classifications as good as possible, images with a high spectral and spatial resolution were needed. Besides, images should be available since the beginning of the villagization policy in the mid-1970s. Therefore, images from the Landsat program of the National Aeronautics and Space Administration (NASA) and the United States Geological Survey

(USGS) are chosen. The first satellite of the program, Landsat 1, produced images from 1972 until 1978. It had a Multispectral Scanner System (MSS) on board with 4 bands (0.5-1.1 µm) and a spatial resolution of approximately 60 m. According to Woodcock and Strahler (1987), this resolution is too low to properly classify land cover. Hence, images made with the MSS-sensor were not used. Landsat 2 and 3 had similar specifications compared to Landsat 1. Landsat 4 was launched in 1982 and was the first satellite carrying a Thematic Mapper scanner (TM) with 7 spectral bands (0.45-12.5 µm) and a spatial resolution of 30 m, next to the MSS. The image size of TM is 185 km x 172 km and the temporal resolution is 16 days. Landsat 5 has similar specifications compared to Landsat 4. Landsat 6 was lost at the launch. Landsat 7 has only the Enhanced Thematic Mapper + scanner (ETM+) aboard with one more band compared with the TM (band 8, panchromatic, 15 m resolution). However, Landsat 7 experienced a malfunction in one of its instruments, the Scan Line Corrector, since May 31, 2003. Therefore, Landsat 7 images are of poor quality and were not used. Landsat 8 is equipped with the Operational Land Imager scanner (OLI, 9 bands (30 m) including one panchromatic band (15 m)) and the Thermal Infrared Sensor (TIRS, 2 thermal bands (100 m)). It has a temporal resolution of 16 days. Landsat 7 and 8 are still operational.

Considering all above mentioned facts, Landsat 4, 5 and 8 images could be used. The images were chosen depending on quality (value ranging from 0-9), cloud cover (0-100%) and acquisition date. Quality should not be lower than 7. Cloud cover should not exceed 10%, otherwise the visibility is too low. Acquisition date should be in the dry season when cloud cover is mostly low. Since the fieldwork of this thesis research was conducted in January, February and March 2016 and the first dry period occurs in the first two months of the year, images of January and February were used. The chosen images are listed below in Table 3.1. Those images are freely available and downloaded from the USGS Global Visualization (GLOVIS) website (glovis.usgs.gov). The process of making the land cover maps from the satellite images is shown in Figure 3.1 and is described in the next paragraphs.

Table 3.1: Remote sensing images selected for land cover classification.

Latitude	**Longitude**	**Acquisition date**	**Satellite**	**Sensor**	**Spatial resolution (m)**	**Quality**	**Cloud cover (%)**
-2.9	36.8	18-01-1985	Landsat 5	TM	30	9	10
-4.3	36.5	18-01-1985	Landsat 5	TM	30	9	0
-2.9	36.8	28-03-2016	Landsat 8	OLI	30	9	1
-4.3	36.5	28-03-2016	Landsat 8	OLI	30	9	4

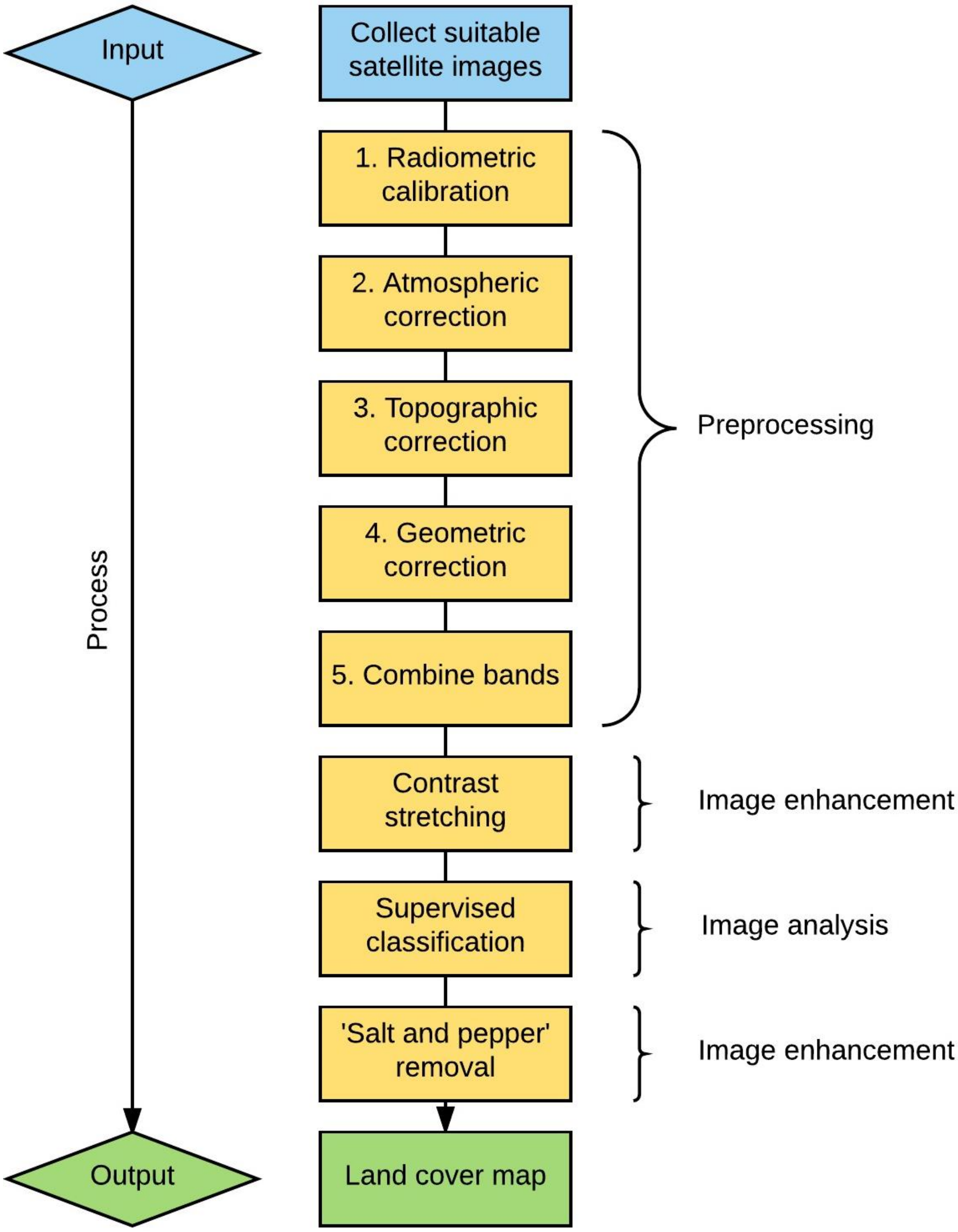


Figure 3.1: Process of land cover map making.

After downloading, the images have been preprocessed in order to prepare them for analysis. First step is radiometric calibration. This is necessary, because the format of the downloaded images is a digital number (DN) per pixel, whereas physically meaningful reflectance values area needed to classify the image (Chander et al., 2009). Therefore, the DNs have to be converted into reflectance values per band. The bands needed for classification are the bands in the visible light, near infrared (NIR) and short wave infrared (SWIR) wavelengths. The conversion of DNs into reflectance per band differs between Landsat 5 and Landsat 8-images. For the Landsat 8-images the conversion is calculated as follows (USGS, 2015):

$$\rho\lambda = \frac{\rho\lambda\prime}{\sin\theta_{SE}} \tag{3.1}$$

Where θ_{SE} (°) is local sun elevation angle, ρλ (-) is reflectance with correction for solar angle and ρλ' (-) is reflectance without correction for solar angle. The latter is defined as;

$$\rho\lambda' = M_p Q_{cal} + A_\rho \tag{3.2}$$

Where M_p (-) is band specific multiplicative rescaling factor, Q_{cal} (-) is quantized calibrated pixel value (DN) and A_ρ (-) is band specific additive rescaling factor. The local sun elevation angle, additive rescaling factor and multiplicative rescaling factor can be found in the metadata file of the image. The pixel values (Q_{cal}) are the digital numbers.

The conversion of DNs into reflectance per band was calculated as follows for the Landsat 5-images (Chander et al., 2009):

$$\rho\lambda = \frac{\pi\, L_\lambda\, d^2}{ESUN_\lambda\, \cos\theta_{SE}} \tag{3.3}$$

Where L_λ (W/sr/m^2) is radiance, d^2 (-) is Earth-Sun distance in astronomical units and $ESUN_\lambda$ (W/m^2) is mean exoatmospheric solar irradiance. The radiance is given by:

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{calmax} - Q_{calmin}}\right)(Q_{cal} - Q_{calmin}) + LMIN_\lambda \tag{3.4}$$

Where $LMAX_\lambda$ (W/sr/m^2) is radiance scaled to Q_{calmax}, $LMIN_\lambda$ (W/sr/m^2) is radiance scaled to Q_{calmin}, Q_{calmax} is maximum quantized calibrated pixel value and Q_{calmin} is minimum quantized calibrated pixel value. The maximum and minimum pixel values and the local sun elevation angle can be found in the metadata file of the image. The maximum and minimum radiance, Earth-Sun distance and mean exoatmospheric solar irradiance can be found in tables from Chander et al. (2009).

The second preprocessing step is atmospheric correction. However, Song et al. (2001) argue that atmospheric correction is not necessary for a supervised classification when the ground truth data is derived from the image being classified and when the maximum likelihood classifier is used. Since both things are the case, the images were not atmospherically corrected.

The third step is topographic correction, which aims to homogenize differences between illuminated and non-illuminated areas due to topographic differences (Pimentel et al., 2014). Since these differences are small in the study area, because it has only got some small isolated mountains, no topographic correction was performed.

The fourth preprocessing step is geometric correction, which diminishes geometric distortions like rotation of the Earth and variation in satellite altitude, position and velocity

(De Jong et al., 2012). This step is already carried out by the supplier of the satellite images (i.e. USGS). The user only has to decide which resampling method (i.e. compute DNs for the new image grid) will be used. The cubic convolution method was chosen, because it resulted in more smooth images.

After all these steps the different bands were combined to one new file. The preprocessed file, or image, could now be analyzed. In order to perform the analysis more easily, some enhancements were made to the image. Histogram stretching was performed to increase the contrast of the image before classification. This means that the pixel values (DNs) are displayed on the basis of the histogram, so that the contrast is increased at the peaks of the frequency distribution.

To map changes in land cover classes the satellite images from Table 3.1 were classified using a supervised classification. This means that each pixel is assigned to a class based on the match of the spectral signature with a set of sample spectral signatures. The latter were obtained by selecting polygons in the image with a known class based on the training stage. During the training stage (or fieldwork), so called training areas or ground truth polygons were specified, which are representative areas of known cover type. These areas must be larger than 30 m, i.e. the spatial resolution of the RS-images after 1982. To reduce the possibility of incorrect classification, 14 training areas per class (larger than 30 m) were selected in the field.

Based on literature (Igoe and Brockington, 1999; FAO, 2009; Homewood et al., 2009; MDC, 2014; Miller, 2015) the classes that have been specified in the field are:

- Urban area
- Grassland
- Savanna
    - Bushed savanna (grass and shrubs)
    - Wooded savanna (grass and trees)
    - Bushed wooded savanna (grass, shrubs and trees)
- Forest
- Agricultural area
- Bare soil
- Water

The spectra of 7 of the 14 training areas were combined to make one reference spectrum for each class. The other 7 training areas were used for validation of the classification. With the reference spectra, the pixel values of the other 7 training areas were checked. This resulted in a confusion matrix, which shows how many pixels were correctly classified per class.

After obtaining the ground truth data in the field, the supervised classification was performed. The maximum likelihood classifier was used as classification method, because it is the most advanced per-pixel method (De Jong et al., 2012). After classification, a majority filter was used to remove the 'salt and pepper' pattern (e.g. speckles of forest in a vast savanna area). This pattern arises because of small spectral differences between pixels. The filter modifies a pixel based on the mean values of its 8 neighboring pixels. In this way, the classified image becomes smoother.

After the fieldwork, it turned out that the spectral signatures of the three savanna sub-classes are very similar, so those classes were combined. Furthermore, bare soil is spectrally very difficult to distinguish from urban area. Because only five small villages are present in the study area, the 'urban area' class is manually added after the supervised classification.

The result of the classification is a land cover map for each image. Statistics of the classes of the different images were calculated and compared to quantify the changes in land cover. These calculations were made for the entire study area and for only the southern part. Furthermore, for the southern part the land cover classes were also determined per soil type and per elevation class. In this way it is possible to see if land cover changes are equally distributed over the study area, or if they occur more frequently on a specific soil type or at a specific elevation class.

3.3 Meteorological conditions

To obtain an indication of the meteorological conditions in the study area, a weather station has been placed in the field (Figure 3.2). The weather station measured the following meteorological conditions for about 1.5 month (18 February 2016 until 2 April 2016):

- Temperature (°C)
- Humidity (%)
- Wind speed (m/s)
- Radiation (W/m^2)
- Rainfall (mm)

Wind speed was measured at a height of 2.5 m (Figure 3.2). The wind speed results were used as input for the wind erosion model described in chapter 3.4. The location of the weather station (lat/lon: -3.52719; 36.07320) was chosen after visual exploration of the study area and in consultation with the local inhabitants. The location is an open field where almost no trees are present in the southwest and southeast direction and where some trees and shrubs are present in the northwest and northeast direction of the station (Figure 3.3). The location was used as agricultural land, which means that the inhabitants have cleared parts of the traditional vegetation. Because trees are important obstacles for wind reduction (Wolfe and Nickling, 1993; Leenders, 2005), the wind speed will likely be higher than on a traditional savanna landscape.

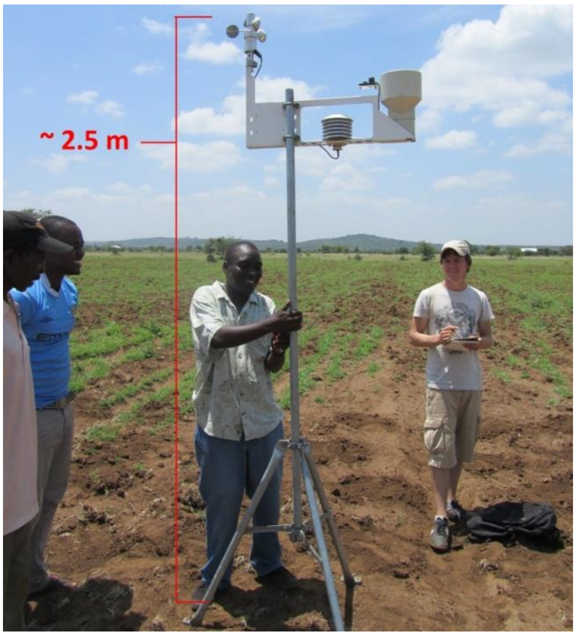


Figure 3.2: Meteorological station located near Makuyuni, northern Tanzania with height of its anemometer shown.

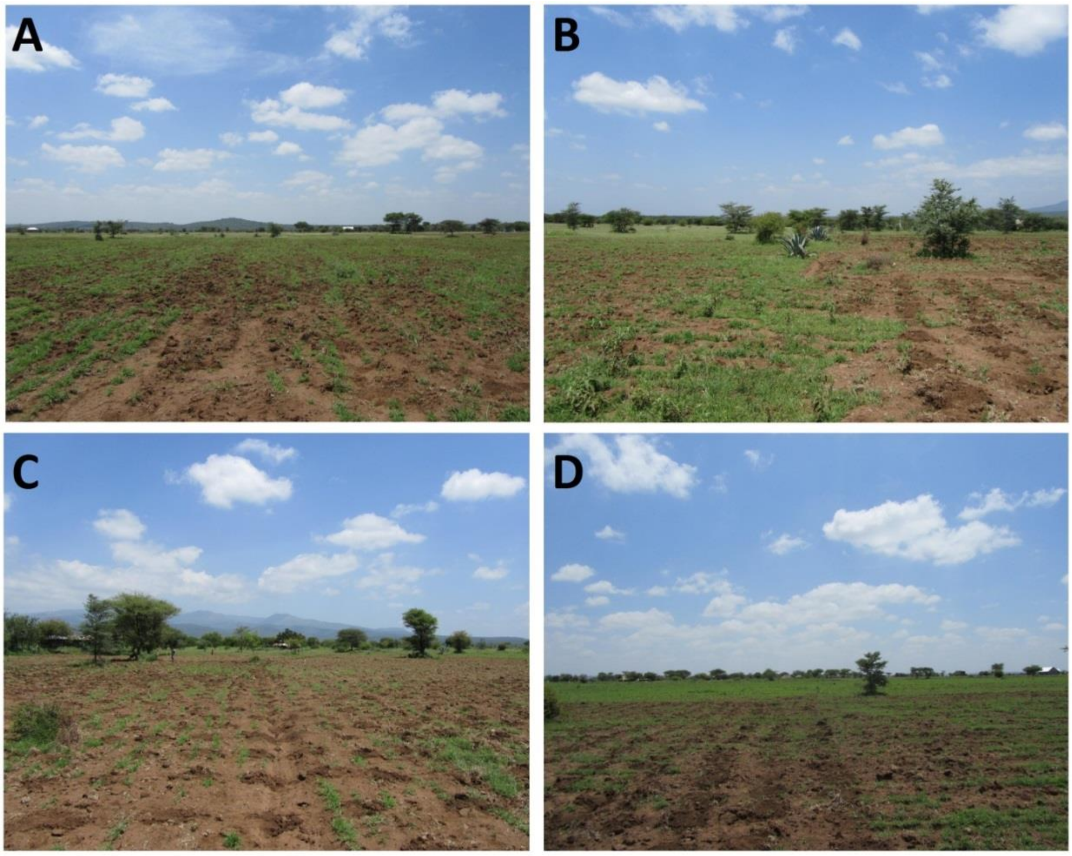


Figure 3.3: Field conditions in the surroundings of the meteorological station located in Makuyuni, northern Tanania. A: southwest direction; B: northwest direction; C: northeast direction; D: southeast direction.

3.4 Wind erosion risk

3.4.1 Model

To estimate the increase in wind erosion risk due to land clearance in the areas where (Maasai) people have settled, a two-dimensional model developed by Kersten (2015) was used. The scale of the model is a field plot-size of 1 hectare. The model is executed in spreadsheet program Microsoft Excel. The output is a sediment flux ($g*m^{-1}*s^{-1}$) for a certain configuration of environmental conditions. The model calculations consist of four steps:

1) Input of environmental conditions;
2) Calculate the wind profile;
3) Calculate the drag partitioning;
4) Calculate the sediment flux.

For an extensive description of the model, see Kersten (2015). Here, the model is briefly described.

Step 1: Input of environmental conditions

The model requires environmental conditions (Table 3.3) as inputs, which are categorized into:

- Atmospheric conditions;
- Vegetation properties;
- Soil properties;
- Physical constants.

Step 2: Calculate the wind profile

The wind profile determines the wind speed at a certain height above the surface. The higher the wind speed near the surface, the higher the risk of wind erosion. The wind profile is determined by the aerodynamic roughness length (z_0), which in turn is determined by the vegetation configuration. In other words, the vegetation configuration plays an important role in controlling wind speed and the associated wind erosion risk.

The wind speed of a turbulent air flow in thermally neutral air is described by Stull (1988) as;

$$u_z = \frac{u_*}{k} \ln \frac{z}{z_0}, \; z \geq z_0 \qquad (3.5)$$

Table 3.2: Variables and constants needed for the initial wind erosion model.

Atmospheric conditions	**Vegetation properties**		**Soil properties**	**Physical constants**
	Trees	***Shrubs***		
z: wind height	w_t: width	w_s: width	S: total surface	k: Von Karman
u_z: wind speed at height z	h_t: height	h_s: height	d: mean grain size	g: gravitation acceleration
ρ_a: air density	n_t: quantity	n_s: quantity	ρ_s: particle density	A_k: grain size constant
	μ_t: porosity	μ_s: porosity	C_{so}: drag coefficient soil surface	D: reference grain size
	C_t: drag coefficient tree	C_s: drag coefficient shrub		
	w_b: width bark			
	h_b: height bark			

Where u_z (m/s) is wind speed at height z (m), u_* (m/s) is friction velocity, k (-) is the Von Karman constant, which is 0.40 (Stull, 1988) and z_0 (m) is the aerodynamic roughness length. The friction velocity is defined as;

$$u_* = \sqrt{\frac{\tau_0}{\rho_a}} \tag{3.6}$$

Where τ_0 (Pa) is shear stress at surface and ρ_a (kg/m^3) is air density (Raupach, 1992).

The first part in determining the wind speed is the calculation of aerodynamic roughness length z_0 (m). The roughness length represents the ability of the surface to absorb momentum from the wind and is most affected by vegetation height. To determine the roughness length, an equation developed by Lettau (1969) was used. This equation takes physical characteristics of the vegetation into account, like height and porosity:

$$z_0 = 0.5\, h_v\, L_c \tag{3.7}$$

Where h_v (m) is the average vegetation height and L_c (-) is vegetation density. The constant value of 0.5 can be seen as the drag coefficient of an individual vegetation element with averaged sizes. The average vegetation height is calculated as follows:

$$h_v = \frac{n_t h_t + n_s h_s}{n_t + n_s} \tag{3.8}$$

Where n_t (-) is number of trees, h_t (m) is height of trees, n_s (-) is number of shrubs and h_s (m) is height of shrubs. The vegetation density L_c (-) is calculated as follows:

$$L_c = \frac{(A_t n_t)+(A_s n_s)}{S} \tag{3.9}$$

Where A_t (m^2) is silhouette area for trees, A_s (m^2) is silhouette area for shrubs and S (m^2) is total surface area. Because the model considers shrubs as a sphere and trees as a sphere on a rectangle (i.e. the bark), the silhouette areas are calculated differently. For trees the A_t is defined as;

$$A_t = 0.25\,\pi\,w_t^2\,\mu_t\; + (w_b(h_t - w_t) \tag{3.10}$$

Where w_t (m) is tree width, μ_t (-) is tree porosity, w_b (m) is bark width and h_t (m) is tree height. For shrubs the second part of equation 3.10 can be omitted:

$$A_s = 0.25\,\pi\,w_s^2\,\mu_s \tag{3.11}$$

Where w_s (m) is shrub width and μ_s (-) is shrub porosity. Hence, in this model the vegetation is only determined by trees and shrubs. In other words, presence of grass is not taken into account in the equations, because the effect of grass on the aerodynamic roughness length z_0 is negligible. Moreover, equations 3.10 and 3.11 are only valid when the height and width of the vegetation element do not differ significantly from each other (Raupach, 1992).

The second part in determining the wind speed is the calculation of friction velocity u_* (m/s). Friction velocity is a quantity which describes the shear stress by wind on the surface in units of velocity. Equation 3.5 can be rewritten into:

$$u_* = \frac{u_z\,k}{\ln\frac{z}{z_0}} \tag{3.12}$$

To see the change in wind profiles and sediment fluxes for different vegetation configurations, the input wind speed should be fixed for all scenarios and it should be the speed at height z = 100 m, because at this height the wind is not directly affected anymore by the vegetation elements on the ground. Based on literature, the wind speed in equation 3.13 is set at u_z = 10 m/s at height z = 100 m. Now, the friction velocity can be calculated for different vegetation configurations, because it is only dependent on het aerodynamic roughness length z_0. The third step is to calculate the wind speed u_z (m/s) in equation 3.5 for different heights z. The results are plotted in a graph and interpolated to get the wind profile.

Step 3: Calculate the drag partitioning

Drag, or shear stress, is the force of the wind on the soil surface and on the vegetation elements. The mean total drag is therefore defined as;

$$\tau_0 = \tau_v + \tau_s \tag{3.13}$$

Where τ_v (Pa) is the mean drag on vegetation elements and τ_s (Pa) is the mean drag on soil surface. The mean drag on the vegetation elements is given by (Raupach, 1992):

$$\tau_v\,(L_c) = L_c\,\rho_a\,C_v\,u_z^2 \exp\left(-L_c\,\frac{u_z}{u_*}\right) \tag{3.14}$$

Where C_v (-) is drag coefficient of vegetation elements, which is calculated as follows:

$$C_v = \frac{n_{shrub}C_{shrub} + n_{tree}C_{tree}}{n_{shrub} + n_{tree}} \tag{3.15}$$

Where C_{shrub} (-) is drag coefficient of shrubs and C_{tree} (-) is drag coefficient of trees, which are both derived from literature (Taylor, 1988).

The mean drag on soil surface in equation 3.14 is given by:

$$\tau_s\,(L_c) = \rho_a\,C_{so}\,u_z^2 \exp\left(-L_c\,\frac{u_z}{u_*}\right) \tag{3.16}$$

Where C_{so} (-) is drag coefficient of soil surface, derived from literature (Raupach; 1992). Hence, the total drag (eq. 3.14) can be rewritten into the following equation;

$$\frac{\tau_s}{\tau_0} = \frac{1}{1 + L_c\,\frac{C_v}{C_{so}}} \tag{3.17}$$

This equation indicates that the ratio between drag coefficient of vegetation elements (C_v) and drag coefficient of soil surface (C_{so}) completely controls the drag partitioning. The latter, however, is only relevant if the value of vegetation density is lower than 0.1 (Shao, 2000).

Step 4: Calculate the sediment flux

The rate of sediment transport is described by the sediment transport equation (Bagnold, 1941), which was modified by Dong et al. (2002):

$$Q = f(d)(1 - R_t)^{0.25}\left(\frac{\rho_a}{g}\right)u_*^3 \tag{3.18}$$

Where Q (kg/m/s) is transport rate, f(d) is a function dependent on grain size diameter d (mm), g (m/s^2) is gravitational acceleration, u_* (m/s) is friction velocity, u_{*t} (m/s) is threshold friction velocity and R_t (-) is the ratio between threshold friction velocity and friction velocity:

$$R_t = \frac{u_*^t}{u_*} \tag{3.19}$$

To determine Q, the u_{*t} (m/s) and f(d) have to be calculated before. Threshold friction velocity is calculated as follows;

$$u_{*t} = A_k \left(\frac{gd(\rho_s - \rho_a)}{\rho_a}\right)^{0.5} \tag{3.20}$$

Where A_k is the grain size constant (0.1 - 0.2) and ρ_s (kg/m^3) is particle density. The function dependent on grain size diameter is determined as;

$$f(d) = 1.41 + 4.98 \exp 0.5 \left(\ln\left(\frac{d}{1.55D}\right)^2\right) \tag{3.21}$$

Where D (mm) is the reference grain size and d (mm) is mean grain size, which should be representative for the entire area.

3.4.2 Model adjustments

Adjustments have been made to the initial model so that it could be applied to the situation in the study area in northern Tanzania. First of all, the scale was adjusted from 1 hectare to 0.25 hectare, since the field measurements (section 3.4.3) were made on plots of 0.25 hectare. Secondly, crops have been added to the equations 3.8, 3.9 and 3.15 as a third vegetation element, next to the trees and shrubs. In this way, agricultural fields can be compared with traditional landscapes. Secondly, the initial model considered only one type of tree and one type of shrub. Since different kinds of trees, shrubs and crops were present in the field (section 3.4.2), the characteristics of these vegetation elements have been added to the equations 3.8, 3.9 and 3.15. Concretely, this means that the aerodynamic roughness length z_0 (eq. 3.7) was calculated differently, since the average vegetation height h_v and the vegetation density L_c have been changed. The equation for average vegetation height (eq. 3.8) has been extended with a crop section so that it becomes;

$$h_v = \frac{n_{t1}h_{t1} + n_{s1}h_{s1} + n_{c1}h_{c1}}{n_{t1} + n_{s1} + n_{c1}} \tag{3.22}$$

Where n_c (-) is number of crops and h_c (m) is height of that crop. The '1' means one type of a vegetation element. Obviously, when for example two types of trees are present, a section of $n_{t2}h_{t2}/n_{t2}$ was added to the equation. The same applies for more types of shrubs and crops. The equation for vegetation density (eq. 3.9) has been extended in the same way:

$$L_c = \frac{(A_{t1}n_{t1}) + (A_{s1}n_{s1}) + (A_{c1}n_{c1})}{S} \tag{3.23}$$

Furthermore, the drag partitioning was calculated differently compared to the initial model, since the drag coefficient vegetation C_v (-) as well as the vegetation density have been changed. Therefore, equation 3.15 has been extended with a crop section:

$$C_v = \frac{n_{t1}C_{t1} + n_{s1}C_{s1} + n_{c1}C_{c1}}{n_{t1} + n_{s1} + n_{c1}} \tag{3.24}$$

Now, the drag partitioning can be calculated with equation 3.17.

3.4.3 Model input

Because of the model adjustments, Table 3.2 should be extended with a crop section (Table 3.3). Air density, drag coefficients and physical constants were derived from literature (Stull, 1988; Taylor, 1988). The other variables were measured in the field. Vegetation and soil properties were measured at different locations in the field. Because of practical reasons, the plot size was fixed at 2,500 m^2. However, in case a high vegetation density was visually estimated (i.e. more than 50 vegetation elements), the measurements were made on plots of 25 m^2, assuming that this smaller plot was a good representation of the entire area. A detailed description of the field plots and their vegetation configurations, including some photos, can be found in Appendix III. In the plots, the width and height of vegetation was measured with a tape-measure or estimated. The number of vegetation elements was manually counted. Vegetation porosity was estimated based on a photo through the vegetation cover. The ratio between dark and light parts of the photo was visually estimated. The model assumes that this two-dimensional optical porosity is equal to the actual porosity, which is three-dimensional. The mean grain size was measured in the laboratory from field samples. The wind speed was measured with the meteorological station described in chapter 3.3. Both the measured wind speed and the wind speed found in a similar environment (i.e. savanna woodland) by Kainkwa and Stigter (1994) were used in the model. However, both wind speeds were measured at height z = 2.5 m (Figure 3.2). Since the input wind speed should be the speed at height z = 100 m (section 3.4.1), the wind speeds were first converted to the speed at height z = 100 m with the following equation:

$$u_{100} = \frac{u_{2.5} \ln\frac{100}{z_0}}{\ln\frac{2.5}{z_0}} \tag{3.25}$$

Where u_{100} (m/s) is wind speed at height z = 100 m, $u_{2.5}$ (m/s) is wind speed at height z = 2.5 m and z_0 (m) is roughness length as calculated in equation 3.7.

Next to the measured wind speed and the wind speed found in by Kainkwa and Stigter (1994), a hypothetical wind speed of 10 m/s at height z = 2.5 m was also used as input for the calculation of the sediment flux. To see what the effect is of only one type of vegetation on sediment flux, the model has been run with scenarios with a different number of trees, shrubs or crops. In this way it is possible to see at what number of a vegetation type no sediment flux occurs anymore.

Table 3.3: Variables and constants needed for the adjusted wind erosion model.

Atmospheric conditions	**Vegetation properties**			**Soil properties**	**Physical constants**
	Trees	***Shrubs***	***Crops***		
z: wind height	n_t: quantity	n_s: quantity	n_c: quantity	Total surface S: 2,500 m^2	Von Karman k: 0.4
u_z: wind speed at height z	w_t: width	w_s: width	w_c: width	Mean grain size d: 0.1 mm	Gravitation acceleration g: 9.81 m/s^2
Air density ρ_a: 1.1839 kg/m^3	h_t: height	h_s: height	h_c: height	ρ_s: particle density: 2,650 kg/m^3	Grain size constant A_k: 0.17
	μ_t: porosity	μ_s: porosity	μ_c: porosity	Drag coefficient soil C_{so}: 0.0033	Reference grain size D: 0.25 mm
	C_t: drag coefficient tree	C_s: drag coefficient shrub	C_c: drag coefficient crop		
	w_b: width bark				
	h_b: height bark				

4. Results

4.1 Interviews

The interviews with local inhabitants of the study area serve as a first indication of the causes and consequences of land cover changes. 15 semi-nomadic people have been interviewed, all of them of the Maasai tribe. 15 settled people have been interviewed as well, from whom only 3 were Maasai. It turned out that most settled people are members of the Waarusha, which is a tribe closely related to the Maasai (Kuney, 1994). The statistics of the most important questions are listed in Table 4.1 and Table 4.2. A list with answers to all questions is attached to this document in Appendix II.

Despite the semi-nomadic character of the Maasai (n = 15), the average time living at current place of residence is 18 years. 73% of these people said that they were not forced by the government to settle at this place, but that it was their own choice. 5 of the 15 Maasai are living from pastoralism only, the other 10 carry out agriculture next to the traditional pastoralism (agro-pastoralism). Around 67% of the agro-pastoralists told that they started with agriculture out of necessity a few years after their last movement. In order to make the land suitable for agricultural purposes, 47% of the semi-nomadic Maasai said they have cleared the land from trees and shrubs. Next to (agro-) pastoralism, 53% of the semi-nomadic interviewees carry out other activities for their livelihood as well. Most of them sell products like milk, tobacco, beadwork and charcoal or have a paid job as guard or gemstone seller at a neighboring city (like Arusha). Besides the self-induced land alteration by land clearance, 93% of the Maasai have seen the advent of commercial farms and have faced some problems related to this. The expansion of national parks has caused problems as well for 40% of the Maasai. Some of the mentioned problems are conflicts with wildlife managers, prohibition of grazing in some areas, wild animals killing the livestock, wild animals eating and destroying crops and forced relocations.

The settled people (n = 15) are living on average for 28 years at their current place of residence. 87% of these people said that they were not forced by the government to settle at this place, but that it was their own choice. Only 1 interviewee is living from crop production only. The other 14 people are still holding livestock next to their farming activities. The farming was necessary to survive and 87% started with agriculture immediately after settlement. In order to make the land suitable for agricultural purposes, 40% of the settled people said they have cleared the land from trees and shrubs. Not everybody had to clear the land, because in the other 60% of the cases, the land was already cultivated. Next to agro-pastoralism, 53% of the settler interviewees carry out other activities for their livelihood as well. Many of them have a shop and sell products like milk, charcoal and surplus crops, because most of the farms (12) do not sell crops on a commercial basis. The charcoal is mainly made in the dry periods, when crops cannot grow. Besides the self-induced land alteration by land clearance for agricultural purposes and for charcoal production, 53% of the settlers have seen the advent of commercial farms and have faced some problems related to this. The expansion of national parks has caused problems as well for 53% of the settlers. Some of the mentioned problems are conflicts with wildlife managers, prohibition of grazing in some areas, wild animals killing the livestock, wild animals eating and destroying crops and forced relocations.

Table 4.1: Statistics of answers of interview questions regarding livelihood and land cover changes in northern Tanzania.

Question		**Semi-nomadic**	**Settled**
Average time living at current place of residence	Mean	18 years	28 years
	Min.	2 years	2 years
	Max.	68 years	55 years
Own choice to start living here		73%	87%
Livelihood	Pastoralism	5	0
	Agro-pastoralism	10	14
	Agriculture only	0	1
When started with crop cultivation after 'settlement'	Immediately	40%	87%
	After few years	60%	13%
Crop cultivation necessary to survive		67%	100%
Other activities next to farming		53%	53%
Cleared vegetation		47%	40%
Seen advent commercial farms		93%	53%
Seen expansion national park		40%	53%
Faced negative consequences because of advent commercial farms and expansion national parks		67%	73%

In terms of environmental changes, more than 40% of the semi-nomadic Maasai have experienced a decrease in quality of both the pastures and agricultural fields. This is an ongoing process which started some 23 years ago, according to the semi-nomadics. The Maasai call more frequent periods of drought and population and livestock increase as possible causes. 87% thinks it is drier and 33% thinks it is also warmer nowadays. Regarding wind and dust, 67% mentioned presence of more wind and 73% mentioned presence of more dust. 40% of the semi-nomadic people also experienced dust storms every now and then, but especially in the dry season around August. The heavy winds and dust causes health problems, damage on the rooftops of the huts and destruction of crops. Half of the Maasai think that the destroying winds and dust storms are caused by the land clearance and that it could be counteracted by planting trees. The other half, however, does not have a clue and assign it to the will of God.

More than 80% of the settled people have experienced a decrease in quality of both the pastures and agricultural fields. This is an ongoing process which started some 10 years ago, according to the settlers. The settled farmers call more frequent periods of drought and population and livestock increase as possible causes. All interviewees think it is drier and it is warmer nowadays. Regarding wind and dust, 80% of the Maasai mentioned presence of more wind and 73% mentioned presence of more dust. 80% of the settled people also experienced dust storms every now and then, but especially in the dry season around August. The heavy winds and dust causes health problems and destruction of crops. Since most settled people are living in solid concrete houses, their homes are not prone to the heavy winds. Most of the settlers are aware that the destroying winds and dust storms are caused by the land clearance and that it could be counteracted by planting trees.

Table 4.2: Statistics of answers of interview questions regarding meteorological changes in northern Tanzania.

Question		**Semi-nomadic**	**Settled**
Experience decrease in quality of pastures		40%	67%
Since how many years		23 years	11 years
Experience decrease in quality of agricultural land		47%	100%
Since how many years		24 years	10 years
Is it drier or more wet nowadays	Drier	87%	100%
	No change	13%	0%
	More wet	0%	0%
Is it warmer or colder nowadays	Warmer	33%	100%
	No change	67%	0%
	Colder	0%	0%
Experience presence of more wind		67%	80%
Experience presence of dust		100%	100%
Experience presence of more dust		73%	73%
Experience presence of dust storms		40%	80%

4.2 Land use and land cover

4.2.1 Land cover in 1985

The 1985 land cover map of the entire Monduli District (cloud cover = ± 8%) is shown in Figure 4.1. The land cover classes present and their sizes in hectares and in percentage of the entire area can be found in Table 4.3. The classes 'urban area' (red) and 'clouds' (black) were manually added to the land cover map based on visual interpretation of the satellite image. Urban area covers only 0.01% of the district. It seems that in 1985 only two villages were present: Mto wa Mbu north of Lake Manyara and Monduli in the east. Grassland (light green) is mostly found around the isolated mountains and in the southern part where Tarangire National Park is located. This park was established in 1970 and is known for its large grasslands and swamps (Kiffner et al., 2016). Savanna (orange) is the most abundant land cover class with more than 53% and is found in the entire area. Forest (dark green) is located on the tops of the isolated mountains and is barely present on the lower lying plains. Agriculture (purple) is mainly concentrated in the southern part of the district close to the current villages of Makuyuni and Lolkisale. In the northeast some agricultural fields can be found as well, close to the slopes of Mount Kilimanjaro. These areas account for less than 1% land cover. Bare soil is the second largest land cover class, is depicted in gray and mainly found in the northern part of the district. These are vast, more or less contiguous areas. Other areas where bare soil is present are along the shorelines of Lake Manyara in the south and Lake Natron in the north. Water (blue) accounts for almost 4% of the total land cover.

Table 4.3: 1985 land cover classes and their sizes of Monduli District, northern Tanzania.

Land cover class	Area	
	Hectare	***Percentage***
Urban area	153	0.01
Clouds	131,980	8.27
Grassland	165,785	10.39
Savanna	853,503	53.49
Forest	58,050	3.64
Agricultural area	11,453	0.72
Bare soil	311,477	19.52
Water	63,126	3.96
TOTAL	1,595,527	100.00

The 1985 land cover map of the southern part of Monduli District (cloud cover = ± 5%) is shown in Figure 4.2. The land cover classes present and their sizes in hectares and in percentage of this area can be found in Table 4.4. Compared with the entire district, the southern part has higher percentages of grassland, savanna and agricultural areas and a much lower amount of bare soil as land cover class.

Table 4.4: 1985 land cover classes and their sizes of southern part of Monduli District, northern Tanzania.

Land cover class	Area	
	Hectare	***Percentage***
Urban area	42	0.01
Clouds	26,855	5.13
Grassland	83,800	16.02
Savanna	344,707	65.88
Forest	12,257	2.34
Agricultural area	10,531	2.01
Bare soil	25,161	4.81
Water	19,905	3.80
TOTAL	523,260	100.00

For the southern part of Monduli District a comparison between land cover classes and soil types has been made for the 1985 situation (Figure 4.3). It should be noted that areas covered with clouds are not taken into account for these calculations. Andosols, chernozems and leptosols are mainly covered with savanna, whereas luvisols and solonetz are mainly covered with grassland. Agricultural land is mostly present on luvisols in the southern part of the district. The vertisols on the shores of Lake Manyara are for almost 40% covered with bare soil. The other soil types show almost no bare soil cover.

For the southern part of Monduli District a comparison between land cover classes and height has been made for the 1985 situation (Figure 4.4). It should be noted that areas covered with clouds are not taken into account for these calculations. The DEM in Figure 2.5 shows the distribution of the three different elevation classes. Since its lowest elevation, the first class contains almost all the water. Besides, probably due to the low water level of Lake Manyara in 1985, bare soil cover is the highest in this class as well. The second class shows a pattern of land cover types, with mainly savanna and a little bit of agriculture. The highest elevation class is rather different from the lower ones. Here the amount of forest cover is large, and no agriculture and bare soil is found. This is in line with the findings of MDC (2014), which were described in chapter 2.3.

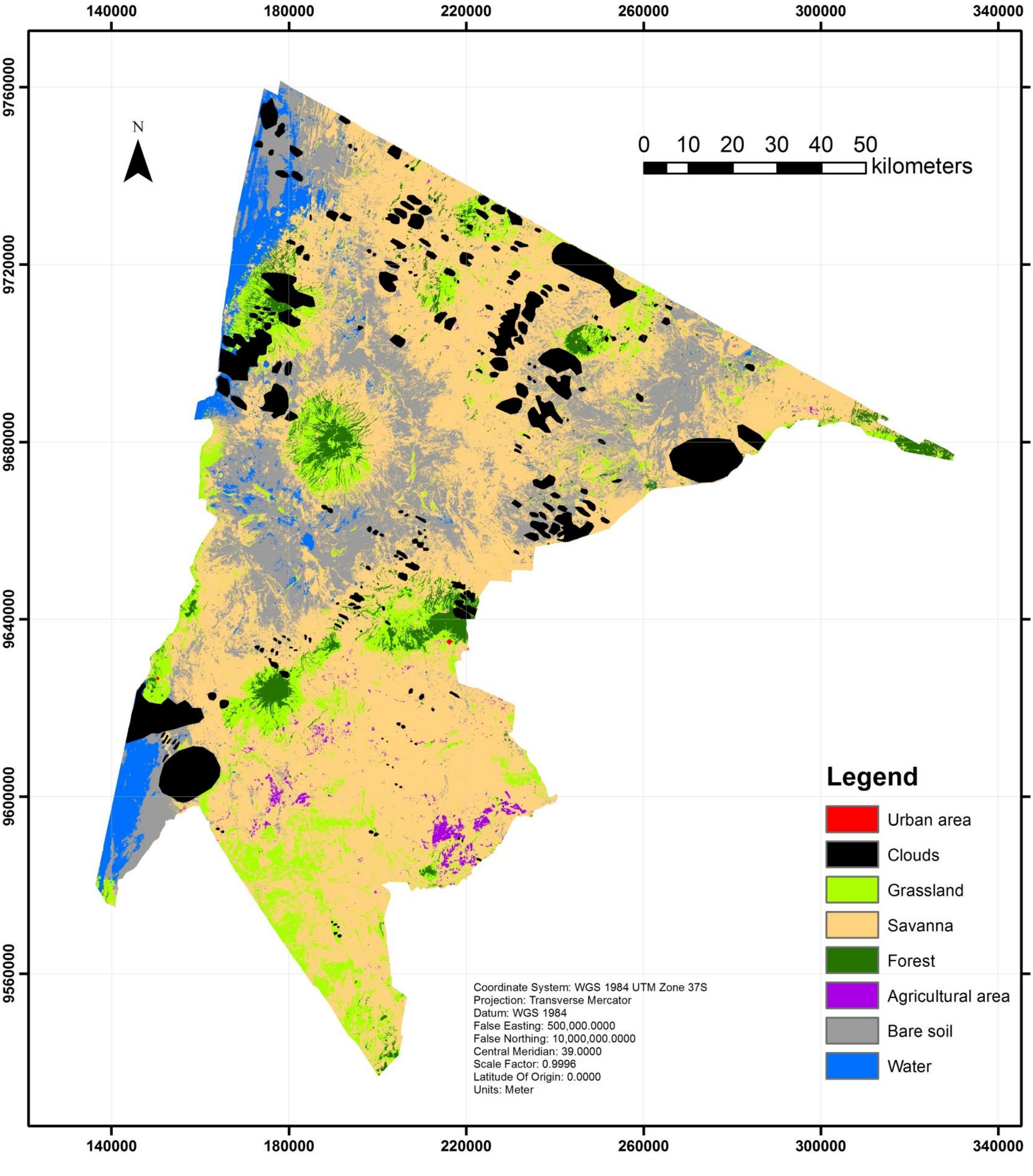


Figure 4.1: 1985 land cover map of Monduli District, northern Tanzania.

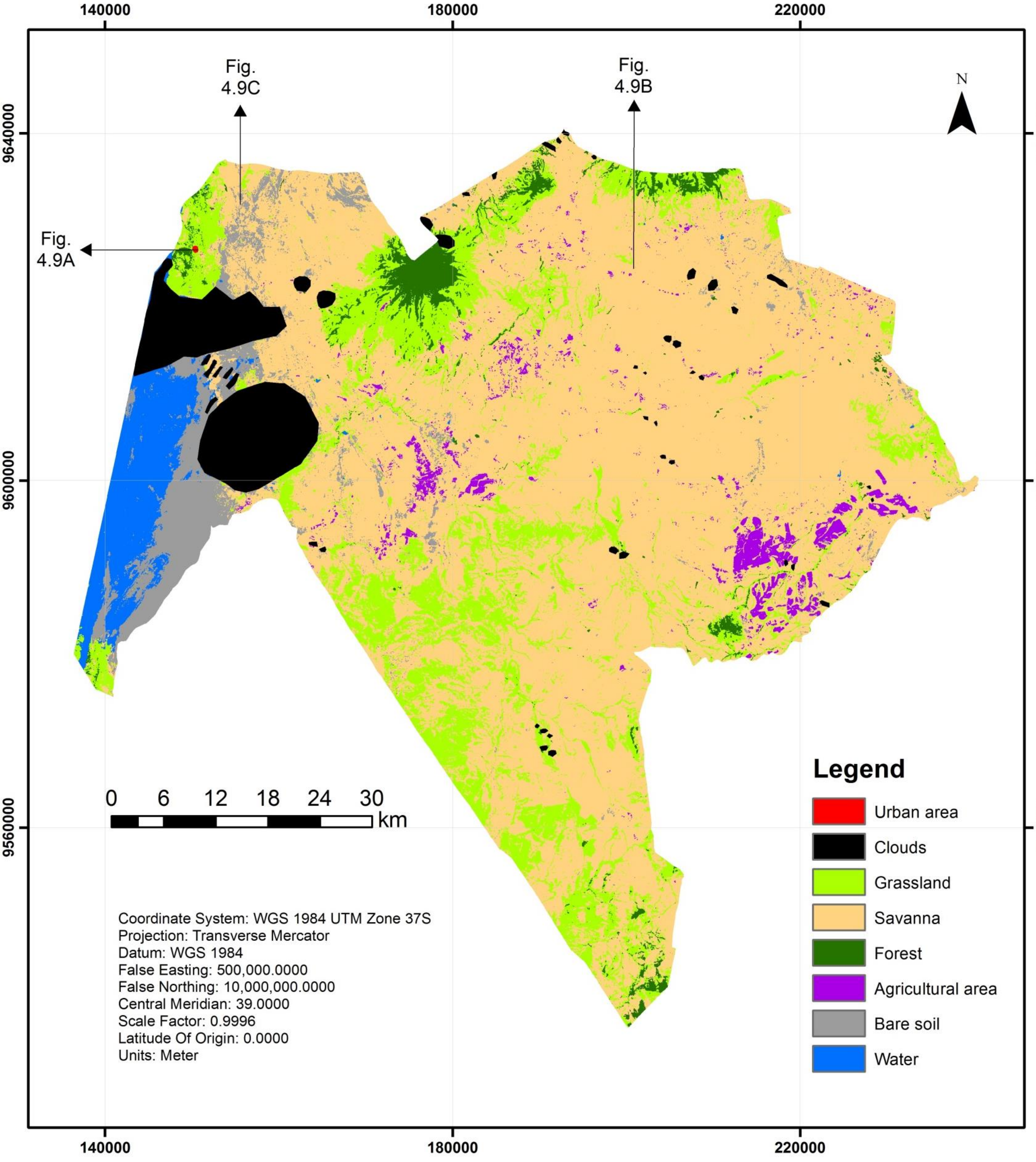


Figure 4.2: 1985 land cover map of southern part of Monduli District, northern Tanzania.

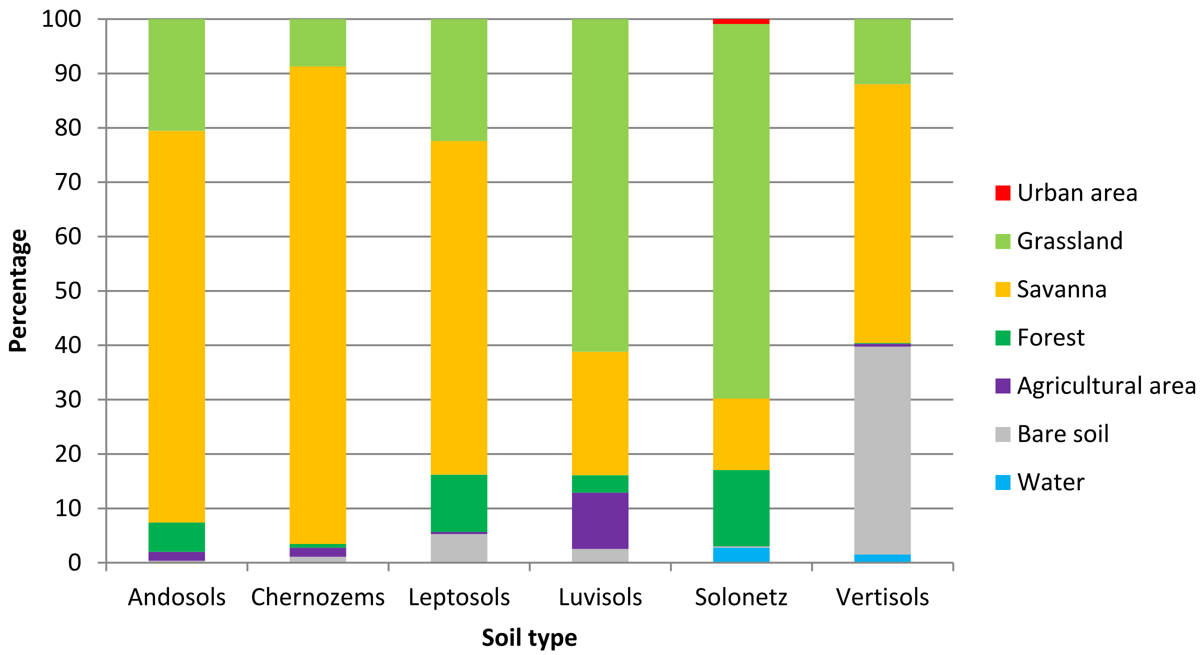


Figure 4.3: Percentages land cover classes per soil type in southern part of Monduli District, northern Tanzania in 1985.

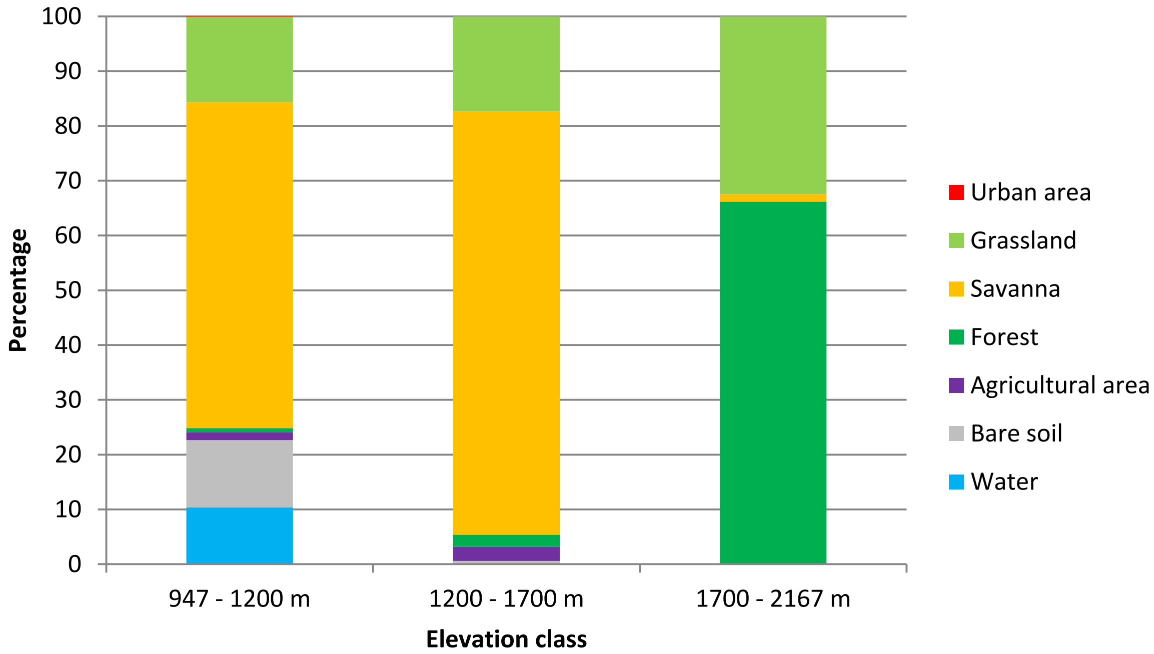


Figure 4.4: Percentages land cover classes per elevation class in sourthern part of Monduli District, northern Tanzania in 1985.

4.2.2 Land cover in 2016

The confusion matrix of the 2016 classification is shown in Table 4.5. The classes 'urban area' and 'clouds' were manually added to the land cover map and are therefore not present in the confusion matrix. The overall accuracy of the 2016 classification is 93.5%.

Table 4.5: Confusion matrix of the maximum likelihood classification of the 2016 image.

	Grassland	Savanna	Forest	Agriculture	Bare soil	Water	TOTAL
Grassland	990	119	188	1	9	0	1307
Savanna	108	4139	175	147	484	0	5053
Forest	32	0	2453	3	0	0	2488
Agriculture	0	29	0	448	384	0	861
Bare soil	212	490	0	0	5252	2696	8650
Water	0	0	0	0	0	59704	59704
TOTAL	1342	4777	2816	599	6129	62400	78063
Accuracy (%)	73.8	86.6	87.1	74.8	85.7	95.7	93.5

Water is sometimes classified as bare soil, probably due to high sediment content in some lakes, but overall water is the most correctly interpreted class. Grassland, savanna and forest are occasionally confused because vegetation generally reflects the same type of wavelengths, despite the difference in vegetation types and densities. Since the satellite image was acquired at the end of March, many agricultural areas had already mature crops. Therefore, agricultural areas are sometimes misinterpreted as savanna. On the other hand, when an agricultural field is only ploughed and has got no (mature) crops yet, the field is interpreted as bare soil.

The 2016 land cover map of the entire Monduli District (cloud cover = ± 2%) is shown in Figure 4.5. The land cover classes present and their sizes in hectares and in percentage of the entire area can be found in Table 4.6. Urban area covers only 0.04% of the district. Five villages are present: Selela, Mto wa Mbu and Kigongoni north of Lake Manyara, Makuyuni east of Lake Manyara and Monduli in the east. Grassland (light green) is mostly found around the isolated mountains and in the southern part where Tarangire National Park is located. This park is known for its large grasslands and swamps (Kiffner et al., 2016). Savanna (orange) is the most abundant land cover class with more than 50% and is found in the entire area. Forest (dark green) is located on the tops of the isolated mountains and is barely present on the lower lying plains. Agriculture (purple) is mainly concentrated in the southern part of the district, in the northeast close to the slopes of Mount Kilimanjaro and in the north. Bare soil is depicted in gray and mainly found in the northern part of the district. These are vast, contiguous areas. Water (blue) accounts for almost 5% of the total land cover.

Table 4.6: 2016 land cover classes and their sizes of Monduli District, northern Tanzania.

Land cover class	Area	
	Hectare	***Percentage***
Urban area	640	0.04
Clouds	27,124	1.70
Grassland	74,237	4.65
Savanna	806,926	50.57
Forest	73,652	4.62
Agricultural area	47,602	2.98
Bare soil	491,610	30.81
Water	73,734	4.62
TOTAL	1,595,525	100.00

The 2016 land cover map of the southern part of Monduli District (cloud cover = ± 4%) is shown in Figure 4.6. The land cover classes present and their sizes in hectares and in percentage of this area can be found in Table 4.7. Compared with the entire district, the southern part is covered with more natural vegetation (grassland, savanna and forest) and less bare soil. Besides, the agricultural area is more than two times as large.

Table 4.7: 2016 land cover classes and their sizes of southern part of Monduli District, northern Tanzania.

Land cover class	Area	
	Hectare	***Percentage***
Urban area	384	0.07
Clouds	18,289	3.50
Grassland	53,549	10.23
Savanna	320,854	61.32
Forest	26,323	5.03
Agricultural area	38,256	7.31
Bare soil	26,079	4.98
Water	39,532	7.55
TOTAL	523,266	100.00

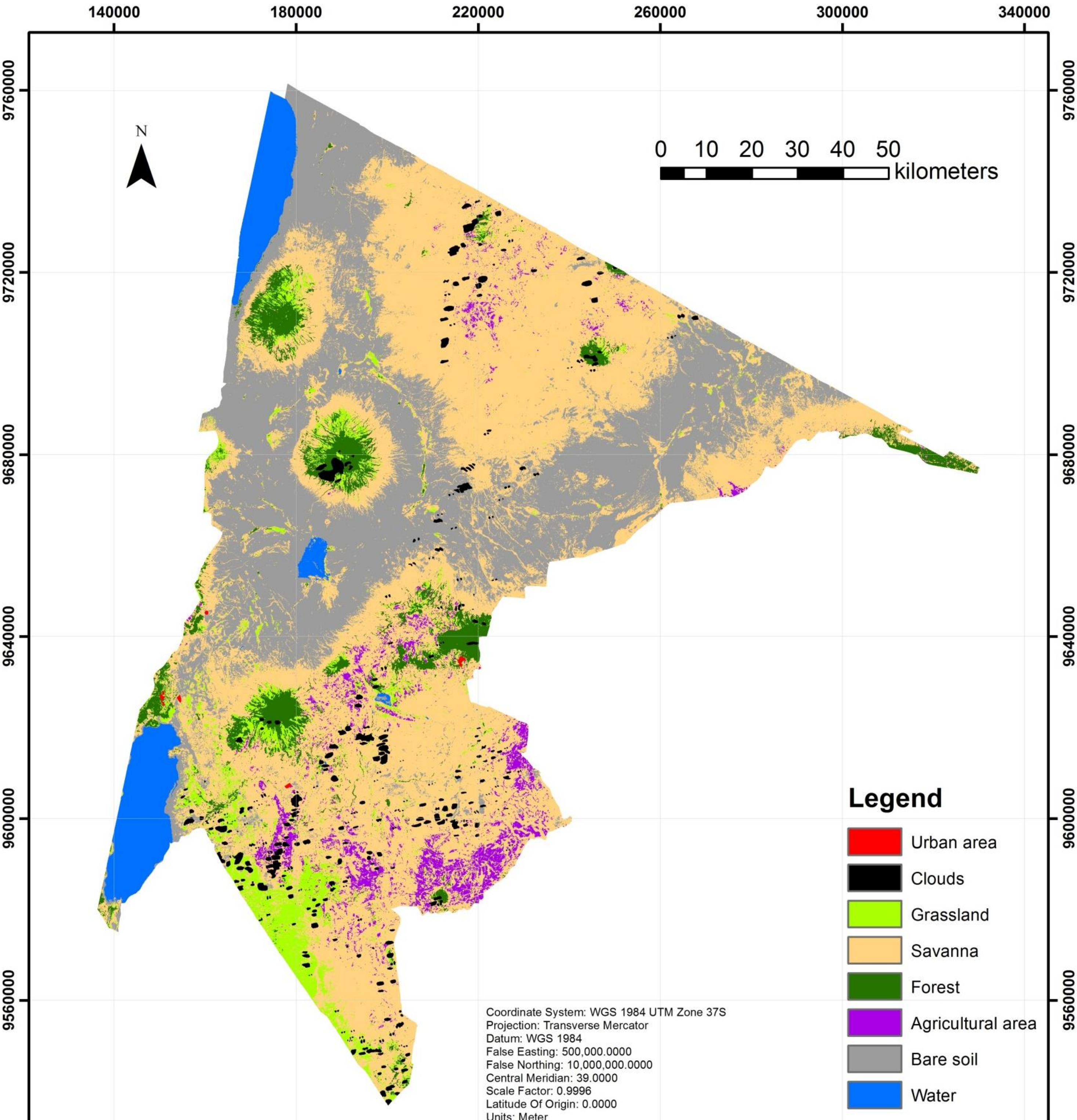


Figure 4.5: 2016 land cover map of Monduli District, northern Tanzania.

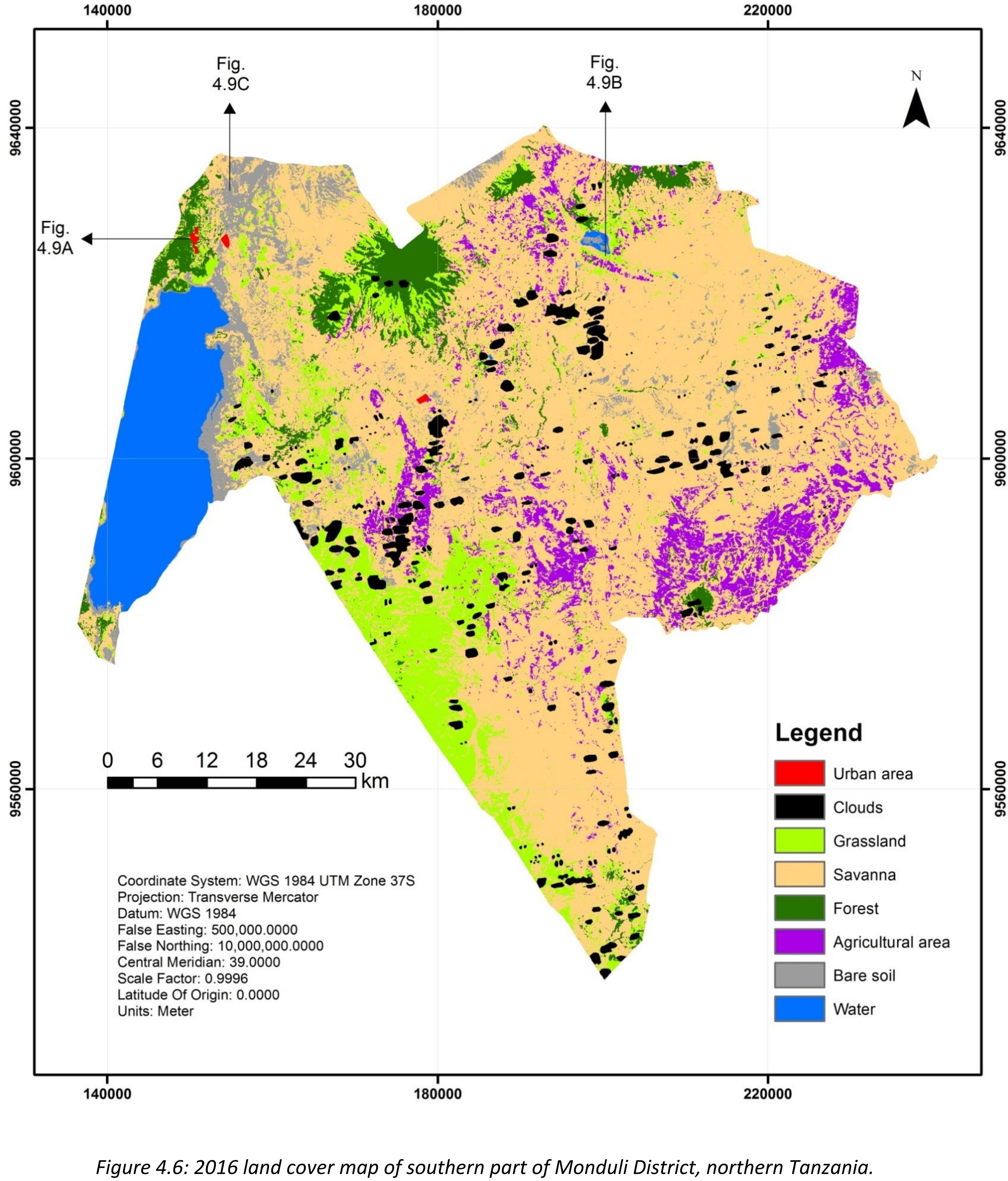


Figure 4.6: 2016 land cover map of southern part of Monduli District, northern Tanzania.

For the southern part of Monduli District a comparison between land cover classes and soil types has been made for the 2016 situation (Figure 4.7). It should be noted that areas covered with clouds are not taken into account for these calculations. Andosols, chernozems, leptosols and luvisols are mainly covered with savanna, whereas solonetz is mainly covered with forest. Agricultural land is mostly present on luvisols in the southern part of the district and on andosols and chernozems in the north. All these three soil types have got favorable physical and chemical properties, which makes them suitable for agricultural purposes (FAO, 1993). The area of the chernozems is intersected by a paved road (A104, Figure 2.1). Lots of agricultural fields are concentrated along that road (Figure 4.9B). Besides the advantage of the presence of the road, chernozems are well suited for agriculture as mentioned before (FAO, 1993). The vertisols on the shores of Lake Manyara are for almost 25% covered with bare soil. Bare soil is also present (10%) on the leptosols in the north.

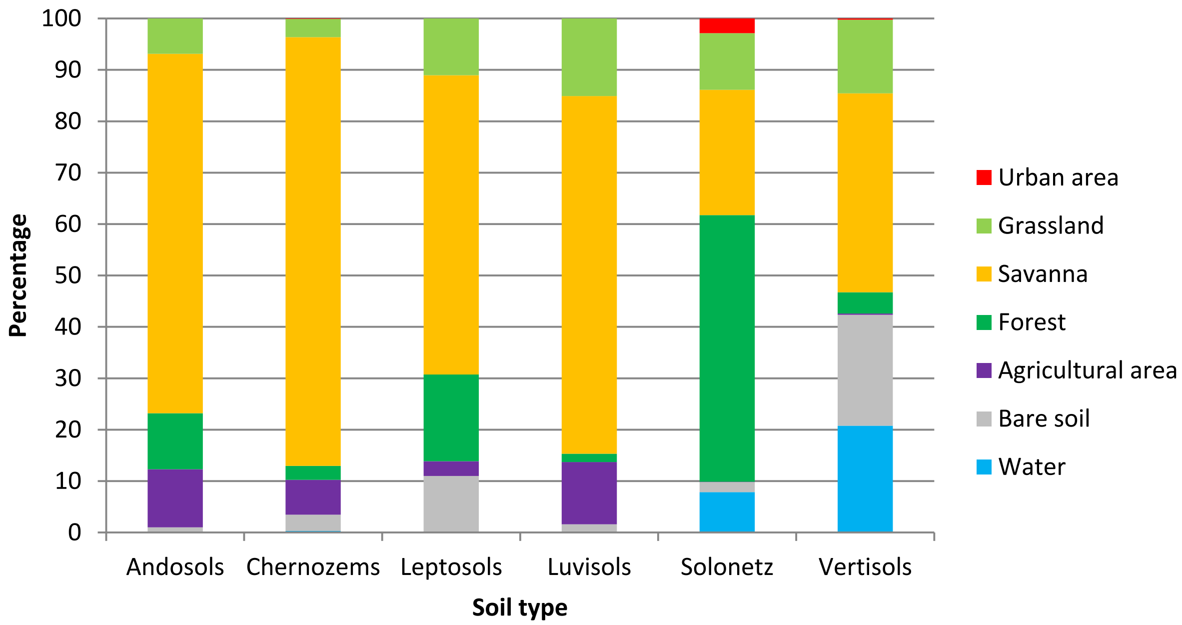


Figure 4.7: Percentages land cover classes per soil type in southern part of Monduli District, northern Tanzania in 2016.

For the southern part of Monduli District a comparison between land cover classes and height has been made for the 2016 situation (Figure 4.8). It should be noted that areas covered with clouds are not taken into account for these calculations. Figure 4.8 shows the results of this comparison in a graph with the percentages of land cover classes for the different elevation classes present in the study area. The DEM in Figure 2.5 shows the distribution of the three different elevation classes.

Since its lowest elevation, the first class contains almost all the water. Besides, bare soil cover is the highest in this class as well. The second class consists mainly of savanna and agricultural area. The highest elevation class is rather different from the lower ones. Here the amount of forest cover is large, and only small agricultural fields and no bare soil are found. This is in line with the findings of MDC (2014), which were described in chapter 2.3.

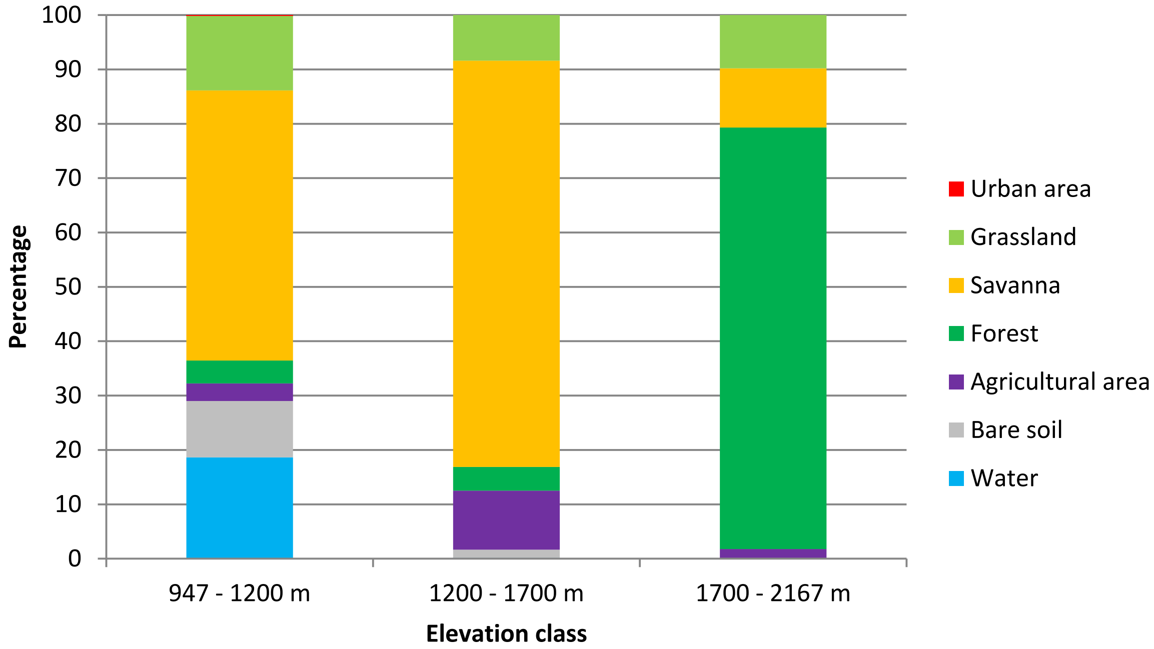


Figure 4.8: Percentages land cover classes per elevation class in southern part of Monduli District, northern Tanzania in 2016.

4.2.3 Land cover changes

The changes in land cover in terms of surface area of the entire Monduli District are depicted in Table 4.8. Urban area and agricultural area have expanded the most. Both classes are in 2016 approximately 4 times as large as in 1985. Forest, bare soil and water have grown as well, but to a smaller extent. The grassland and savanna classes are less abundant in 2016 than in 1985. The decrease in savanna cover (-5.46%) is small, whereas the decrease in grassland is large (-55.22%).

In 1985, bare soil is present along the shorelines of Lake Manyara in the south and Lake Natron in the north, whereas in 2016 these areas are covered with water. Those 1985 bare soil areas seem to be expanded alkaline mud flats due to a lower water level in the lakes. The lower water level does not only reveal sediment, but formation of soda crystals also takes place due to the high alkalinity of the lake waters after evaporation in the dry period (June – October) (Beadle, 1974). After the dry period, the short rains occur in November and December. The used satellite images were acquired in January (1985) and March (2016). It appears that in 1984 only a small amount of rain has fallen in the short rains period, resulting in lower lake levels. In 2015, the short rains were very intense, resulting in higher lake levels and less mud flats.

The changes in land cover in terms of surface area of the southern part of Monduli District are depicted in Table 4.9. Urban area has grown the most. This land cover class is 9.5 times as large as in 1985. Agricultural area is about 4 times as large. Figures 4.9A and 4.9B clearly show these increases on enlargements of the land cover maps. The locations of these images are displayed on Figures 4.2 and 4.6. Forest (114.68%) and water (98.54%) have significantly increased in size as well, whereas bare soil has grown only a very little (3.66%) (Figure 4.9C). The grassland and savanna classes are less abundant in 2016 than in 1985. The decrease in savanna cover (-6.92%) is small, whereas the decrease in grassland is much larger (-36.10%).

Table 4.8: Land cover changes between 1985 and 2016 in Monduli District, northern Tanzania.

Land cover class	Area in 1985		Area in 2016		Change	
	10^3 ha	%	10^3 ha	%	10^3 ha	%
Urban area	0.15	0.01	0.64	0.04	0.49	326.67
Grassland	165.79	10.39	74.24	4.65	-91.55	-55.22
Savanna	853.50	53.49	806.93	50.57	-46.57	-5.46
Forest	58.05	3.64	73.65	4.62	15.60	26.87
Agricultural area	11.45	0.72	47.60	2.98	36.15	315.72
Bare soil	311.48	19.52	491.61	30.81	180.13	57.83
Water	63.13	3.96	73.73	4.62	10.6	16.79

Table 4.9: Land cover changes between 1985 and 2016 in southern part of Monduli District, northern Tanzania.

Land cover class	Area in 1985		Area in 2016		Change	
	10^3 ha	%	10^3 ha	%	10^3 ha	%
Urban area	0.04	0.01	0.38	0.07	0.34	850.00
Grassland	83.80	16.02	53.55	10.23	-30.25	-36.10
Savanna	344.71	65.88	320.85	61.32	-23.86	-6.92
Forest	12.26	2.34	26.32	5.03	14.06	114.68
Agricultural area	10.53	2.01	38.26	7.31	27.73	263.34
Bare soil	25.16	4.81	26.08	4.98	0.92	3.66
Water	19.91	3.80	39.53	7.55	19.62	98.54

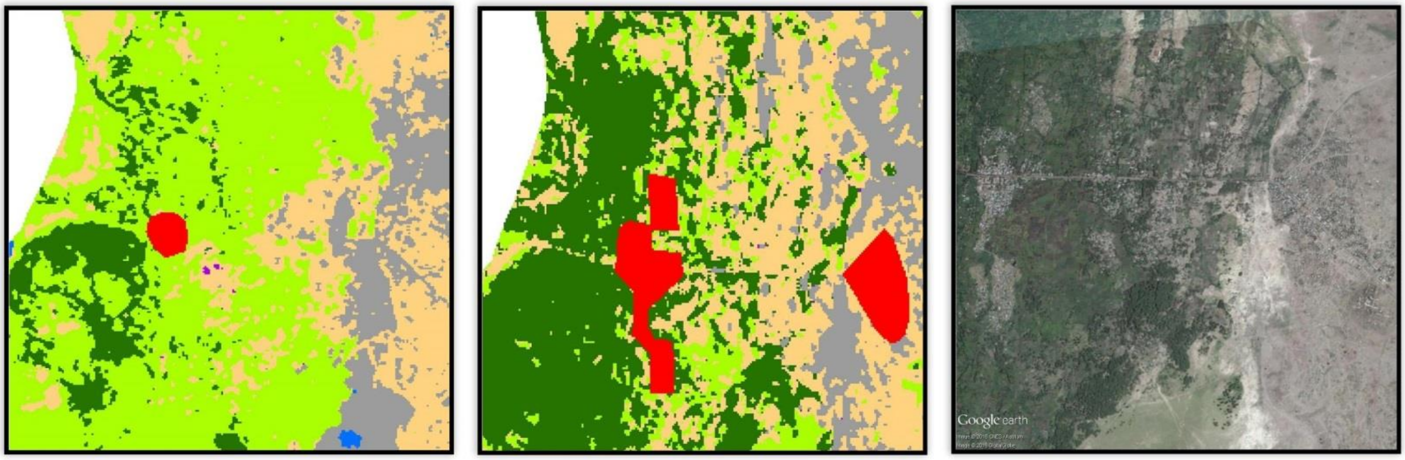


Figure 4.9A: Urban area (in red) increase. From left to right: 1985 situation, 2016 situation, 2016 Google Earth image.

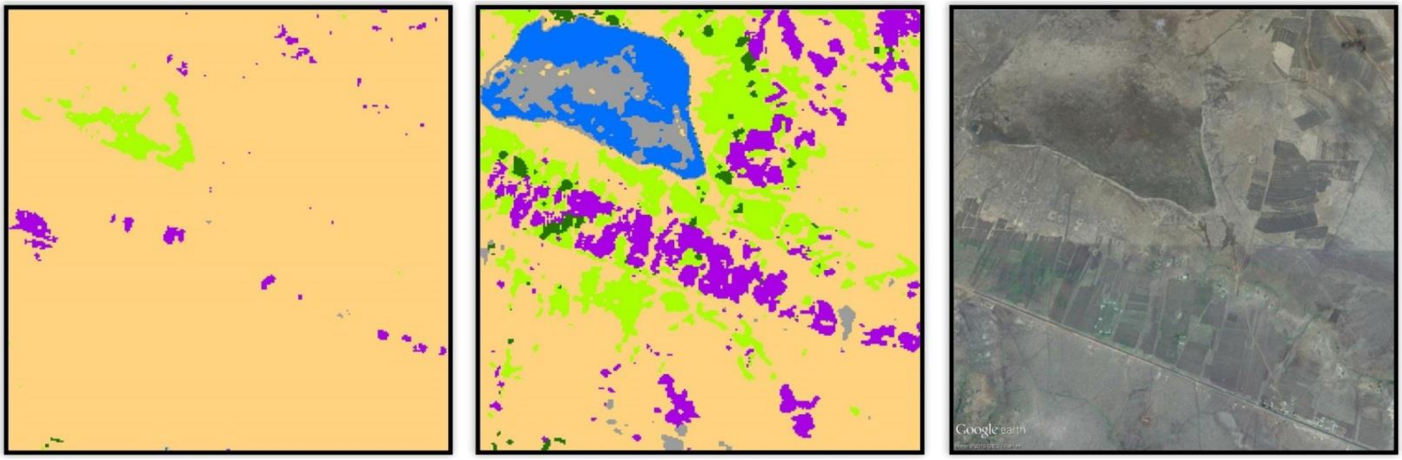


Figure 4.9B: Agricultural area (in purple) increase. From left to right: 1985 situation, 2016 situation, 2016 Google Earth image.

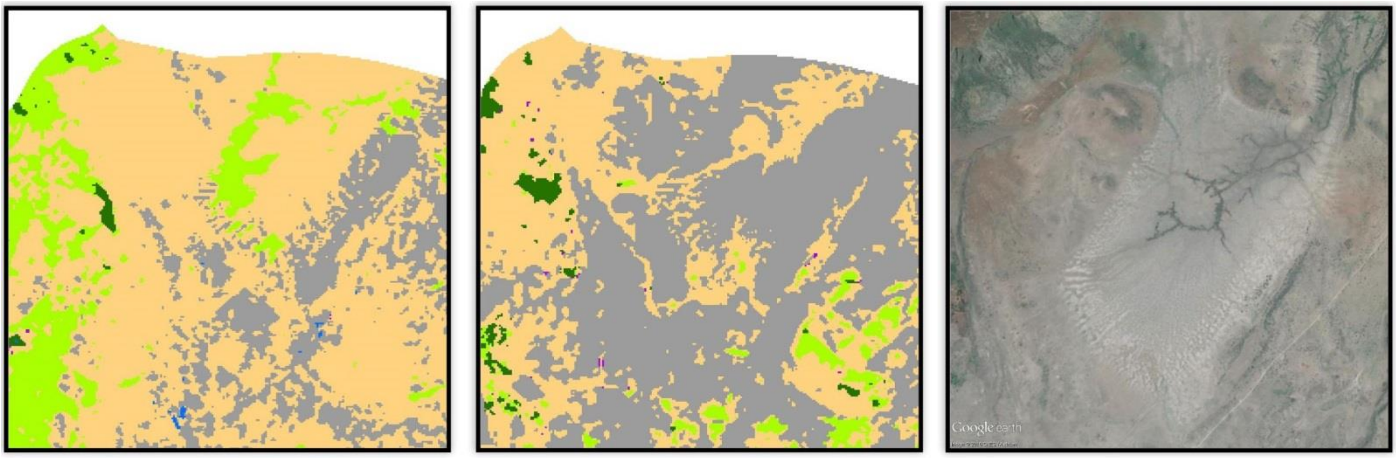


Figure 4.9C: Bare soil (in gray) increase. From left to right: 1985 situation, 2016 situation, 2016 Google Earth image.

4.3 Wind erosion risk

4.3.1 Wind profile

The measurement results of the meteorological station are listed in Table 4.10. The results show that the average measured wind speed at height z = 2.5 m is 0.9 m/s. Because this is a very low value compared with the average wind speed of 8.9 m/s found by Kainkwa and Stigter (1994) in a similar environment (i.e. savanna woodland), not the mean but the maximum wind speed measured by the weather station was used in the wind erosion model, which is 5.7 m/s. The conversion of this wind speed to the wind speed at height z = 100 m (eq. 3.26) gives 8.4 m/s. The model has also been run with the input wind speed found by Kainkwa and Stigter (1994): 8.9 m/s. The conversion of this wind speed to the wind speed at height z = 100 m (eq. 3.26) gives 13.0 m/s. The conversion of a hypothetical wind speed of 10.0 m/s to the speed at height z = 100 m (eq. 3.26) gives 14.7 m/s.

Table 4.10: Mean, minimum and maximum values of meteorological conditions measured near Makuyuni, northern Tanzania from 18 February 2016 until 2 April 2016.

Variable	Mean	Minimum	Maximum
Air temperature (°C)	25.2	17.9	34.3
Humidity (%)	74.9	28.6	100.0
Wind speed (m/s)	0.9	0.3	5.7
Radiation (W/m^2)	253.0	0.0	1,283.0
Rainfall (mm)	0.0	0.0	0.0

The wind erosion model generated wind profiles for all field plots (A-F). A detailed description of the field plots and their vegetation configurations as measured in the field, including some photos, can be found in Appendix III. The wind profiles are shown in Figure 4.10A and 4.10B. Considering traditional landscapes (A, B, C and D), the graph shows the more vegetation, the stronger is the reduction in wind speed, a result which was also found by Kainkwa and Stigter (1994). At height z = 1 m, the wind speed reduction on a savanna landscape (plot D) is 80% compared with a bare landscape (plot A). The graphs of Figures 4.10A and B suggest a difference in wind speed reduction between trees and shrubs. For example plot C (with only trees) reduces the wind speed considerably more than plot B (with only shrubs). It should be noted that plot C has got more vegetation elements, but even if the model was run with a scenario (B2) where as much vegetation elements are present as in plot C (i.e. 35), the difference between plot C and plot B2 is still considerable. Since the silhouette area of a tree is larger than that of a shrub, trees have got a larger area available to reduce the wind compared to the same number of shrubs. When the number of shrubs in plot B is increased so that the total silhouette area is as large as the total silhouette area of plot C, the difference in wind speed reduction can better be compared. Because the mean silhouette area of trees in plot C is approximately 3 times as large as the mean silhouette area of shrubs in plot B, the number of shrubs is increased to 105 (scenario B3). The difference between plot C and B3 is still significant. In other words, the trees reduce wind speed to a larger extent than shrubs. This result is in line with the findings of Leenders et al. (2007). The factor responsible for the difference is probably the vegetation height, because high vegetation (like trees) has got a larger effect on the calculation of the roughness length and on the wind profile than low vegetation (shrubs), resulting in more wind reduction by trees (Leenders et al., 2007).

The profiles of the agricultural field plots E and F show a difference by number of crops. The more crops, the weaker is the reduction in wind speed. This result seems contradictory with the previous findings, however it should be noted that in plot E the average height of the crops (1.5 m) is much higher than in plot F (0.37 m). This fact is having a large effect on the calculation of the roughness length and on the wind profile, resulting in more wind reduction. The savanna plots with many trees (C and D) seem to reduce the wind more than the agricultural field plots. The latter are meant for agriculture, so the assumption can be made that lots of trees have been cleared to make the land suitable for crop cultivation. Figure 4.10 showed that trees have a larger effect on wind reduction than shrubs and crops. Hence, areas with trees (like plot D with 50 trees) reduce wind speed to a larger extent than areas with crops (like plot E with 2,500 crops), despite the fact that the latter has got many more vegetation elements.

The results of the model with input wind speed of 13.04 m/s as measured by Kainkwa and Stigter (1994) are shown in Figure 4.10B. The courses of the wind profiles show no differences with Figure 4.10A, but obviously the wind speeds are higher at same heights. The wind speed reduction in this case is 75%.

4.3.2 Sediment flux

The sediment fluxes calculated by the model (Table 4.11) show that only at plots A and B sediment fluxes occur, using the input wind speeds of 5.7 and 8.9 m/s. At plot A, no vegetation elements are present. Because of this vegetation absence, the wind is not hampered and can blow away the loose material on the surface. At plot B, only 20 shrubs are present. It turns out that the shrubs prevent sediment transport to a large extent, because the difference with completely bare soil is approximately 66%. The shrubs cover the soil surface and trap soil particles, which results in less sediment flux (Wolfe and Nickling, 1993).

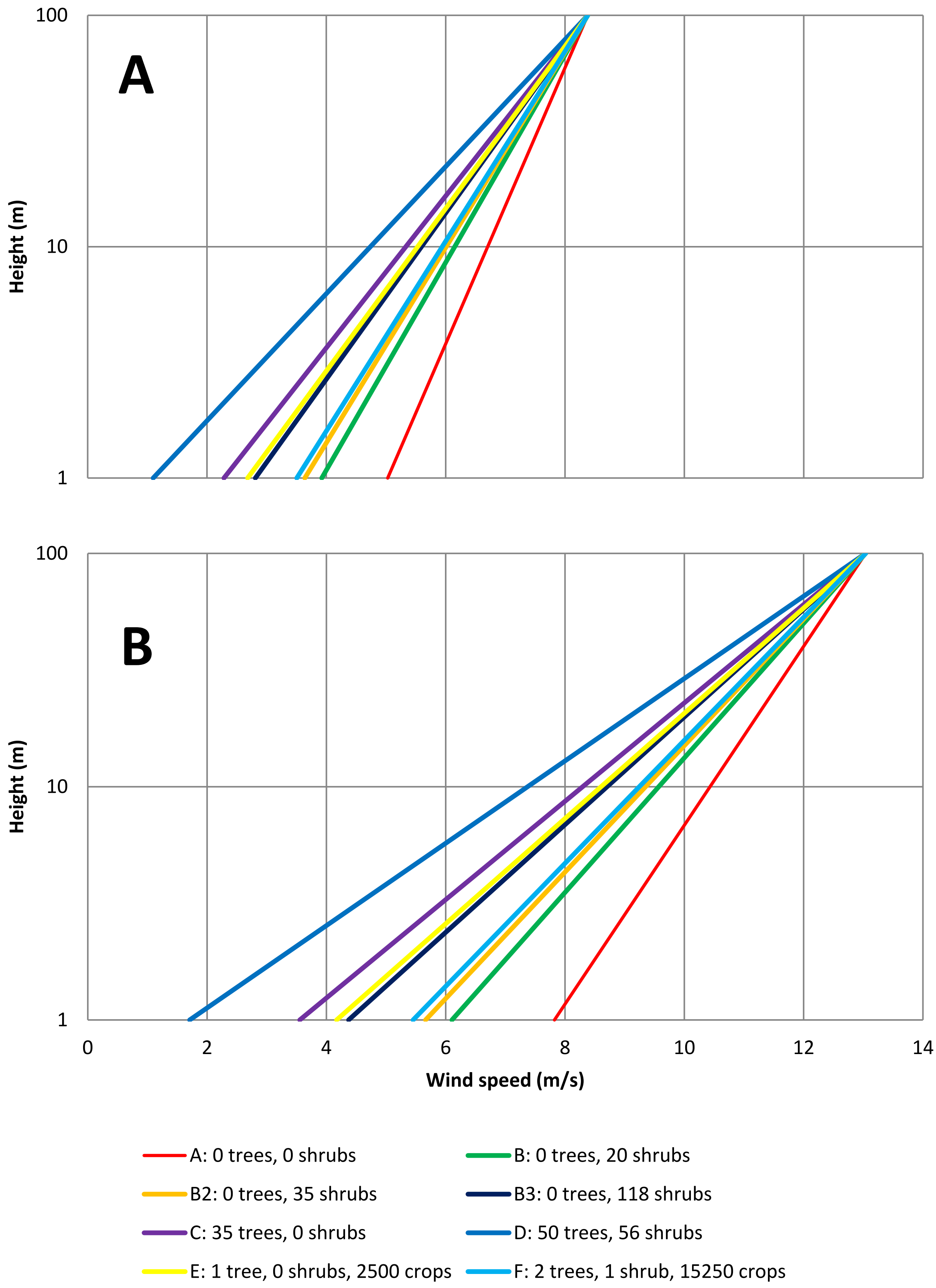


Figure 4.10: Wind profiles over eight field plots (A-F) of 2,500 m^2 with different vegetation configurations in northern Tanzania, using an input wind speed of 8.4 m/s (A) and 13.0 m/s (B) at height z = 100 m. B2 and B3 are scenarios, because they are not based on field measurements.

At all other plots, more vegetation elements are present and no sediment flux occurs at all. In the agricultural fields (plots E and F), trees and shrubs are very sparse, crops are generally small in height and have got a high porosity. However, because the high number of crops most of the surface is covered. As a consequence, the threshold friction velocity is not exceeded and soil particles will remain in place. Obviously, the sediment fluxes at plot A and B are much higher when an input wind speed of 8.9 m/s was used. But besides the higher wind speed, still no sediment fluxes occur at plots C, D, E and F. In plot C and D the high number of trees is preventing the wind from exceeding the threshold friction velocity by extracting momentum from the air. In plot E and F the crops cover a large part of the soil surface, preventing particle entrainment. With the hypothetical input wind speed of 14.7 m/s, sediment flux occurs at plot E. This field plot consists of 1 tree and 2,500 maize crops (Appendix III). It seems that the maize, which is not very high (1.5 m) and does not cover a large extent of the soil surface, is not able to prevent sediment flux, although the amount of sediment (15.69) is very low.

Table 4.11: Sediment fluxes (g/m/s) of six field plots (A-F) of 2,500 m^2 with different vegetation configurations in northern Tanzania, using different input wind speeds.

Field plot	Sediment flux with wind speed of 8.4 m/s (measured speed)	Sediment flux with wind speed of 13.0 m/s (Kainkwa and Stigter, 1994)	Sediment flux with wind speed of 14.7 m/s (hypothetical)
A	32.02	185.28	277.09
B	21.05	156.22	234.78
C	0.00	0.00	0.00
D	0.00	0.00	0.00
E	0.00	0.00	15.69
F	0.00	0.00	0.00

Figure 4.11 shows the results of the sediment flux calculations for scenarios with different numbers of the same vegetation type. The graph shows that trees have the highest capability of reducing sediment flux, followed by shrubs, beans and maize. With 7 trees or more present (per 0.25 ha), no sediment flux occurs anymore, whereas this number is higher for shrubs, beans and maize: respectively 30, 295 and 623. Hence the graph shows that the sediment flux reduction capability of 4 shrubs is as large as that of 1 tree, since 30/7 ≈ 4.

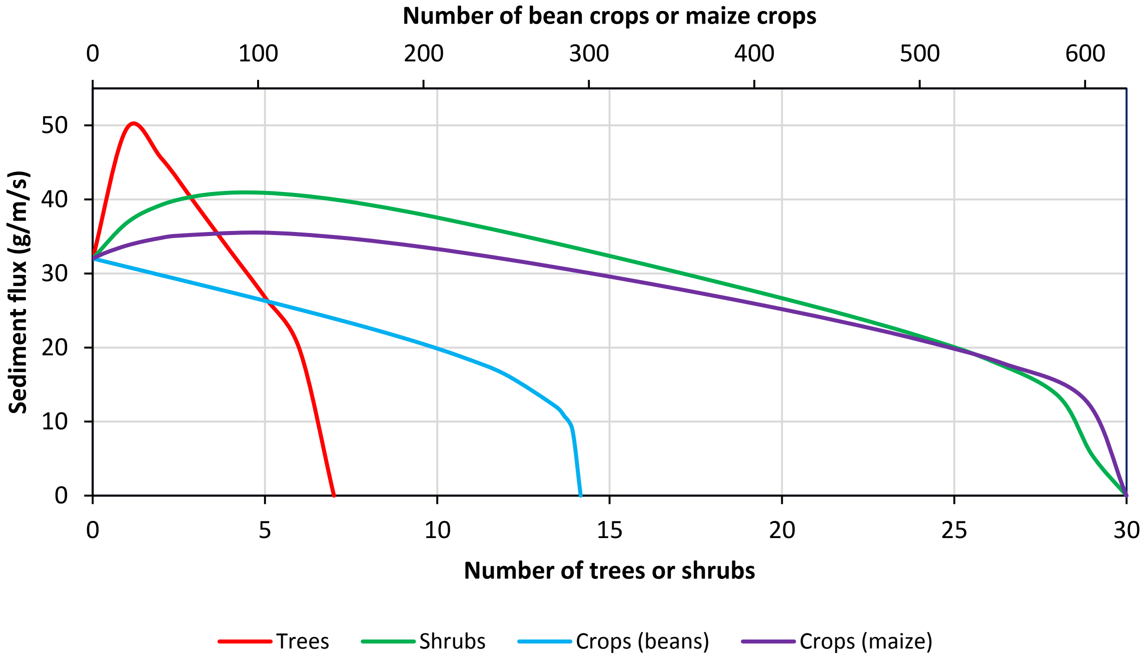


Figure 4.11: Sediment flux for different number of trees, or shrubs or crops with input wind speed of 8.4 m/s at height z = 100 m.

Because the silhouette or frontal area of trees is more than 4 times as large as that of a shrub, it seems that the size of the frontal area plays an important role in preventing wind erosion. For the crops the situation is different, because the frontal area is approximately the same, but the results show that beans are more capable of sediment flux reduction than maize. The probable reason is the difference in porosity and sheltered area. Trees and shrubs have got the same porosity, but maize has got a much higher porosity (0.75) than beans (0.5). Moreover, the sheltered area of a crop of beans is larger than that of maize, so the soil surface is covered to a larger extent and beans crops protect wind erosion from occurring more than maize crops.

The courses of the graphs show a similar pattern: first a short increase in sediment flux and after that a long decrease when increasing the number of vegetation elements. The increase seems contradictory, because the wind profiles showed that with more vegetation elements, more wind reduction occurs and this likely means less wind erosion occurs. However, the air flow around a porous vegetation element is accelerated to the sides and top of the obstacle (Judd et al., 1996). This acceleration in wind speed creates the ability to entrainment of soil particles around a vegetation element. When only a few vegetation elements are present, this effect will occur since no other vegetation elements are around to counteract the accelerated wind and the subsequent sediment flux (Leenders et al., 2007). Figure 4.11 shows that this effect is the largest in case of trees, because trees have a bark and hence a smaller sheltered area than shrubs and crops.

The decreasing part of sediment flux shows more or less linear graphs, but the last part of the graphs shows a higher decrease. This is due to the fact that the sediment flux (eq. 3.21) decreases exponentially when more vegetation elements are present. More elements result in decreasing surface drag, since the surface is covered to a larger extent. Subsequently the friction velocity decreases. Because this element of the equation is to the power of 3 (u_*^3), the sediment flux decreases exponentially.

5. Discussion

Several causes and consequences of land cover changes can be distinguished in Monduli District in the period 1985 – 2016, both environmental and socio-economic. Population growth is one of the main drivers of land cover change (Kiunsi and Meadows, 2006; FAO, 2009). The total population of Tanzania increased from 12,313,469 people in 1967 to 44,928,923 people in 2012 (Figure 5.1) (NBS, 2012). Hence, in 2012 the population was 3.7 times as large as in 1967. Between 2002 and 2012 the total population increased with an average growth rate of 2.7% (NBS, 2012). The average growth rate in the same time period for Arusha Region was 2.7% and for Monduli District 3.9% (MDC, 2014). This increase in residents of Monduli District explains the increase in urban areas, as shown in Table 4.8 and Table 4.9. In 2016, the villages Mto wa Mbu and Monduli have been expanded and Selela, Kigongoni and Makuyuni are new villages compared with 1985. The expansion of urban area is mainly present in the southern part of the district, probably because the only two paved roads (Figure 2.1) are present in this area.

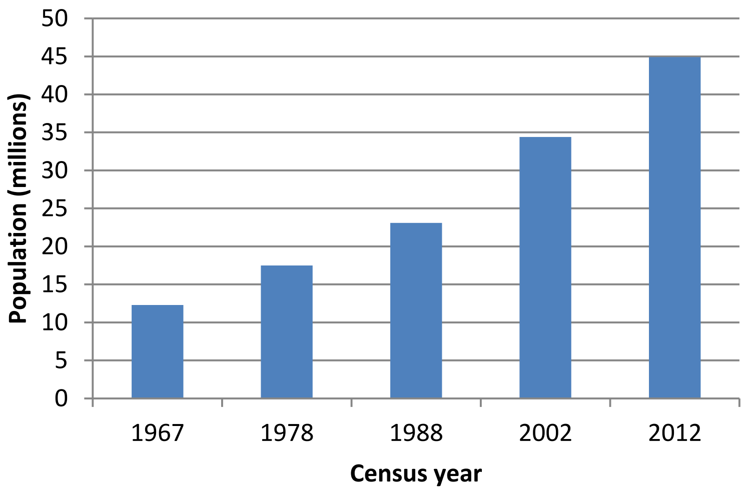


Figure 5.1: Population growth Tanzania 1967 – 2012. Modified from NBS (2012).

A consequence of the rise in population is the increase in livestock, especially among the semi-nomadic Maasai (Fratkin, 2001). More livestock means higher pressure on the available pastures, and overgrazing could occur. This pressure could be exacerbated by climate, because the IPCC (2011) showed an increase in temperature over the last 50 to 100 years, which will continue to a temperature rise of 2-4 °C by the end of this century. This temperature rise is also being observed by 67% of the interviewees (n = 30). 90% of the interviewees think it is also drier than a few decades ago. The pressure on pastures seems high in the northern part of Monduli District, since in this area the amount of bare soil has increased a lot in 2016 compared to 1985 (Figure 4.5). This area is inhabited by many Maasai and no conservation areas and national parks are present, which means this vast area could be used for grazing purposes by the Maasai (Homewood et al., 2009). In a large part of the area leptosols are present, which are shallow soils susceptible to drought and erosion (FAO, 1993). Therefore, overgrazing together with the warmer and drier climate and the soil type which is susceptible to droughts and erosion, could explain the decrease in grassland and savanna cover and the subsequent increase in amount of bare soil (Table 4.8 and 4.9, Figure 4.5). However, since no data was obtained in this area, it is hard to say if so much bare soil is actually present there and which factor contributes the most to the increase in bare soil.

Another result of the population increase is the expansion of agricultural areas, because 90% of the inhabitants of the study area are involved in agriculture (MDC, 2014). Besides, the cultural shift among the Maasai made people start with crop cultivation for several reasons, not only due to the population growth (McCabe, 2010). One of the reasons revealed by Maasai during the interviews is to be not dependent on only livestock anymore, because the animals could suffer and eventually die from epidemics, wild animal attacks and shortages of water and forage. Moreover, due to the government's villagization policy, some Maasai were forced to settle and are not allowed to migrate anymore (Ruppert and Schrüfer, 1995). This makes traditional pastoralism as a livelihood difficult. Therefore, people started with other activities to gain food and income, like crop cultivation and the sale of products like charcoal, beadwork, tobacco and milk. Despite the villagization campaign, it turned out that only 3 of the 15 interviewed permanently settled people were Maasai. 9 of the 15 people belonged to the Waarusha, a tribe living in the neighborhood of the city of Arusha, close to the eastern border of the study area. The Waarusha is related to the Maasai, but the largest difference is that the economy of the Waarusha is based on agro-pastoralism (Kuney, 1994). Since many Waarusha (9) were living in permanent settlements in the study area, it looks like that due to the population increase the Waarusha have been moving to other areas, like the Monduli District, and hence were partially responsible for an increase in agricultural land.

The advent of large farms is another reason, according to Galaty (1992), Fratkin (2001) and 22 of the 30 interviewees, for the observed increase in agricultural area in the study area (Table 4.8 and 4.9, Figure 4.9A). These farms produce mainly wheat, barley, maize and flowers to a large extent. This trend seems to be a consequence of governmental policy, which favors crop cultivation over livestock farming (Homewood et al., 2009). Therefore, commercial farming gets support from the government and since the government considers all areas with no registered owner as national property (Kuney, 1994; Ruppert and Schrüfer, 1995), many large farms arose on land which used to be used as pastures by Maasai (Fratkin, 2001).

One of the consequences of land conversion to agricultural areas and bare soil was the effect on the wind speed and sediment flux. The model used to calculate the wind speed and sediment flux had a field-plot scale. The model is therefore only applicable to small areas (i.e. 1 hectare or smaller) and not suitable to extrapolate to the entire study area. The latter is also not possible because the vegetation densities differ much in the study area. Furthermore, the model does not take grasses into account, since the initial model was developed for environmental conditions of the Sahel in Africa, where almost no grasses grow. Grasses will not have a large effect on wind reduction, since the aerodynamic roughness length (eq. 3.7) will be low because of the small height of grasses. However, the Tanzanian savanna is covered with grass, especially after the rain period. The grass could have a positive effect on covering the surface and preventing particle entrainment. With grasses added to the model, the sediment fluxes of Table 4.13 will probably be lower. Despite the absence of grass elements in the model, the results were in line with previous findings of Wolfe and Nickling (1993), Kainkwa and Stigter (1994) and Leenders et al. (2007). This means that the wind profiles and sediment fluxes showed that trees have a larger effect on wind reduction than shrubs and crops, but that shrubs and crops have a larger effect on preventing sediment flux.

6. Conclusions

Many land use and land cover changes have taken place in Monduli District, northern Tanzania in the past decades. Urban area has increased from 0.01% to 0.04% of the surface area of the study area between 1985 and 2016. Agricultural area is also more than four times as large as in 1985 (from 0.72% to 2.98%). Bare soil has increased from 19.52% to 30.81%. Water and forest have also increased. The amount of grassland has decreased in this period from 10.39% to 4.65%. The largest land cover class in 1985, savanna, is still the largest class in 2016, but the amount of savanna in the study area has decreased from 53.49% to 50.57%.

The land cover changes were caused by different factors. First of all, population increase caused expanding urban areas and conversion of traditional landscapes to agricultural areas, because the economy of many tribes in Monduli District is based on agro-pastoralism. Secondly, the villagization policy of the Tanzanian government forced nomadic tribes like the Maasai to settle in a village. After settlement, the pastoralist Maasai started to diversify their livelihood, mainly by adopting crop cultivation. The Maasai, who were not forced to settle, started to adopt crop cultivation as well, as part of a cultural shift to diminish the risks of a livelihood of pastoralism only and to search for more wealth. The third cause of land cover changes was that the government allocated conservation areas, expanded national parks, and started to build large commercial farms in areas used by the Maasai as pastures. In other words, the Maasai were restricted in their movements. As a consequence, the pressure on the available pastures became higher, since the livestock density per unit area increased. The high pressure led to overgrazing and together with the warmer and drier climate, the traditional landscapes (i.e. savanna and grasslands) slowly degraded to bare soil.

In this way, northern Tanzania has become a fragmented landscape, with negative consequences for both the livelihoods of the inhabitants and the wildlife. One of these consequences is the change in wind speed and wind erosion risk due to land clearance in the areas where Maasai people have settled. The vegetation has been cleared to make a plot suitable for crop cultivation. However, trees are important for reducing wind speed and shrubs and crops are important for covering the soil surface, trapping soil particles and in this way preventing wind erosion. When no vegetation elements were present anymore, the wind speed at a height of 1 m is on a savanna plot with 50 trees and 56 shrubs approximately 80% reduced compared to a bare plot with no vegetation elements. The sediment flux on the bare plot is approximately 32 g/m/s, whereas no wind erosion occurs on the savanna plot. Hence, when a plot is completely cleared from vegetation, the wind erosion risk becomes high.

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Appendices

Appendix I: Questionnaire for interviews

Date:

Interviewer:

Translator:

Village:

GPS-location village:

Tribe:

Name family:

Name member:

Gender:

Age:

Comments:

Section 1: General questions

1: Do you live here permanently and are you officially registered as a Tanzanian citizen?

2: How long have you been living here/migrating in this area?

3: Why did you start living here? Was it your own choice or were you forced by the government?

4: What did you change to the land when you start living here?

5: What type of farming do you carry out: pastoralism, agro-pastoralism or only agriculture?

In case of agro-pastoralism or only agriculture:

6: When did you start with agriculture?

7: Did you start with agriculture out of necessity?

8: In order to make the land suitable for agriculture, what did you change to the landscape?

9: Do you carry out other activities next to farming to gain income?

Section 2: Questions regarding livestock and agriculture

In case of pastoralists or agro-pastoralists:

10: What is your herd size?

11: How do you obtain drinking water for your cattle?

12: Is enough grazing land available and is the quality good?

13: What is the (estimated) size of the grazing land?

In case of agro-pastoralists or only agriculture:

14: What kind of crops do you cultivate?

15: Is the quality of the agricultural land good?

16: Is enough water available for the agriculture?

17: What is the (estimated) size of the agricultural land?

18: How do you obtain drinking water for yourself?

Section 3: Questions regarding experiences and opinions about land use and land cover changes

In case of pastoralists or agro-pastoralists:

19: Do you experience a decrease in quality of the grazing lands?

20: If you do, for how long is this process ongoing?

In case of agro-pastoralists or only agriculture:

21: Do you experience a decrease in quality of the agricultural fields?

22: If you do, for how long is this process ongoing?

23: Is it more dry or wet than … years ago?

24: Is it warmer or colder than … years ago?

25: Is more wind present than … years ago?

26: Do you observe the presence of dust in the air every now and then?

27: Is more dust in the air present than … years ago?

28: Do you even observe dust storms every now and then?

29: Which consequences of the above mentioned differences do you observe?

30: What do you think causes the above mentioned consequences?

In case the person mentions the presence of more winds and (more) dust:

> 31: Do you know how to prevent the presence of (heavy) winds and dust in the air?
>
> 32: If you know, is the presence of (heavy) winds and (more) dust also a problem in other villages?

33: Have you seen the advent of commercial farms around your residence/in your migration area?

34: Have you seen the expansion of national parks around your residence/in your migration area?

35: Do you experience negative consequences due to commercial farms and/or national parks?

36: Do you want to stay here or do you want to move?

37: If you want to move, why do you want to move?

Appendix II: Results interviews

15 interviews with semi-nomadic people: SN 01 – SN 15.

15 interviews with settled people: S 01 – S 15.

Question	Interview				
	SN 01: male, 74 years, Maasai	SN 02: male, 27 years, Maasai	SN 03: female, 55 years, Maasai	SN 04: male, 60 years, Maasai	SN 05: male, 75 years, Maasai
General questions					
1	No	No	No	No	No
2	Since 10 years	Since 11 years	Since 20 years	Since 7 years	Since 4 years
3	Forced	Forced	Own choice	Forced	Forced
4	Nothing	Nothing	Clear vegetation	Clear vegetation	Clear vegetation
5	Agro-pastoralism	Agro-pastoralism	Agro-pastoralism	Agro-pastoralism	Pastoralism
6	After 5 years	After 5 years	Immediately	Immediately	-
7	Yes	Yes	Yes	Yes	-
8	Clear vegetation	Clear vegetation	Clear vegetation	Clear vegetation	-
9	No	No	No	Job as guard at a hotel	No
Questions regarding livestock and agriculture					
10	200 cows	80 cows, 100 sheep and goats	40 cows	40 cows, 30 sheep and goats	30 cows, 50 sheep and goats
11	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)
12	Yes	Yes	Yes	Yes	Yes
13	Do not know	About 10 acres	About 5 acres	About 7 acres	About 10 acres
14	Maize, beans, tomatoes	Maize and beans	Maize, beans and rice	Maize and beans	-
15	Yes	Yes	Yes	Yes	-
16	Depends on rain	Depends on rain	Depends on rain	Depends on rain	-
17	Do not know	About 3 acres	Do not know	Do not know	-
18	From a tank	From a tank	From a tank	From a tank	From a tank
Questions regarding experiences and opinions about land cover changes					
19	No	No	No	No	No
20	-	-	-	-	-
21	No	No	Yes	Yes	-
22	-	-	For 20 years	For 15 years	-
23	Drier	Drier	Drier	Drier	No difference
24	No difference	No difference	No difference	No difference	No difference
25	Yes	Yes	Yes	Yes	No difference
26	Yes	Yes	Yes	Yes	Yes
27	Yes	Yes	Yes	Yes	No
28	No	No	No	No	No
29	More dust	More dust	More dust	More dust and health problems	None
30	Droughts and land clearance	Droughts and land clearance	Climate change	Droughts	Much vegetation around boma
31	Yes, by planting trees	Yes, by planting trees	No	No	-
32	Do not know	Do not know	Do not know	Do not know	-
33	Yes	Yes	Yes	Yes	Yes
34	Yes	Yes	No	No	No
35	Yes: forced movement	Yes: forced movement	No	No	No
36	Want to stay	Want to stay	Want to stay	Want to stay	Want to stay
37	-	-	-	-	-

Question	Interview				
	SN 06: female, 60 years, Maasai	SN 07: male, 68 years, Maasai	SN 08: male, 40 years, Maasai	SN 09: female, 50 years, Maasai	SN 10: male, 60 years, Maasai
General questions					
1	No	No	No	No	No
2	Since 40 years	Since 65 years	Since 2 years	Since 15 years	Since 25 years
3	Do not know	Own choice	Own choice	Own choice	Own choice
4	Nothing	Nothing	Nothing	Nothing	Nothing
5	Pastoralism	Agro-pastoralism	Agro-pastoralism	Pastoralism	Agro-pastoralism
6	-	After 30 years	Immediately	-	Immediately
7	-	Yes	Yes	-	Yes
8	-	Nothing	Nothing	-	Nothing
9	No	Tourist tours and sale of beadwork	No	Sale of tobacco	Sale of tobacco and beadwork
Questions regarding livestock and agriculture					
10	6 cows	20 cows	40 cows, 100 sheep and goats	100 cows, 200 sheep and goats	20 cows, 20 sheep and goats
11	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)	From a swamp	From a water reservoir (dam)
12	Yes	Yes	Yes	Yes	Yes
13	About 6 acres	Do not know	About 3 acres	About 10 acres	About 3 acres
14	-	Maize and beans	Maize and beans	-	Maize, beans and grams
15	-	No	No	-	No
16	-	Yes	Depends on rain	-	Depends on rain
17	-	Do not know	About 2 acres	-	About 6 acres
18	From a tank	From a tank	From a water tower	From a swamp	From a tap
Questions regarding experiences and opinions about land cover changes					
19	No	Yes	Yes	Yes	Yes
20	-	Since 50 years	Since 25 years	Since 15 years	Since 25 years
21	-	Yes	Yes	-	Yes
22	-	Since 50 years	Since 25 years	-	Since 25 years
23	Drier	Drier	Drier	Drier	Drier
24	No difference	No difference	Warmer	Warmer	No difference
25	Yes	Yes	Yes	No difference	No difference
26	Yes	Yes	Yes	Yes	Yes
27	Yes	Yes	Yes	Yes	No
28	No	No	Yes	Yes	No
29	None	Wind destroys houses, dust causes health problems	Quality of land decreases and wind destroys houses	Quality of land decreases and wind destroys houses	More droughts
30	Do not know	Presence of more droughts and wind	Climate change	Will of God	Do not know
31	Do not know	Yes, by moving to lower lying area	Do not know	Do not know	Do not know
32	Do not know	Do not know	Yes	Yes	Yes
33	Yes	Yes	Yes	Yes	Yes
34	No	No	Yes	Yes	Yes
35	No	No	Yes	Yes	Yes
36	Want to stay	Want to stay	Want to stay	Want to stay	Want to stay
37	-	-	-	-	-

Question	Interview				
	SN 11: male, 75 years, Maasai	SN 12: male, 31 years, Maasai	SN 13: male, 50 years, Maasai	SN 14: female, 30 years, Maasai	SN 15: male, 31 years, Maasai
General questions					
1	No	No	No	No	No
2	Since 25 years	Since 25 years	Since 8 years	Since 3 years	Since 12 years
3	Own choice	Own choice	Own choice	Own choice	Own choice
4	Nothing	Nothing	Nothing	Nothing	Clear vegetation
5	Agro-pastoralism	Agro-pastoralism	Agro-pastoralism	Pastoralism	Pastoralism
6	After 4 years	After 4 years	After 2 years	-	-
7	Yes	Yes	Yes	-	-
8	Nothing	Clear vegetation	Nothing	-	-
9	Sale of tobacco	No	Sale of tobacco and beadwork	Sale of gemstones	Sale of beadwork and artifacts
Questions regarding livestock and agriculture					
10	45 cows, 75 sheep and goats	200 cows, 500 sheep and goats	30 cows, 100 sheep and goats	10 cows, 15 sheep and goats	10 cows, 15 sheep and goats, 30 chickens
11	From a swamp	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)
12	Yes	Yes	Yes	Yes	Yes
13	About 10 acres	About 5 acres	About 5 acres	Do not know	Do not know
14	Maize and beans	Maize and beans	Maize and beans	-	-
15	No	No	Yes	-	-
16	Depends on rain	Depends on rain	Depends on rain	-	-
17	About 10 acres	About 5 acres	About 5 acres	-	-
18	From a tank	From a water reservoir (dam)	From a tap	From a tap	From a tank
Questions regarding experiences and opinions about land cover changes					
19	No	Yes	No	No	Yes
20	-	Since 10 years	-	-	Since 10 years
21	Yes	Yes	No	-	-
22	Since 20 years	Since 10 years	-	-	-
23	Drier	Drier	No difference	Drier	Drier
24	Warmer	Warmer	No difference	Warmer	Warmer
25	Yes	Yes	No difference	Yes	No
26	Yes	Yes	Yes	Yes	Yes
27	Yes	Yes	No	Yes	No
28	No	Yes	Yes	Yes	Yes
29	Wind destroys houses, dust causes health problems	Wind destroys houses, dust causes health problems	Dust causes health problems	Wind destroys houses, dust causes health problems	Wind destroys houses, dust causes health problems
30	Do not know	Bad land management	Do not know	Do not know	Land clearance
31	Do not know	Yes, by planting trees	Do not know	Do not know	Yes, by planting trees
32	Yes	Yes	No	Yes	Do not know
33	Yes	Yes	Yes	Yes	No
34	No	No	No	No	Yes
35	Yes	Yes	Yes	Yes	Yes
36	Want to stay	Want to stay	Want to stay	Want to stay	Want to stay
37	-	-	-	-	-

Question	Interview				
	S 01: male, 30 years, Waarusha	S 02: female, 40 years, Waarusha	S 03: female, 45 years, Waarusha	S 04: male, 25 years, Maasai	S 05: male, 55 years, Waarusha
General questions					
1	Yes	Yes	Yes	Yes	Yes
2	Since 30 years	Since 40 years	Since 11 years	Since 30 years	Since 55 years
3	Own choice	Own choice	Own choice	Own choice	Own choice
4	Clear vegetation	Nothing	Nothing	Nothing	Clear vegetation
5	Agro-pastoralism	Agro-pastoralism	Agro-pastoralism	Agro-pastoralism	Agro-pastoralism
6	Immediately	Immediately	Immediately	After 10 years	Immediately
7	Yes	Yes	Yes	Yes	Yes
8	Clear vegetation	Nothing	Nothing	Nothing	Clear vegetation
9	No	My husband is employed	We have a shop	Sale of milk	No
Questions regarding livestock and agriculture					
10	20 cows	50 cows and 12 donkeys	100 cows	50 cows, 80 sheep and goats	10 cows
11	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)
12	Yes	Yes	Yes	Yes	Yes
13	Do not know	Do not know	Do not know	Do not know	Do not know
14	Maize, beans and lablab beans	Maize, beans and lablab beans	Maize and beans	Maize, beans and lablab beans	Maize, beans, grams, onions
15	Yes	Yes	No	No	No
16	Depends on rain	Depends on rain	Depends on rain	Depends on rain	Depends on rain
17	About 10 acres	About 4 acres	About 7 acres	About 8 acres	About 10 acres
18	From a water reservoir (dam)	From a water reservoir (dam)	From a tank	From a water reservoir (dam)	From a water reservoir (dam)
Questions regarding experiences and opinions about land cover changes					
19	Yes	Yes	No	Yes	Yes
20	Since 20 years	Since 5 years	-	Since 6 years	Since 10 years
21	Yes	Yes	Yes	Yes	Yes
22	Since 20 years	Since 5 years	Since 11 years	Since 10 years	Since 20 years
23	Drier	Drier	Drier	Drier	Drier
24	Warmer	Warmer	Warmer	Warmer	Warmer
25	Yes	Yes	Yes	Yes	Yes
26	Yes	Yes	Yes	Yes	Yes
27	Yes	Yes	Yes	Yes	Yes
28	Yes	Yes	Yes	Yes	Yes
29	Wind destroys houses, dust causes health problems	Wind destroys houses, dust causes health problems	Dust causes health problems	Dust causes health problems, drier climate causes food and water shortages	Dust causes health problems
30	Land clearance	Land clearance	Land clearance	Land clearance, climate change	Land clearance
31	Yes, by planting trees	Yes, by planting trees	Yes, by planting trees	Yes, by planting trees	Yes, by planting trees
32	Yes	Yes	Yes	Yes	Yes
33	Yes	No	No	No	Yes
34	Yes	No	No	No	No
35	Yes	No	Yes	No	No
36	Want to stay	Want to stay	Want to stay	Want to stay	Want to stay
37	-	-	-	-	-

Question	Interview				
	S 06: male, 35 years, Waarusha	S 07: female, 45 years, Waarusha	S 08: male, 45 years, Nyaturu	S 09: male, 43 years, Iraqw	S 10: male, 64 years, Zigua
General questions					
1	Yes	Yes	Yes	Yes	Yes
2	Since 35 years	Since 25 years	Since 42 years	Since 15 years	Since 42 years
3	Own choice	Own choice	Own choice	Own choice	Own choice
4	Clear vegetation	Nothing	Nothing	Clear vegetation	Clear vegetation
5	Agro-pastoralism	Agro-pastoralism	Agro-pastoralism	Agro-pastoralism	Agriculture
6	Immediately	After 1 year	Immediately	Immediately	Immediately
7	Yes	Yes	Yes	Yes	Yes
8	Clear vegetation	Clear vegetation	Nothing	Clear vegetation	Clear vegetation
9	We have a shop	No	Sale of locally brewed drinks	Sale of honey	No
Questions regarding livestock and agriculture					
10	10 cows	10 cows, 10 sheep and goats	10 goats	75 cows, sheep and goats	-
11	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)	-
12	Yes	Yes	Yes	Yes	-
13	Do not know	Do not know	Do not know	Do not know	-
14	Maize, beans and grams	Maize and beans	Maize, beans and grams	Maize, beans and grams	Maize, beans, grams, melons
15	Yes	No	Yes	Yes	Yes
16	Depends on rain	Depends on rain	Depends on rain	Depends on rain	Depends on rain
17	About 8 acres	About 6 acres	About 1 acre	About 20 acres	About 120 acres
18	From a water reservoir (dam)	From water tower	From water tower	From water tower	From a tap
Questions regarding experiences and opinions about land cover changes					
19	Yes	Yes	No	No	-
20	Since 8 years	Since 7 years	-	-	-
21	Yes	Yes	Yes	Yes	Yes
22	Since 8 years	Since 7 years	Since 5 years	Since 10 years	Since 10 years
23	Drier	Drier	Drier	Drier	Drier
24	Warmer	Warmer	Warmer	Warmer	Warmer
25	Yes	Yes	Yes	Yes	Yes
26	Yes	Yes	Yes	Yes	Yes
27	Yes	Yes	Yes	Yes	Yes
28	Yes	No	Yes	No	Yes
29	Wind destroys houses, dust causes health problems	Dust causes health problems	Wind destroys houses, dust causes health problems	Dust causes health problems	Dust causes health problems
30	Land clearance	Land clearance	Climate change	Land clearance	Climate change
31	Yes, by planting trees	Yes, by planting trees	Yes, by planting trees	Yes, by planting trees	Yes, by planting trees
32	Yes	Yes	Yes	Yes	Yes
33	Yes	No	No	Yes	Yes
34	Yes	Yes	Yes	Yes	Yes
35	Yes	Yes	Yes	Yes	Yes
36	Want to stay	Want to stay	Want to stay	Want to stay	Want to stay
37	-	-	-	-	-

Question	Interview				
	S 11: male, 66 years, Waarusha	S 12: male, 54 years, Waarusha	S 13: female, 24 years, Waarusha	S 14: female, 65 years, Maasai	S 15: female, 45 years, Maasai
General questions					
1	Yes	Yes	Yes	Yes	Yes
2	Since 5 years	Since 30 years	Since 2 years	Since 34 years	Since 20 years
3	Own choice	Own choice	Own choice	Forced	Own choice
4	Clear vegetation	Nothing	Nothing	Nothing	Nothing
5	Agro-pastoralism	Agro-pastoralism	Agro-pastoralism	Agro-pastoralism	Agro-pastoralism
6	Immediately	Immediately	Immediately	Immediately	Immediately
7	Yes	Yes	Yes	Yes	Yes
8	Clear vegetation	Nothing	Nothing	Nothing	Clear vegetation
9	No	No	No	Sale of charcoal	Sale of beadwork
Questions regarding livestock and agriculture					
10	114 cows, 104 sheep and goats	15 cows and 20 goats	3 cows, 10 sheep and goats	6 cows, 13 sheep and goats	100 cows, 200 sheep and goats
11	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)
12	Yes	No	Yes	Yes	Yes
13	Do not know	Do not know	Do not know	About 5 acres	Do not know
14	Maize, beans and bananas	Maize and beans	Maize and beans	Maize, beans and lablab beans	Maize and beans
15	No	Yes	Yes	Yes	Yes
16	Depends on rain	Depends on rain	Depends on rain	Depends on rain	Depends on rain
17	About 8 acres	About 7 acres	About 4 acres	About 60 acres	About 2 acres
18	From a water tower	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)	From a water reservoir (dam)
Questions regarding experiences and opinions about land cover changes					
19	No	Yes	Yes	Yes	Yes
20	-	Since 25 years	Since 6 years	Since 16 years	Since 10 years
21	Yes	Yes	Yes	Yes	Yes
22	Since 5 years	Since 5 years	Since 6 years	Since 16 years	Since 10 years
23	Drier	Drier	Drier	Drier	Drier
24	Warmer	Warmer	Warmer	Warmer	Warmer
25	No	No	No	Yes	Yes
26	Yes	Yes	Yes	Yes	Yes
27	No	No	No	Yes	No
28	Yes	No	Yes	Yes	Yes
29	Wind destroys houses, dust causes health problems	More droughts, but also water erosion (gullies)	Wind destroys houses, dust causes health problems	Wind destroys houses, dust causes health problems	Drier and warmer climate destroys crops
30	Climate change	Land clearance	Land clearance	Land clearance	Do no know
31	No	Yes, by planting trees	Yes, by planting trees	Yes, by planting trees	Yes, by praying
32	Yes	Do not know	Do not know	Yes	Do not know
33	No	Yes	Yes	Yes	No
34	Yes	No	No	Yes	No
35	Yes	Yes	Yes	Yes	No
36	Want to stay	Want to stay	Want to stay	Want to stay	Want to stay
37	-	-	-	-	-

Appendix III: Description of field plots

Field plot A (bare soil):

Total surface S: 2,500 m^2

	Trees	Shrubs	Crops
Type:	-	-	-
Quantity:	0	0	0
Width:	-	-	-
Height:	-	-	-
Porosity:	-	-	-
Drag coefficient:	-	-	-
Width bark:	-	-	-
Height bark:	-	-	-

Field plot B (bushed savanna):

Total surface S: 2,500 m^2

	Trees	Shrubs		Crops
Type:	-	X	Y	-
Quantity:	0	17	3	0
Width:	-	1.9	3.6	-
Height:	-	2.0	2.5	-
Porosity:	-	0.5	0.4	-
Drag coefficient:	-	0.2	0.2	-
Width bark:	-	-		-
Height bark:	-	-		-

Field plot C (wooded savanna):

Total surface S: 2,500 m^2

	Trees	Shrubs	Crops
Type:	X	-	-
Quantity:	35	0	0
Width:	5.0	-	-
Height:	2.5	-	-
Porosity:	0.5	-	-
Drag coefficient:	0.3	-	-
Width bark:	0.2	-	-
Height bark:	1.5	-	-

Field plot D (bushed wooded savanna):

Total surface S: 2,500 m^2

	Trees			Shrubs	Crops
Type:	X	Y	Z	X	-
Quantity:	18	2	36	50	0
Width:	6.3	11.0	4.5	1.7	-
Height:	5.6	6.23	4.8	1.5	-
Porosity:	0.6	0.4	0.5	0.5	-
Drag coefficient:	0.3	0.3	0.3	0.2	-
Width bark:	0.12	0.0	0.28	-	-
Height bark:	0.85	0.0	1.1	-	-

Field plot E (agricultural field):

Total surface S: 2,500 m^2

	Trees	Shrubs	Crops
Type:	X	-	Maize
Quantity:	1	0	2,500
Width:	5.1	-	0.5
Height:	2.5	-	1.5
Porosity:	0.5	-	0.75
Drag coefficient:	0.3	-	0.2
Width bark:	0.2	-	-
Height bark:	1.3	-	-

Field plot F (agricultural field):

Total surface S: 2,500 m^2

	Trees	Shrubs	Crops	
Type:	X	X	Maize	Beans
Quantity:	2	1	2,450	12,800
Width:	3.5	2.2	0.10	0.30
Height:	3.3	1.8	1.00	0.25
Porosity:	0.5	0.4	0.75	0.5
Drag coefficient:	0.3	0.2	0.20	0.2
Width bark:	0.0	-	-	-
Height bark:	0.0	-	-	-