Productive Protection of Riparian Zones - Good Individual and Community Practices around Mt. Kenya

Masterarbeit der Philosophisch-naturwissenschaftlichen Fakultät der Universität Bern

vorgelegt von

Manuel Fischer

2014

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Cover photo: View of Mt.Kenya from Naro Moru Town (M. Fischer 2012)

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Manuel Fischer, May 2014

Abbreviations

DPSIR	Drivers-Pressures-State-Impact-Responses
ES	Ecosystem Services
GIS	Geographical Information System
ha	hectare(s)
KWS	Kenyan Wildlife Service
LMP	Land management practice
LWF	Laikipia Wildlife Forum
m a.s.l.	metres above sea level
MA	Millennium Ecosystem Assessment 2005
SLM	Sustainable Land Management
SCMP	Sub-Catchment Management Plan
UNEP	United Nations Environment Program
WOCAT	World Overview of Conservation Approaches and Technologies
WRMA	Water Resource Management Authority
WRUA	Water Resource Users Association
WSTF	Water Services Trust fund

Abstract

The goal of this thesis was to get a broader understanding of the condition and management of riparian zones in the Mt. Kenya area, especially the Naro Moru and Kapingazi sub-catchments. The specific objectives were (1) the assessment of effects that land use systems have on adjacent riparian zones in terms of degradation and conservation. This was accompanied by a comparison of the riparian forest cover between 1961 and 2011. The second objective was the (2) identification of certain land management practices and their effect on ecosystem services. The third objective (3) was the investigation of Water Resource Users Associations (WRUAs) on their ways and means of spreading land management technologies.

As a conceptional framework the DPSIR model was used. It stands for Drivers-Pressures-State-Impact-Responses and is appropriate to analyse environmental problems.

The applied methods were manifold. Interviews with land users were performed to gather information on the land management practices and on the water resource management of the WRUA using the WOCAT Technologies and Approaches Questionnaires. The mapping was carried out with the WOCAT Mapping Questionnaire. Additionally, land use classification, riparian width classification and forest classification were performed with ArcGIS 10.0. Data basis for the calculations were a Google earth RGB picture dating from 2011 and two black-and-white aerial photographs of the Naro Moru sub-catchment dating from 1961.

The results show five major land use systems adjacent to riparian zones in the Naro Moru sub-catchment: Cropland, grazing & bush land, large scale grazing land, used forest and natural forest. Degradation was mostly concentrated adjacent to cropland and grazing land while conservation measures were mainly applied on cropland and large scale grazing land. The riparian vegetation width was assessed in the three zones of the sub-catchment. In the savannah zone 42.6% of the riparian zone show a width below 1m, whereas this share amounts to 24.4% in the foot zone and 0% in the forest zone. Between 1961 and 2011, riparian forest (with a width of 100 m) was reduced from 69.2% to 37.8% in the foot zone and from 62.7% to 24.5% in the savannah zone. This underlines the land use change and deforestation tendencies during this time span in the Naro Moru sub-catchment. Eight land management practices in riparian zones were investigated in detail. The analysis was focussed on ecosystem services and labour input. It turned out that the productive and protective land management practices were much more successful in providing ecosystem services than certain bad land management practices. Nevertheless, there is a trade-off between production and protection. Two WRUAs were investigated on the principles of water resources management. Their weaknesses are: unequal participation in terms of gender, unequal representation of the stakeholders in the committee and the missing possibility to pursue violations of the laid down rules. Strengths of the association are the commitment of the members and the WRUA as a discussion forum also for conflict resolution.

This thesis underlined the importance of riparian zones and riparian forest and their necessity for community and nature. There are possibilities which improve the condition of these areas and lead to benefits for all stakeholders. Nevertheless, increasing population forces the people to meet their basic human needs and forgetting long term perspectives. The goal of the water management should be to provide enough and good quality water for all stakeholders although demand is growing and supply is far from having a reliable development in the future.

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1 Introduction

1.1 *Problem Statement*

Riparian zones are critical for protecting water quality and quantity as well as for flood protection and wildlife. However, riparian zones are often affected by anthropogenic activities. Protection and restoring of riparian zones is a crucial aspect of water conservation (Owers 2012: 543). Riparian zones stabilise stream banks, decrease riverbank degradation, absorb sediments, nutrients and pesticides before they join the stream. Additionally, they moderate stream temperature and incident light, increase habitat and water quality for aquatic organisms and provide habitat corridors for terrestrial wildlife. Considering these ecological functions, riparian zones are widely recognized for their importance (Owers 2012: 543; Wenger 1999: 6; Salemi 2012: 195).

Another aspect of riparian zones is their exceptional richness in biodiversity due to their role as a boundary between the aquatic and the upland ecosystem. They even display a greater variation in characteristics than either of the systems they connect to; rather than being averages of the two systems, they are something unique (Naiman et al 1993: 209).

Unfortunately, especially the riparian zones are under a certain pressure nowadays. Policy makers and local communities show concerns about the loss of the ecological functions, for example the sediment retention. In many developing countries, extensive areas are undergoing land use changes due to afforestation and deforestation activities, leading to conflicts in water use due to agricultural demands for irrigation. Hence, participatory planning and management is needed. *Hedelin 2007* detects water shortages as an international trend that also sets a constraint on social and economic development (Mungai et al 2004: 136).

UNEP 2000 acknowledges riverbanks as a crucial link of the erosion chain polluting rivers and lakes with nutrients and agricultural chemicals. Especially man made changes to river and stream banks result in increased erosion of exposed riverbanks. This is mainly done by removal of tree cover and removal of secondary and ground cover for agricultural production. Bank collapse and large-scale damage is also being caused by livestock trampling riparian vegetation down when drinking.

Research on the so-called interface between terrestrial and aquatic environments, the riparian zone, is being done in diverse disciplines. Depending on the scientific approach, the terminology that is used in literature differs. If the riparian is perceived as a technical buffer to filter the runoff from the fields, the term “riparian buffer” is often mentioned. Alternatively, the word riparian zone is used to focus more on ecosystem services, habitats and vegetation type. Considering trees as the most pronounced factor of the riverbank the term “riparian or riverine forest” is used. From a hydrological point of view the riparian is rather seen as riverbank that is associated with riverbank erosion or degradation. Taking stream morphology into consideration, the terms slip-off slope and river-cut cliff are commonly used to describe the characteristics of the riverbank (Bach 2000: 2).

In this thesis the term "riparian zone" stands for the transition zone between the river and its upland. It is characterized by its various functions as wildlife habitat, filtering function of runoff of adjacent fields, source for fuel wood and even as recreation area.

Mungai et al 2004 conclude for the Upper Ewaso Ng'iro basin in Kenya that the major change in the last 30 years has been the conversion of grazing land, bush land and natural forest into small scale farming areas.

In the Naro Moru sub-catchment, which is part of the Ewaso Ng'iro basin, water management is a serious matter. In the years of 1999, 2000 and 2003 the lower parts of Naro Moru River below Naro Moru town were completely drying up, which has not happened before (Aeschbacher 2003: 17). There are several reasons for the reduced river flows during dry season headed by the growing number of water abstractions due to recent land use changes for irrigation, livestock and domestic purposes (Notter et al 2007: 267). Following the drying up of the river bed, a conflict among downstream and upstream water users developed, where water users downstream blamed upstream water users for stealing water by irrigating their fields with abstracted water. This accusation is supported by runoff monitorings that report a decreasing annual mean river flow in the savannah zone from 1982 to 2003, whereas the runoff in the forest zone is even slightly increasing. This convergent runoff development can be explained by increasing water abstractions in the whole catchment. In the period from 1960 to 1990, runoff was shrinking during dry season from $9m^3$ per second to less than $1m^3$ per second. Immigration and the following conversion of grassland or natural vegetation to small-scale farming as in Naro Moru is even depicted as common in many river basins in the world. These developments undermine the critical circumstances in which riparian protection is situated (Ngigi et al 2008: 1867; Kiteme et al 2008: 20).

Christ 2013: iv noted the widespread degradation of common or unsettled land such as riparian zones. This is a result of unsustainable resource use due to high population densities and its pressure on woodlands. The Mathanya area, in the lower parts of the Naro Moru sub-catchment, is characterized by a widely conserved tree and bush cover on private land. In contrast, the overuse because of firewood collection, charcoal production and uncontrolled grazing led to a strong decline of the tree and bush cover on unsettled land.

1.2 *Goals and Objectives*

The main goal of this MSc thesis was to identify productive and protective land management practices within the riparian zone of Kapingazi and Naro Moru River in the Mount Kenya region and to identify ways and means to propagate improved land management.

Fig. 1: Farmers replacing riparian vegetation with cropland (Sutter 2012).

The specific objectives of the master thesis are to:

(1) Map the land use systems and their degradation and conservation patterns in the riparian zone in two river catchments, one in the rain shadow and one in the rain facing side of Mt. Kenya.

(2) Show the development of the forest cover in Naro Moru sub-catchment between 1961 and 2011.

(3) Identify and document in both sub-catchments six “good” and two “bad” land management practices.

(4) Compare the different land management systems in terms of productivity, environmental protection and compliance to the law.

(5) Document the Water Resource Users Associations.

(6) Identify key elements for spreading good land management practices in riparian zones.

(7) Assess suitability of the WOCAT tools in view of productive protection of land management along rivers.

1.3 *Research Questions*

Research question 1: How widespread are the land use systems adjacent to riparian zones, how can they be characterized and what is their spatial expansion and what are their degradation and conservation attributes?

Research question 2: Are there differences in the forest cover between 1961 and 2011 in the Naro Moru sub-catchment?

Research question 3: Are there land management technologies in riparian zones which combine good productivity, low labour input, and a low degree of degradation in riparian areas and thus lead to sustainable land management?

Research question 4: Why are bad land use practices persistent? Why are better land management systems not adopted?

Research question 5: What are the strengths and weaknesses of Water Resource Users Associations relating to water management?

Research question 6: What are effective means for spreading sustainable land management practices along rivers?

Research question 7: Are the WOCAT tools suitable for identification of sustainable land management practices and assessment of their impacts?

1.4 *Research Area*

The two study areas are situated at the slopes of Mt. Kenya in the centre of Kenya. Mt. Kenya is the highest point of the country with an elevation of 5199 m a.s.l. The mountain slopes receive high rainfall and are the source of perennial rivers which are the only source of surface freshwater in semi-arid Laikipia during the dry season (Liniger 1998: 10; Notter: 267).

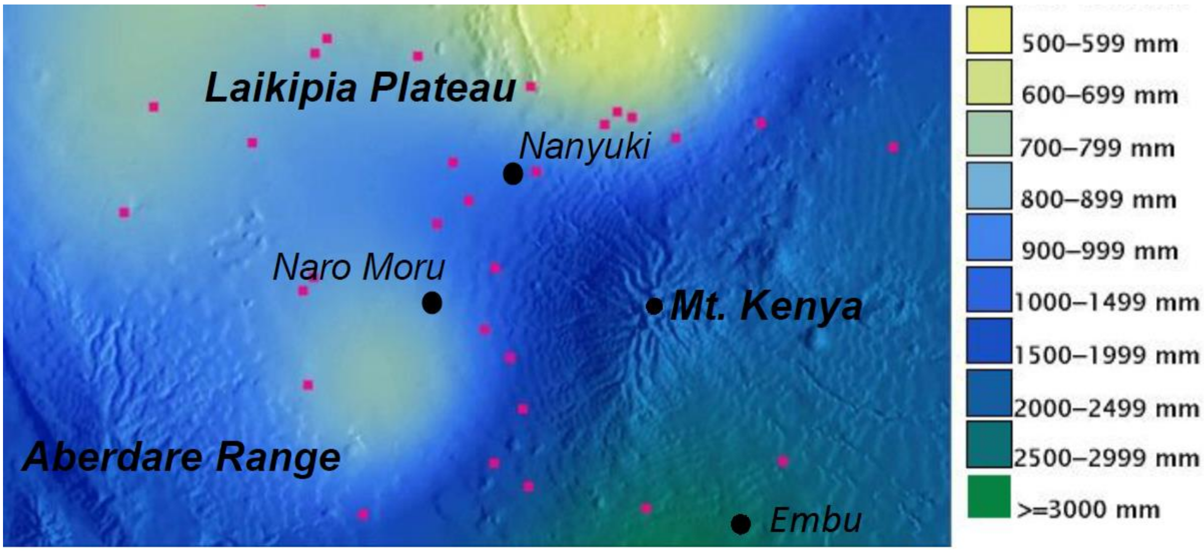


Fig. 2: Mean annual rainfall distribution (adapted after Sturm 2001: 121 in Schmocker 2013: 9)

Fig. 2 depicts the mean annual rainfall distribution around the Mt. Kenya massif. In the northwest of Mt. Kenya, the Laikipia Plateau is situated as part of the Ewaso Ng'iro basin. The Ewaso Ng'iro River is draining to the north and later on to the west of Mt. Kenya, ending up in the Lorian Swamp. The Laikipia Plateau lies at an elevation of around 2000 m a.s.l. and consists mostly of arid and semi-arid areas, developing to semi-humid areas at the mountain slopes of the Aberdare Range and Mt. Kenya. On the south-western face of Mt. Kenya the rivers join the Tana River, Kenya's longest stream that eventually ends up in the Indian Ocean (Sutter 2012: 7; Gichuki et al 1998: 5). The annual amount of rainfall is strongly influenced by the elevation, with precipitation increasing with higher altitudes. It ranges from 500 mm in the lowland, to 1500 mm in the forest areas of the north-western slopes of Mt. Kenya, to 2000 mm and even more on the south-western slopes in the area of Embu (Schmocker 2007: 8).

The region experiences two distinct rainy seasons when the intertropical convergence zone crosses the equator and leads to convective rainfall events. The "long rains" during the boreal spring last from March to May and the "short rains" during the boreal autumn occur between October and December (Notter et al 2007: 267; Olson 2007: 8; Schmocker 2013: 7).

The wet seasons alternate with drier counterparts. From December to March a distinct "Dry season" takes place and leads to nearly negligible amounts of rainfall, maintained by dry winds coming from the region of Somalia and Saudi Arabia. The period from July to October is characterised by "Continental rains" that bring limited precipitation to the region (Aeschbacher 2003: 9).

Highland-Lowland Systems

The Mt. Kenya area can be defined as a highland-lowland system based on the relationships and dependencies of two zones. The resource rich but small highland area is surrounded by a vast area of resource poor lowlands (Gichuki et al 1998: 5).

> *According to Kiteme et al 1998: 45 „Highland-lowland systems illustrate the dynamic interrelationships that exist between high-altitude, and usually resource-rich/source areas and the lowland resource-deficit/recipient areas. These highland-lowland systems are important for the transfer of natural resources from the highlands to the surrounding, usually low-potential lowlands, especially in the tropics and subtropics. These systems also display unique and often undisturbed ecological diversity. "*

Highland-lowland systems are generally characterized by a set of properties. They show steep vertical gradients, zonal and azonal conditions, and dominance of gravity-controlled processes. This describes the obvious transport of the vital water from highlands to lowlands and also erosion in terms of sediment transport. Additionally, highland-lowland systems show sensitivity to human interventions giving rise to natural hazards and changes in the quality of the natural resources (Kiteme et. al 1998: 45).

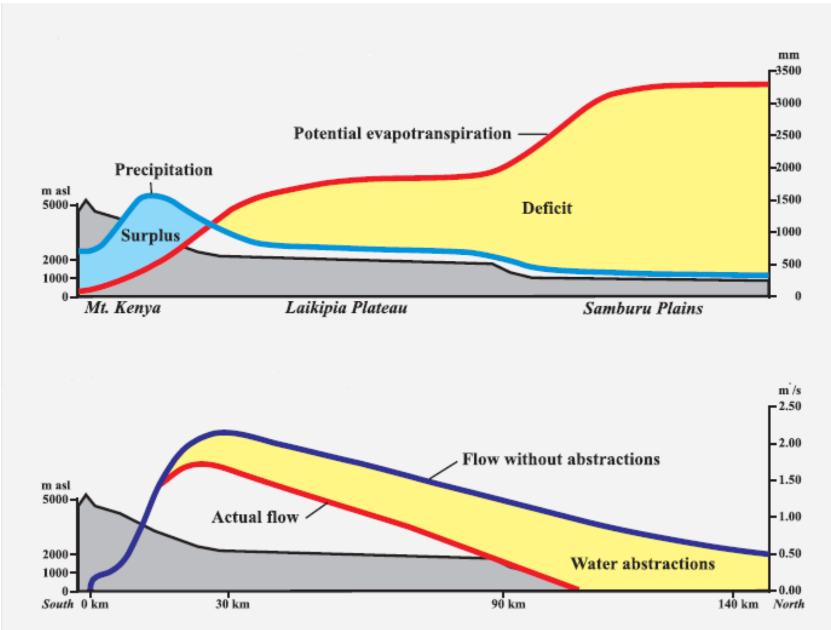


Fig. 3 top: Annual water balance. Bottom: dry season river flow (Wiesmann et al 2000: 11)

Fig. 3 on top depicts the most important attributes of the Naro Moru watershed, namely the relation of precipitation and potential evapotranspiration that lead to areas of water surplus in the highland and water deficit in the lowlands. This deficit is partly being removed by the river flow. Fig. 3 on the bottom shows the influence of intensified land use and subsequent abstractions in the highland area that lead to runoff deficits in the lowland. Water abstractions reduce the actual flow.

This concept shows exactly the relationships between up- and downstream users and the obvious dependence of downstream users on a reliable stream flow especially during dry seasons with low flows. Land use in upper parts of the catchment has significant influence on the runoff or respectively water quantity and quality in lower parts of the catchment.

The Ewaso Ng'iro River is heavily dependent on the water from Mt. Kenya during dry periods. Whereas the lowland plains contribute significantly to river flows during the wet period because of the high surface runoff at the onset of rains (Mungai et al 2004: 137).

1.4.1 The Sub-Catchment Naro Moru

Naro Moru sub-catchment is part of the Ewaso Ng'iro basin that is situated at the western to northern face of Mt. Kenya. It reaches nearly from the top of the mountain to the confluence with Ewaso Ng'iro River at an elevation of 1793 m a.s.l. The sub-catchment has a length of 47 km and covers an area of 182 km^2. *Aeschbacher 2003* divided the catchment into 5 ecological zones (see Fig. 4) derived from their elevation and thus specific properties based on the altitudinal belts.

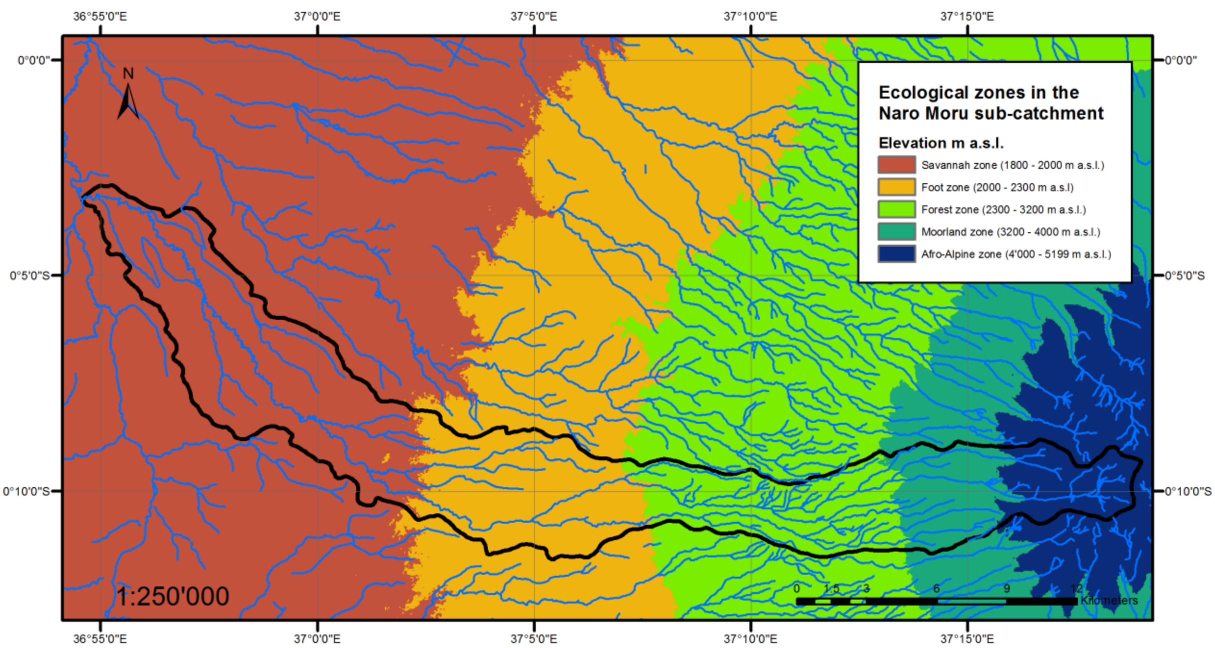


Fig. 4: The five ecological zones in the Naro Moru sub-catchment.

The Afro-Alpine Zone

The afro-alpine zone is situated at the steep top of Mt. Kenya. It is the place where the important tributaries to the Naro Moru River originate. Through the high elevation of between 4000 and 5200 m a.s.l the climate is cold and the rains are plentiful, which allows a considerable amount of glacial ice to survive the warm periods, though it has been shrinking in the recent decades. The perennial ice and episodic snow cover are responsible for the reliable water supply from the high altitudes of the mountain. Besides the dominating ice, snow and rock cover, some tussock grass, giant senecios, thistles and lobelias can be found as representative of the flora (Aeschbacher 2003).

Moorland Zone

Below the afro-alpine zone, from 3200 to 4000 m a.s.l, the Moorland zone spreads. It comprises the same plants as in the zone above, partly supplemented with swamps and wetlands, accompanied by their typical vegetation. The upper forest belt, also located in the lower moorland zone is an area with high rainfalls and low evapotranspiration, which results in a large contribution to runoff since the water storage capacity is low (Liniger 1992; Aeschbacher 2003).

Forest Zone

The upper part of the forest zone is mainly comprised of dense bamboo forest. With decreasing elevation, the bamboo forest is being replaced by tropical montane forest. The mentioned zone stretches from 2300 to 3200 m a.s.l. (Liniger 1992: 386; Aeschbacher 2003: 8; Notter et al 2007: 267)

Footzone

The foot zone is a transition area between the forested mountain slopes and the Laikipia Plateau between an elevation of 2000 and 2300 m a.s.l. The gentle slopes and sufficient precipitation are a favourable base for farming activities and the area shows therefore a high population density (Aeschbacher 2003: 8).

Savannah Zone

The savannah zone is the only part of the catchment which is located on the Laikipia Plateau and thus exhibits only a very small slope. Typical vegetation cover for this area is grassland alternating with bush land containing mainly acacia species. The rivers are surrounded by characteristic alley vegetation of bushes and trees that form dense forests. There have been large conversions to small-scale farming, destroying parts of the riparian forests. Main crops are maize, potatoes, cabbages and horticultural crops (Aeschbacher 2003: 8).

Mungai et al 2004 identified 3 main changes in the Upper Ewaso Ng'iro basin, which comprises the Naro Moru sub-catchment:

- The conversion of grazing land, bush land and natural forest into small-scale farming during the last 30 years, which lead to resource conflicts.
- In the upper mountain areas with higher rainfall, major land use changes are taking place with limited soil and water conservation measures.
- Major problems in the semi-arid areas are not only soil erosion but more importantly limited water supply, which is even decreasing caused by abstractions upstream.

1.4.2 The Sub-Catchment Kapingazi

The Kapingazi sub-catchment is situated at the south-eastern face of Mt. Kenya. Like the Naro Moru sub-catchment it is a high potential area with plenty rainfalls and subsequently a high population density. However, the ecological diversity within the sub-catchment is not as pronounced as in the Naro Moru sub-catchment. It contains three agro-ecological zones having each its own speciality, namely tea, coffee and crops. The sub-catchment has a length of roughly 26 km (Gachimbi 2002, SCMP Kapingazi 2009).

In the **upper zone** of the Kapingazi sub-catchment hills and steep valleys dominate the landscape. The altitude reaches up to 2100 m a.s.l. This zone provides an ideal environment for growing tea as a main crop. Because of its high altitude these areas are relatively cold, which can be experienced especially during the months of July, August and September. The valleys are V shaped and the river cross section is narrow (SCMP Kapingazi 2009, Haugerud 1981).

In the **middle zone** of the Kapingazi sub-catchment the climate favours the plantation of coffee, which can be considered a main crop in this zone. The area is gently steep and the climate is suitable for the growth of other food crops like maize beans and horticultural crops. Dairy farming is also practiced in this zone. The river cross section is wider than in the upper zone (SCMP Kapingazi 2009, Haugerud 1981).

The **lower zone** is characterised by a semi-arid climate, relatively flat grounds and high temperatures. Subsistence farming with small livestock is dominant in this zone. However, also cotton is produced (SCMP Kapingazi 2009, Haugerud 1981).

1.4.3 Development of Land Use and Land Ownership Patterns

After *Wiesmann et al (2000: 11)* the Mt. Kenya area has undergone major population and land use changes during the last century. Up to the 20th century the region of the Laikipia Plateau was used by pastoralists of the Masai and Samburu tribes, who profited of the large grazing grounds to feed their livestock. Shifting of the pastures and knowledge of the local natural conditions were a strategy to overcome natural hazards as for example droughts.

During the following colonial influence of the British Empire the so-called White Highlands were assigned to white settlers who established large scale ranches or monoculture farming. This urged the pastoralists to move to more arid areas, intensifying degradation processes there. After the Independence of the Republic of Kenya some of the large farms and ranches were subdivided and sold to small scale agro pastoralists, mainly coming from overpopulated areas in the south and east of Mt. Kenya. The new settlers introduced water intensive agricultural practices adapted to their very humid homeland, leading to increased water needs and thus increasing abstractions. Nevertheless, population growth remained at a level of 7-8% per year (Gichuki et al (HI-LO) 1998b: 6). This led to the land tenure that is still persistent today, while the subdivision of the large farms is still continuing today at a slower pace. (Kiteme et al 1998: 46-47; Wiesmann et al 2000: 11)

After *Olson et al (2007: 8-10)* in the Embu area to the southeast of Mt. Kenya, the dynamics were a bit different. The traditional production system has been agriculture based on sorghum, millet and root crops. However, in the 1950ies first aerial photographs of the area showed large extensive grazing lands accompanied by smaller portions of farming zones, while hills and riverbanks were reserved as woodlands. Meanwhile, population density was increasing due to declining infant mortality rates. In 1959, following the Mau-Mau revolts, the agricultural land owned by clans and managed with shifting cultivation was divided and assigned by the British colonial government to families to boost production and hence the exports. Meanwhile, coffee and tea became main cash crops to be planted, also due to support by the government. Population was increasing, similar to the Laikipia area, at a high rate. For example, in a location near Embu called Kianjuki, population density increased from 339 people/km^2 in 1969 to 662 in 2001.

2 Theoretical Background

2.1 *Definitions*

The most important terms of this thesis will be described briefly in the following sub-chapter to ease the understanding.

2.1.1 The Riparian Zone

In this thesis the term "riparian zone" will be defined as:

> *Riparian zones possess an unusually diverse array of species and environmental processes. The ecological diversity is related to variable flood regimes, geographically unique channel processes, altitudinal climate shifts, and upland influences on the fluvial corridor. The resulting dynamic environment supports a variety of life-history strategies, biogeochemical cycles and rates, and organisms adapted to disturbance regimes over broad spatial and temporal scales. Innovations in riparian zone management have been effective in ameliorating many ecological issues related to land use and environmental quality (Naiman & Décamps 1997: 621).*

Additionally, riparian zones are characterized by their various functions as processing nutrients, providing shade, wildlife habitat, filtering function of runoff of adjacent fields, source for fuel wood, recreation area and many others. Unfortunately, riparian zones are highly impacted by anthropogenic activities (Naiman et al 1993). Decrease or even destruction of riparian zones lead to several negative effects such as an accumulation of suspended solids in the river, solution of N and P, which result in reduced water quality (Willet et al 2012: 249). Also, the loss of soil in considerable amounts is likely. The species diversity in riparian zones is high because of the availability of water and the vegetation as shelter for special plants and animals. A study at the Njoro River, which flows into Lake Nakuru, 100 km from Naro Moru town, shows that approximately 55% of the riparian plants are used for herbal medicine, treating more than 330 health problems (Mathooko & Kariuki 2000).

2.1.2 Legal Background

According to the Land Act, riparian zones are government-owned and thus public property. This includes the vegetation that grows along the river. Thus, riparian zones are accessible to anybody and belong legally to the government (Lelo et al 2005: 3). The width of the riparian zone is less precisely specified. Different legislations such as the Water Act, the Agriculture Act and the Survey Act give different specifications on riparian width. The minimum lies mostly between 6 m from the edge of the river for small rivers and 30 m from the edge of the river for larger rivers (Charles 2010: 3). This is also the guideline the WRUAs (Water Resource Users Associations) promote in the Naro Moru and Kapingazi sub-catchments.

2.1.3 Riparian Buffer

In literature, the term "riparian buffer" is used to set focus on the filtering functions of the riparian zone. Especially, if the runoff is coming from adjacent fields, it can contain heavy loads of sediments and chemicals that pollute the stream.

According to *Wenger (1999: 10)*, riparian buffers are exceptionally rich in biodiversity due to their role as a boundary between ecosystems. They even display a greater variation in characteristics than either of the systems they connect to; rather than being averages of the two systems, they are something unique. In addition, riparian zones perform a range of other providing functions for nature and society. From a biophysical perspective riparian buffers are sinks for sediments, nutrients (e.g. nitrogen and phosphorus), pollutants (e.g. herbicides fungicides and pesticides) as well as storage of floods. They are also habitat for animals and plants. Riparian trees provide shade for the river whereby fishes and aquatic organisms find a convenient habitat. Additionally, riparian areas can be seen as recreational and aesthetic benefit (Wenger 1999: 10).

Concerning the retention of agrochemicals in riparian buffers, *Arora et al (1996)* made a research study about herbicides. The examined herbicides were atrazine, metolachlor and cyanazine. They quantified that 8% to a 100% of the field applied herbicides were held back by either vegetation and/or soil of the riparian buffer. The wide range is mostly explained by the rainfall pattern that was applied in the experiment. Short rains were completely infiltrated and thus 100% of the herbicides were adsorbed. However, events with more precipitation led to the smaller absorption percentages. The percent retention between the three examined herbicides was not statistically different. The buffer strip consisted only of grasses; the buffer strip was 20.1 m wide along the riparian zone.

Mankin et al (2007) studied the retention of the pollutant family of nutrients as well as the removal of sediments. The examined nutrients were phosphorus and nitrogen. The retention of nutrients is generally higher than for herbicides. Mankin et al (2007) state, that > 85% of phosphorus, > 85% of nitrogen and > 99% of sediments were trapped in the riparian buffer system in their experiment. The study was conducted with several buffer types differing in width (8.3 m to 16.1 m) and in vegetation type. Crucial is the finding that the vegetation type, rather than the width of the buffer zone, is the determining parameter influencing the retention.

According to Zaimes et al (2004) the design of the riparian zone and the neighbouring land use highly influence the riverbank degradation processes. Comparisons of different land uses like riparian forest buffer, crop land without buffer and grazing land without buffer emphasize the importance of riparian buffer systems. Crop land and grazing land showed 10 times and 4 times higher riverbank erosion rates and thus soil loss than a riparian forest buffer. The riparian forest buffer was 20 m wide and consisted of grass, shrubs and trees. The crucial advantages of a forest buffer are the perennial roots that stabilise the soil and prevent thus riverbank degradation to some extent. However, it is still a fact that riverbank degradation is a natural process and cannot be avoided completely. Thus, the goal of sustainable riparian land management should be to minimize erosion to avoid larger losses.

Beeson and Doyle (1995) show that the high discharges occurring during flood events contribute mostly to riverbank erosion and consequently to lateral migration of the riverbed. According to *Nanson and Hickin (1986)* the rate of lateral migration is from a hydraulic point of view depending on five factors: Stream power, channel width, size of the sediment at the base of the channel, bank height and bending radius.

2.1.4 Ecosystem Services

In this study the framework of the Millennium Ecosystem Assessment 2005 (MA) was used. The aim of the MA is to:

> *"…assess consequences of ecosystem change for human well-being and to establish the scientific basis for actions needed to enhance the conservations and sustainable use of ecosystems and their contributions to human well-being. Focussing on the ecosystem services that are directly linked with the human needs the MA provides frameworks to conceptualize ecosystem services. The goal of the provided frameworks is to enable to answer the following questions: How have the ecosystems and their services changed? What has caused these changes? How have these changes affected human well-being?" (MA 2005: ii)*

The importance of the ecosystems services (ES) for this paper arises through their direct influence on human well-being and welfare.

ES are benefits that are provided by the ecosystem. The different services are divided into four groups: provisioning services, regulating services, cultural services and supporting services. The first three of them affect people directly, while the supporting services are needed to maintain the others, thus it is grouped on the left of Fig. 5. (MA 2005: 39)

Provisioning services represent products that are directly obtained from the ecosystem such as food, fresh water, fibre materials like wood, cotton and wool. Another direct provisioning service is fuel in form of dung and wood. (MA 2005: 39-40)

Fig. 5: Schema of ecosystem services (MA 2005: 50)

Regulating services are benefits generated by the regulation of the ecosystems. They regulate the climate in terms of CO_2, temperature or air quality. Water quality is regulated through filtering out and decomposition of organic wastes. Furthermore, erosion and pest regulations are done and natural hazards mitigated. (MA 2005: 39-40)

Cultural services are nonmaterial benefits that people obtain through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences. These can be cultural heritages, spiritual values or educational values. (MA 2005: 39-40)

Supporting services are necessary for the supply of the provisioning, regulating and cultural services. They can be seen as background processes that enable the provision of the other ES. Examples of supporting services are soil formation, photosynthesis, nutrient cycling or water cycling (MA 2005: 39-40).

2.2 *Conceptual Framework - the DPSIR Model*

The conceptual framework, in which this master thesis is embedded, will be explained in the following sub-chapters.

2.2.1 The DPSIR Framework

The DPSIR framework is a tool for the reporting and analysis of environmental problems, developed by *Smeets et al 1999* during a project of the European Environmental Agency (EEA) in 1999. It has been widely adopted and has proven to be useful in understanding the genesis and persistence of environmental problems at different scales and to better understand and overcome barriers to sustainability.

The framework consists of the five variables: drivers, pressures, state, impact and responses (Carr et al 2007: 543). Fig. 6 shows the relationships of the five variables. *Drivers* (societal changes, new trends) provoke *pressures* (human activities) that result in changes of the *state*. Changes of the state lead to modified *impacts* that are provoking responses by society. These *responses* are able to feedback on all of the previous variables and to change them (Kristensen 2004:1). It is clear that the real world is much more complex than this simple diagram. However, from a policy point of view, there is need for clear and specific information on the different categories (Smeets et al 1999: 6).

Driving Forces are demands or needs that human beings express, they can be divided into primary and secondary driving forces. While primary driving forces are the basic human urges for water, food and shelter, the secondary driving forces depict the more extended needs for mobility, entertainment and culture. (Kristensen 2004: 2)

Pressures are actions that have been triggered by driving forces mentioned above and thus are ways to meet a need. These human activities exert pressures on the environment as a result of the resource use patterns, which can be divided into three main types: (i) excessive use of environmental resources, (ii) changes in land use and (iii) emissions to air, water and soil. (Kristensen 2004: 2)

The pressures influence the **state** of the environment. This means the quality of environmental compartments is being changed. The state of the environment is thus represented through physical, biological or chemical conditions that are measurable. As examples air quality, water quality, soil quality and ecosystems can be named. (Kristensen 2004: 2)

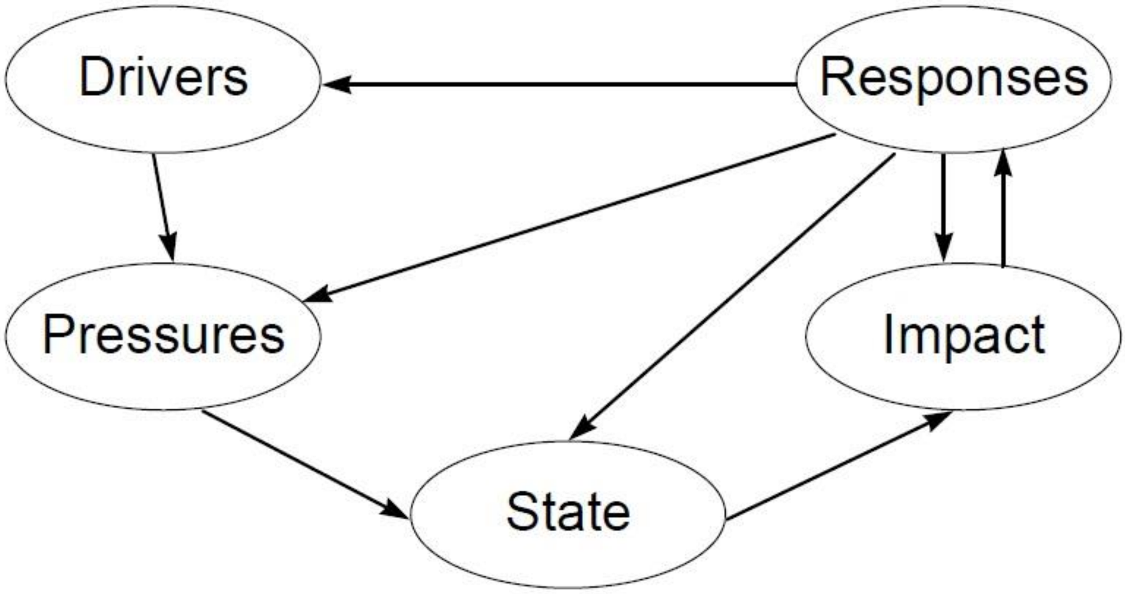


Fig. 6: Visual illustration of the DPSIR framework (Smeets et al 1999)

The above changes in the state mean a modification of the environment that have a direct influence on the welfare of human beings, called **impact**. Through the change of the ecosystems, they will not be able to provide the same ES as before. (Kristensen 2004: 3)

Responses by society or policy makers are the reaction to undesired impacts and can affect any part of the chain from driving forces to impacts. Their goal is to re-establish the ES demanded by the population. (Kristensen 2004: 3)

In literature there are also sources found, which criticise the use of the framework in the context of environment and sustainable development. According to *Carr et al 2007: 543* the main weaknesses lie in the reproduction of problematic hierarchies and power relationships and can be partially responsible for project failures. This happens through the unacknowledged hierarchy of the actors that the framework implicitly creates through its typology.

3 Methodology

The methodological process of this thesis consists of three main steps (see Fig. 7). First, a mapping of the riparian zone in the sub-catchment is made. The goal is to identify different land uses, degradation patterns and conservation approaches in the sub-catchment. Necessary for this was an extensive exploration of the area and a total of 17 interviews out of which eleven were considered in the results. Six of them were dismissed because the corresponding land uses were not used in the classification. As questionnaire for the interview, a standardized tool, the WOCAT Mapping Questionnaire was used. Additionally to the topics land use, degradation and conservation also the tree cover in the riparian zone was depicted by applying supervised classification on the Google earth pictures from 2011 and on the black-and-white aerial photographs from 1961.

The second methodological step was a series of eight interviews with land users who applied outstanding, either positive or negative, land management practices. The first step of mapping gave a good spatial overview of the sub-catchment and thus eight land users were carefully chosen to be interviewed. The goal of these interviews was to document and assess the technologies in detail. Six out of them present land use technologies that show protective or productive practices. Two technologies were chosen as negative examples of land management to undermine the positive

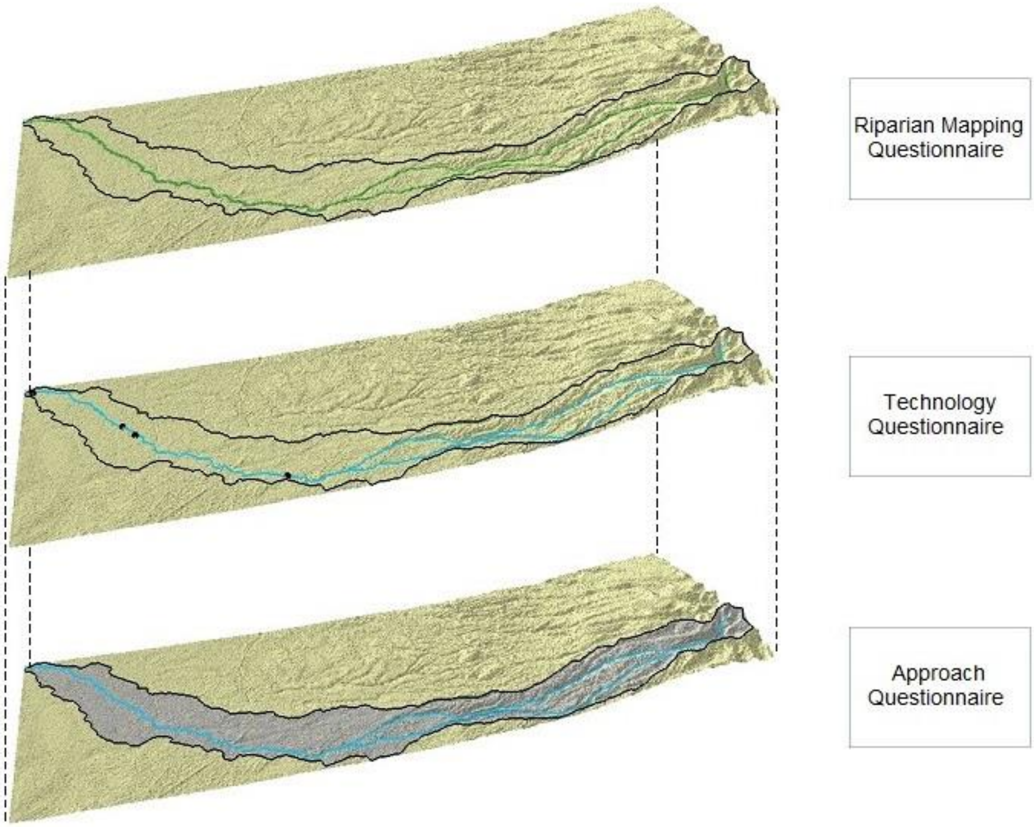


Fig. 7: Scheme of the applied methodologies.

impacts that productive and protective land management can have. The interviews were conducted using the WOCAT Technologies Questionnaire.

As a third step, the promotion and spreading of riparian land management technologies was assessed with the WOCAT Approach Questionnaire. The goal of this was to describe ways and means of how land management technologies are brought to the attention of land users. Interview partners were members of the WRUA of the two examined sub-catchments. The WRUA formed around the year 2000 and were supported shortly after by the Kenyan government. Their main concern is water management in the sub-catchment, where riparian management is the key task.

The WOCAT Mapping was only made for the Naro Moru sub-catchment, not for the Kapingazi sub-catchment (see Tab. 1). The WOCAT Mapping is a very time consuming activity, because nearly the whole catchment has to be visited. Thus, it has only been carried out for one sub-catchment. Still, the other two steps have been done for the Kapingazi sub-catchment. The three steps will be further explained in the following sub chapters.

	WOCAT Mapping	WOCAT Technologies	WOCAT Approaches
Naro Moru sub-catchment	3 zones with 3-4 land use systems = 10 Mapping Units	3 sustainable land management practices 1 land degrading practice	1
Kapingazi sub-catchment	-	3 sustainable land management practices 1 land degrading practice	1

Tab. 1: Interviews carried out for the two sub-catchments.

3.1 *WOCAT*

WOCAT is the acronym of World Overview of Conservation Approaches and Technologies. It was founded in 1992 to fight persisting degradation processes. Although land users and soil and water conservation specialists had developed an extensive knowledge in this area, its implementation lagged far behind. One reason for this was that much of the knowledge had not been documented properly and was therefore not accessible for distribution.

The WOCAT methodology was originally designed to focus on soil erosion and fertility decline areas vulnerable to erosion. In the course of time, other land degradation types were included, such as water, vegetation and animals. Due to the needs of WOCAT participants, the formerly standardized tools were flexibilized and pure data collection was replaced by evaluation and monitoring as well as by training and research (WOCAT Strategy 2013).

3.1.1 WOCAT Mapping

The mapping along the rivers of the catchments was based on the WOCAT Mapping Questionnaire mentioned above. The Mapping was only carried out for the Naro Moru sub-catchment. The lower two ecological zones of the Naro Moru sub-catchment (savannah zone and foot zone) in Fig. 4 are inhabited and were therefore taken as boundary area of the base map. This boundary area was divided into savannah zone, foot zone and forest zone as major subdivisions. In every zone, the number of different land use systems was defined (see Tab. 2) on field visits.

For every land use system in each zone a WOCAT Mapping Questionnaire was filled out. That means land management specialists were interviewed about area trends as well as degradation patterns and conservation measures. The land use map was created afterward using google earth satellite imagery (see 3.4.1).

The goal of the questionnaire was to define the degradation types, their extent, changing rate, causes and impacts on ecosystems. Additionally, the actual conservation measures were recorded concerning their group, purpose, area of the mapping unit covered, effectiveness, effectiveness trend, impact on ES and period of implementation.

Interviews on certain land uses were not successful because the resource persons were not able to provide the needed information. Therefore, additional resource people had to be approached to collect the needed information.

Zone	Land use	Interviewee
Savannah zone	Used Forest	Ephraim Kagi Kahenya (WRUA)
	Cropland	Ephraim Kagi Kahenya (WRUA)
	Grazing & Bushland	Ephraim Kagi Kahenya (WRUA)
	Large scale grazing land	Ephraim Kagi Kahenya (WRUA)
Foot zone	Grazing & Bushland	Antony Githii & Julius Mwaniki (WRUA) and Elizaphan Kingori & Rachael Muturi (Agricultural Office)
	Cropland	Antony Githii & Julius Mwaniki (WRUA) and Elizaphan Kingori & Rachael Muturi (Agricultural Office)
	Used Forest	Antony Githii & Julius Mwaniki (WRUA)
Forest zone	Grazing & Bushland	David Miano (Forester)
	Cropland	David Miano (Forester)
	Used Forest	David Miano (Forester)
	Natural forest	David Miano (Forester)

Tab. 2: Resource persons for Mapping Questionnaire interviews.

3.1.2 WOCAT Technology

Based on the experiences, observations and recommendations of the mapping in the Naro Moru sub-catchment and due to talks with the WRUA members in the Kapingazi sub-catchment, eight case studies of riparian land management practices were chosen. Four of them were located in the Kapingazi sub-catchment and four in the Naro Moru sub-catchment. Among them were six productive and protective riparian land management practices and two land degrading riparian land management practices. Productive and protective practice means low degradation, stable riverbanks, low pollution of the river and also a productive benefit. Negative practice means loss of soil, loss of tree cover as well as diminished water quality and quantity. Among the productive and protective land management practices, three land management practices were chosen with a productive focus and three with a protective focus.

To investigate the study sites properly, the WOCAT Technologies Questionnaire was used. The WOCAT Technologies Questionnaire helps to record a land management technology systematically. The main topics are the specifications, the natural and human environment and the impacts on the ES of a land management technology.

The selection of the case study sites was performed after the mapping in the two sub-catchments had been carried out. In the Naro Moru sub-catchment, three study sites were located in the savannah zone and one in the foot zone. In the Kapingazi sub-catchment two study sites were located in the upper zone, one in the middle zone and one in the lower zone.

With the knowledge of the observations in the field, land users in both sub-catchments were chosen to perform WOCAT Technology interviews. The detailed interviews took about two hours each. Also, knowledge of members of the WRUA was considered to identify suitable interview partners.

3.1.3 WOCAT Approach

The WOCAT Approach Questionnaire on the other hand deals with the question of how a land management system was implemented and by whom. Water Resource Users Associations are promoting land management practices and are therefore a suitable target group. The WOCAT Approaches Questionnaire focuses on how the interest group was formed, their objectives, participation processes, information about the area, financing, external support as well as the methods of the monitoring and the impact analysis.

For every WRUA of the sub-catchment one interview was conducted. Resource persons were exclusively recruited among the members of the WRUA committee.

The analysis of the two approaches was conducted considering the four “Dublin guiding principles for water resource management” of the International Conference on Water and the Environment (ICWE) as well as Elinor Ostrom's eight "Design principles of stable local common pool resource management". Together, there are 12 principles.

Out of the 12 principles, 3 were not considered. The following principles were not considered: Guiding principle one, demanding to accept fresh water as an important resource was not considered, because the WRUA's purpose is to protect water resources. Guiding principle four concerns the economic value of water. This was not answerable in this context. Design principle eight was not answered because it applies only to larger common pool resources.

The exclusion of principles was possible, since none of the upper two guidelines on riparian water management argue that congruence with all the principles was neither necessary nor sufficient (Poteete et al 2010: 282).

3.2 *Field Work*

The field work was conducted during October and November in the year 2012. The beginning rainy season made field work partly difficult, because of the wet conditions and impassable roads. As a first step many points in the Naro Moru sub-catchment were visited as indicated on Fig. 8. Transport was provided by a vehicle with its driver. Additionally, a field assistant was present to translate from the local dialect "Kikuyu" into English. Point 21, the border of the protected forest was the highest point where one could get without any further permission. The area above point 21 was not interesting for this thesis because no productive land use by people is performed. Thus, the investigations were propagated from this point further downstream.

The visiting points were chosen before the step into the field. The deciding attribute for the selection of the points was the access via a road to the river. Also, the points were supposed not to be closer to each other than 1 km. Especially in the forest zone access was quite difficult due to the steep riverbanks. In the foot zone the challenge was to find a way to the river between the fields. Altogether, enough points were visited to get a broad picture of the riparian zones and to combine the status on the map with the observations on the ground.

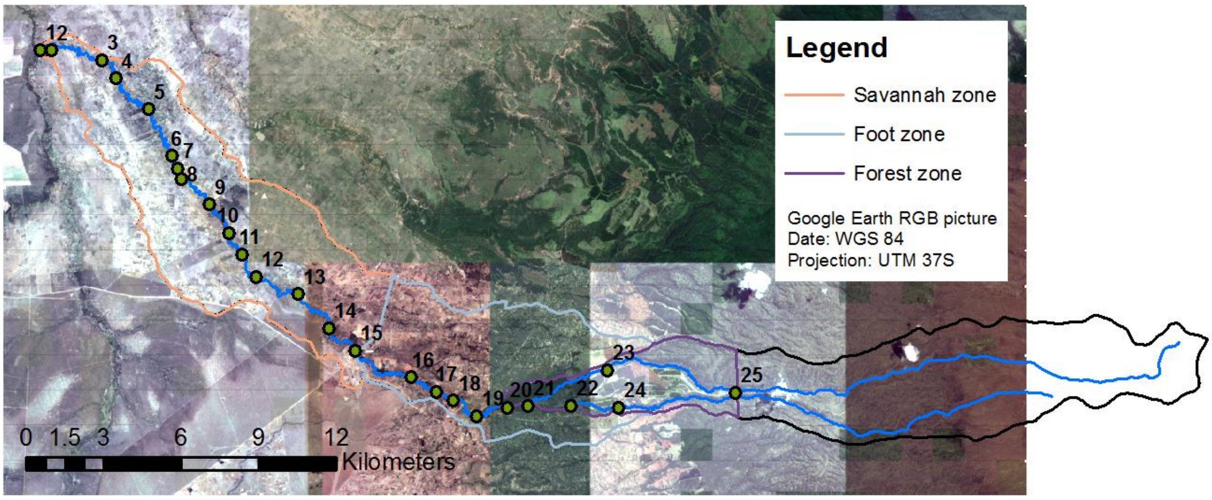


Fig. 8: Field work visitation points in the Naro Moru sub-catchment.

After the visitation of the area, the present land use systems were defined for each subdivision. The creation of subdivisions is a mandatory part of the WOCAT Mapping Questionnaire. It is a first step to structure the sub-catchment and it is an important step for chosing the interview partners. The sub-catchment was divided into three subdivisions that will be called "zones" from now on. The zones in the Naro Moru sub-catchment are the forest zone, the foot zone and the savannah zone. Following the WOCAT Mapping methodology, interviews were conducted with experts of each land use system in every zone concerning area tendencies, degradation and conservation patterns in each land use system.

3.3 *Data*

For the field work, the following interviews and for the determination of the land uses, a proper map was vital. For this purpose a map of the area provided by Google earth was chosen. The advantage of this is the quite good actuality and the easy availability. The mosaics of the Google earth picture have different acquisition dates (see Fig. 9). Drawbacks are mainly their mosaicked style that admittedly shows a low cloud cover, but exhibits some further problems: The unequal resolution, colour composition and size make it difficult to elaborate standardized criteria for the recognition of objects. Field maps were printed at a scale of 1:25000. Also, Google earth pictures were taken as a base to determine the riparian forest cover.

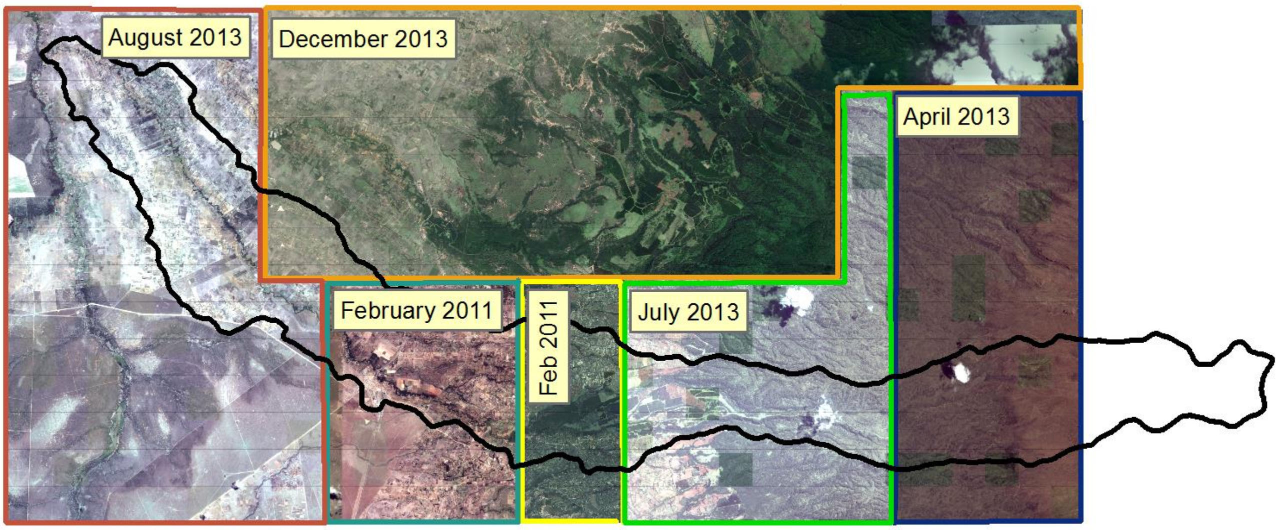


Fig. 9: Google earth picture of the Naro Moru sub-catchment with date of acquisition indicated.

Additionally to the quite up-to-date Google earth image, older black-and-white aerial photographs of the area were acquired. They date from 1961, when the area was poorly populated. With these two images it was possible to show the land use and vegetation changes over a temporal horizon of 50 years (see Fig. 19 and Fig. 20). The aerial photographs do not cover the whole sub-catchment area of Naro Moru River. The savannah zone and the foot zone are completely covered, while there is no data for the forest zone. To show the development of the riparian vegetation, the Google earth picture and the aerial photograph were used for a supervised classification of the forest area.

3.4 *GIS Processes*

3.4.1 Land Use Classification

The land use map is an integral part of the WOCAT Mapping Questionnaire. Since there was no appropriate foundation in terms of land use, a land use map had to be created. From the beginning it was clear that an inspection of the entire riparian zone in the sub-catchment is virtually impossible, because there is no trail existing along the river and many points are not even reachable. Hence the option was chosen to visit spots along the river in regular distances of at least 1 km. These observation points were used to verify the Google earth picture. The Google earth picture has good pixel resolution and accurate actuality and was thus a good base. The field visits were performed as documented in Fig. 8.

First field visits gave the impression of uncountable different land uses, which had to be summarized, since they had to be distinguishable on the satellite imagery.

Land uses were digitally delineated by hand on the map. The area of interest was the 100m on either sides of the river (see Fig. 13 and Fig. 14). The polygons were distributed to one of the main land uses identified earlier during the mapping.

3.4.2 Supervised Classification

Supervised classification is a GIS-method, which is used to categorize satellite images or aerial photographs. Its advantages for this thesis were the accurate results and the avoidance of a time intensive field campaign. Depending on the purpose and the specifications of the imagery one can chose the number of categories. For each category test plots were defined. Based on the test plots the spectral characteristics were computed with maximum likelihood method. These spectral characteristics are similar to thresholds that define whether a pixel fits in one category or the other.

Supervised classification was used for the differentiation of “Forest” and “Non forest land uses” (see chapter 4.2) on the aerial photographs of 1961 and on the Google earth pictures of 2011. For the Google earth picture an individual supervised classification was done for each of the six segments (see Fig. 9) of the map. In the aerial photograph only two segments had to be classified separately. All the computations were performed with ArcGIS 10.0.

3.4.3 Riparian Width

One important issue of this thesis is to assess the ES of the riparian zone. The performance of the riparian zone is highly linked with the size of the riparian area: The wider it is, the more trees and bushes are able to grow and the higher the trees are the more biomass can be produced. Since the height cannot be determined with satellite imagery, the riparian width was chosen as indicator for the performance of a riparian ecosystem.

The riparian width was delineated by hand considering the satellite image and the “Forest” - “Non forest land uses” classification. The classes of the riparian width were defined as < 1 m, 1 - 5 m, 5 - 10 m, 10 - 20 m and > 20 m. A riparian width of < 1 m means no trees or bushes can occur. Correspondingly, the riverbank is seriously prone to degradation. A riparian width of 1 – 5 m stands for a riparian area including small trees and bushes. Large trees are not present since their canopy would have a diameter of more than 5 m by far. In a 5 – 10 m riparian area medium sized trees are occurring and bush and grass vegetation sustain a riparian ecosystem. The width is mostly above the legally provided width of 6 m. A 10 – 20 m riparian width gives space for a good development of flora and fauna and can be seen as prime example. The largest riparian width of > 20 m can actually only be found if the adjacent land use is forest. However, this size provides the best protection against riverbank degradation.

4 Results & Discussion

This chapter illustrates the results of this master thesis. The first subchapter depicts maps and figures of the dominant land use systems as well as degradation and conservation patterns that were identified.

The second subchapter compares the riparian vegetation cover of an aerial photograph dating from 1961 and a Google earth picture dating from 2011 concentrating on changes of the area.

The third subchapter analyses eight carefully chosen land use practices in riparian zones including 6 positive and 2 negative examples in terms of productivity and protection. Emphasis will be set on the ES that the different land management practices show.

The fourth subchapter sets a special focus on the sub-catchment characteristic WRUA (Water Resource User Associations) whose distinct goals are – amongst others – to promote protective technologies among the riparian land users. Two examples of these WRUAs will be characterized, compared and assessed.

4.1 *Mapping*

4.1.1 Characterization of Land Use Systems in the Naro Moru Sub-Catchment

Five main land use systems were identified right next to the riparian zones in the Naro Moru sub-catchment. While some of them are commonly found in all the three zones, others are very distinct and appear only in one zone.

Cropland

The term cropland stands for many different types of agricultural land uses. The most common field crops are maize, french beans, potatoes, cabbage and other vegetables. Perennial crops are barely seen in the catchment. Especially in the foot zone, fields are additionally irrigated with water from the local water project to enlarge the production. The plots are clearly separated from the neighbour's land. The agricultural practice is mostly done without any mechanization but with hoes and spades. In the Savannah zone portable gasoline pumps are used for irrigation.

Grazing & Bushland

The whole Foot zone and Savannah zone of the sub-catchment were originally grazing land of the Masai tribe. Since the middle of the last century this nomadic use has completely vanished and was replaced by other uses. Only few patches of grazing land are left. Most of the farmers let their small livestock graze on marginal patches on their own plot. Public grazing land in the Savannah and Foot zone show several degradation signs.

Large Scale Grazing Land

Large Scale Grazing Land is a special feature of the Savannah zone. Big farms have vast grazing areas available for their livestock. Rotational grazing on fenced areas allows keeping degradation at a minimum.

Used Forest

Forest areas can be discovered in all three zones, although most dominantly in the forest zone. The land use system used forest is characterized by a dense network of trees and bushes. Compared to the Natural forest, the used forest is still in use by farmers for example through little grazing, gathering of fuel wood or forestry. In the Savannah zone some forests are even used as recreation area of lodges.

Natural Forest

Natural forest is the kind of forest that is not used by humans. It is characterized by a canopy, dense bushes and trees. Due to root penetration the riverbanks are very stable. It occurs only in the Forest zone. Its steep valley slopes prevent it from being used by humans.

Tab. 3: Characterization of the identified land use systems.

4.1.2 Spatial Distribution and Area of Land Use Systems

Land use systems are described in the preceding sub-chapter. Fig. 10 above gives an overview of the areas of land use in the Naro Moru sub-catchment. Throughout the whole sub-catchment, cropland is with 40% and 438 ha the dominant land use system. Natural forest and grazing & bush land cover both with 197 ha and 242 ha respectively about half of the area of cropland. Smaller portions are covered by large scale grazing and forest. The land use large scale grazing consists only of three big ranches. However, they cover 8% of the catchment and feature a different land management than the common grazing land. The category forest is comprised of smaller patches in the savannah and foot zone and larger areas in the forest zone.

In the **forest zone** (see Fig**.** 10 bottom left), 30 % (109 ha) is used for grazing land, 16% (57 ha) for forest and 54% (197 ha) for natural forest. Generally, the population density in this area is considerably lower than in the other two zones. However, vast areas are used for public grazing.

In the **foot zone** (see Fig. 10 bottom middle), 58% (120 ha) of the area is used for cropland, 32 % (65 ha) for grazing land and 10% (21 ha) for forest. The foot zone has a significantly higher share in grazing land than the savannah zone, although it is generally an ideal region for agriculture. This can be explained by the steepness of the area adjacent to the riparian zone and the vast public grazing lands in the upper area of the foot zone.

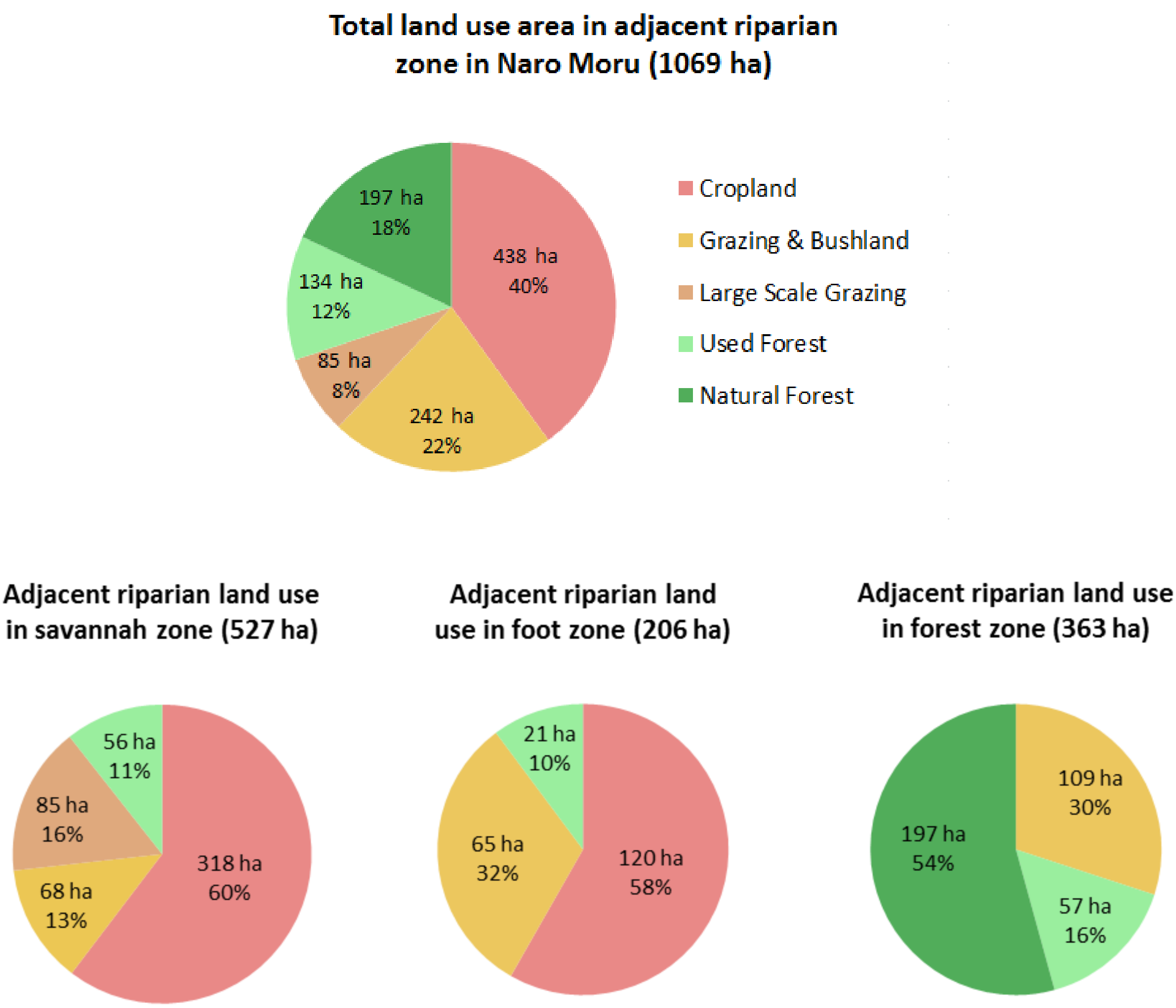


Fig. 10: Land use in riparian zone: The upper pie chart shows area and percentages of the observed land use systems of the whole sub-catchment. The lower pie charts show area and area percentages of the land use systems for the three zones of the sub-catchment.

In the **savannah zone** (see Fig. 10 bottom right), cropland is the most common land use with a percentage of 60% (318 ha), followed by large scale gazing land with 16% (85 ha), grazing land with 13% (68 ha) and forest with 11% (56 ha). The share of cropland in the savannah zone is larger than in the foot zone, because the near river plots are especially favourable for cropping due to the higher water availability. In the foot zone, on the contrary, the higher rainfalls and piped water ensure an even favourability of the land for cropping.

4.1.2.1 Area Trend and Intensity Trend

Area and intensity (see Fig. 11 and Fig. 12) trends are part of the first question of the WOCAT Mapping Questionnaire. The area trend describes the development of the area of the land use systems, while the intensity trend describes the change of the intensity. Both variables were observed over the last 10 years.

The **grazing & bushland** areas of the Naro Moru sub-catchment can be described as stable to diminishing. In the savannah zone, grazing land is getting smaller with a trend of -2 which means a major decrease. This decrease can be seen as replacement by cropland due to the good water availability in the near river area.

The area trend of **used forest** is mixed. While in the forest zone a slow increase is detectable, the area diminished slowly in the foot and savannah zone during the last ten years.

The area of **cropland** is increasing moderately in the foot zone and in the savannah zone. The two zones together add up to an area of more than 400 ha. Thus, it is the major trend and a sign of population increase.

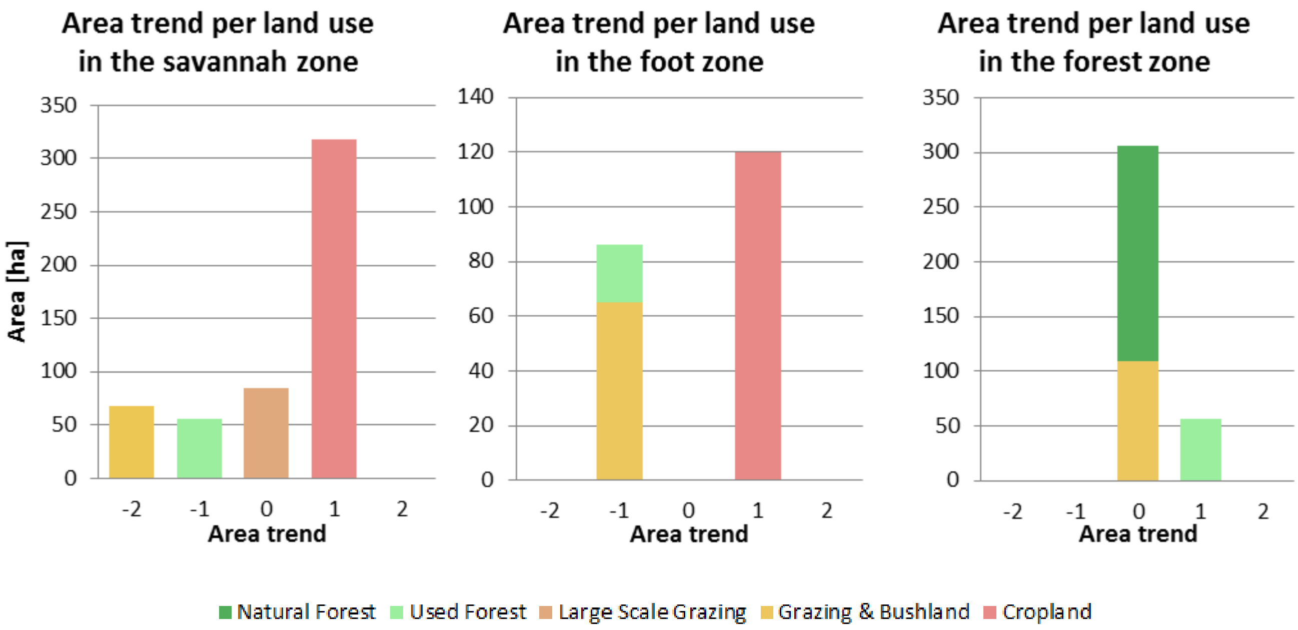


Fig. 11: Area trend per land use system and zone (-2= rapidly decreasing, 1=slowly decreasing, 0= stable, 1=slowly increasing, 2=rapidly increasing) during the last 10 years.

Large scale grazing and **natural forest** show no area trend, moreover they remain stable. Large scale grazing is owned by a few land owners who normally do not sell parts of their property. The natural forest is partly under protection and consequently partly immune against land decrease.

Looking at the area of the regions it becomes obvious that a transformation is taking place, where decreasing land uses like used forest and grazing & bushland are transformed into increasing land uses like cropland.

The **grazing & bushland** is stable in the savannah zone, but shows an intensification trend in the foot and forest zone of 1 and 2 respectively. The intensification in the forest zone takes place on public grazing land that is accessible for everybody. Since the area is generally under a higher pressure of land use, especially public areas are increasingly used.

Cropland land use is intensifying moderately in the savannah zone and majorly in the foot zone. This happens due to the increasing population trend. Since the intensification covers over 400 ha, it is the major intensification trend in the sub-catchment.

The **used forest**, **natural forest** and **large scale grazing** land uses show no trend of intensity. The Large scale grazing areas are not affected by population dynamics because it is owned by large scale ranchers. The used forest and natural forest areas are either under protection or are owned by individuals who are not willing to change the intensity.

To summarize, there is generally a distinct intensification trend on grazing & bushland and on cropland while used forest, natural forest and large scale grazing areas remain stable.

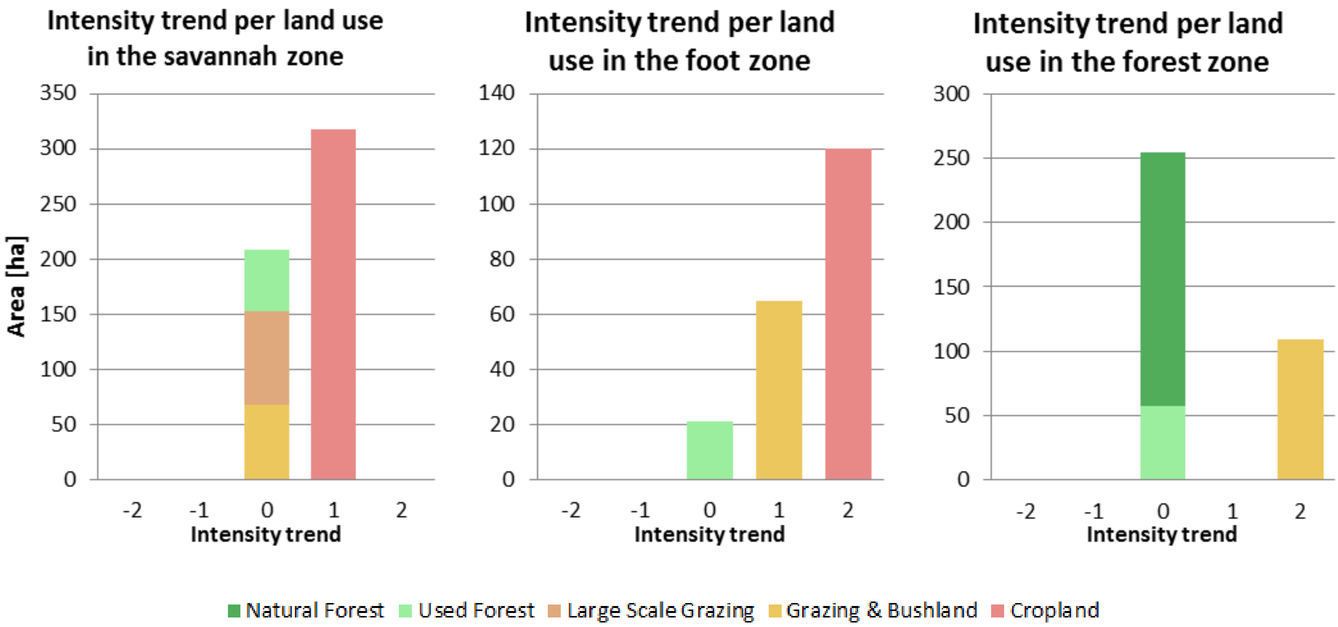


Fig. 12: Intensity trend per land use and zone (-2=major decrease, -1=moderate decrease, 0=no major changes, 1=moderate increase, 2= major increase).

4.1.2.2 Land Use and Riparian Width in the Savannah Zone

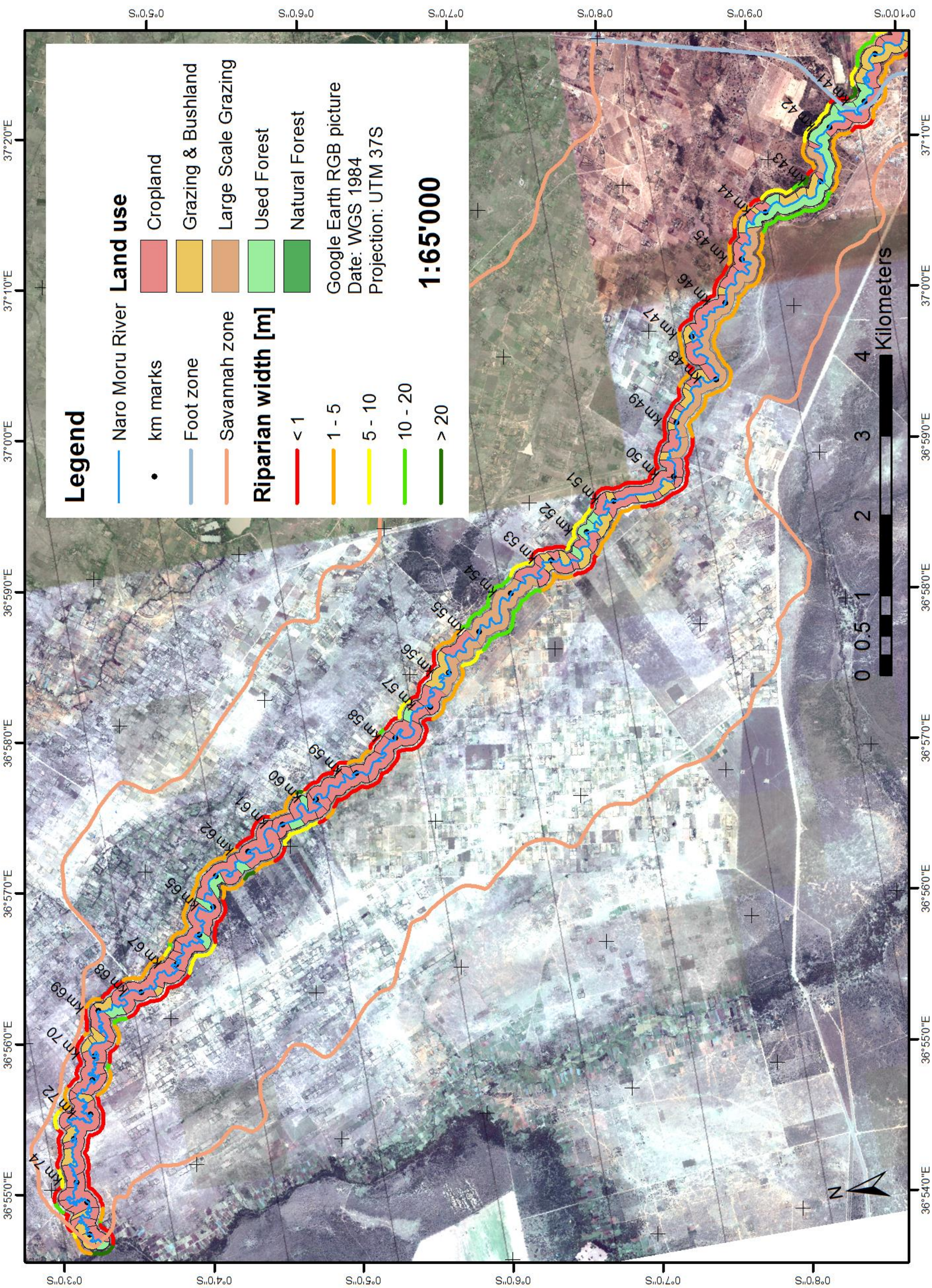


Fig. 13: Map of Savannah zone with identified land use systems as well as the width of the riparian vegetation.

Fig. 13 shows the land use systems in the savannah zone as well as the width of the riparian vegetation. The savannah zone has a length of about 20 km and a width of about 5 km at most. It has been experiencing a major increase in population, which pushed a transformation and intensification of land use. Formerly, most of the area was characterized by grazing land of indigenous tribes or vast ranches. Nowadays agriculture dominates the land adjacent to riparian zones, due to its higher productivity per area and the possibility for irrigation with portable water pumps. Thus, the region is able to sustain a higher number of people with food.

Large scale grazing land can be found only on three areas between km 53 and 56 on the left river bank and between km 53 and 55 on the right river bank. Another big plot is between km 44 and 50 on the left riverbank. However, these three polygons are among the largest in the whole zone. The land use is accompanied by quite wide riparian vegetation widths between 5 and 20 m. On the two large scale grazing plots on the left river bank, this wide vegetation is due to fencing of the riparian zone that prohibits livestock from encroachment of the riparian zone and ensures thus a constant growth of the vegetation. On the right side the owner does only gentle extensive grazing and implements several conservation measures as gabions and fences. It must be said that these farmers - with their large properties - are not typical for this area.

Forest land use is the smallest portion in the savannah zone. The largest area can be found between km 42 and 44 on the left side of the river. It is used by a lodge business that situated its bungalows partly in the forest. In this way the forest is used as a recreation area. Thus, there is no encroachment of the riparian zone and the vegetation width of up to 20 m is quite broad. The left over forest area is consisted of few and small patches scattered over the whole savannah zone. They are barely natural forests but areas where farmers plant and cut trees for income generation.

Grazing & bushland covers 13% of the savannah zone adjacent to the riparian zone, a quite low percentage. These grazing areas are quite small compared to the large scale grazing land use category. Remarkable is its small patched pattern and the very low riparian width, that is associated with this land use. This can be explained by the damage that livestock causes in vegetated areas of the riparian zone, especially when livestock goes to the river for drinking while trampling down vegetation. Browsers, for example goats, attack thus the leaves of bushes and trees and grazers eat the ground vegetation cover. Most of the grazing land is owned by private land users, while some parts are public grazing land. Public grazing land is especially prone to degradation because there is no accurate and functioning management of these commons.

Cropland is the largest land use portion (60%) adjacent to the riparian zone in the savannah zone. Its distribution is more or less even only interrupted by the large patches of large scale grazing land. The riparian widths vary between <1 m and 20 m. However not all of these categories have the same occurrence. Most common is a riparian with of below 1 m followed by the 1 m – 5 m category that has the second most occurrence. 5 m - 10 m and 10 m - 20 m widths can be found but are very rarely. This dominance of very low riparian widths can be attributed to the need for firewood and wood for construction that the farmers have. Additionally, the farmers are probably dependent on short term revenues which they can gain clearing riparian vegetation and plant crops. The disadvantage of this short term revenue is the loss of the ES, decline of the river water quality and - in an extreme case – the loss of soil and land by riverbank degradation. Also, the riparian habitat diminishes and exhibits lower biodiversity.

With the conversion of the grazing land to agricultural land an intensification process is visible, because the available land has to support a higher population. With this intensification also the riparian zone gets more under pressure due to its various services as wood and water supply, provision of a cold microclimate, clear water and so forth.

4.1.2.3 Land Use and Riparian Width in the Foot Zone and Forest zone

Fig. 14 shows the foot zone and the forest zone with its land uses and riparian widths. The foot zone has a length of about 7 km, the forest zone has a length of about 8 km. In the foot zone 58% (120 ha) of the area is used for cropland, 32 % (65 ha) for grazing & bushland and 10% (21 ha) for forest.

The *forest* area is very small in the **foot zone**. It is mostly associated with riparian widths of 5 m to 20 m. Most of the forest was replaced because the land is ideal for agriculture.

The g*razing land* is mostly situated between km 30 and 34. On the right riverbank - between the mentioned km marks – a large patch of bushland is located which is used for public grazing. On the said patch, trees do not exist anymore; they were probably cut by local individuals for their own use. The riparian width ranges from below 1 m up to 20 m. No distinct pattern can be found, it is depending on the local situation.

Cropland is also the most common land use in the foot zone, as has been the case in the savannah zone. However, it concentrates between km 33 and 40. The riparian widths are between 1 and 10 m except for two distinct spots: The first spot is on the right river side between km 37 and 41 and is managed by a horticultural farm that does not disturb the riparian habitat. The other spot is on the left river side between km 30 and 32 where the steep relief forces farmers to leave a certain distance between the river and the farming land where the vegetation can develop. Although the riparian widths have low values, the observed degradation is not as dramatic as in some cultivated areas in the savannah zone.

In the **forest zone**, 30 % (109 ha) of the area is used for grazing land, 16% (57 ha) for forest and 54% (197 ha) for natural forest. Cropland was not found. Generally, the population density in this area is considerably lower than in the other two zones. The only way agriculture is allowed, is in terms of shamba systems, which temporarily replace the forest. Large areas are cultivated as shamba systems (clearly visible on Fig. 14 on the area between the northern and the southern arm of Naro Moru River). The shambas do not interfere with the riparian zone though.

The *forest* area is quite small with 15 percent. The vegetation in this land use category is not dramatically disturbed. Interventions that can be named are limited grazing and collection of firewood. The widths of the riparian vegetation are very high, mostly 50m. Only one spot has a width of 5m, this can be seen as an artefact.

Cropland is visible on the lowest parts of the Forest zone on the left side of the river. The riparian vegetation width ranges from 5 to 20 m. It is not lower than 5 m because the riverbank is very steep and not ideal for cultivation.

Grazing land is also tendentially situated at the lower elevated end of the forest zone. The character of the grazing land is different than in the other zones though. It consists of bushland which is used for grazing in between and it is organised as public grazing land. The width of the riparian vegetation is consistently 5 m. This is due to the missing tree vegetation. The bushes are able to provide certain stability to the riverbank, but no riparian habitat can be created.

The *natural forest* land use can be described as most dominant in the forest zone. This is the original vegetation type for this agro-ecological zone. It is virtually undisturbed by human interference due to steep riverbank slopes and because it is a protected part of the Mount Kenya Forest Reserve. The riparian vegetation width is 50 m throughout.

Altogether the forest zone exhibits a solid condition of the riparian zones and little degradation.

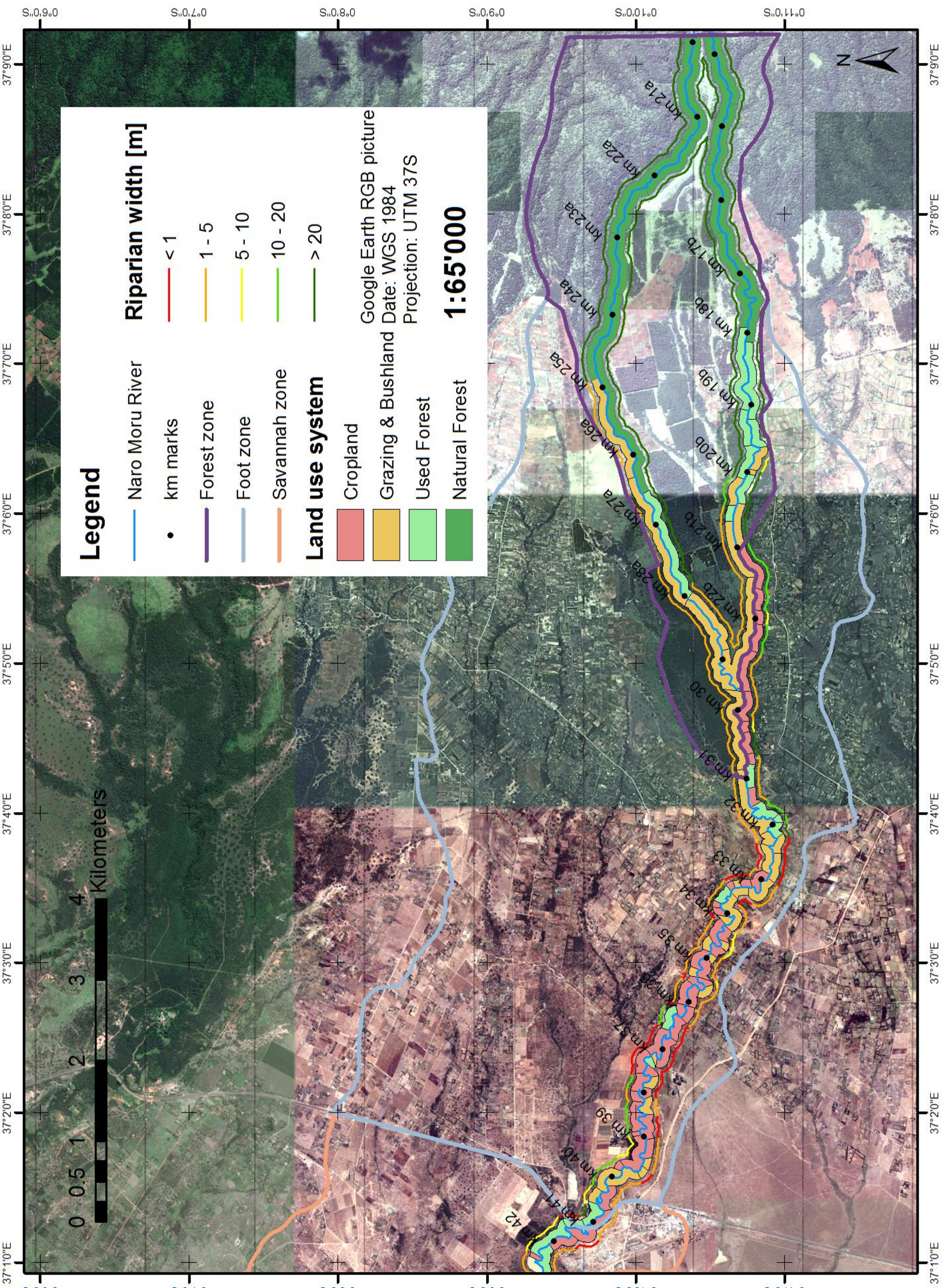


Fig. 14: Map of Foot zone and Forest zone with identified land use systems as well as width of the riparian vegetation.

4.1.3 Riparian Vegetation Width per Zone

The riparian vegetation width was assessed after the forest cover was computed with supervised classification on the whole Naro Moru sub-catchment. Starting from the classification of *forest* and *non-forest land uses*, the width of the riparian vegetation was estimated in the whole sub-catchment. Afterwards, every patch was assigned to one of the five categories and visualized as a line. Visible is this riparian vegetation width line on Fig. 13 and Fig. 14. On Fig. 15 the riparian vegetation widths of the three zones are depicted. The riparian vegetation width was assessed because it is essential for the establishment of a riparian habitat and thus for the provision of the associated ES to the population.

The **savannah zone** has a negligible area of 0.8% of riparian area that shows a width of 20 m or more. 21.3% of the riparian area has a width over 5 m. This area is quite clearly assignable to the land uses of large scale grazing and forest. The largest part (77.9%) of the riparian area is – nearly evenly - attributed to the two classes below 5 m of riparian vegetation, which are mostly associated with cropland and grazing land use.

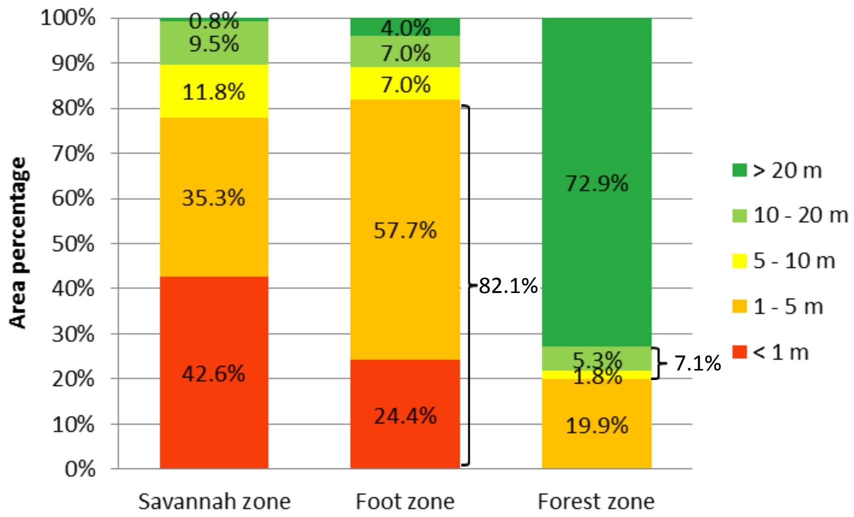


Fig. 15: Width of riparian vegetation in the three zones.

In the **foot zone**, a similar picture manifests as in the savannah zone on the first glance. Indeed 18% riparian area shows a width of higher than 5 m, which is a quite similar value as the 22.1% of the savannah zone. However, a larger difference is visible in the 5 m category where the savannah zone has a very high percentage of 57.7. The 82.1% of below 5 m are an outstanding value and highlight the generally low riparian vegetation width in the foot zone.

The **forest zone** shows a fundamentally different composition of the area percentages. Due to the vast area of natural forest most of the riparian areas are in nearly original condition, this results in a big share of 72.9% of 20 m and above riparian vegetation width. 19.9% belong to the category 1 – 5 m, which is mostly referring to the bushland area that brings along a narrow riparian vegetation width. The area shares of between 5 m and 20 m are a nearly negligible issue with their 7.1%.

Altogether the savannah zone stands out with its high percentage of 77.9 below 5 m of riparian width. The foot zone even exceeds this amount with 82.1%. The forest zone has very broad riparian zones, which speaks for its well preserved riparian habitats. In contrast to this, the riparian habitats are not well developed or have been destructed in the foot zone and the savannah zone.

4.1.4 Influence of Land Use on Riparian Vegetation Width

The data on the riparian vegetation width in the whole Naro Moru sub-catchment was used to show the influence of the land use system on the riparian vegetation.

Fig. 16 shows this relationship clearly. The riparian zones bordering on *cropland* have in 48.4% of the cases a vegetation width below 1 m and in 33.8% of the cases a width between 5 and 10 m. This is very low and underlines the vulnerability of the riparian zone in this area.

Adjacent to *grazing & bushland*, the most dominant class is 1 – 5 m with 57.4%. *Large scale grazing* shows nearly the same percentage in the class 1 – 5 m, but has on the other hand also a significant share in the class of 10 – 20 m. Adjacent to *used forest* is mainly a riparian vegetation width above 20 m detectable. Natural forest is exclusively accompanied by a vegetation width above 20 m.

The riparian vegetation width is directly depending on the adjacent land use. *Cropland* diminishes the riparian vegetation the most, followed by *grazing & bushland*, *large scale grazing* and *used forest*. *Natural forest* land use goes along with wide riparian vegetation.

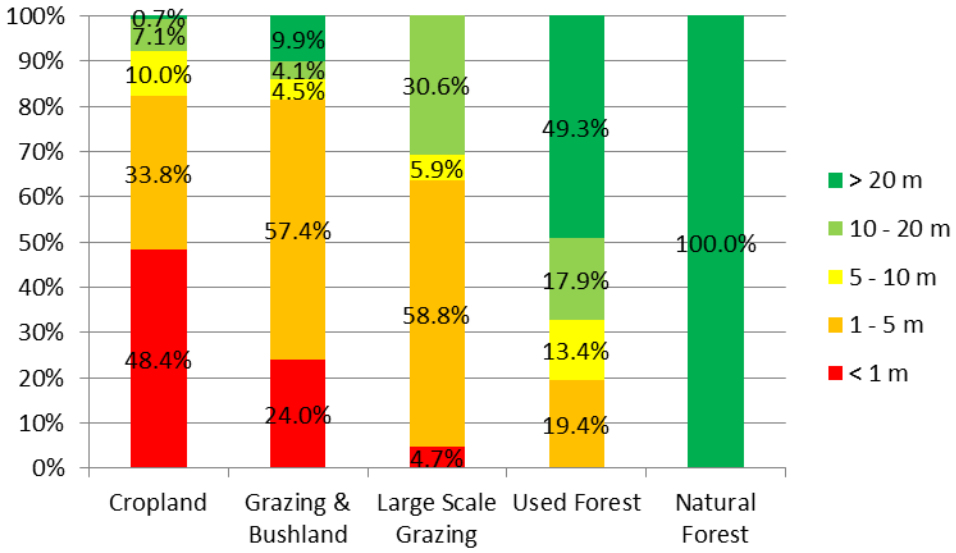


Fig. 16: Width of riparian vegetation per land use system.

4.1.5 Degradation and Conservation Patterns

The following sub-chapter describes the degree, rate and spatial pattern of degradation as well as the spatial extent of degradation and conservation measures. Data was gathered using the WOCAT Mapping Questionnaire. The main land degradation types mentioned by interviewees were riverbank erosion and reduction of vegetation cover. The main conservation measures were planting of grass, planting of trees, installation of gabions and rotational grazing.

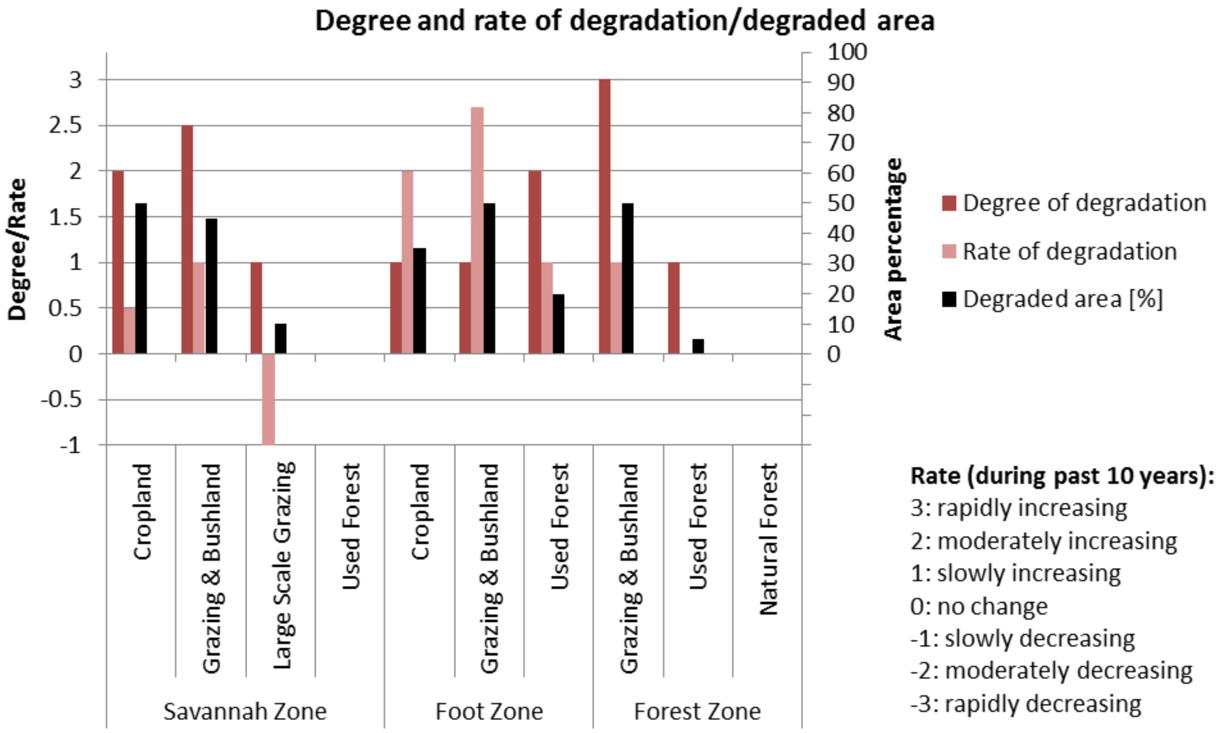


Fig. 17: Degree and rate of degradation per land use as well as the affected area percentage. The main land degradation types were riverbank erosion and reduction of vegetation cover. The degree points out the actual situation of degradation (1=light, 2=moderate, 3=strong, 4=extreme) while the rate describes the development during the last 10 years. The percentage of degraded area is depicted on the second axis.

In the ***savannah zone***, grazing & bushland as well as cropland exhibit moderate degradation. On these two land uses the degradation was slowly increasing during the last ten years and remarkably high area percentages between 45% and 50% are affected. The large scale grazing land has only a light degree of degradation, even slowly decreasing during the last ten years. Used forest is not affected by degradation.

In the **foot zone**, the degree of degradation lies between moderate and light. However, the rate is moderately increasing on the cropland and grazing & bushland while it is slowly increasing in the used forest. The degradation on grazing & bushland is accentuated since 50% of the area is affected by the degradation.

In the **forest zone**, the grazing & bushland exhibits strong degradation that has been slowly increasing during the last ten years. Affected is 50% of total land use area. A lot of degradation has been taking place on this land use during the last ten years. Used forest and cropland show a light degree of degradation that has not been changing too much during the last ten years.

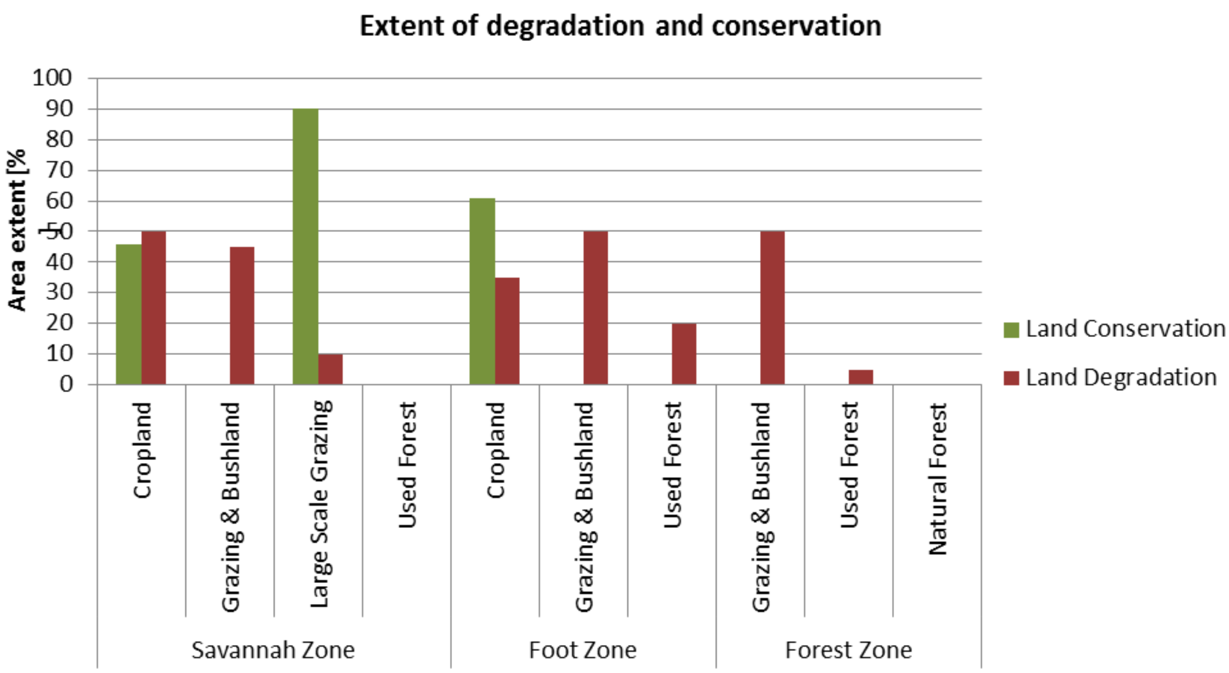


Fig. 18: Extent of degradation and conservation in the Naro Moru sub-catchment. The main land degradation types were riverbank erosion and reduction of vegetation cover. The main conservation measures were planting of grass, planting of trees, installation of gabions and rotational grazing.

Fig. 18 depicts area extent in percentage of degraded and conserved regions in the Naro Moru sub-catchment. In the **savannah zone**, the high degradations with 50% and 45% appear on cropland and grazing & bushland of the respective land use. There is very low degradation on large scale grazing land and used forest. The highest conservation, 90%, is present on large scale grazing land. This is due to the strict application of rotational grazing in this area. Like this, the riparian zone is protected. Cropland exhibits also a remarkable conservation percentage of 45%. This can be justified, as in the foot zone, with the land user's intention to protect his agricultural land.

The **foot zone** shows also large degradation signs on cropland and grazing & bushland. The most degraded land use is the grazing & bushland with 50%, followed by cropland with 35%. Used forest is degraded by 20%, which is quite high compared to the other two zones. Standing out is the high percentage of conservation, 60%, on cropland. This is because the land users do not want their plots to be damaged by floods.

In the **forest zone**, the grazing & bushland areas are severely affected by degradation covering 50% of land use area. This area is former natural forest, but all trees were cut and only bushland is left which is commonly used by the community as public grazing land. Natural forest has no degradation, used forest only 5% of the area. Cropland is only degraded on 15%, which is very little compared to the other zones since cropland is very vulnerable to degradation.

4.2 *Forest Cover Change*

This sub-chapter tries to show the development the riparian zones of the Naro Moru sub-catchment have undergone during the past 50 years. The bases for this are an aerial photograph from 1961 and a Google earth image dating from around 2011. The classification within the adjacent riparian zone (100m on either sides of the river) has been specified using supervised classification, distributing every pixel to the categories "forest" or "non-forest land uses".

4.2.1 Forest Cover in 1961

Fig. 19 shows a map with the coverage of the riparian zone portraying forest as well as non-forest land uses. The map consists of two overlaid aerial photographs that together cover the savannah zone and the foot zone of the Naro Moru sub-catchment, but excludes the forest zone.

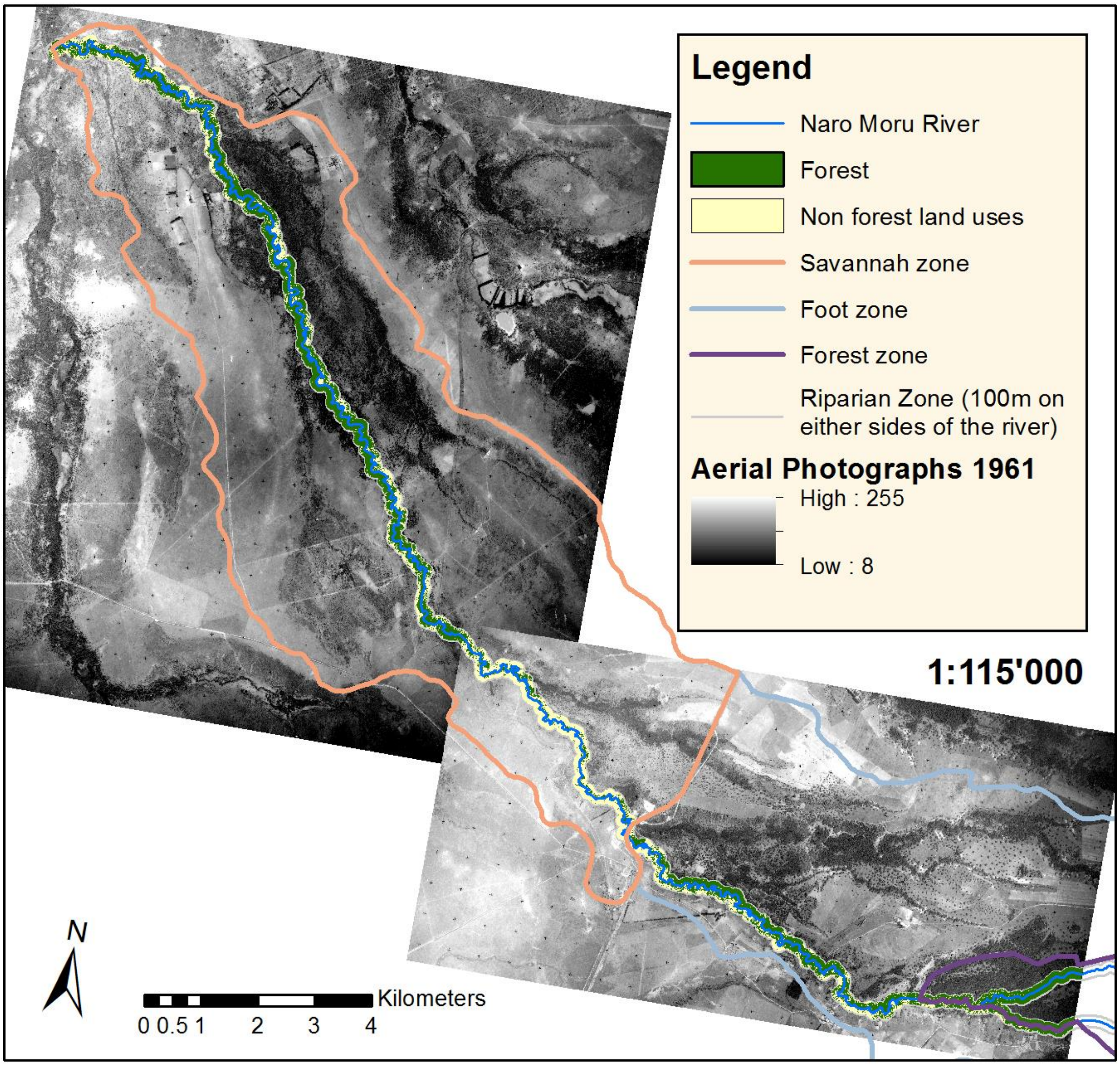


Fig. 19: Two aerial photographs were combined to derive the forest cover with supervised classification afterwards.

On the black-and-white photograph, forest areas and savannah-esque structures can be easily recognised. Also roads and streets are visible assets of the landscape. The Ewaso Ng'iro River is visible as a dark stripe on the left side of the map. The first ranch buildings of the Savannah zone can be seen in the upper left corner. Grassland, which is surrounded by bush land, can be identified in the foot zone north of the Naro Moru River. The clear boundary between bush land and grassland implies a human alteration of the environment.

The **savannah zone** contains a large forest area at the northern end. The riparian zone in these surroundings has a considerable forest area. Further to the northwest, the dense forest vanishes, but the riparian vegetation still shows a good coverage. To the southeast, the forest cover in the riparian zone declines, reaching a minimum on the last 5 km before the border to the foot zone. These last 5 km beside the river are mostly dominated by non-forest land uses. The question remains open as to whether this is the natural condition of this area or if it has man-made origins.

In the **foot zone** a difference can be detected between the two sides of the river. The right side of the river consistently shows denser forest coverage than the left side. However, the forest is thinning out on both sides of the river where it borders on the Savannah zone. Contrary this, the vegetation cover bordering the forest zone becomes denser, virtually converting to forest.

1961 / 2011	Forest [km^2]	Forest [%]	Non-forest land uses [km^2]	Non-forest land uses [%]
Savannah zone	3.3 / 1.3	62.7 / 24.5	1.9 / 3.9	37.3 / 75.5
Foot zone	1.4 / 0.7	69.2 / 37.8	0.6 / 1.2	30.8 / 62.2
Forest zone	N.A. / 2.8	N.A. / 76.3	N.A. / 0.9	N.A. / 23.7
Total	4.7 / 4.8	- / -	2.5 / 6.0	- / -

Tab. 4: Forest as well as non-forest land uses areas in the two zones.

In 1961 the proportion of vegetation in the area was not equally distributed between the two zones. The savannah zone has a forest portion of 24.5% and a non-forest land use of 75.5% while the foot zone has a forest portion of 37.8% and a non-forest land use of 62.2%. The forest zone has a proportion of 76.3% forest and 23.7% non-forest land uses.

In 2011 the distribution of the vegetation in the area was also not equally divided between the two zones. The savannah zone has a forest portion of 62.7% and a non-forest land use of 37.3% while the foot zone has a forest portion of 69.2% and a non-forest land use of 30.8%.

4.2.2 Forest Cover 2011

The classification in the adjacent riparian zone (100m on either sides of the river) has been defined using supervised classification, distributing every pixel to the categories “forest” or “non-forest land uses”. The classification result of the Google earth image from 2011 is described below.

The **savannah zone** has experienced big changes. In the classification result of 2011 (see Fig. 20) a small forest is recognizable. This forest was formerly part of the big forest on Fig. 19 in the savannah zone. It is situated in the middle of the savannah zone bordering the right side of the river and gives an impression of how large this forest originally was. In the area of the remains of the former forest the riparian vegetation is remarkably denser than upstream and downstream. In fact, the rest of the savannah zone has a uniformly scattered vegetation cover apart from the area furthest upstream, bordering the foot zone, where there is a densification of the vegetation cover.

Compared to the classification from 1961, the **foot zone** on the right side of the river has clearly lost forest cover. On the right side of the river at the border to the savannah zone, the forest area is quite dense. This can be explained by the conservation measures implemented by the horticultural farm situated there. A dense little forest is visible on the left side of the river in the upstream region close to the forest zone.

The **forest zone** has a steady trend of increasing forest cover from its lower end to the higher end. At the western end of the forest zone, the vegetation cover is very low. This is due to the large public grazing areas in this region, which lead to an encroachment of the riparian zone, leaving bush vegetation behind. Large afforestation is visible as part of the shamba system and thus is cultivated regularly. Broad parts of the riparian zones are under protection by law in the forest zone.

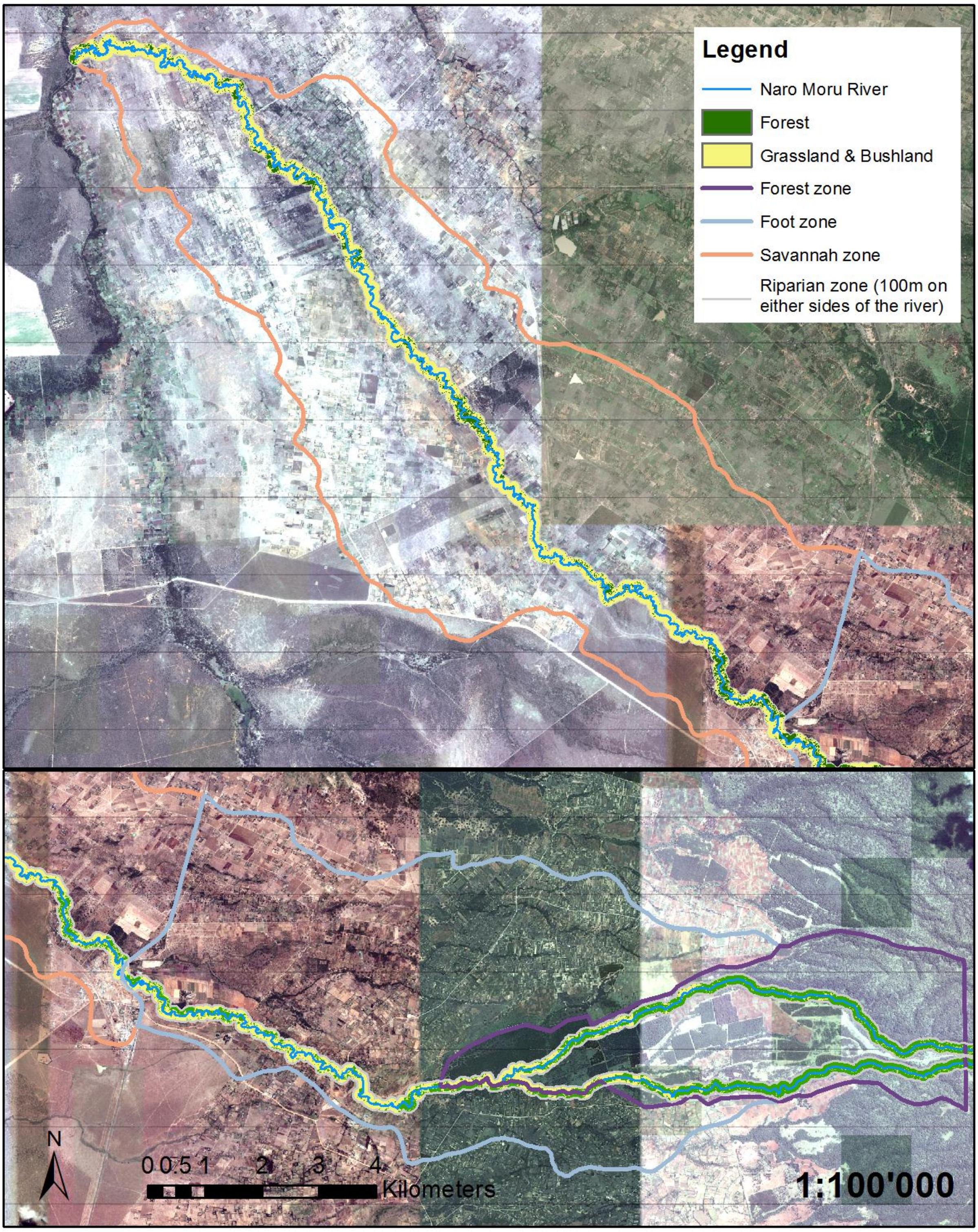


Fig. 20: Forest cover derived with supervised classification on a Google earth picture dating from 2011.

4.2.3 Forest Cover Comparison

The development of the riparian forest cover is an outcome of the defined forest classification. Fig. 21 shows the development for the different zones over 50 years between 1961 and 2011.

In the **savannah zone**, 62.7% of the adjacent riparian area was covered by forest in 1961. This number dropped by 38.2% points to 24.5% in 2011. This means that a riparian forest area of 2.0 km^2 has disappeared.

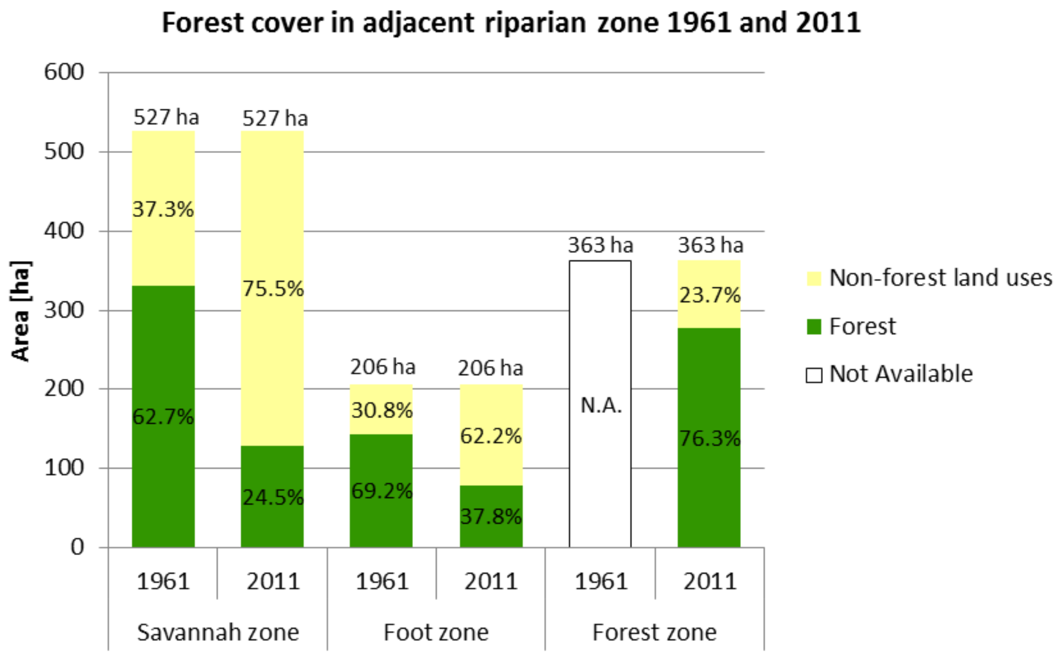


Fig. 21: The change of the riparian forest cover derived by supervised classification between 1961 and 2011 in the three zones. In the savannah zone and foot zone, the forest cover has decreased tremendously. In the forest zone, the forest cover in 2011 is fairly high. Data from 1961 in the forest zone is not available.

In the **foot zone** the drop was not that drastic. The forest cover decreased from 69.2% in 1961 to 37.8% in 2011, which makes a difference of 31.4% of the points. The decline of the riparian forest cover in the foot zone sums this up to 0.7 km^2.

Data from 1961 on the **forest zone** does not exist as the aerial photographs did not cover the whole region of the Naro Moru sub-catchment. However, the state of the riparian forest cover was very high in 2011, reaching 76.3% of forest zone. This percentage is even higher than in the savannah zone and the foot zone in 1961. Of the three areas the forest zone clearly shows the least human influence.

4.2.4 Discussion

The supervised classification was made more complicated by the varying brightness of the single aerial photographs. For example, the upper left corner of the lower photograph of Fig. 18 is much brighter than its upper right hand corner. Since the classification was performed with one single threshold per photograph, the forest cover can be under- or overestimated in some areas. The most obvious point is the transition from one photograph to the other, where the thresholds seem to be significantly different. In fact, this point appears to be very inconsistent but, balanced over the whole photograph, the thresholds make sense.

Some inconsistencies also appeared on the Google earth picture. The number of classification thresholds was even greater here, namely seven. This is one threshold for every mosaic. This has led to a few abrupt changes at borders of map mosaics. An example is in the forest zone, where a vertical mosaic border has a significant influence on the forest density although this is not present in reality.

The state of the riparian forest in 1961 cannot be considered as a natural or original state. On the one hand, the present white settlers influenced the environment by building trenches for irrigation and introducing large scale cattle ranching. On the other hand, the previous inhabitants – the Masai and Samburu pastoralists – supposedly influenced the surrounding forest clearing by fires to make more land for grazing later on. Burning the forest shortly before the long rains improved the growth of grass afterwards (Bussmann & Beck 1995).

A major problem in the “forest” and “non-forest land uses” classification was the differentiation between river pixels and dense forest, since they almost had the same spectral properties. What complicated the classification even more was that they often occurred close together. However, since the river area is quite small, this aspect was ignored.

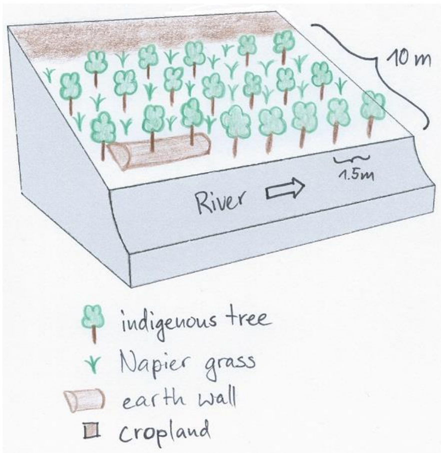
4.3 *Land Management Practices and Their Impacts*

Sub-chapter 4.3 shows the results of 8 land management practices assessed using the WOCAT Technologies Questionnaire. The interviews were performed in the sub-catchments of Naru Moru River in the west of Mt. Kenya and in the Kapingazi sub-catchment near Embu in the south-east of Mt. Kenya.

The assessment focused on ecosystem services to evaluate the land management practices on their productive and protective function. The first three practices focus on production, practice 4 to 6 focus on protection. However, the last two practices are bad land management practices. One is neglecting riparian maintenance and one is over productive in the short-term and exerting meanwhile disadvantages. Summaries of the questionnaires are provided in Annex B.

4.3.1 Characterization of Land Management Practices

Productive 1 - Tree planting in riparian for riverbank stabilization and wood production



Picture & drawing: M. Fischer

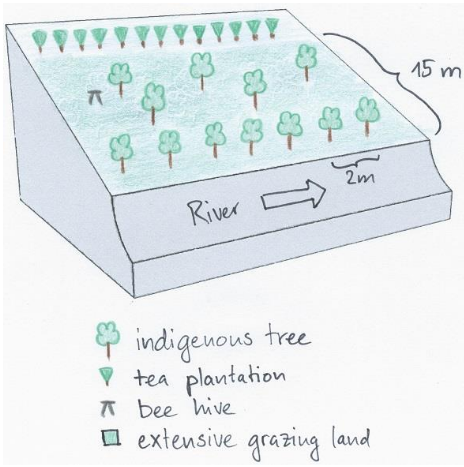
At the foot slopes of Mt. Kenya a farmer has developed a technology to protect the own land plot from riverbank erosion. The technology consists of three main measures: A wall along the riverbed, trees that are aligned on the wall as well as beside it and Napier grass wildly scattered between the trees. The wall was built on a highly exposed spot of the riverbank. Trees along and beside the wall ensure its stability. The combination of the two measures results in an effective protection of the riverbank in terms of erosion. Side effects of the technology are higher runoff during the dry season, better water quality due to less erosion and an improved riparian habitat for animals and plants.

For a small scale farmer, planting of trees can have advantages in an economic, an ecologic and an aesthetic point of view. The trees stabilize the soil, allow the riparian vegetation to establish, and prevent major damages through flooding. Furthermore, there are several advantages of an intact riparian zone, such as enhanced biodiversity, increased water quality as well as retention of agrochemicals. The trees also work as a kind of bank account, since the prices for wood are quite high. Trees can be cut and sold from time to time to generate an income that can be used for further investments like local entrepreneurship or building houses for family members. Last but not least,

the farmer emphasized the beautiful appearance of the trees including the relatively cool micro-climate the trees are able to provide during the hot months of the dry period.

The trees were planted during the rainy season. Braches are pruned regularly and provide mulch material as well as fire wood. When trees are reaching maturity they will selectively be cut and replanted. The Napier grass is cut regularly for fodder to be feed to animals. At this particular time, there is a regular hay yield (weed). Seedlings for trees and the grasses are produced on site. Occasional pruning ensures fuel wood supply.

Productive 2 - Tree planting and grass strip to sustain protective function of the riparian zone



Picture & drawing: M. Fischer

On the south-eastern slopes of Mt. Kenya, the conditions are ideal for agricultural activities. There is plenty of rainfall (2100 mm/year) which is usually reliable. However in the year 2000, the river Kapingazi dried up for the first time since many decades during a dry spell. This led to community activities that finally came up with a system of vegetative interventions to strengthen the riparian zones. The intervention consists of tree planting and establishment of grass strips along the river. Napier grass is planted to stabilize steep slopes and to supply material for the construction of tea baskets.

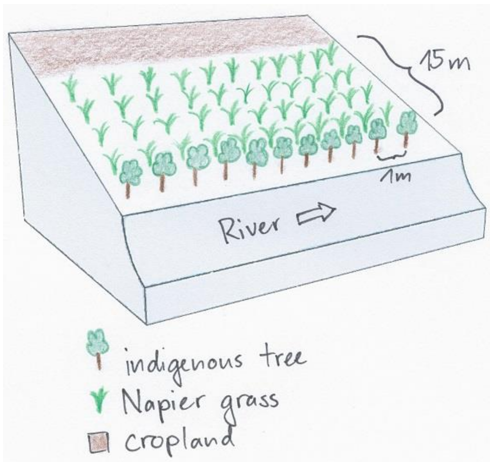
The goals of this technology are manifold. Firstly, the vegetation prevents surface water and eroded soil flowing from the agricultural fields directly into the river. Therefore, sediments and chemicals used on the field are retained in the riparian soils and do not pollute the river. Surface water flow from runoff during heavy storms is slowed down and infiltration on soils covered by grass and trees is increased. As a result more groundwater is recharged during the wet seasons, which can be released during the dry season. Thus peak or flood flows are reduced and low flows are improved. Damage during flood flows on the riverbank (through erosion and destabilizing the riparian vegetation) as well as damages of floods downstream can be reduced or avoided.

Before planting the indigenous trees, water guzzlers like eucalyptus trees were cut down. Indigenous seedlings were planted right along the river at a distance of 2m. Between the trees and the tea plantation a grass strip of up to 10m is established. Some trees were planted scattered on the grass strip. The young trees are surrounded by grasses which are cut regularly every 2 weeks. This reduces competition and enhances growth of the trees. As soon as the trees are big enough, they function as a source of firewood, they can be pruned every 5 months.

The studied plot is situated right below the natural mountain forest of Mt. Kenya at the south-eastern slope. The source of Kapingazi River can be found at 1.5 km of walking distance upslope of the plot.

Agricultural circumstances are good because of the fertile, volcanic plots and the abundant precipitations. However, the terrain is quite steep.

Productive 3 - Productive use of the riparian area using Napier grass and protection of the riverbank with indigenous trees



Picture & drawing: M. Fischer

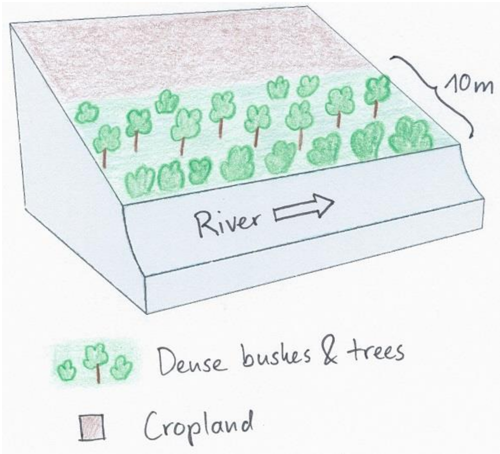
On the southeastern slopes of Mt. Kenya, the circumstances are ideal for agricultural activities, the rains are plenty and normally reliable. The plot owner started realizing a problem of riverbank degradation 17 years ago. But still he continued the traditional way of agriculture, planting beans and maize. Since his plot is on the slip-off slope only few metres above the river level, it experienced regular floods in case of heavy rainfalls, destroying the plants and leading to crop failures.

Conventional plants like maize and beans do not resist such an excess of water. To fight the land loss and the bad harvest, the farmer introduced indigenous trees along the river and Napier fighting the riverbank degradation. Behind that, several rows of the flood resistant Napier grass were planted to still use the area in a productive way.

Above all, the goal of this technology is to get a high grass production. As a side effect results a quite good protection of the riparian area. The vegetation prevents rainwater from running directly from the fields into the water. Therefore, the chemicals from the field get stuck in the riparian soils and don't pollute the river. In the same way the infiltration in the riparian enlarges the total infiltration since the water would go to the river directly. Especially the raw surface of the riparian allows more infiltration and interception storage of water. This surplus of stored water is able to provide river water for a longer period, when rains are humble for a longer period. In case of floods, the increased infiltration potential can cut the peak flow and thus prevent damages. The grass yield is used as a fodder for the cows.

Before planting the indigenous trees, water guzzlers like eucalyptus trees were cut down. Indigenous seedlings were planted right along the river at a distance of 1 m. Behind the tree row, Napier grass is planted and harvested twice a year. The cutting and harvesting of the grass is done regularly such that animals can be provided with fodder every day. As soon as the trees are big enough, they function as a source of fire wood, they can be pruned every 5 months.

Protective 1 - Riparian forest for riverbank stabilization



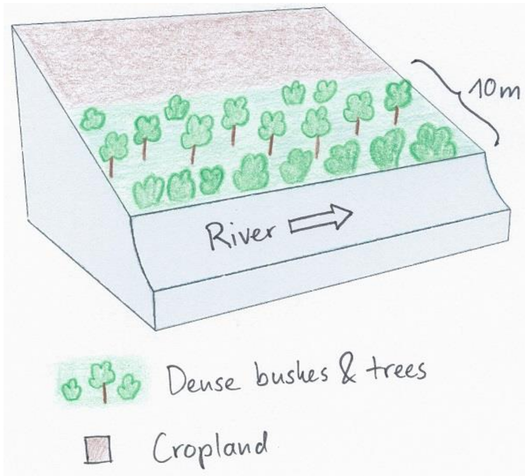
Picture & drawing: M. Fischer

The farmers' land plot is situated right alongside the river. Heavy floods have eroded a major part of the riverbank and have led to crop failures on the arable land. The farmer reacted to the degradation by stopping agriculture activities on a certain riparian area in order to enable natural vegetation to reclaim the area. The idea is that during the next years, further floods will deposit sediments, which will increase the elevation and fertility of the plot. As soon as enough soil has accumulated and the elevation has increased enough, the farmer wants to plant French beans in the area. Trees were planted in the riparian zone to stabilize the riverbank and to ensure water quality in the river by retaining sediments from nearby fields. Agricultural chemicals are trapped in the riparian buffer as well.

The purpose is to deal with the regular floods of Kapingazi River and to gain advantages for the farmer and the environmental conditions. Floods are a natural event and happen regularly, therefore strategies are necessary to diminish their negative effects. Furthermore, the human impact on a riparian ecosystem should be kept as small as possible by trapping chemicals and sediments that reduce water quality for down streamers.

The area where sediments are trapped is not touched by any human interference, the vegetation grows in its natural way. The stabilizing trees of the riparian are planted at the beginning of the rainy season in March or October. Dead seedlings have to be replaced regularly.

Protective 2 - Not influencing the riparian vegetation to sustain a stable riparian



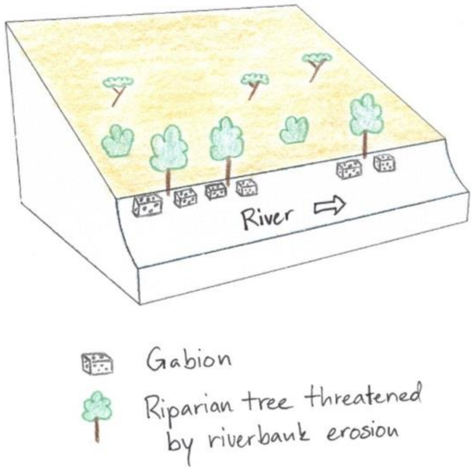
Picture & drawing: M. Fischer

The studied land plot is situated in the semi-arid savannah zone of the Naro Moru sub-catchment at the foot of Mt. Kenya. A small-scale farmer leaves the riparian vegetation undisturbed, which enables the growth of dense bushes. On the one hand, the riparian vegetation contributes to prevent land loss caused by riverbank erosion, on the other hand it is a habitat for the special riparian fauna and flora.

Despite semi-arid conditions, there is a high probability of flooding. Heavy rainfalls on upper slopes of Mt. Kenya lead to flood events in the semi-arid areas of Naro Moru River. These events have a destructive effect on the riverbanks, which have become instable by human induced activities such as overgrazing and deforestation. The instable riparian soils are eroded easily. The farmers lose their precious land and the water is polluted.

A good way to overcome the riverbank degradation triggered by high runoff is a passive approach: simply leaving the riparian area undisturbed by human interference. Trees, bushes and grasses stabilize even steep riverbanks with their invading roots. As a result, almost no erosion takes place and infiltration is enhanced during rain events. The riparian microclimate, which is characterized by cooler temperatures during the day and slightly warmer temperatures during the night, is very special compared to the surrounding semi-arid zones. Also water availability is much higher than in the surroundings. Thus, this habitat offers a high biodiversity.

Protective 3 - Keeping natural riparian vegetation and stabilizing riparian with gabions



Picture & drawing: M. Fischer

The studied land plot is situated in the semi-arid savannah zone of the Naro Moru sub-catchment at the foot of Mt. Kenya. A large-scale farmer owns a spacious land plot bordering Naro Moru River where he grows herbs and special plants to produce human care products. He rarely intervenes in the riparian area but is still interested in a good protection of water resources. Therefore, big stone control structures called gabions were installed to prevent big riparian trees from being undermined by water and destabilized by erosion. This method is cost intensive but can be applied locally for the protection of certain goods. The action was promoted by the Water Resource Users Association of the sub-catchment.

Despite semi-arid conditions, there is a high probability of flooding. Heavy rainfalls on upper slopes of Mt. Kenya lead to flood events in the semi-arid areas of Naro Moru River. These events have a destructive effect on the riverbanks, which have become instable by human induced activities such as overgrazing and deforestation. The instable riparian soils are eroded easily. The farmers lose their precious land and the water is polluted.

Big riparian trees are important for stabilizing the riverbed and riverbanks and for building a canopy that provides shade which enables the typical riparian conditions with its vast biodiversity. Thus, large metal nets (2x1x0.5 m) are filled with stones and placed in front of the roots to protect them from the direct current. These metal nets are called gabion and are placed at especially prone places. This structural measure contributes to mitigate or even stop riverbank degradation. High efforts are required to establish gabions. The costs for the metal net amount to 80 US-Dollar per net. Additionally, workforce must be found to fill the nets with stones from the river. Once installed, they ensure a good local protection. They are also used to protect bridge pillars. The life expectance of a gabion net is about 20 years if not destroyed by extreme events.

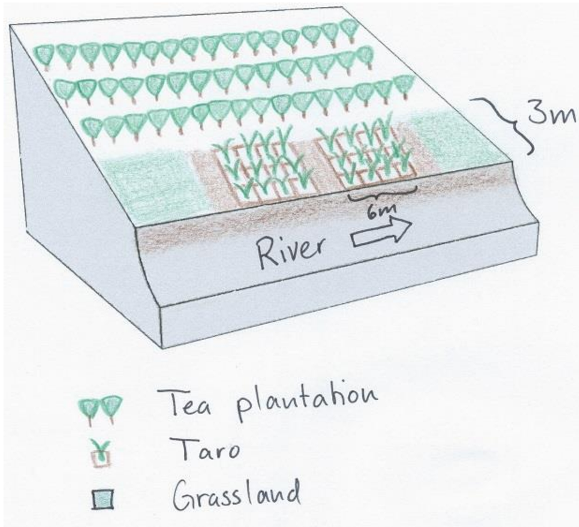
Neglection - Destruction of the riparian vegetation due to overgrazing leading to huge riverbank degradation

Picture & drawing: M. Fischer

This land plot has been abandoned for more than 20 years since then the plot is unused and is degrading steadily. The community uses it as a common grazing area. During the last 20 years the land plot has undergone a dramatic change. The former opulent riparian vegetation and adjacent savannah is now replaced by a highly degraded grazing area and mostly destroyed riparian vegetation. Grazing goats eat the last leaves and off the bushes. Left over large single trees are still at the riverbank testifying the former large riparian vegetation.

Through the not defined land ownership there is no responsibility for the management of this land plot especially the riparian vegetation. It would be the community's mandate to install rehabilitative measures. This plot stands for all publicly used river segments like similar riverbank degradation patterns can be observed for example at streets following the river course.

Productive Overexploitation - Productive use of arrow root (Taro) in the riparian zone



Picture & drawing: M. Fischer

Right beside the river a mid-scale tea farmer has planted a patch of arrow roots. The number of plants is enough to sustain the family with one root per day. Ecosystem services are diminished and the river is being polluted with sediments. Agro-chemicals applied on the tea plantation reach the river unfiltered.

The goal of this technology is to establish a stable provision of arrow root to the farmer's family, since arrow root is a traditional food and even very tasty. The farmer's main business is the cultivation of tea. Thus there is only a small family garden beside the house. To decrease the amount of food that has to be bought on the market, these arrow roots were installed. There are enough plants on the plot to provide the household with one root per day which serves as breakfast for 2 people.

The arrow root profits out of the near river area with its tremendous water availability. However too much water makes the roots rot thus the ditches around the arrow roots were dug. They are maintained every 4 to 5 months. Manure is applied regularly.

The near river location of the arrow roots prohibits the positive ecosystem services that a natural vegetation cover would have. The unstable situation of the riverbank leads to an increase of the sediment load.

4.3.2 Analysis of Ecosystem Services and Costs of Land Management Practices

The aim of this sub-chapter is to analyse the relation between land management practice and the environment as well as to find a way to compare them. This was achieved by comparing the eight land management practices and their impacts on the environment, ecosystem services and costs.

This comparison was based on descriptions with the WOCAT Technologies Questionnaire that provides a systematic assessment of land management practices.

Ecosystem services are subdivided into four groups: productive ecosystem services, socio-cultural ecosystem services, ecological ecosystem services and off-site ecosystem services. Each land use system provides specific ecosystem services for the land user.

The assessment of the ecosystem services of land management practices is categorized from little over medium to high whereas the change of little is 5 to 20%, the change of medium is 20 to 50% and high means a change of more than 50%. These categories are displayed as points in the following graphs. Little change corresponds to 1 point, medium change corresponds to 2 and high change corresponds to 3 points. Negative ecosystem services are measured with the same categories and are assessed beside the positive ones. In this way, the strengths and weaknesses of an ecosystem service are reflected in its amount of positive and negative points.

The ecosystem services were recorded as changes from the common land management practice. That is why they cannot be seen as independent factor of a land management practice but as variable that compares two states. Therefore, high rankings in ecosystem benefits do not necessarily indicate the best land management practice, but change of the land management practice that has provided big ecosystem benefits.

4.3.2.1 Productive Ecosystem Services

Productive ecosystem services provide basic goods for human life. Benefits are for example increasing amounts of fuel wood, crop yield, wood, fodder, reduced risk of production failure and diversification of income. Disadvantages are decreasing amounts of wood, fodder and crop production as well as loss of productive land. After the *MA 2005: 40* these are provisioning ecosystem services such as food, fresh water as well as wood and fibre.

Fig. 22 shows production and socio-economic benefits at the bottom of the graph and disadvantages at the top of the graph for the 8 land management practices.

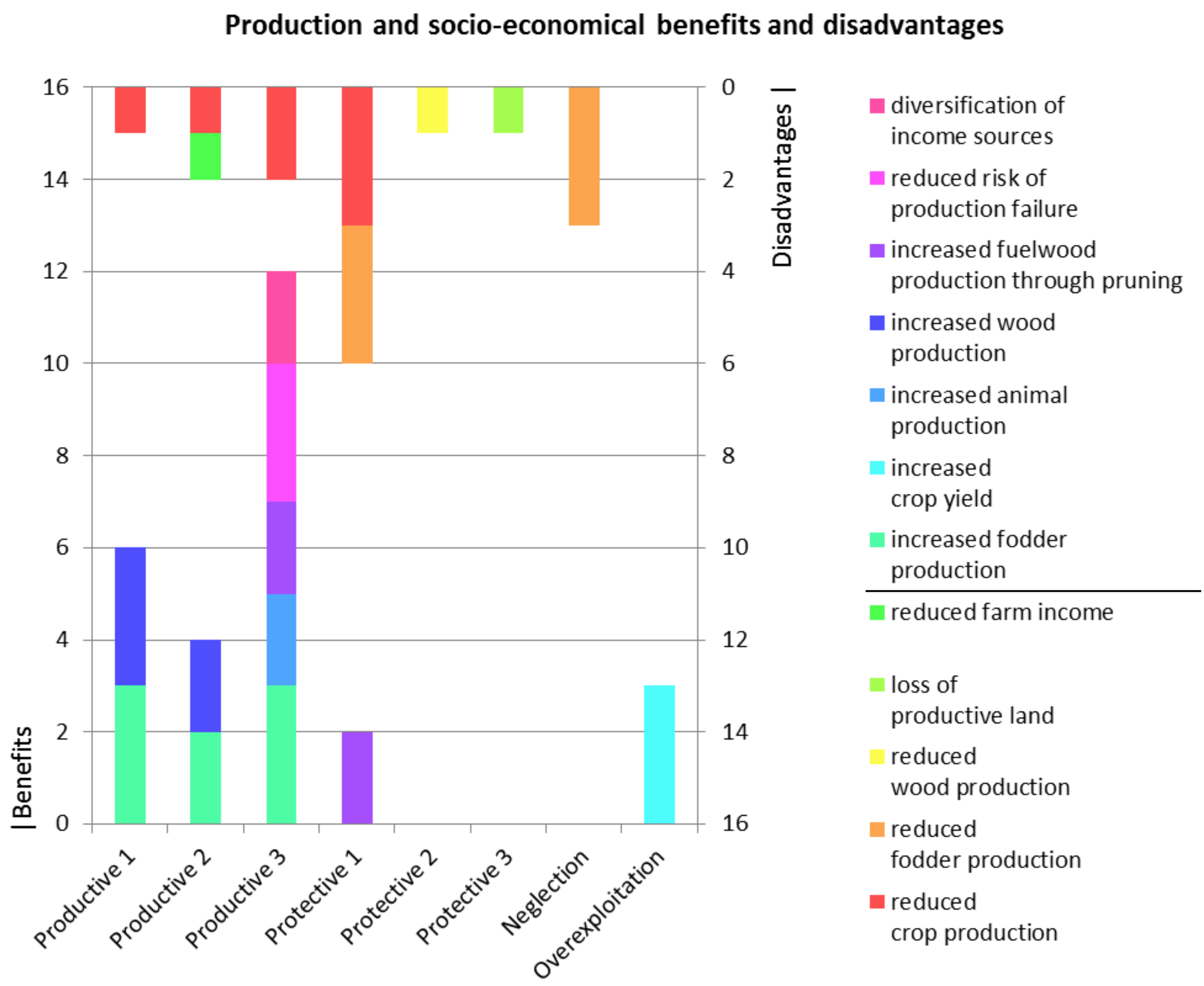


Fig. 22: Production and socio-economic benefits and disadvantages

The **productive land management practices** show benefit points between four and twelve while disadvantages remain low at 2 points or less. Benefits concentrate on fodder, wood as well as diversification of income and reduced risk of production failure. The disadvantages are reduced crop production and loss of productive land. The overall benefits are relatively high compared to the disadvantages; this means that production is increased.

The **protective land management practices** are not as uniform as the productive ones. Protective 1 has more disadvantages than benefit points. This is due to the new land management practice being less productive than the old one. Nevertheless, the cessation of the old land management practice was necessary due to regular flooding of the plot. Protective 3 has diminished its grazing area to protect the riparian zone but has no productive benefits because it is not used further in a productive way.

The neglected plot shows a reduced fodder production due to overgrazing. The overexploiting land management practice has a big benefit in crop yield.

4.3.2.2 Socio-Cultural Ecosystem Services

Socio-cultural ecosystem services consist of aesthetic, educational, recreational and spiritual benefits as described by *MA 2005: 40*. Fig. 23 shows socio-cultural benefits at the bottom of the graph and disadvantages at the top of the graph of the eight land management practices.

The **productive** land management practices have three to four benefit points while there are no disadvantages. The benefits are food security, improved aesthetics and improved conservation knowledge.

The **protective** land management practices have two to four benefit points while there are no disadvantages. Protective 1 shows improved conservation knowledge, protective 3 additionally community institution strengthening, while protective 2 has improved aesthetics.

In the cases of neglection and overexploitation, the disadvantages are in both cases loss of recreational opportunities.

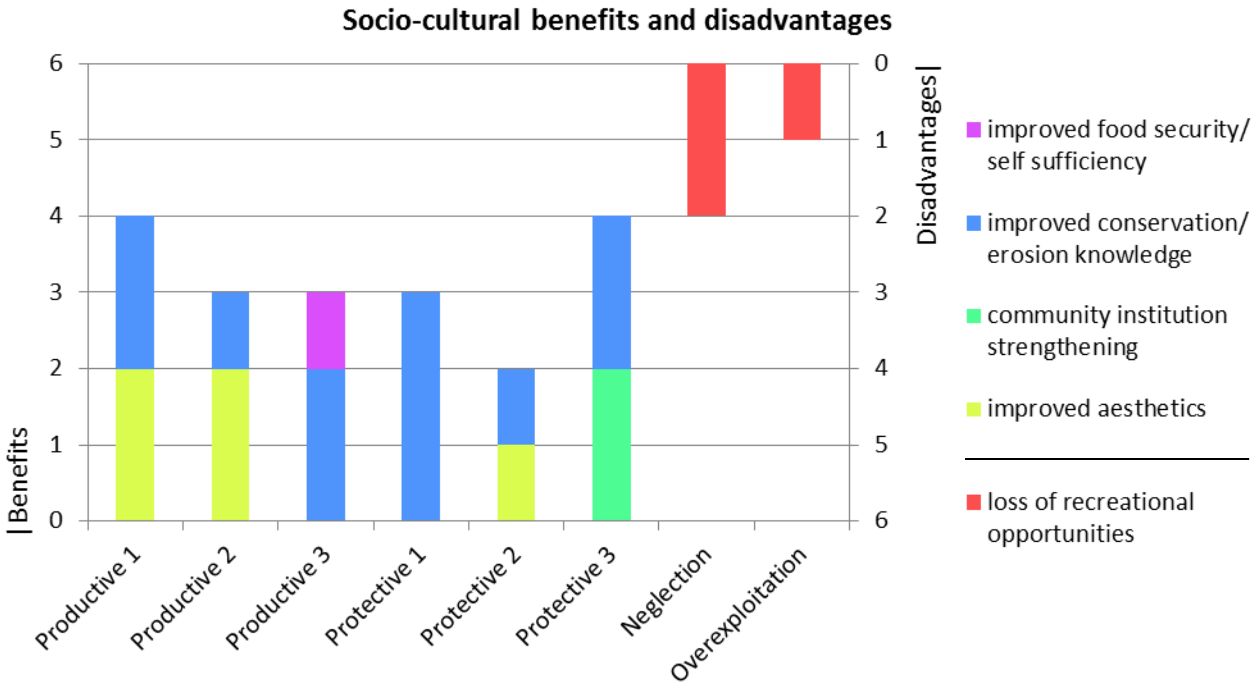


Fig. 23: Socio-cultural benefits and disadvantages.

4.3.2.3 Ecological Ecosystem Services

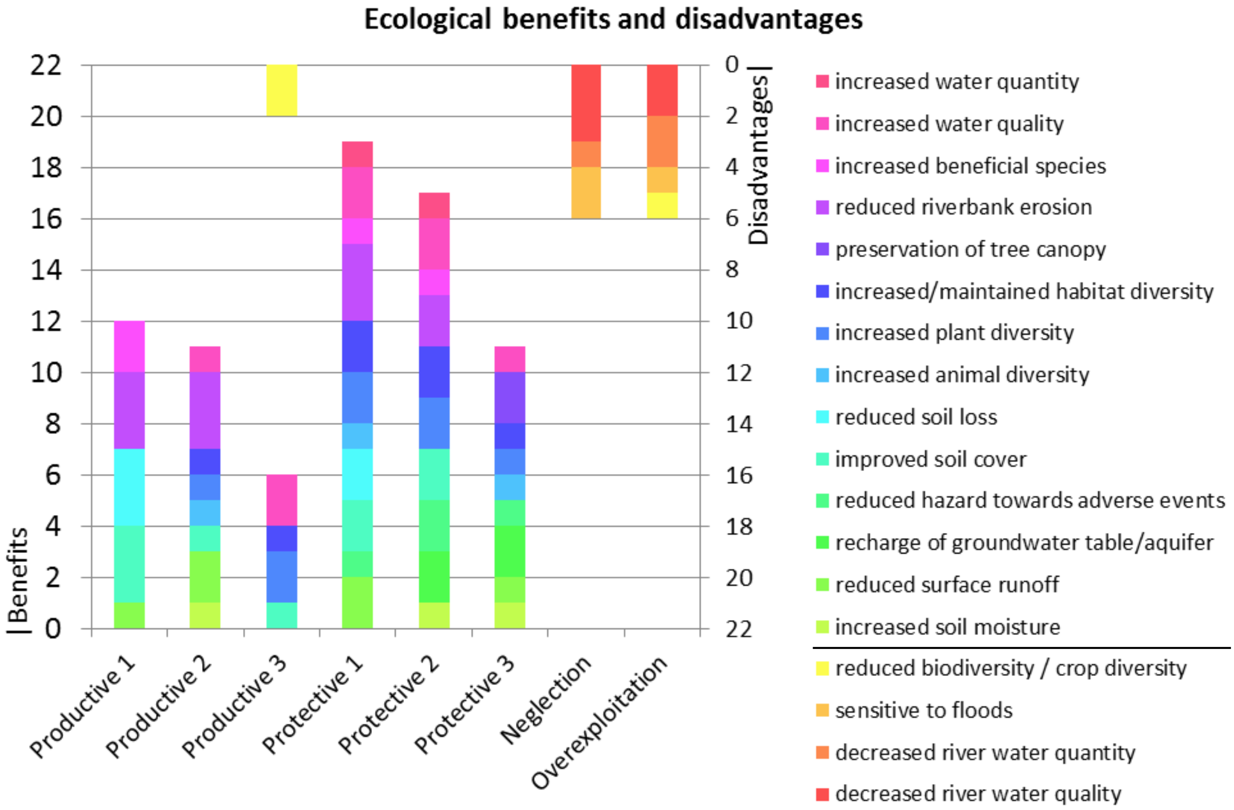


Fig. 24: Ecological benefits and disadvantages.

Ecological ecosystem services (see Fig. 24) consist of the condition of soil, soil cover, water resources, vegetation cover including biodiversity aspects and change due to the applied land management practice.

A huge difference between the productive/protective practices and the bad practices is detected. The **productive** land management practices show various different ecological benefits that are totalling from six to twelve points whereas disadvantages are very low. Productive 1 has ecological benefits in fighting extreme events but also in increasing soil cover and reducing riverbank erosion to name only some of them. Productive 2 has benefits like increased habitat diversity and reduced surface runoff as well as reduced riverbank erosion. However, no disadvantages occur. Productive 3 has the least benefits among the productive and protective land management practices. Increased water quality and increased plant diversity are its main benefits, although reduced biodiversity is a drawback. The reduced biodiversity is due to uniform plantation of Napier grass that has replaced several former crops.

The benefits of **protective** land management practices are generally higher between eleven and 19 points. Protective 1 has the highest number of benefit points going up to 19. They are consisting of increased biodiversity, reduced riverbank erosion, improved soil cover and improved protection against risks. Protective 2 has quite similar ecological benefits as protective 1, since the land management practice is quite similar. Differences arise from protective 2 not showing a reduced hazard toward adverse events like floods. Protective 3 has strengths in the improvement of biodiversity and protection against riverbank erosion.

The bad practices lack any ecological benefits. However, their disadvantages are totalling both at six points, consisting of decreased water quality and quantity and sensitivity to floods. Productive overexploitation is additionally accompanied by reduced biodiversity.

The numerous benefits of protective 1 can be explained by the fact that the former land management practice was showing very bad ecological services, which makes the benefits of the new land management practice more obvious. It is remarkable that among the productive and protective land management practices only one has an ecological disadvantage.

4.3.2.4 Off-Site Benefits and Disadvantages

Off-site benefits and disadvantages are impacts of land management practices on off-site areas. In this case, off-site areas are the downstream neighbours who are affected by the land management practice. Because the river is the connecting element, all the considered ecosystem services are connected to the river water.

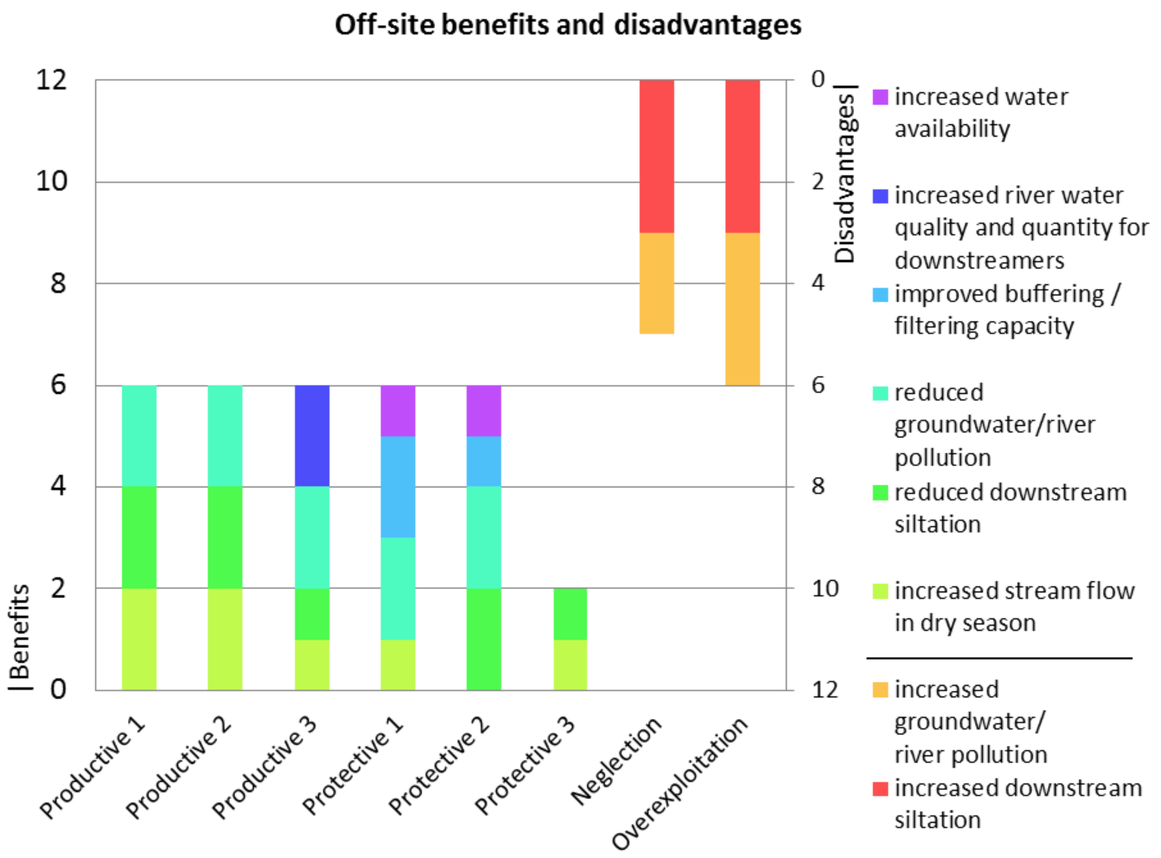


Fig. 25: Off-site benefits and disadvantages.

The off-site benefits depicted in Fig. 25 show a clear distribution. The productive and protective land management practices have only benefits while neglection and overexpoitation have only disadvantages. The benefits of the productive and protective land management practices concern river water quality and quantity, reduced downstream siltation, reduced groundwater/pollution, improved filtering capacity and increased stream flow during the dry season. It is no surprise that all good land management practices show these effects since they are the main goals of riparian protection. However, protective 3 shows only two benefit points.

Off-site disadvantages are provided by the bad practices in terms of increased groundwater/river pollution and increased downstream siltation.

4.3.2.5 Cost Analysis of Technologies

The calculation of the establishment and maintenance costs is a crucial part of the WOCAT Technologies Questionnaire. It enables an estimation of the costs for a large scale implementation. The ratio of costs and ecosystem benefits can be critical for the implementation of a land management practice. The costs were calculated for a riparian length of 100 m. Included in the costs are working hours as well as material acquisitions that have to be made, for example the purchase of seedlings. Establishment costs occur only once at the introduction of the land management practice, while maintenance costs are calculated over a year. The working hours were valued with 300 KSh per hour, which corresponds to 2.70 US$.

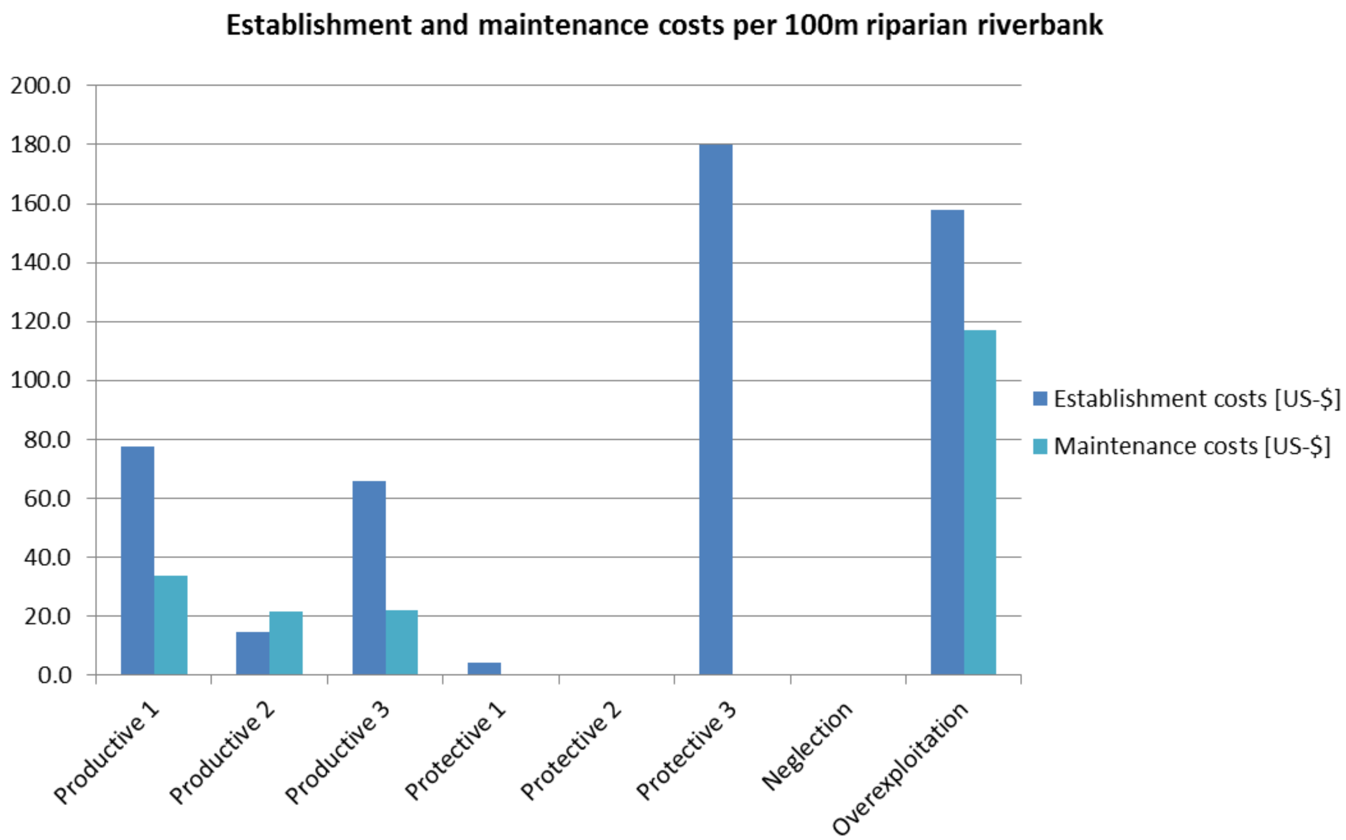


Fig. 26: Establishment and maintenance costs of the different technologies.

In Fig. 26, the differences in costs appear to be quite high while both establishment and maintenance costs are varying considerably.

Among the productive land management practices the establishment costs vary between 13 US$ and 77 US$, whereas the maintenance costs range from 22 US$ to 33.5 US$. The establishment costs of productive 1 are quite large because the land management practice consists of a riparian protection that needs many trees to be planted and is thus cost intensive. Productive 2 has low maintenance and establishment costs. The major cost factor of productive 3 is the establishment of many trees, further maintenance of the intensive grazing land is not labour intensive.

Protective 1 exhibits very small establishment costs of 4 US$ for the few trees that were planted, maintenance costs are not existing. Protective 2 induces no establishment costs since it is a passive approach which gives the vegetation time to develop on its own. In contrast, protective 3 has extremely high establishment costs of 180 US$ and maintenance costs of 0 US$. The reason for the high establishment costs are the high material costs of gabions. The advantages of gabions are their strong protection effects regarding erosion and their long durability of up to 20 years. They are often placed to protect important buildings like bridges. However, for small-scale farmers, the financial efforts are too high.

The neglected land plot has neither establishment nor maintenance costs. The overexploited land exhibits very high costs. Establishment and maintenance costs are this high, because arrow root is normally not planted on 100 m along the river, in this case it was only 30 m. The costs consist of seedling purchase and the trenches around the plants that have to be dug.

4.3.3 Overview of Ecosystem Services of the Eight Assessed Land Management Practices

Tab. 5 provides an overview of the eight land management practices concerning their ecosystem services and labour input. The numbers in the rows of production and socio-economic, socio-cultural, ecological and off-site benefits and disadvantages were calculated by subtracting the benefits and the disadvantages (from Figs. 22-25) for each cell. For example the production and socio-economic benefits of productive 1 are eight. Afterwards two disadvantage points are removed from the benefits which ends up in six. Establishment and maintenance labour input were taken from Fig. 26. For every row, certain thresholds were defined to assign them to an assessment category (poor, fair, average, good, excellent). Thresholds are provided in Annex A.

Productive 1 exhibits good and excellent production, socio-cultural, ecological and off-site ecosystem services. Only labour input for establishment and maintenance is average. Productive 2 shows average production but good ecological, socio-cultural and off-site benefits. The establishment and maintenance labour input are few. Productive 3 exhibits good socio-cultural and off-site ecosystem services while ecological ecosystem services are average and production even excellent. Establishment labour input is average but maintenance labour input is good.

Ecological ecosystem services and labour input of protective 1 are excellent. However, production is average and socio-cultural and off-site effects are good. Protective 2 shows nearly the same pattern except that socio-cultural ecosystem services are average and productive ecosystem services are fair. Socio-cultural and ecological ecosystem services of protective 3 are excellent whereas productive ecosystem services are fair and off-site ecosystem services are good. Establishment labour input is very high but no maintenance labour input has to be spent.

Neglection has strong weaknesses in ecological and off-site ecosystem services and fair productive and socio-cultural ecosystem services. However, there is no labour input. Overexploitation shows the same weaknesses in ecological, off-site and socio-cultural ecosystem services but has very high productive ES. Negative features are the poor establishment and fair maintenance labour inputs.

The productive land management practices have their strengths in productive, socio-cultural and off-site ecosystem services while labour input and ecological benefits are average. Compared to the others, the productive land management practices The Protective land management practices show nearly throughout good to excellent ecosystem services except for production and socio-economic benefits that are fair. The bad land management practices exhibit fair to poor socio-cultural, ecological and off-site ecosystem services. Production and socio-economic benefits as well as labour inputs are very different for the two land management practices.

	Good Practices						Bad Practices	
	Productive Focus			Protective Focus			Neglection	Productive Overexploitation
	Productive 1	Productive 2	Productive 3	Protective 1	Protective 2	Protective 3	Neglection	Overexploitation
Production and socio-economic benefits and disadvantages	**5**	**2**	**10**	**-4**	**-1**	**-1**	**-2**	**3**
Socio-cultural benefits and disadvantages	**4**	**3**	**3**	**3**	**2**	**4**	**-2**	**-1**
Ecological benefits and disadvantages	**12**	**11**	**6**	**19**	**17**	**11**	**-6**	**-6**
Off-site benefits and disadvantages	**6**	**6**	**6**	**6**	**6**	**2**	**-5**	**-6**
Establishment labour input	**77.5**	**11**	**65.8**	**4**	**0**	**180**	**0**	**158**
Maintenance labour input	**33.5**	**21**	**22**	**0**	**0**	**0**	**0**	**117**

poor fair average good excellent

Tab. 5: Overview of the ecosystem services of the assessed land management practices. The numbers in the squares show the sum of positive minus negative ecosystem services points visible in Figs. 22-25. Establishment and maintenance inputs are derived from Fig. 26. The assessment with the categories poor, fair, average, good and excellent was done with thresholds (see Annex A).

4.4 *Water Resource Users Associations (WRUA)*

WRUAs were examined in the two sub-catchments Naro Moru and Kapingazi using the WOCAT Approaches Questionnaire. These associations started their actions mostly during the last decade performing a strong process of change in these years. In the first sub-chapter, the typical characteristics of WRUAs are depicted. The two following sub-chapters show the specific features in the two examined sub-catchments. In the last sub-chapter the two WRUA are assessed how they perform in managing water resources. Further information about the 2 WRUAs can be seen in Appendix B.

4.4.1 Water Resource Users Associations – Their Establishment, Goals and Activities

The WRUAs have their roots in the 1980s where multiple initiatives, started by research communities, and government tried to implement multi-stakeholder campaigns focusing on sustainable and equitable water use (Kiteme et al 2008: 21). Their formation is often community based and builds on the community's need to solve conflicts or fight water scarcity (Watson 2007: 3). Later on, based on the Kenyan Water Act 2002, existing WRUAs were supported by the Water Resource Management Authority (WRMA) with financial and know-how transfers to professionalize their work. The establishment of new WRUAs was also supported. Meanwhile, nearly every sub-catchment has its own WRUA in the Upper Ewaso Ng'iro basin. The distinct goal of the WRUA is to manage the water resources sustainably. This includes protection of the riparian zone, pollution prevention of surface water and groundwater, establishment of an equitable distribution of water resources, promotion of water conservation practices and work towards reducing conflicts.

Formally, a WRUA consists of members who are water users, riparian land owners or other stakeholders who associated for sharing, managing and conserving a water resource. This includes also water abstractors. They form an official association with a chairman, a secretary and a treasurer. The members join the association voluntarily without earning any allowances. In this way, the WRUA should draw really committed members (Aarts 2012: 26).

To meet the goals mentioned above the members of the WRUA committee meet regularly to discuss their activities. The WRUAs carry out regular activities. For example the undertaking of a water abstraction survey in the sub-catchment to identify all legal and illegal water abstractions. It is crucial to know the accurate water flows before someone can conserve the water resources. The goal is to convince illegal abstractors to apply for a permit to legalise the abstractions.

The WRUA organises meetings, called barazzas, with the local chief and the riparian land users. In these meetings special conservation measures applied in the riparian area are discussed together with land management specialists. The conservation measures are for example cutting of water guzzling trees, planting of water-friendly trees, raising public awareness of pollution and rehabilitating of riverbanks.

Introduction of new technologies like drip irrigation and rooftop water harvesting is made on special plots to motivate land users to apply water saving technologies. To raise public awareness of the importance of the riparian zone, the WRUA members conduct a pegging campaign along the river of the sub-catchment. The water act 2002 dictates a riparian area of at least 6 metres on either sides of the river. This area is being delineated to indicate the location of the protected riparian zone to the land users. During water shortages (for example a dry spell), the WRUA has specific rules for water abstractions to ensure water supply for all land users.

An important aspect of the WRUA is not only to provide technological knowledge and provide water for all land users, but more importantly to construct a platform of discussion and a contact institution for any kind of problems in the region but mostly around water resource topics. This has led to several successes in the Upper Ewaso Ng'iro basin, where by the end of the year 2003 52 conflicts were treated. This emphasises that the WRUA can be considered as crucial grassroots institution (Liniger et al 2005: 169).

4.4.2 Case Study WRUA Naro Moru

In chapter 4.4.1, most of the basic information about WRUAs was given. In the following, the very specific features that complement the mentioned standard characterizations are pointed out.

The start of the first informal meetings in the Naro Moru catchment was in the year 1999, when a serious dry spell hit the region. The river was drying up until Naro Moru town and downstream users walked up the river in search of water. They blamed the upstream users for their irrigation activities while downstream users did not even have drinking water. From this moment on, discussions were started that were intensified in the following years. In 2003, the WRUA was officially registered at the WRMA and pursued mostly capacity building and awareness creating among the members until the year 2006. From 2008 on, regular meetings (barazzas) were held about conservation measures, sensitization and discussion of ideas from the members. It was decided that each of the three zones of the catchment has three representatives participating at the meetings of the committee. In October 2010, trainings concerning conservation measures were performed, mostly in the savannah zone. Following this, a pegging campaign in the savannah zone was initiated. The WRUA members delineated the mandatory 6 m of riparian zone, where no agriculture or grazing can be performed. In the same month, 25000 seedlings were distributed to the people in needing areas to plant in the riparian zone. In spring 2012, important buildings like bridges were secured with gabions. The activities were supported by the Kenyan Wildlife Service (KWS), government officials as well as Rural Focus, a small engineering company.

Most hindering in the implementation were people with conservative attitudes. The meetings show a participation of 60%. Financing was provided by the Water Services Trust Fund (WSTF) with 57% and by the Laikipia Wildlife Forum (LWF) with 43%.

A positive point is the good turn up of riparian land users and the fact that the WRUA members manage themselves independently. However, a part of the WRUA members is too less committed.

4.4.3 Case Study WRUA Kapingazi

In chapter 4.4.1, most of the basic information about WRUAs was given. In the following, the very specific features that complement the mentioned standard characterizations are pointed out.

In August 2002, a first informal convention of people took place discussing the actual water scarcity in the Kapingazi sub-catchment at that time. Indeed, this dry season had very low flows, which made some water abstractors come together because they were dependant on the water supply. Later on, they contacted the district water officer for authorization patrols to identify illegal abstractors. Also, the contact with WRMA was intensified to issue permits for the legal abstractors and a cooperation contract between WRMA and WRUA. In 2009, the WRUA obtained funding by the WSTF for capacity building and the drafting of the Sub-Catchment Management Plan (SMCP).

The planned activities from the SMCP were implemented in March 2011, consisting of an abstraction & pollution survey, a pegging and marking campaign and purchase of seedlings. The field campaign was performed in cooperation with the local chiefs. The WRUA, the WRMA and the local chief agreed on a date, afterwards the chief spread the information among the land users. At the meeting itself, the WRMA specialists promoted protective riparian land management practices. Topics were the removal of arrow root and eucalyptus trees as well as planting of Napier grass and water-friendly trees. About 50% to 60% of the stakeholders were participating at the meetings. Subsequently, the pegging campaign was performed to delineate the riparian zone. Patrols are done in the whole sub-catchment to control pollution and the adherence of irrigation restrictions during dry spells. A challenge was the problem that the motivation of the chiefs turned out to be a low, because they did not see any personal benefit in the approach. The WRUA members see it as a weakness that there are no possibilities to impose sanctions on people who do not apply the recommendations.

4.4.4 Assessment of Water Resource Management by Two WRUAs

To assess the management of water resources by the WRUAs, the “Dublin guiding principles for water resource management” and Elinor Ostrom’s “design principles of stable local common pool resource management” were chosen. Out of the 12 principles, 9 were chosen for the further process (see sub-chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**). By applying these 9 principles, the strengths and weaknesses relating to water management of the WRUA approach can be revealed (Ostrom 1990; Solanes & Gonzalez-Villarreal 1999). Subsequent the principles are being answered for the two WRUAs of the two sub-catchments.

(1) Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels

WRUA Naro Moru	**WRUA Kapingazi**
All riparian land users, water users, water abstractors and other stakeholders are welcome to join the meetings and activities of the WRUA. However only three elected people per administrative zone can take part at the committee meetings. The committee does not involve planners and policy-makers, but is in contact with them when working out their projects.	The WRUA is open to riparian land users, water users, water abstractors and other stakeholders are welcome. The committee does not involve planners and policy-makers, but is in contact with them when working out their projects.

(2) **Women** play a central part in the provision, management and safeguarding of water

WRUA Naro Moru	**WRUA Kapingazi**
The committee consists mostly of men, except of the treasurer who is a woman. At the meetings with the land users mostly men showed up. However, in one morning session the participation of women was significantly higher because most of the men had other business to do in the morning.	The participation of men and women at the barazza meetings was very different. In fact only 10% of the participants were women, while the other 90% were men. The reason for this is, that men are the land owners and family patriarch in the traditional Kenyan family.

(3) **Clearly defined boundaries** which defines who has rights to resource use and who has not

WRUA Naro Moru	WRUA Kapingazi
There is the possibility to apply for permits for water abstraction. This is the official way. However, many water abstractors use portable pumps for water abstraction. This cannot be controlled.	It is clearly defined which people are allowed either to be part of the WRUA and also who is allowed to abstract water and in which amount. If a land user wants to abstract water he can apply for a permit, otherwise it is not allowed.

(4) **Rules** regarding the appropriation and provision of common resources that are adapted to local conditions

WRUA Naro Moru	WRUA Kapingazi
The WRUA committee is giving out rules during dry seasons concerning the abstraction of water. This is affecting the portable pumps applied in the lower areas of the catchment. Also, people connected to the water project are urged to stop the irrigation of fields in these times.	In case of low river flows the water intakes connecting to neighbouring areas are urged to decrease the abstraction and irrigation has to be stopped.

(5) **Collective-choice arrangements** that allow most resource appropriators to participate in the decision-making process

WRUA Naro Moru	WRUA Kapingazi
It is mostly the committee members who decide about the activities and decisions of the WRUA. The base of all members is only being involved on the barazza meeting level. Decisions of the committee are made by the representatives, the committee members.	By definition the WRUAs are associations of water users, riparian land owners or other stakeholders. In the case of the Kapingazi WRUA this composition is unbalanced, since the majority of the WRUA members do not live in the catchment itself but in an area with a water intake bringing water from the Kapingazi catchment to their farms outside of the catchment. Their interest in the reliable provision of water to their farms is clear.

(6) Effective **monitoring** by monitors who are accountable

WRUA Naro Moru	**WRUA Kapingazi**
Monitoring has been done in the catchment in earlier times. But at the moment there are no funds for it, nobody is willing to do it at one's own expense. However, the WRUA members are well informed about the activities of their neighbours and in this way some kind of social control is possible.	Monitors are accountable since they are members of the WRUA. Unfortunately, there are mostly not enough funds to patrol regularly.

(7) A scale of **graduated sanctions** for resource appropriators who violate community rules

WRUA Naro Moru	**WRUA Kapingazi**
In fact, there are no sanctions that could be imposed by WRUA members. It is only agreed upon, that certain activities (i.e. 6 m riparian zone) are offending the water act. However, there is no institution which sanctions these violations.	There are no sanctions being imposed. It is a fact that sometimes individuals act against the law, but there is no institution which has the competence and the means to prosecute it.

(8) Mechanisms of **conflict resolution** that are cheap and of easy access

WRUA Naro Moru	**WRUA Kapingazi**
The WRUA Naro Moru is an institution that can be addressed if conflicts are coming up. Since many conflicts are grouped around water resources, it makes sense that the WRUA attends to them. The committee can be a mediator or can make contact with other concerned institutions.	Conflict resolution is a side task of the WRUA Kapingazi. However, the network might not be that effective in this, since most of the committee members are not residents in the sub-catchment but outside.

(9) **Self-determination of the community** recognized by higher-level authorities

WRUA Naro Moru	**WRUA Kapingazi**
After the registration of the WRUA, it is recognized as an association representing stakeholders of the water sector by governmental institutions.	

4.4.5 Overview of Weaknesses and Strengths

The preceding sub-chapter addressed important principles of successful water management systems and in what way the two WRUAs were fulfilling these principles or not. Subsequently, the major weaknesses and strengths are discussed.

Major weaknesses of the two WRUAs:

- The first weakness is addressing principle no. 5 which is not fulfilled in both of the sub-catchments. In both sub-catchments the participation is reaching a level of about 60% and often the participation is due to the free seedlings that are provided. A better acceptance could be reached if the participation was higher. A special fact in the Kapingazi WRUA committee is that surprisingly many members are residents outside of the catchment, being dependant on water abstractions. This distorts the goals of the WRUA, because this sub-group gets an over proportional influence.
- A weakness in both sub-catchments is the missing possibility to pursue violations of the laws and commonly agreed rules of the WRUA. For example the legally prescribed 6 m of riparian zone is violated often, but monitors can only advise land users instead of more effective measures like direct sanctions.
- It is still a fact that gender equality is not yet reached in Kenya. Especially property laws are commonly associated with men. This diminishes the participation possibilities of women drastically.

Major strengths of the two WRUAs:

- The foundation of the WRUA provides nearly no financial incentives for the members. This is on the one hand cost effective, on the other hand it attracts especially motivated people to the institution.
- As a side effect, the regular meetings of the water users are also a good occasion to discuss unresolved conflicts, before they develop severe consequences. It is thus an institution for uncomplicated and early conflict resolution.

5 Conclusion and Outlook

The goal of this study was to get a broader view on the condition and management of riparian zones in the Mt. Kenya area. This includes the assessment of effects that land use systems have on adjacent riparian zones in terms of land degradation and conservation. A further interest was a forest cover comparison between the years 1961 and 2011. Another objective was the identification of certain land management practices and their effect on ecosystem services as well as an investigation of WRUAs (Water Resource Users Associations) on their ways and means of spreading land management technologies.

The investigation of riparian land use systems in the Naro Moru sub-catchment ended in the definition of 5 land use types: cropland, grazing & bushland, large scale grazing land, used forest and natural forest. The distribution pattern was different in the three zones considered and different degradation and conservation conditions in the adjacent riparian zones were identified. Conservation measures like tree planting, Napier grass and rotational grazing were only applied on cropland and large scale grazing land while riverbank degradation and vegetation decline affected mostly cropland as well as grazing & bushland.

The analysis of the forest cover revealed some clear trends. In 1961, the riparian forest cover was between 60% and 70% in the savannah and foot zone. This percentage decreased to values between 30% and 40% in 2011, due to land use change. Grazing & bushland was mostly converted to cropland and riparian forests were diminished. In the forest zone, the riparian forest cover from 1961 could not be determined because aerial photographs were missing. In 2011 though, the cover in the forest zone accounted to 76%.

Altogether, eight land management practices have been assessed mainly focusing on ecosystems services and labour input. Six sustainable land management practices could be identified. Three land management practices have a productive focus, three a protective focus, one is an overexploiting management and one a neglecting management. It turned out that the productive and protective land management practices are much more successful in providing ecosystem services. Nevertheless, there is a trade-off between production and protection.

The two “bad” land management practices exist because of different reasons. One is very productive and thus attractive for the land user, although exerting many ecosystem disadvantages. The other is a public land plot where nobody is interested in prohibition of degradation.

WRUAs are responsible for the management of water resources. Strengths of the association are the commitment of the members, which is a result of its voluntary structure and the regular meetings as a discussion forum also for conflict resolution. Weaknesses of them are unequal participation in terms of gender, unequal representation of the stakeholders in the committee and the missing possibility to pursue violations of the rules.

WRUA are an effective way of spreading sustainable land management practices. Reasons are the grassroots approach they are based on and the great commitment of the members.

The WOCAT tools, especially the Approaches and Technologies Questionnaires are a good guideline for a comprehensive investigation. They help to cover all important aspects. The drawback is their large number of questions and complicated user guidance that gets only comfortable after some interviews. The WOCAT Mapping Questionnaire is more open in its application and leads thus to more diverse results that might worsen comparability.

This thesis underlines the importance of riparian zones and riparian forest and their necessity for community and nature. There are possibilities which improve the condition of these areas and lead to benefits for all stakeholders. Nevertheless, increasing population forces the people to meet their basic human needs and forgetting long term perspectives. The goal of the water management should be to provide enough and good quality water for all stakeholders although demand is growing and supply is far from having a reliable development in the future.

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Figures & Tables

Appendix

Appendix A	Thresholds for assessment of land management practices
Appendix B	WOCAT Technology Summaries
DVD Appendix	Shapefiles and rasters for the GIS maps in the thesis
	Thesis in pdf format

Appendix A - Thresholds for assessment of land management practices

	excellent	good	average	fair	poor
Production and socio-economic benefits and disadvantages	excellent > 7	7 > good > 4	4 > average > 1	1 > fair > -1.5	-1.5 > poor
Socio-cultural benefits and disadvantages	excellent > 3.5	3.5 > good > 2	2 > average > 0.5	0.5 > fair > -1.5	-1.5 > poor
Ecological benefits and disadvantages	excellent > 15	15 > good > 9	9 > average > 3	3 > fair > -3	-3 > poor
Off-site benefits and disadvantages	excellent > 7	7 > good > 3	3 > average > 1	1 > fair > -3	-3 > poor
Establishment labour input [US$]	excellent < 10	10 < good < 50	50 < average < 100	100 > fair > 150	150 < poor
Maintenance labour input [US$]	excellent < 10	10 < good < 30	30 < average < 80	80 > fair > 150	150 < poor

Appendix B - WOCAT Technology Summaries

Trees in the riparian area as a protective and aesthetic advantage at Naro Moru River
Kenya

Trees are planted along the riparian zone to stabilize the riverbank and to prevent degradation. The wood can be used to establish a building or to generate income on the market.

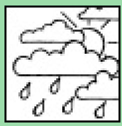
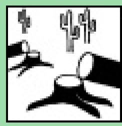
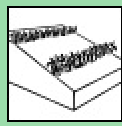
At the foot slopes of Mt. Kenya a farmer has developed a technology to protect the own land plot from riverbank erosion. The technology consists of three main measures: A wall along the riverbed, trees that are aligned on the wall as well as beside it and Napier grass wildly scattered between the trees. The wall was built on a highly exposed spot of the riverbank. Trees along and beside the wall ensure its stability. The combination of the two measures results in an effective protection of the riverbank in terms of erosion. Side effects of the technology are higher runoff during the dry season, better water quality due to less erosion and an improved riparian habitat for animals and plants.
For a small scale farmer, planting of trees can have advantages in an economic, an ecologic and an aesthetic point of view. The trees stabilize the soil, allow the riparian vegetation to establish, and prevent major damages through flooding. Furthermore, there are several advantages of an intact riparian zone, such as enhanced biodiversity, increased water quality as well as retention of agrochemicals. The trees also work as a kind of bank account, since the prices for wood are quite high. Trees can be cut and sold from time to time to generate an income that can be used for further investments like local entrepreneurship or building houses for family members. Last but not least, the farmer emphasized the beautiful appearance of the trees including the relatively cool micro- climate the trees are able to provide during the hot months of the dry period.
The trees were planted during the rainy season. Braches are pruned regularly and provide mulch material as well as fire wood. When trees are reaching maturity they will selectively be cut and replanted. The Napier grass is cut regularly for fodder to be feed to animals. At this particular time, there is a regular hay yield (weed). Seedlings for trees and the grasses are produced on site. Occasional pruning ensures fuel wood supply.
The plot is situated at the western side of Mt. Kenya in its foot zone, a moderate hilly region. Actually, the foot zone is a transition area between the humid mountain forest above elevations of 2500 m.a.s.l and the semi-arid savannah zone below 2000 m a.s.l. Although the region is located in the rain shadow of Mt. Kenya, there is just enough precipitation (740mm) to sustain rain fed agriculture and the farmers even benefit from a water project. During the last decades, the region has experienced a still continuing population growth which increases population pressure in the area. The good accessibility and the moderate tourism allow even off-farm income-generation.

left: Riparian trees and some Napier grass. River is in the back. (Photo: Manuel Fischer)
right: Farmer in front of young riparian trees. (Photo: Manuel Fischer)

Location: Kenya/Central Province
Region: Naro Moru
Technology area: < 0.1 km2 (10 ha)
Conservation measure: vegetative
Stage of intervention: prevention of land degradation
Origin: Developed through land user`s initiative, recent (<10 years ago)
Land use type:
Cropland: Annual cropping
Land use:
Cropland: Annual cropping (before), Forests / woodlandsrests / woodlands: Plantations, afforestations (after)
Climate: subhumid, subtropics
WOCAT database reference: T_KEN656en
Related approach: Water Resource Users Association for the management of water resources in a river sub-catchment (A_KEN019en)
Compiled by: Manuel Fischer, CDE Centre for Development and Environment
Date: 2012-11-14
Contact person: Wanjiru Cecilia,

Classification

Land use problems:
- Surface water pollution and riverbank degradation as well as a diminished habitat of riparian flora and fauna. (expert's point of view)
An unstable riparian zone being eroded by the river and unattractive aesthetics. (land user's point of view)

Land use	Climate	Degradation	Conservation measure
		  	
Annual cropping Cropland: Annual cropping (before) Forests / woodlandsrests / woodlands: Plantations, afforestations (after)	subhumid	Soil erosion by water: riverbank erosion, Biological degradation: quality and species composition /diversity decline, Water degradation: decline of surface water quality	vegetative: Tree and shrub cover

Stage of intervention

- Prevention
- Mitigation / Reduction
- Rehabilitation

Origin

- Land users initiative: recent (<10 years ago)
- Experiments / Research
- Externally introduced

Level of technical knowledge

- Agricultural advisor
- Land user

Main causes of land degradation:
Direct causes - Human induced: deforestation / removal of natural vegetation (incl. forest fires), over-exploitation of vegetation for domestic use
Indirect causes: population pressure, education, access to knowledge and support services

Main technical functions:
- increase of infiltration
- improvement of water quality, buffering / filtering water
- sediment retention / trapping, sediment harvesting
- stabilization of riverbank by trees and grasses

Secondary technical functions:

Environment

Natural Environment

Average annual rainfall (mm)

- > 4000 mm
- 3000-4000 mm
- 2000-3000 mm
- 1500-2000 mm
- 1000-1500 mm
- 750-1000 mm
- 500-750 mm
- 250-500 mm
- < 250 mm

Altitude (m a.s.l.)

- > 4000
- 3000-4000
- 2500-3000
- 2000-2500
- 1500-2000
- 1000-1500
- 500-1000
- 100-500
- <100

Landform

- plateau / plains
- ridges
- mountain slopes
- hill slopes
- footslopes
- valley floors

Slope (%)

- flat
- gentle
- moderate
- rolling
- hilly
- steep
- very steep

Soil depth (cm)

- 0-20
- 20-50
- 50-80
- 80-120
- >120

Growing season(s): 90 days (april to may), 90 days (october to november)
Soil fertility: high
Topsoil organic matter: medium (1-3%)
Soil drainage/infiltration: good

Ground water table: < 5 m
Availability of surface water: good
Water quality: good drinking water

Tolerant of climatic extremes: temperature increase, seasonal rainfall increase, seasonal rainfall decrease, heavy rainfall events (intensities and amount), wind storms / dust storms, floods, droughts / dry spells, decreasing length of growing period

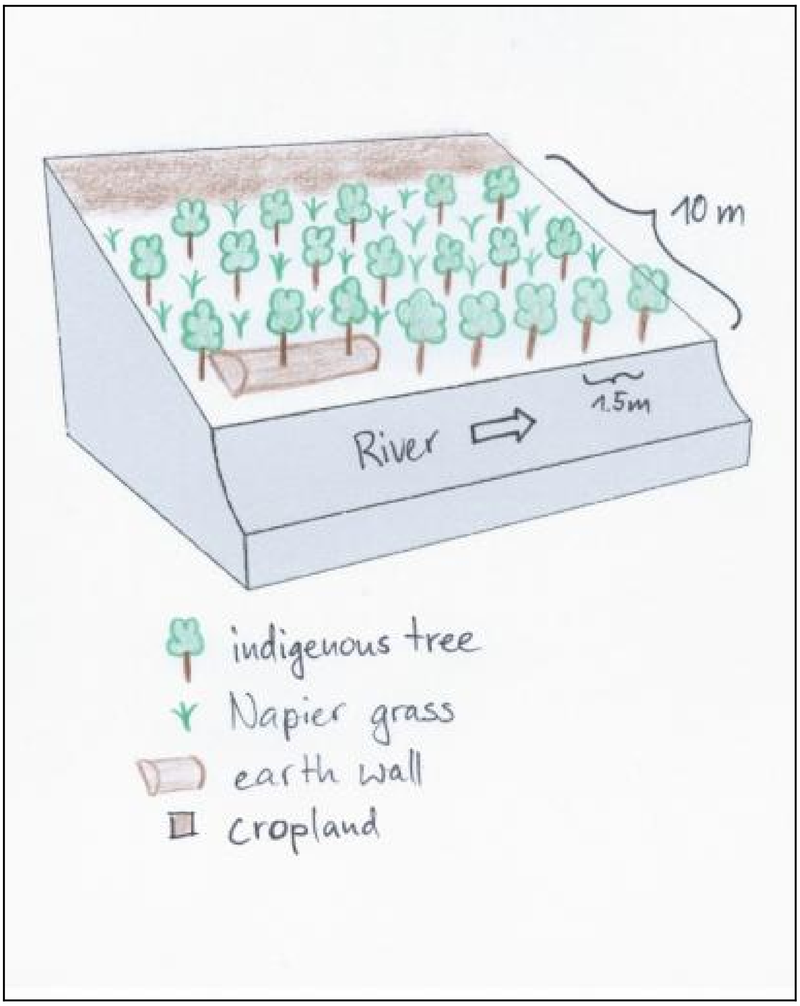
Human Environment

Cropland per household (ha)

- <0.5
- 0.5-1
- 1-2
- 2-5
- 5-15
- 15-50
- 50-100
- 100-500
- 500-1,000
- 1,000-10,000
- >10,000

Land user: Individual / household, Small scale land users, common / average land users, men and women
Population density: 200-500 persons/km2
Land ownership: individual, not titled
Land use rights: individual
Water use rights: communal (organised) (Mostly small scale farmers are using the land.)
Relative level of wealth: average

Importance of off-farm income: less than 10% of all income:
Access to service and infrastructure: moderate: technical assistance, employment (eg off-farm), market, financial services; high: health, education, roads & transport, drinking water and sanitation
Market orientation: subsistence (self-supply)
Mechanization: manual labour
Livestock grazing on cropland: no



Technical drawing

Indigenous trees, a wall and Napier grass are installed between the agricultural land and the river. The wall prevents erosion at a very endangered spot. The trees and the grass provide fodder and wood. (Manuel Fischer)

Implementation activities, inputs and costs

Establishment activities

- Setting up a tree nursery
- Planting seedlings
- Establishment of wall

Establishment inputs and costs per ha

Inputs	Costs (US$)	% met by land user
Labour	77.77	100%
TOTAL	**78.00**	**100.00%**

Maintenance/recurrent activities

- Replanting trees that dried up
- Cutting the Napier grass and pruning trees

Maintenance/recurrent inputs and costs per ha per year

Inputs	Costs (US$)	% met by land user
Labour	33.33	100%
TOTAL	**33.00**	**100.00%**

Remarks:

Establishment has been carried out over a time period of 5 years. Considering this time frame, the establishment costs are smaller than the maintenance costs. The costs per hectare were calculated for a riparian area with the length of 100 m and a width of 10 m, since hectares are difficult to apply in a riparian context. The determining factor for the costs is labour. In this case, the labour costs are quite high because the seedlings were produced in the own nursery. This explains the high labour costs. Some of the seedlings had to be replanted, because they dried up. The required equipment like a spade is available on nearly every farm or can be borrowed from neighbours and is thus not added to the costs.

Assessment

Impacts of the Technology

Production and socio-economic benefits

+++ increased fodder production
+++ increased wood production

Production and socio-economic disadvantages

+ reduced crop production

Socio-cultural benefits

++ improved conservation / erosion knowledge
++ improved aesthetics

Socio-cultural disadvantages

Ecological benefits

+++ improved soil cover
+++ reduced soil loss
+++ reduced riverbank erosion
++ improved excess water drainage
++ increased beneficial species
++ reduced flooding impact
+ reduced surface runoff

Ecological disadvantages

Off-site benefits

++ increased stream flow in dry season
++ reduced downstream siltation
++ reduced groundwater river pollution
++ reduced damage on public / private infrastructure

Off-site disadvantages

Contribution to human well-being / livelihoods

Benefits /costs according to land user

Benefits compared with costs	short-term:	long-term:
Establishment	very negative	very positive
Maintenance / recurrent	negative	very positive

Acceptance / adoption:

100% of land user families have implemented the technology voluntary.

Concluding statements

Strengths and → how to sustain/improve	Weaknesses and → how to overcome
Wood production through selective felling is sustainable. → No widespread felling of trees, only selective intervention.	There is less crop yield, because an area of the plot was formerly used for maize production and now it is part of the riparian. → The productive and protective benefits of the riparian overcome decreased size of the agricultural plot.
Fodder production enables the keeping of cattle. → Before dry periods, some fodder should be stored to ensure fodder supplies.	
There is a recreational aspect of the riparian zone. Especially during hot days the farmer is enjoying the slightly colder temperatures because of the canopy and the cooling stream. The aesthetic aspects of the riparian are also enhanced. → If the canopy of the riparian is maintained, it can serve still as recreation area and convince with beautiful looks.	
Long term benefits in terms of wood and timber provided by the trees. → If trees are not chopped too early, they will have a good price on the market.	
The maintenance of the riparian is not tiring and still gives a good harvest. → Benefits can be sustained by continuing the management practices.	
Diversification: Formerly, there was maize at the river, but it died due to cold temperatures. Forests do not die due to frost. → Every plant has its special needs that should be kept in mind.	


Tree row and grass strip to sustain filtering and productive function of the riparian zone

Kenya

Tree line with adjacent grass strips as example of a productive and protective riparian area at Kapingazi River

On the south-eastern slopes of Mt. Kenya, the conditions are ideal for agricultural activities. There is plenty of rainfall (2100 mm/year) which is usually reliable. However in the year 2000, the river Kapingazi dried up for the first time since many decades during a dry spell. This led to community activities that finally came up with a system of vegetative interventions to strengthen the riparian zones. The intervention consists of tree planting and establishment of grass strips along the river. Napier grass is planted to stabilize steep slopes and to supply material for the construction of tea baskets.
The goals of this technology are manifold. Firstly, the vegetation prevents surface water and eroded soil flowing from the agricultural fields directly into the river. Therefore, sediments and chemicals used on the field are retained in the riparian soils and do not pollute the river. Surface water flow from runoff during heavy storms is slowed down and infiltration on soils covered by grass and trees is increased. As a result more groundwater is recharged during the wet seasons, which can be released during the dry season. Thus peak or flood flows are reduced and low flows are improved. Damage during flood flows on the riverbank (through erosion and destabilizing the riparian vegetation) as well as damages of floods downstream can be reduced or avoided.
Before planting the indigenous trees, water guzzlers like eucalyptus trees were cut down. Indigenous seedlings were planted right along the river at a distance of 2m. Between the trees and the tea plantation a grass strip of up to 10m is established. Some trees were planted scattered on the grass strip. The young trees are surrounded by grasses which are cut regularly every 2 weeks. This reduces competition and enhances growth of the trees. As soon as the trees are big enough, they function as a source of firewood, they can be pruned every 5 months.
The studied plot is situated right below the natural mountain forest of Mt. Kenya at the south-eastern slope. The source of Kapingazi River can be found at 1.5 km of walking distance upslope of the plot. Agricultural circumstances are good because of the fertile, volcanic plots and the abundant precipitations. However, the terrain is quite steep. The zone which is used for tea production reaches from an elevation of 1700 m.a.s.l to 2000 m.a.s.l. Most tea farmers own between 4 and 20 acres. The area of the riparian zone covers 6 m from the river edge and belongs to the government. Since the harvest of the tea leaves requires a high labour input, local workers are hired. Most of the harvest is done during the rainy season because the tea plants are growing fast in this period. For the tea production only the youngest leaves are used, transported in a basket on the worker’s back to the tea factory in the evening.

left: A grass strip and trees have productive and protective effects on the riparian area. (Photo: Manuel Fischer)
right: Beehives do perform very well in riparian areas and provide an additional income. (Photo: Manuel Fischer)

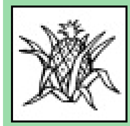
Location: Kenya/Eastern Province
Region: Embu
Technology area: < 0.1 km2 (10 ha)
Conservation measure: vegetative
Stage of intervention: prevention of land degradation, mitigation / reduction of land degradation
Origin: Developed through land user`s initiative, recent (<10 years ago); externally / introduced through project, recent (<10 years ago)
Land use type:
Cropland: Perennial (non-woody) cropping
Climate: subhumid, subtropics
WOCAT database reference: T_KEN654en
Related approach: Water Resource Users Association for the management of water resources in a river sub-catchment (A_KEN018en)
Compiled by: Manuel Fischer, CDE Centre for Development and Environment
Date: 2012-11-08
Contact person: Mary Njagy Muthoni, Tel: 0727 906 945

Classification

Land use problems:

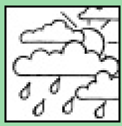
- The main land use problems are pollution of the riverwater, low rainwater storage that provokes floods, too few water during the dry season and riverbank erosion. (expert's point of view)
The main problem is the few water in the dry season that prevents irrigation. (land user's point of view)

Land use



Perennial (non-woody) cropping

Climate

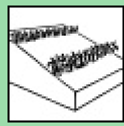


subhumid

Degradation

Water degradation: decline of surface water quality, reduction of the buffering capacity of wetland areas

Conservation measure



vegetative: Tree and shrub cover
vegetative: Grasses and perennial herbaceous plants

Stage of intervention

Prevention
Mitigation / Reduction
Rehabilitation

Origin

Land users initiative: recent (<10 years ago)
Experiments / Research
Externally introduced: recent (<10 years ago)

Level of technical knowledge

Agricultural advisor
Land user

Main causes of land degradation:
Direct causes - Human induced: deforestation / removal of natural vegetation (incl. forest fires)
Indirect causes: education, access to knowledge and support services, planting directly next to river

Main technical functions:
- improvement of ground cover
- increase of infiltration
- sediment retention / trapping, sediment harvesting

Secondary technical functions:
- promotion of vegetation species and varieties (quality, eg palatable fodder)

Environment

Natural Environment

Average annual rainfall (mm)

> 4000 mm
3000-4000 mm
2000-3000 mm
1500-2000 mm
1000-1500 mm
750-1000 mm
500-750 mm
250-500 mm
< 250 mm

Altitude (m a.s.l.)

> 4000
3000-4000
2500-3000
2000-2500
1500-2000
1000-1500
500-1000
100-500
<100

Landform

plateau / plains
ridges
mountain slopes
hill slopes
footslopes
valley floors

Slope (%)

flat
gentle
moderate
rolling
hilly
steep
very steep

Soil depth (cm)

0-20
20-50
50-80
80-120
>120

Growing season(s): 60 days (april to may), 60 days (november to december)
Soil texture: medium (loam)
Soil fertility: medium
Topsoil organic matter: medium (1-3%)
Soil drainage/infiltration: good

Soil water storage capacity: very high
Ground water table: < 5 m
Water quality: good drinking water
Biodiversity: medium

Tolerant of climatic extremes: temperature increase, seasonal rainfall increase, seasonal rainfall decrease, heavy rainfall events (intensities and amount), wind storms / dust storms, decreasing length of growing period
Sensitive to climatic extremes: floods

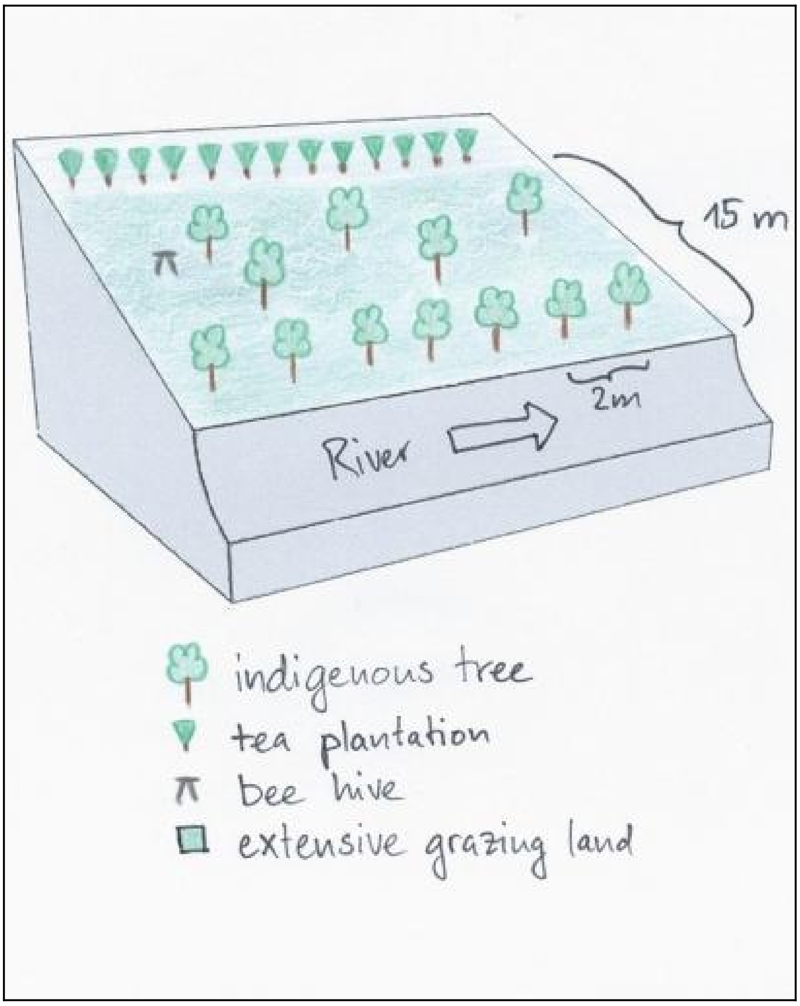
Human Environment

Cropland per household (ha)

<0.5
0.5-1
1-2
2-5
5-15
15-50
50-100
100-500
500-1,000
1,000-10,000
>10,000

Land user: employee (company, government), medium scale land users, Leaders / privileged, men and women
Population density: > 500 persons/km2
Land ownership: individual, not titled
Land use rights: individual
Water use rights: individual
(Land user was a former member of parliament)
Relative level of wealth: rich

Importance of off-farm income: > 50% of all income: Owner is a member of the parliament.
Access to service and infrastructure: low: financial services; moderate: health, technical assistance, market, energy; high: education, employment (eg off-farm), roads & transport, drinking water and sanitation
Market orientation: commercial / market
Mechanization: manual labour
Livestock grazing on cropland: no



Technical drawing

The area between the river and the tea plantation is used to establish a riparian habitat. Trees are planted along the river and also on the adjacent grazing land. The grass is cut regularly and used as fodder. A bee hive was installed to generate additional income. (Manuel Fischer)

Implementation activities, inputs and costs

Establishment activities

- Tree planting
- Replanting of seedlings which dried up
- Planting trees

Establishment inputs and costs per ha

Inputs	Costs (US$)	% met by land user
Labour	10.50	100%
Agricultural		
- seedlings	4.00	0%
TOTAL	**14.50**	**72.41%**

Maintenance/recurrent activities

- Weeding the area around the trees to get fodder and boost the tree growth
- Weeding the lawns for better growth of the trees and for fodder

Maintenance/recurrent inputs and costs per ha per year

Inputs	Costs (US$)	% met by land user
Labour	21.33	100%
TOTAL	**21.33**	**100.00%**

Remarks:

The costs were calculated for a riparian area with a length of 100m and a width of 10m, since hectares are difficult to apply on a riparian context. The determinant factor for the costs is labour. In this case, the costs are very low because the trees were only planted every 10 metres along the riparian. The seedlings have to be bought in a nursery. Most of the bushes regrow naturally and do not need any management. Some of the seedlings had to be replanted, because they dried up. The required equipment like a spade is available on nearly every farm or can be borrowed from neighbours and is thus not added to the costs.

Assessment

Impacts of the Technology

Production and socio-economic benefits

- ++ increased fodder production
- ++ Napier grass for basket production.
- \+ increased wood production

Production and socio-economic disadvantages

- \+ reduced crop production
- \+ decreased farm income

Socio-cultural benefits

- ++ improved cultural opportunities
- \+ improved conservation / erosion knowledge

Socio-cultural disadvantages

Ecological benefits

- +++ reduced riverbank erosion
- ++ reduced surface runoff
- \+ increased water quality
- \+ improved harvesting / collection of water
- \+ increased soil moisture
- \+ improved soil cover
- \+ increased animal diversity
- \+ increased plant diversity
- \+ increased / maintained habitat diversity

Ecological disadvantages

Off-site benefits

- ++ increased stream flow in dry season
- ++ reduced downstream siltation
- ++ reduced groundwater river pollution

Off-site disadvantages

Contribution to human well-being / livelihoods

- \+ Through the increase of the water quality, the technology improves the access to clean water.

Benefits /costs according to land user

Benefits compared with costs	short-term:	long-term:
Establishment	slightly negative	positive
Maintenance / recurrent	slightly negative	slightly positive

Acceptance / adoption:

70% of land user families have implemented the technology with external material support. 10% of all the riparian land users have adopted the technology. The external support was the provision of seedlings.
30% of land user families have implemented the technology voluntary.
There is moderate trend towards (growing) spontaneous adoption of the technology. Through the action of several organisations, the attention of the land users is drawn to a proper riparian management.

Concluding statements

Strengths and → how to sustain/improve

A vivid and stable riparian ecosystem is the key to ensure biodiversity and stability of the riverbanks. This leads to a smaller vulnerability to floods or droughts and combats degradation. → continuous awareness raising among the land users.

The river does not dry up easily during dry seasons. The grass yield can be used for fodder purposes. → disseminating the knowledge among the farmers.

Weaknesses and → how to overcome

Labour input for weeding is high → cutting grass at a bigger height

Productive use of the riparian area using Napier grass and protection of the riverbank with indigenous trees at Kapingazi River

Kenya

left: Trees stabilizing the riverbank, Napier grass in the back. (Photo: Manuel Fischer)
right: Ground stabilizing Napier grass that is used for fodder. (Photo: Manuel Fischer)

Location: Kenya/Eastern Province
Region: Embu
Technology area: < 0.1 km2 (10 ha)
Conservation measure: vegetative
Origin: Developed through land user`s initiative, 10-50 years ago
Land use:
Cropland: Annual cropping (before), Grazing land: Intensive grazing/ fodder production (after)
Climate: subhumid, tropics
WOCAT database reference: T_KEN655en
Related approach: Water Resource Users Association for the management of water resources in a river sub-catchment. (A_KEN018en)
Compiled by: Manuel Fischer, CDE Centre for Development and Environment
Date: 2012-11-16
Contact person: Robinson Nyaga, 0726-408-839

A riparian area that is frequently flooded requires a special treatment because conventional agriculture is not possible. Trees along the riverbank and Napier grass on the remaining space still allow a productive use despite the difficult circumstances.

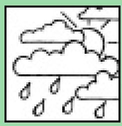
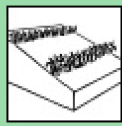
On the southeastern slopes of Mt. Kenya, the circumstances are ideal for agricultural activities, the rains are plenty and normally reliable. The plot owner started realizing a problem of riverbank degradation 17 years ago. But still he continued the traditional way of agriculture, planting beans and maize. Since his plot is on the slip-off slope only few metres above the river level, it experienced regular floods in case of heavy rainfalls, destroying the plants and leading to crop failures. Conventional plants like maize and beans do not resist such an excess of water. To fight the land loss and the bad harvest, the farmer introduced indigenous trees along the river and Napier fighting the riverbank degradation. Behind that, several rows of the flood resistant Napier grass were planted to still use the area in a productive way.
Above all, the goal of this technology is to get a high grass production. As a side effect results a quite good protection of the riparian area. The vegetation prevents rainwater from running directly from the fields into the water. Therefore, the chemicals from the field get stuck in the riparian soils and don't pollute the river. In the same way the infiltration in the riparian enlarges the total infiltration since the water would go to the river directly. Especially the raw surface of the riparian allows more infiltration and interception storage of water. This surplus of stored water is able to provide river water for a longer period, when rains are humble for a longer period. In case of floods, the increased infiltration potential can cut the peak flow and thus prevent damages. The grass yield is used as a fodder for the cows.
Before planting the indigenous trees, water guzzlers like eucalyptus trees were cut down. Indigenous seedlings were planted right along the river at a distance of 1 m. Behind the tree row, Napier grass is planted and harvested twice a year. The cutting and harvesting of the grass is done regularly such that animals can be provided with fodder every day. As soon as the trees are big enough, they function as a source of fire wood, they can be pruned every 5 months.
The studied plot is situated between the tea and the coffee zone at an elevation of 1663 m.a.s.l. This small-scale farm does not produce tea nor coffee, there is mainly subsistence agricultural production and some few products are sold on the market. Rainfall is reliable and ensures a regular production.

Classification

Land use problems:

- The excessive water on the plot hinders conventional agriculture and the floods lead to riverbank degradation. (expert's point of view)

The land plot is situated right beside the river and is less than a metre above the river. Flood destroyed regularly the harvest of maize or french beans. Parts of the riparian have been removed. (land user's point of view)

Land use	Climate	Degradation	Conservation measure
			
Cropland: Annual cropping (before) Grazing land: Intensive grazing/ fodder production (after) intensive grazing land rainfed	subhumid	Soil erosion by water: riverbank erosion, Water degradation: decline of surface water quality	vegetative: Grasses and perennial herbaceous plants

Stage of intervention

- ■ Prevention
- ■ Mitigation / Reduction
- □ Rehabilitation

Origin

- ■ Land users initiative: 10-50 years ago
- □ Experiments / Research
- □ Externally introduced

Level of technical knowledge

- ■ Agricultural advisor
- ■ Land user

Main causes of land degradation:
Direct causes - Human induced: over-exploitation of vegetation for domestic use
Direct causes - Natural: floods

Main technical functions:
- stabilisation of soil (eg by tree roots against land slides)
- improvement of water quality, buffering / filtering water

Secondary technical functions:
- improvement of ground cover

Environment

Natural Environment

Average annual rainfall (mm)

- □ > 4000 mm
- □ 3000-4000 mm
- □ 2000-3000 mm
- ■ 1500-2000 mm
- □ 1000-1500 mm
- □ 750-1000 mm
- □ 500-750 mm
- □ 250-500 mm
- □ < 250 mm

Altitude (m a.s.l.)

- □ > 4000
- □ 3000-4000
- □ 2500-3000
- □ 2000-2500
- ■ 1500-2000
- □ 1000-1500
- □ 500-1000
- □ 100-500
- □ <100

Landform

- □ plateau / plains
- □ ridges
- □ mountain slopes
- □ hill slopes
- ■ footslopes
- □ valley floors

Slope (%)

- ■ flat
- □ gentle
- □ moderate
- □ rolling
- □ hilly
- □ steep
- □ very steep

Soil depth (cm)

- □ 0-20
- □ 20-50
- □ 50-80
- □ 80-120
- ■ >120

Growing season(s): 90 days (march to may), 90 days (october to december)
Soil texture: medium (loam)
Soil fertility: low
Topsoil organic matter: low (<1%)
Soil drainage/infiltration: good

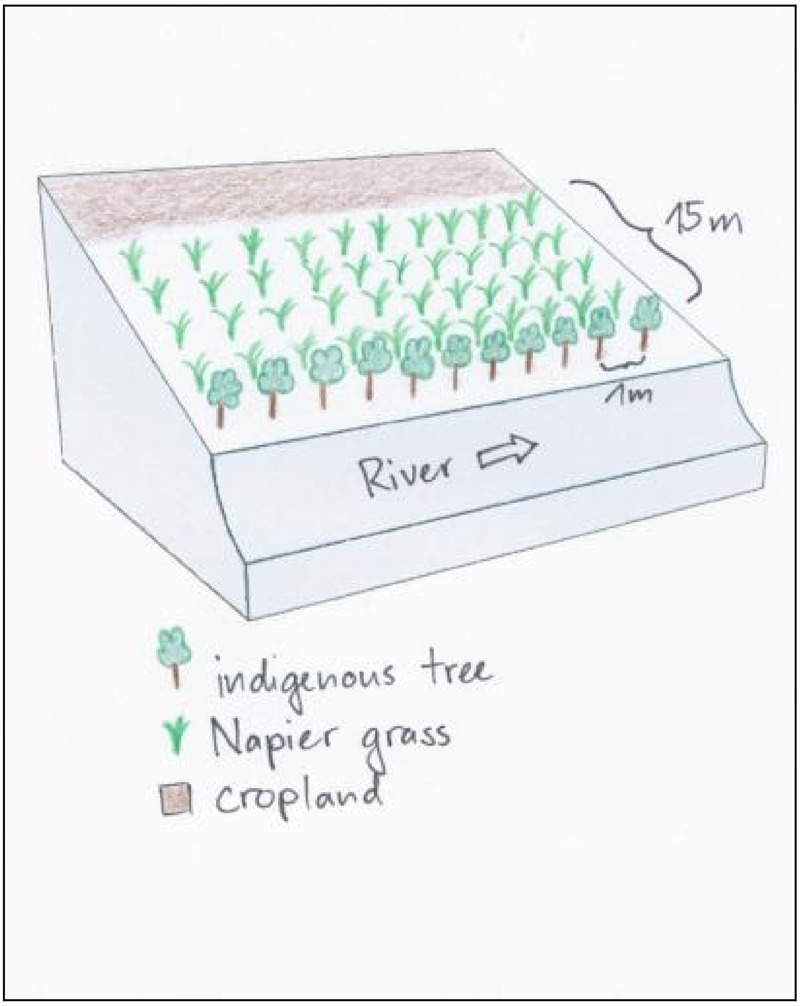
Soil water storage capacity: medium
Ground water table: < 5 m
Availability of surface water: good
Water quality: poor drinking water
Biodiversity: medium, low

Tolerant of climatic extremes: temperature increase, seasonal rainfall increase, heavy rainfall events (intensities and amount), wind storms / dust storms, decreasing length of growing period
Sensitive to climatic extremes: seasonal rainfall decrease, floods, droughts / dry spells

Human Environment

Land user: Individual / household, Small scale land users, common / average land users, men and women
Population density: > 500 persons/km2
Land ownership: individual, not titled
Land use rights: individual
Water use rights: individual
(Abstractions are controlled by the local Water Resource Users association (WRUA), but everybody can take water by hand.)

Importance of off-farm income: less than 10% of all income:
Access to service and infrastructure: low: employment (eg off-farm), financial services; moderate: health, technical assistance, market, energy; high: education, roads & transport, drinking water and sanitation



Technical drawing

A tree row is aligned directly beside the riverbed with a spacing of 1m. Directly behind the trees, Napier grass is planted up to a width of 15m. Adjacent to the Napier grass, there is cropland. (Manuel Fischer)

Implementation activities, inputs and costs

Establishment activities

- Chopping bad trees
- Tree planting
- Planting of Napier grass

Establishment inputs and costs per ha

Inputs	Costs (US$)	% met by land user
Labour	52.80	100%
Agricultural		
- seedlings	13.00	100%
TOTAL	**65.80**	**100.00%**

Maintenance/recurrent activities

- Adding manure
- Harvest of Napier
- Pruning

Maintenance/recurrent inputs and costs per ha per year

Inputs	Costs (US$)	% met by land user
Labour	22.00	100%
TOTAL	**22.00**	**100.00%**

Remarks:

The plot is situated right at the riverside and gets flooded regularly. 70 trees were planted along the river in one row. The area of the Napier grass is approximately 750m2 big, harvest is two times a year. Costs were calculated in 2012. The costs per hectare were calculated for a riparian area with a length of 100m and a width of 10m, since hectares are difficult to apply on a riparian context. The determinant factor for the costs is labour and the area of the plot. The required equipment like a spade is available on nearly every farm or can be borrowed from neighbours and is thus not added to the costs.

Assessment

Impacts of the Technology

Production and socio-economic benefits	Production and socio-economic disadvantages
+++ increased fodder production +++ reduced risk of production failure ++ increased animal production ++ diversification of income sources ++ increased fuelwood production through pruning	++ reduced crop production

Socio-cultural benefits	Socio-cultural disadvantages
++ improved conservation / erosion knowledge + improved food security / self sufficiency	

Ecological benefits	Ecological disadvantages
+++ stabilization of riverbank ++ increased water quality ++ increased plant diversity + improved soil cover + increased / maintained habitat diversity + increased infiltration	

Off-site benefits	Off-site disadvantages
++ reduced groundwater river pollution ++ increased river water quality and quantity + increased stream flow in dry season + reduced downstream siltation	

Contribution to human well-being / livelihoods

Benefits /costs according to land user

Benefits compared with costs	short-term:	long-term:
Establishment	negative	positive
Maintenance / recurrent	negative	positive

Establishment and maintenance costs are quite low.

Acceptance / adoption:

15% of land user families have implemented the technology voluntary.
There is moderate trend towards (growing) spontaneous adoption of the technology. The knowledge is spreading and people acknowledge the benefits.

Concluding statements

Strengths and → how to sustain/improve	Weaknesses and → how to overcome
Riverbank stabilisation due to the plantation of trees. → A good idea would be to establish a second row of trees along the river and thus enlarging the number of trees and their positive effects on riverbank stabilisation and filtering of the runoff.	After the harvest of the Napier, the land is bare and vulnerable to erosion. → Instead of cutting the whole plot at once, only a quarter of the Napier grass should be cut at once. So that the land is not completely vulnerable to rain.
Protection of the riverbank and reduced riverbank erosion. → Regular management of riparian trees by replacing dead trees with new ones.	
Productive function of the Napier grass in terms of fodder and of the trees in terms of pruning for fire wood. → Careful use of the trees and the grass enables a sustainable use of the plants.	
No more crop failures. → One should only cultivate plants that can cope with the local excess or scarcity of water.	

Riparian forest to improve riverbank stabilization

Kenya

Protection of the riparian zone at Kapingazi River by leaving it undisturbed of human interference

The farmers' land plot is situated right alongside the river. Heavy floods have eroded a major part of the riverbank and have led to crop failures on the arable land. The farmer reacted to the degradation by stopping agriculture activities on a certain riparian area in order to enable natural vegetation to reclaim the area. The idea is that during the next years, further floods will deposit sediments, which will increase the elevation and fertility of the plot. As soon as enough soil has accumulated and the elevation has increased enough, the farmer wants to plant French beans in the area. Trees were planted in the riparian zone to stabilize the riverbank and to ensure water quality in the river by retaining sediments from nearby fields. Agricultural chemicals are trapped in the riparian buffer as well.
The purpose is to deal with the regular floods of Kapingazi River and to gain advantages for the farmer and the environmental conditions. Floods are a natural event and happen regularly, therefore strategies are necessary to diminish their negative effects. Furthermore, the human impact on a riparian ecosystem should be kept as small as possible by trapping chemicals and sediments that reduce water quality for down streamers.
The area where sediments are trapped is not touched by any human interference, the vegetation grows in its natural way. The stabilizing trees of the riparian are planted at the beginning of the rainy season in March or October. Dead seedlings have to be replaced regularly.
Kapingazi River is situated at the south eastern face of Mt. Kenya.It is an agriculturally favourable place due to abundant and reliable rainfall and fertile soils. The studied plot is located at an elevation of 1295 m.a.s.l where mainly maize and vegetables are cultivated. The precipitation amounts to 1150mm a year. Due to the good conditions, this area experiences a steady increase in both population growth and population density.

left: Farmer Fredrick Njiru in front of his wildly sprawling bushes. (Photo: Manuel Fischer)
right: River is nearly not visible behind the bushes. (Photo: Manuel Fischer)

Location: Kenya/Eastern Province
Region: Embu West
Technology area: < 0.1 km2 (10 ha)
Conservation measure: vegetative, management
Stage of intervention: prevention of land degradation, rehabilitation / reclamation of denuded land
Origin: Developed through land user`s initiative, recent (<10 years ago)
Land use type:
Cropland: Annual cropping
Land use:
Cropland: Annual cropping (before), Forests / woodlandsrests / woodlands: Natural (after)
Climate: subhumid, tropics
WOCAT database reference: T_KEN664en
Related approach: Water Resource Users Association for the management of water resources in a river sub-catchment (A_Ken018en)
Compiled by: Manuel Fischer, CDE Centre for Development and Environment
Date: 2012-11-07
Contact person: Fredrick Njiru, P.O box 727 Embu, 0723-836-235

Classification

Land use problems:

- Riverbank degradation and small riparian area. (expert's point of view)
Riverbank degradation and destroyed yield due to floods. (land user's point of view)

Land use

Annual cropping
Cropland: Annual cropping (before)
Forests / woodlandsrests / woodlands: Natural (after)
rainfed
pruning

Climate

subhumid

Degradation

Soil erosion by water: riverbank erosion, Water degradation: decline of surface water quality

Conservation measure

vegetative: Tree and shrub cover
management: Change of land use type

Stage of intervention

- [x] Prevention
- [ ] Mitigation / Reduction
- [x] Rehabilitation

Origin

- [x] Land users initiative: recent (<10 years ago)
- [ ] Experiments / Research
- [ ] Externally introduced

Level of technical knowledge

- Agricultural advisor
- Land user

Main causes of land degradation:
Direct causes - Human induced: deforestation / removal of natural vegetation (incl. forest fires), over-exploitation of vegetation for domestic use
Direct causes - Natural: Heavy / extreme rainfall (intensity/amounts), floods
Indirect causes: education, access to knowledge and support services

Main technical functions:
- stabilisation of soil (eg by tree roots against land slides)

Secondary technical functions:
- improvement of ground cover
- sediment retention / trapping, sediment harvesting
- promotion of vegetation species and varieties (quality, eg palatable fodder)

Environment

Natural Environment

Average annual rainfall (mm)

- [ ] > 4000 mm
- [ ] 3000-4000 mm
- [ ] 2000-3000 mm
- [ ] 1500-2000 mm
- [x] 1000-1500 mm
- [ ] 750-1000 mm
- [ ] 500-750 mm
- [ ] 250-500 mm
- [ ] < 250 mm

Altitude (m a.s.l.)

- [ ] > 4000
- [ ] 3000-4000
- [ ] 2500-3000
- [ ] 2000-2500
- [ ] 1500-2000
- [x] 1000-1500
- [ ] 500-1000
- [ ] 100-500
- [ ] <100

Landform

- [ ] plateau / plains
- [ ] ridges
- [ ] mountain slopes
- [ ] hill slopes
- [x] footslopes
- [ ] valley floors

Slope (%)

- [ ] flat
- [x] gentle
- [ ] moderate
- [ ] rolling
- [ ] hilly
- [ ] steep
- [ ] very steep

Soil depth (cm)

- [ ] 0-20
- [ ] 20-50
- [ ] 50-80
- [ ] 80-120
- [x] >120

Growing season(s): 60 days (march to may), 60 days (october to november)
Soil texture: fine / heavy (clay)
Soil fertility: very high
Topsoil organic matter: medium (1-3%)
Soil drainage/infiltration: medium

Soil water storage capacity: very high
Ground water table: < 5 m
Availability of surface water: good
Water quality: for agricultural use only
Biodiversity: medium

Tolerant of climatic extremes: temperature increase, seasonal rainfall increase, seasonal rainfall decrease, heavy rainfall events (intensities and amount), wind storms / dust storms, floods, droughts / dry spells, decreasing length of growing period

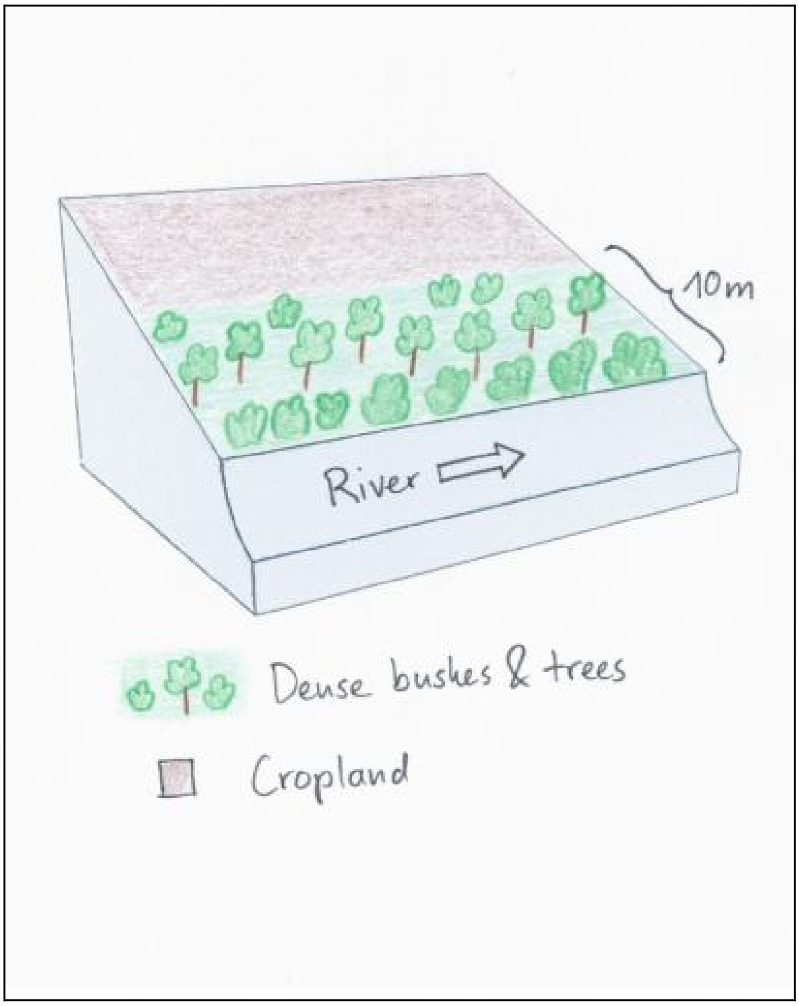
Human Environment

Cropland per household (ha)

- [ ] <0.5
- [ ] 0.5-1
- [x] 1-2
- [x] 2-5
- [ ] 5-15
- [ ] 15-50
- [ ] 50-100
- [ ] 100-500
- [ ] 500-1,000
- [ ] 1,000-10,000
- [ ] >10,000

Land user: groups / community, Small scale land users, Leaders / privileged, men and women
Population density: > 500 persons/km2
Land ownership: individual, not titled
Land use rights: individual
Water use rights: communal (organised)
Relative level of wealth: rich

Importance of off-farm income: less than 10% of all income:
Access to service and infrastructure: moderate: market; high: health, education, technical assistance, employment (eg off-farm), energy, roads & transport, drinking water and sanitation, financial services
Market orientation: mixed (subsistence and commercial)
Mechanization: manual labour
Livestock grazing on cropland: no



Technical drawing

The riparian area was regularly affected by floods and riverbank erosion. The land user decided to stop cultivation which allows the development of riparian vegetation to stabilize the riverbank and to raise the elevation. (Manuel Fischer)

Implementation activities, inputs and costs

Establishment activities

- Planting tree seedlings
- Replant dead tree seedlings
- change of land use

Establishment inputs and costs per ha

Inputs	Costs (US$)	% met by land user
Labour	3.11	100%
Agricultural		
- seedlings	1.11	%
TOTAL	**4.22**	**100.00%**

Maintenance/recurrent activities

Remarks:

The costs were calculated for a riparian area with a length of 100m and a width of 10m, since hectares are difficult to apply on a riparian context. The determinant factor for the costs is labour. In this case, the costs are very low because the trees were only planted every 10 metres along the riparian. The seedlings must be bought in a nursery. Most of the bushes regrow naturally and do not need any care. Some of the seedlings had to be replanted, because they dried up. The required equipment like a spade is available on nearly every farm or can be borrowed from neighbours and is thus not added to the costs.

Assessment

Impacts of the Technology

Production and socio-economic benefits	Production and socio-economic disadvantages
++ increased wood production through pruning	+++ reduced crop production +++ reduced fodder production

Socio-cultural benefits	Socio-cultural disadvantages
+++ improved conservation / erosion knowledge	

Ecological benefits	Ecological disadvantages
+++ reduced riverbank erosion ++ increased water quality ++ reduced surface runoff ++ improved soil cover ++ reduced soil loss ++ increased plant diversity ++ increased / maintained habitat diversity + increased water quantity + reduced hazard towards adverse events + increased animal diversity + increased beneficial species	

Off-site benefits	Off-site disadvantages
++ reduced groundwater river pollution ++ improved buffering / filtering capacity + increased water availability + increased stream flow in dry season	

Contribution to human well-being / livelihoods

Benefits /costs according to land user

Benefits compared with costs	short-term:	long-term:
Establishment	slightly negative	slightly positive
Maintenance / recurrent	neutral / balanced	slightly positive

Acceptance / adoption:

There is moderate trend towards (growing) spontaneous adoption of the technology. The other farmers noticed the positive impacts and adopt the technology.

Concluding statements

Strengths and → how to sustain/improve

The established forest is a great success for the local fauna and flora in terms of biodiversity → More areas like this could be established

There are no more crop failures and the riverbank is stabilized → In the other areas that are not much more elevated than the river, flood resistant plants like Napier grass should be planted.

The trees and the riparian bushes provide timber and fuelwood. → Careful use of the resources ensures sustainability.

Weaknesses and → how to overcome

As soon as the riparian forest is silted up and floods become more rare, the farmer plans a deforestation and cultivation of beans in the riparian area with riparian vegetation strips of 5m. → The riparian forest should be kept there to improve ecological benefits and to sustain reduced erosion.

The shrub-covered area is no longer available for cultivation and leads to a decrease in income. → If the farmer depends on the productivity of the riparian, he could plant Napier grass and prune the trees.

left: Riparian bushes and trees in the back. Maize field in the front. (Photo: Manuel Fischer)
right: Dense riparian vegetation prevents riverbank erosion. (Photo: Manuel Fischer)

Natural riparian vegetation to sustain a stable riverbank at Naro Moru River
Kenya

Riverbank erosion and biodiversity decline in the riparian area can be overcome by leaving the natural vegetation undisturbed.

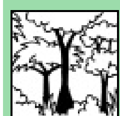
The studied land plot is situated in the semi-arid savannah zone of the Naro Moru sub-catchment at the foot of Mt. Kenya. A small-scale farmer leaves the riparian vegetation undisturbed, which enables the growth of dense bushes. On the one hand, the riparian vegetation contributes to prevent land loss caused by riverbank erosion, on the other hand it is a habitat for the special riparian fauna and flora.
Despite semi-arid conditions, there is a high probability of flooding. Heavy rainfalls on upper slopes of Mt. Kenya lead to flood events in the semi-arid areas of Naro Moru River. These events have a destructive effect on the riverbanks, which have become instable by human induced activities such as overgrazing and deforestation. The instable riparian soils are eroded easily. The farmers lose their precious land and the water is polluted.
A good way to overcome the riverbank degradation triggered by high runoff is a passive approach: simply leaving the riparian area undisturbed by human interference. Trees, bushes and grasses stabilize even steep riverbanks with their invading roots. As a result, almost no erosion takes place and infiltration is enhanced during rain events. The riparian microclimate, which is characterized by cooler temperatures during the day and slightly warmer temperatures during the night, is very special compared to the surrounding semi-arid zones. Also water availability is much higher than in the surroundings. Thus, this habitat offers a high biodiversity.
The plot is situated on a plateau at the western side of Mt. Kenya. There is not the same amount of precipitation as at the foot slopes of Mt. Kenya. However, the area still benefits from the runoff that is generated on the mountain. Precipitation in the so-called savannah zone ranges from 600mm to 900mm per year. Due to the high evaporation, rain-fed agriculture is only partly possible. Therefore most land users depend on irrigation using river water. During the last decades, the region has experienced a still continuing population growth which increases population pressure in the area and removal and use of the vegetation along the rivers. The good accessibility and the moderate tourism allow even off-farm income-generation.

Location: Kenya/Central Province
Region: Naro Moru
Technology area: < 0.1 km2 (10 ha)
Conservation measure: management
Stage of intervention: prevention of land degradation
Origin: Developed through land user`s initiative, 10-50 years ago
Land use type:
Forests / woodlands: Natural
Climate: semi-arid, subtropics
WOCAT database reference: T_KEN665en
Related approach: Water Resource Users Association for the management of water resources in a river sub-catchment (A_KEN018en)
Compiled by: Manuel Fischer, CDE Centre for Development and Environment
Date: 2012-11-15
Contact person: Simon Ngunjiri, 0712-714-542

Classification

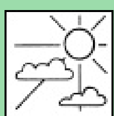
Land use problems:
- In not treated areas, land users have to fight serious riverbank erosion. Due to steep riverbanks, stabilisation is very tricky. (expert's point of view)
Deforested riverbanks are very difficult to control, land loss is a consequence. (land user's point of view)

Land use



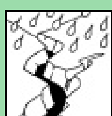
Natural
Protected riparian forest

Climate



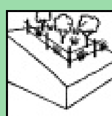
semi-arid

Degradation



Soil erosion by water: riverbank erosion, Water degradation: decline of surface water quality

Conservation measure



management: Control / change of species composition

Stage of intervention

- [x] Prevention
- [ ] Mitigation / Reduction
- [ ] Rehabilitation

Origin

- [x] Land users initiative: 10-50 years ago
- [ ] Experiments / Research
- [ ] Externally introduced

Level of technical knowledge

- [ ] Agricultural advisor
- [ ] Land user

Main causes of land degradation:
Direct causes - Human induced: deforestation / removal of natural vegetation (incl. forest fires), over-exploitation of vegetation for domestic use, overgrazing
Direct causes - Natural: floods

Main technical functions:
- stabilisation of soil (eg by tree roots against land slides)
- increase of infiltration
- improvement of water quality, buffering / filtering water
- sediment retention / trapping, sediment harvesting

Secondary technical functions:
- improvement of ground cover
- increase of surface roughness
- increase / maintain water stored in soil
- increase of groundwater level / recharge of groundwater

Environment

Natural Environment

Average annual rainfall (mm)

- [ ] > 4000 mm
- [ ] 3000-4000 mm
- [ ] 2000-3000 mm
- [ ] 1500-2000 mm
- [ ] 1000-1500 mm
- [ ] 750-1000 mm
- [x] 500-750 mm
- [ ] 250-500 mm
- [ ] < 250 mm

Altitude (m a.s.l.)

- [ ] > 4000
- [ ] 3000-4000
- [ ] 2500-3000
- [ ] 2000-2500
- [x] 1500-2000
- [ ] 1000-1500
- [ ] 500-1000
- [ ] 100-500
- [ ] <100

Landform

- [x] plateau / plains
- [ ] ridges
- [ ] mountain slopes
- [ ] hill slopes
- [ ] footslopes
- [ ] valley floors

Slope (%)

- [x] flat
- [ ] gentle
- [ ] moderate
- [ ] rolling
- [ ] hilly
- [ ] steep
- [ ] very steep

Soil depth (cm)

- [ ] 0-20
- [ ] 20-50
- [ ] 50-80
- [x] 80-120
- [ ] >120

Growing season(s): 60 days (april to may), 60 days (october to november)
Soil texture: medium (loam)
Soil fertility: medium
Topsoil organic matter: medium (1-3%)
Soil drainage/infiltration: poor (eg sealing /crusting)

Soil water storage capacity: low
Ground water table: < 5 m
Availability of surface water: good
Water quality: poor drinking water
Biodiversity: medium

Tolerant of climatic extremes: temperature increase, seasonal rainfall increase, seasonal rainfall decrease, heavy rainfall events (intensities and amount), wind storms / dust storms, floods, droughts / dry spells, decreasing length of growing period

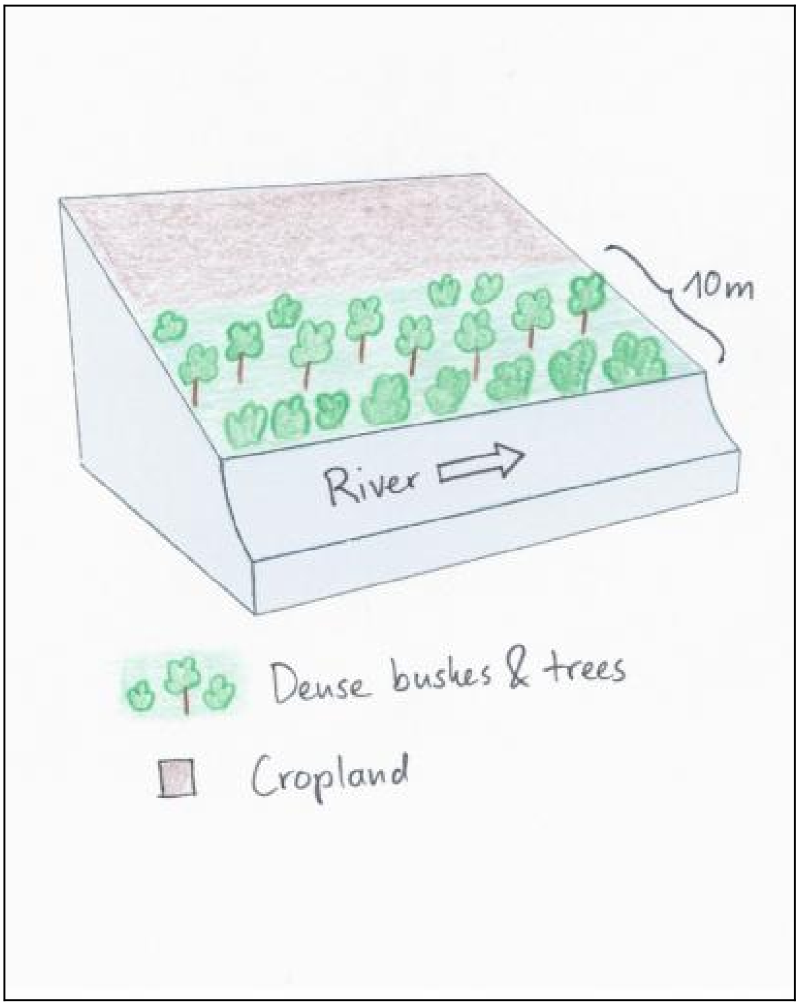
Human Environment

Forests / woodlands per household (ha)

- [x] <0.5
- [ ] 0.5-1
- [ ] 1-2
- [ ] 2-5
- [ ] 5-15
- [ ] 15-50
- [ ] 50-100
- [ ] 100-500
- [ ] 500-1,000
- [ ] 1,000-10,000
- [ ] >10,000

Land user: Individual / household, Small scale land users, common / average land users, men and women
Population density: 200-500 persons/km2
Land ownership: individual, not titled
Land use rights: individual
Relative level of wealth: poor

Importance of off-farm income: less than 10% of all income: The farmer has no off-farm income.
Access to service and infrastructure: low: employment (eg off-farm), financial services; moderate: health, education, technical assistance, market, energy, roads & transport, drinking water and sanitation
Market orientation: subsistence (self-supply)
Purpose of forest / woodland use: nature conservation / protection, protection against natural hazards



Technical drawing

The land user noticed the riverbank erosion problems neighbours had after clearing of the riparian vegetation. This led to the protective approach of natural trees and bushes. Adjacent to the riparian area, crops are cultivated. (Manuel Fischer)

Implementation activities, inputs and costs

Establishment activities

- No activities were needed

Maintenance/recurrent activities

- Control of species composition and destruction of invading plants

Remarks:

Assessment

Impacts of the Technology

Production and socio-economic benefits	Production and socio-economic disadvantages
	+ reduced wood production

Socio-cultural benefits	Socio-cultural disadvantages
+ improved conservation / erosion knowledge	
+ improved aesthetics	

Ecological benefits	Ecological disadvantages
++ increased water quality	
++ recharge of groundwater table / aquifer	
++ reduced hazard towards adverse events	
++ improved soil cover	
++ increased plant diversity	
++ increased / maintained habitat diversity	
++ reduced riverbank erosion	
+ increased water quantity	
+ increased soil moisture	
+ reduced invasive alien species	
+ increased beneficial species	

Off-site benefits	Off-site disadvantages
++ reduced downstream siltation	
++ reduced groundwater river pollution	
+ increased water availability	
+ improved buffering / filtering capacity	

Contribution to human well-being / livelihoods

+ Erosion knowledge was improved.

Benefits /costs according to land user

Benefits compared with costs	short-term:	long-term:
Establishment	neutral / balanced	slightly positive
Maintenance / recurrent	neutral / balanced	slightly positive

There are no establishment costs, that is why the short-term returns ares neutral. After some years, the benefits develop as long-term returns

Acceptance / adoption:

0% of land user families have implemented the technology with external material support.
20% of land user families have implemented the technology voluntary.
There is little trend towards (growing) spontaneous adoption of the technology. There are some farmers who are very convinced. The number of farmers adopting the technology is growing slowly.

Concluding statements

Strengths and → how to sustain/improve	Weaknesses and → how to overcome
The technology creates a habitat for the very specific riparian fauna and flora and this boosts biodiversity. → By enlarging the riparian zone.	There is no productive use of this technology, therefore it is difficult to convince other farmers to adopt this technology. → Slight use of the riparian brings already good returns of fodder and fuelwood and still allows good protection.
There are no problems with riverbank erosion. → Keep the vegetation cover and do not perform too many activities in the riparian zone.	

Keeping natural riparian vegetation and stabilizing riparian with gabions at Naro Moru River
Kenya

Structural riverbank protection by metal nets called gabion that are filled with stones

The studied land plot is situated in the semi-arid savannah zone of the Naro Moru sub-catchment at the foot of Mt. Kenya. A large-scale farmer owns a spacious land plot bordering Naro Moru River where he grows herbs and special plants to produce human care products. He rarely intervenes in the riparian area but is still interested in a good protection of water resources. Therefore, big stone control structures called gabions were installed to prevent big riparian trees from being undermined by water and destabilized by erosion. This method is cost intensive but can be applied locally for the protection of certain goods. The action was promoted by the Water Resource Users Association of the sub-catchment.
Despite semi-arid conditions, there is a high probability of flooding. Heavy rainfalls on upper slopes of Mt. Kenya lead to flood events in the semi-arid areas of Naro Moru River. These events have a destructive effect on the riverbanks, which have become instable by human induced activities such as overgrazing and deforestation. The instable riparian soils are eroded easily. The farmers lose their precious land and the water is polluted.
Big riparian trees are important for stabilizing the riverbed and riverbanks and for building a canopy that provides shade which enables the typical riparian conditions with its vast biodiversity. Thus, large metal nets (2x1x0.5 m) are filled with stones and placed in front of the roots to protect them from the direct current. These metal nets are called gabion and are placed at especially prone places. This structural measure contributes to mitigate or even stop riverbank degradation. High efforts are required to establish gabions. The costs for the metal net amount to 80 US-Dollar per net. Additionally, workforce must be found to fill the nets with stones from the river. Once installed, they ensure a good local protection. They are also used to protect bridge pillars. The life expectance of a gabion net is about 20 years if not destroyed by extreme events.
The plot is situated on a plateau at the western side of Mt. Kenya. There is not the same amount of precipitation as at the foot slopes of Mt. Kenya. However, the area still benefits from the runoff that is generated on the mountain. Precipitation in the so-called savannah zone ranges from 600mm to 900mm per year. Due to the high evaporation, rain-fed agriculture is only partly possible. Therefore most land users depend on irrigation using river water. During the last decades, the region has experienced a still continuing population growth which increases population pressure in the area and removal and use of the vegetation along the rivers. The good accessibility and the moderate tourism allow even off-farm income-generation.

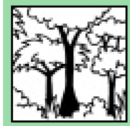
left: Natural riparian vegetation viewed from the savannah. (Photo: Manuel Fischer)
right: A metal net filled with stones (gabion) in the bottom right corner for the stabilization of a big riparian tree. (Photo: Manuel Fischer)

Location: Kenya/Central Province
Region: Nyeri/Naro Moru
Technology area: < 0.1 km2 (10 ha)
Conservation measure: structural
Stage of intervention: prevention of land degradation
Origin: Developed through experiments / research, recent (<10 years ago)
Land use type:
Forests / woodlands: Natural
Climate: semi-arid, subtropics
WOCAT database reference: T_KEN666en
Related approach: Water Resource Users Association for the management of water resources in a river sub-catchment (A_KEN019en)
Compiled by: Manuel Fischer, CDE Centre for Development and Environment
Date: 2012-11-15
Contact person: John Horsey, cinnabar green LTD P.O. box 477, Nanyuki, 10402 Kenya phone: 0721-624-247

Classification

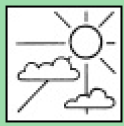
Land use problems:
- Due to the decreasing river flows, the riparian vegetation is being diminished. (expert's point of view)
Big riparian trees are threatened because of being undermined by water. The canopy and the roots of the trees are a vital component of the riparian habitat. (land user's point of view)

Land use



Natural Preservation

Climate

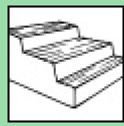


semi-arid

Degradation

Soil erosion by water: riverbank erosion, Water degradation: decline of surface water quality

Conservation measure



structural: Walls / barriers / palisades

Stage of intervention

- ■ Prevention
- ▒ Mitigation / Reduction
- □ Rehabilitation

Origin

- □ Land users initiative
- ■ Experiments / Research: recent (<10 years ago)
- □ Externally introduced

Level of technical knowledge

- ■ Agricultural advisor
- ▒ Land user

Main causes of land degradation:
Direct causes - Human induced: over abstraction / excessive withdrawal of water (for irrigation, industry, etc.)
Direct causes - Natural: floods
Indirect causes: population pressure

Main technical functions:
- stabilisation of soil (eg by tree roots against land slides)
- stabilisation of riverbank

Secondary technical functions:

Environment

Natural Environment

Average annual rainfall (mm)

- □ > 4000 mm
- □ 3000-4000 mm
- □ 2000-3000 mm
- □ 1500-2000 mm
- □ 1000-1500 mm
- □ 750-1000 mm
- ■ 500-750 mm
- □ 250-500 mm
- □ < 250 mm

Altitude (m a.s.l.)

- □ > 4000
- □ 3000-4000
- □ 2500-3000
- □ 2000-2500
- ■ 1500-2000
- □ 1000-1500
- □ 500-1000
- □ 100-500
- □ <100

Landform

- ■ plateau / plains
- □ ridges
- □ mountain slopes
- □ hill slopes
- □ footslopes
- □ valley floors

Slope (%)

- ■ flat
- □ gentle
- □ moderate
- □ rolling
- □ hilly
- □ steep
- □ very steep

Soil depth (cm)

- □ 0-20
- □ 20-50
- □ 50-80
- ■ 80-120
- □ >120

Growing season(s): 60 days (april to may), 60 days (october to november)
Soil texture: medium (loam)
Soil fertility: medium
Topsoil organic matter: medium (1-3%)
Soil drainage/infiltration: medium

Soil water storage capacity: low
Ground water table: < 5 m
Availability of surface water: good
Water quality: poor drinking water
Biodiversity: high

Tolerant of climatic extremes: temperature increase, seasonal rainfall increase, seasonal rainfall decrease, heavy rainfall events (intensities and amount), wind storms / dust storms, floods, droughts / dry spells, decreasing length of growing period

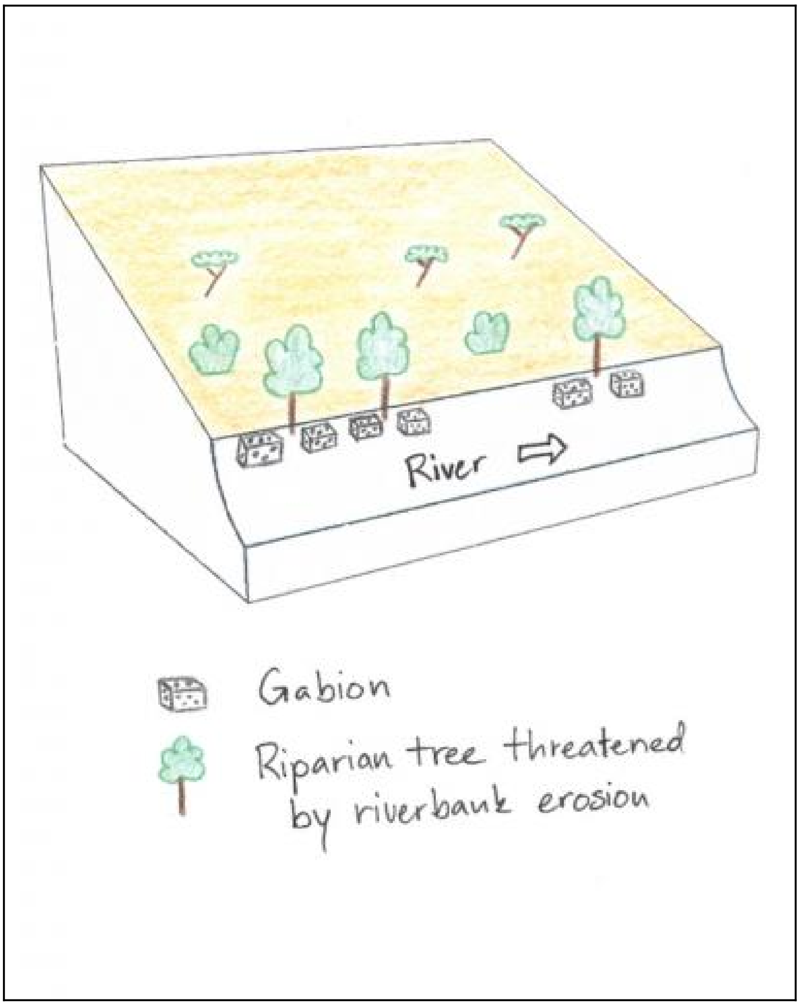
Human Environment

Forests / woodlands per household (ha)

- □ <0.5
- □ 0.5-1
- ■ 1-2
- □ 2-5
- □ 5-15
- □ 15-50
- □ 50-100
- □ 100-500
- □ 500-1,000
- □ 1,000-10,000
- □ >10,000

Land user: employee (company, government), large scale land users, Leaders / privileged, men and women
Population density: 200-500 persons/km2
Land ownership: company, individual, not titled
Land use rights: individual
(The land owner has a company that produces oils and herbs for care products. The company produces in a organic way and preserves the environment.)
Relative level of wealth: very rich, which represents 1% of the land users; 10% of the total area is owned by very rich land users

Importance of off-farm income: > 50% of all income: The land owner has a company that produces oils and herbs for care products. The company produces in a organic way and preserves the environment.
Access to service and infrastructure: low: employment (eg off-farm), market, energy; moderate: health, technical assistance, financial services; high: education, roads & transport, drinking water and sanitation
Market orientation:
Conservation/Preservation
Purpose of forest / woodland use: nature conservation / protection



Technical drawing

In the Savannah zone large riparian trees are threatened, thus gabions are used to protect them and to sustain the canopy. The gabions are applied at the roots of the riparian trees to protect them from the erosive power of the stream. (Manuel Fischer)

Implementation activities, inputs and costs

Establishment activities

- Installing and filling the metal wire with stones

Maintenance/recurrent activities

- Control of fences
- Control of the gabion nets

Remarks:
The price for the metal wire is the most cost determinant factor.

Assessment

Impacts of the Technology

Production and socio-economic benefits	Production and socio-economic disadvantages
	+ loss of land

Socio-cultural benefits	Socio-cultural disadvantages
++ community institution strengthening ++ improved conservation / erosion knowledge	

Ecological benefits	Ecological disadvantages
++ recharge of groundwater table / aquifer ++ preservation of canopy + increased water quality + increased soil moisture + reduced surface runoff + reduced hazard towards adverse events + increased animal diversity + increased plant diversity + increased / maintained habitat diversity + reduced riverbank degradation	

Off-site benefits	Off-site disadvantages
+ increased stream flow in dry season + reduced downstream siltation	

Contribution to human well-being / livelihoods

++ The discussions about water conservation increase education. Also, the dialogue between farmers is improved.

Benefits /costs according to land user

Benefits compared with costs	short-term:	long-term:
Establishment	negative	slightly positive
Maintenance / recurrent	neutral / balanced	positive

The establishment costs are quite high.

Acceptance / adoption:

0% of land user families have implemented the technology with external material support.
100% of land user families have implemented the technology voluntary.
There is no trend towards (growing) spontaneous adoption of the technology. The costs are too high for an average farmer to adopt the technology.

Concluding statements

Strengths and → how to sustain/improve	Weaknesses and → how to overcome
Conservation of the unique riparian habitat → Continue the protective measures and hinder negative intervention in the riparian area.	The implementation of the gabions is very cost-intensive. → Alternatives should be checked out.
Through the environmental activities, the acceptance of the company increases. → Regular interaction improve neighborly relations.	The origin of the vegetation decline, the decreasing river flow, is not being combatted. → Water abstractions in the upper reaches should be diminished.
Ensuring an intact environment to guarantee the organic origin of the company products. → Control that the riparian area is not being polluted or destroyed.	

Erklärung

gemäss Art. 28 Abs. 2 RSL 05

Name/Vorname: Fischer Manuel

Matrikelnummer: 06-117-782

Studiengang: Geographie

Bachelor ☐ Master ☒ Dissertation ☐

Titel der Arbeit: Productive Protection of Riparian Zones - Good Individual and Community Practices around Mt. Kenya

LeiterIn der Arbeit: Prof. Dr. Hans Hurni

Ich erkläre hiermit, dass ich diese Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen benutzt habe. Alle Stellen, die wörtlich oder sinngemäss aus Quellen entnommen wurden, habe ich als solche gekennzeichnet. Mir ist bekannt, dass andernfalls der Senat gemäss Artikel 36 Absatz 1 Buchstabe r des Gesetztes vom 5. September 1996 über die Universität zum Entzug des auf Grund dieser Arbeit verliehenen Titels berechtigt ist.

Ich gewähre hiermit Einsicht in diese Arbeit.

Bern / 28.5.2014

Ort/Datum

Unterschrift