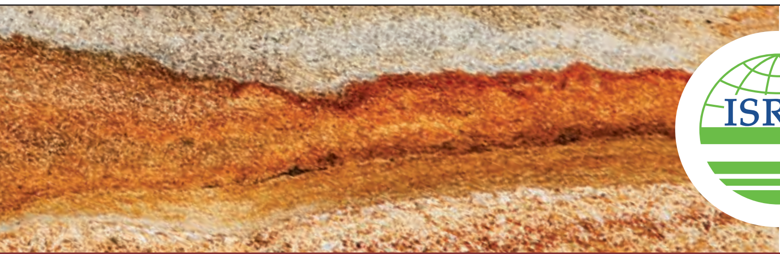
Inventory and Analysis of Existing Soil and Water Conservation Practices in the Upper Tana, Kenya



ISRIC World Soil Information

Green Water Credits Report 12

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Green Water Credits

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Green Water Credits Report 12

Foreword

ISRIC – World Soil Information has the mandate to create and increase the awareness and understanding of the role of soils in major global issues. As an international institution, ISRIC informs a wide audience about the multiple roles of soils in our daily lives; this requires scientific analysis of sound soil information.

The source of all fresh water is rainfall received and delivered by the soil. Soil properties and soil management, in combination with vegetation type, determine how rain will be divided into surface runoff, infiltration, storage in the soil and deep percolation to the groundwater. Improper soil management can result in high losses of rainwater by surface runoff or evaporation and may in turn lead to water scarcity, land degradation, and food insecurity. Nonetheless, markets pay farmers for their crops and livestock but not for their water management. The latter would entail the development of a reward for providing a good and a service. The Green Water Credits (GWC) programme, coordinated by ISRIC – World Soil information and supported by the International Fund for Agricultural Development (IFAD) and the Swiss Agency for Development and Cooperation (SDC), addresses this opportunity by bridging the incentive gap.

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

The study presented here covers the status of soil and water conservation practices ("*green water* management" measures as termed under GWC) in the Upper Tana catchment and had three objectives:

- Identification and documentation of SWC/ *green water* management measures
- Identification of the most suitable measures in each agro-ecological zone
- Establishment of a photo archive of SWC measures used by farmers.

The study was carried out in May 2011 using a transect, from top to bottom of the catchment. The farms for documentation of the conservation measures were randomly chosen along the transect. The data collected principally covered the SWC measures applied, and documentation was effected through photographs and discussions with the farmers. Secondary data was reviewed to verify farmers' testimonies.

Dr ir Prem Bindraban
Director, ISRIC – World Soil Information

Key Points

- This study on the status of soil and water conservation practices ("*green water* management" measures as termed under GWC) in the Upper Tana catchment had three objectives:
  - Identification and documentation of SWC/ *green water* management measures
  - Identification of the most suitable measures in each agro-ecological zone
  - Establishment of a photo archive of SWC measures used by farmers.

- The study was carried out in May 2011 using a transect, from top to bottom of the catchment. The farms for documentation of the conservation measures were randomly chosen along the transect. The study covered three administrative divisions.

- The data collected principally covered the SWC measures applied, and documentation was effected through photographs and discussions with the farmers. Secondary data was reviewed to verify farmers' testimonies.

- Soil erosion by water has been recognised as a major problem impeding productivity of farmlands. Considerable resources have been invested in soil and water management since the colonial days. A change to a more participatory approach in the 1980s led to wide acceptance of soil and water conservation among smallholder farmers.

- This study has established wide adoption of structural, vegetative and agronomic measures across all AEZs, as useful technologies to enhance availability of *green water* for crop production. These include terracing, cut-off drains, retention ditches and microcatchments. These are combined with agronomic and vegetative measures such as contour cropping, grass strips, cover cropping and mulching. Not yet well exploited is the potential of water harvesting in the drier areas, lower in the catchment.

- However, despite the successes over the past decades, soil erosion continues in certain areas under particular forms of land use in the Upper Tana catchment: this is testified to by rivers that are richly coloured with sediment during the rainy season leading to a high siltation rate of reservoirs. The main causes are:
  - Poor maintenance of established SWC measures. When prices of commodities are low, investment in maintenance decreases.
  - Continued cultivation of riverine areas.
  - Soil and water conservation in maize fields is often weak.
  - Isolated hotspot areas where erosion has progressed to an extent that it is not easy to recuperate land by normal agricultural practices.
  - Overgrazing of common lands is frequent, resulting in bare soils and high erosion rates. Due to population pressure there has been migration to the lower zones, and development of sedentary farming in these fragile environment
  - In these lower areas, water harvesting, through microcatchments, and *in situ* water conservation through ridging technologies are not widely adopted.

In conclusion, while there is significant baseline of SWC / *green water* management practices within the catchment, there is potential for significant extra impact through wider adoption. Thus there is a need to intensify farmer education in the heartland of the Upper Tana catchment, and complement this with a financial mechanism under GWC to support implementation of these practices.

Contents

Acronyms and Abbreviations

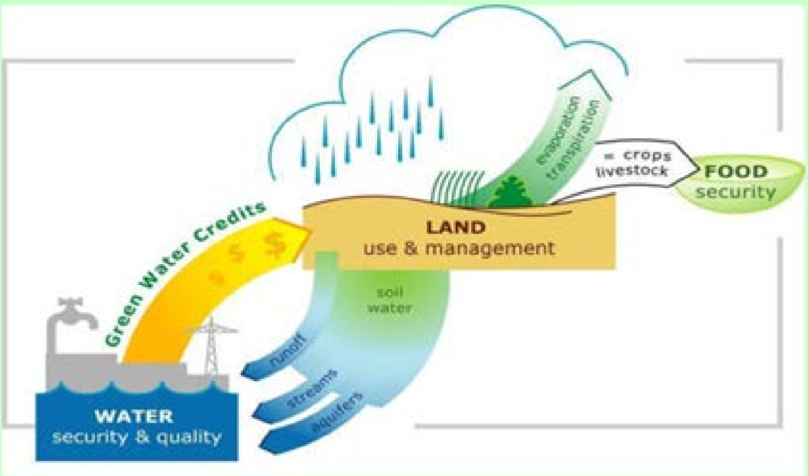
AEZ	Agro-Ecological Zone
ASAL	Arid and Semi-Arid Lands
KARI	Kenya Agricultural Research Institute
LH	Lower Highlands
LM	Lower Midlands
m.a.s.l.	Meters above sea level
MoA	Ministry of Agriculture
MKEPP	Mount Kenya East Pilot Project for Natural Resources Management
NALEP	National Agriculture and Livestock Extension Programme
NSWCP	National Soil and Water Conservation Project
SWC	Soil and water conservation
SIDA/ Sida	Swedish International Development Cooperation Agency
TA	Tropical Alpine
UH	Upper Highlands
UM	Upper Midlands
WOCAT	World Overview of Conservation Approaches and Technologies

Green Water Credits: the concepts

Green water, Blue water, and the GWC mechanism

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

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



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

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

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

1 Objectives of the study

This study, which was carried out for the Green Water Credits (GWC) programme (see "Green Water Credits: the concepts": page 8) had three objectives:

1. Identification and documentation of soil and water conservation measures ("green water management" measures, as termed under GWC) used by farmers in the Upper Tana catchment;
2. Identification of the most suitable measures of soil and water conservation in each agro-ecological zone (AEZ) in the Upper Tana catchment;
3. Establishment of a photo archive of soil and water conservation measures used by farmers in the Upper Tana catchment.

1.1 Introduction

The Upper Tana catchment covers an area of over 100,000 km^2 (Figure 1). Parts of Central, Eastern, Rift Valley, North Eastern and Coast Provinces fall within the catchment. It supports over four million people (Porras *et al*. 2007).

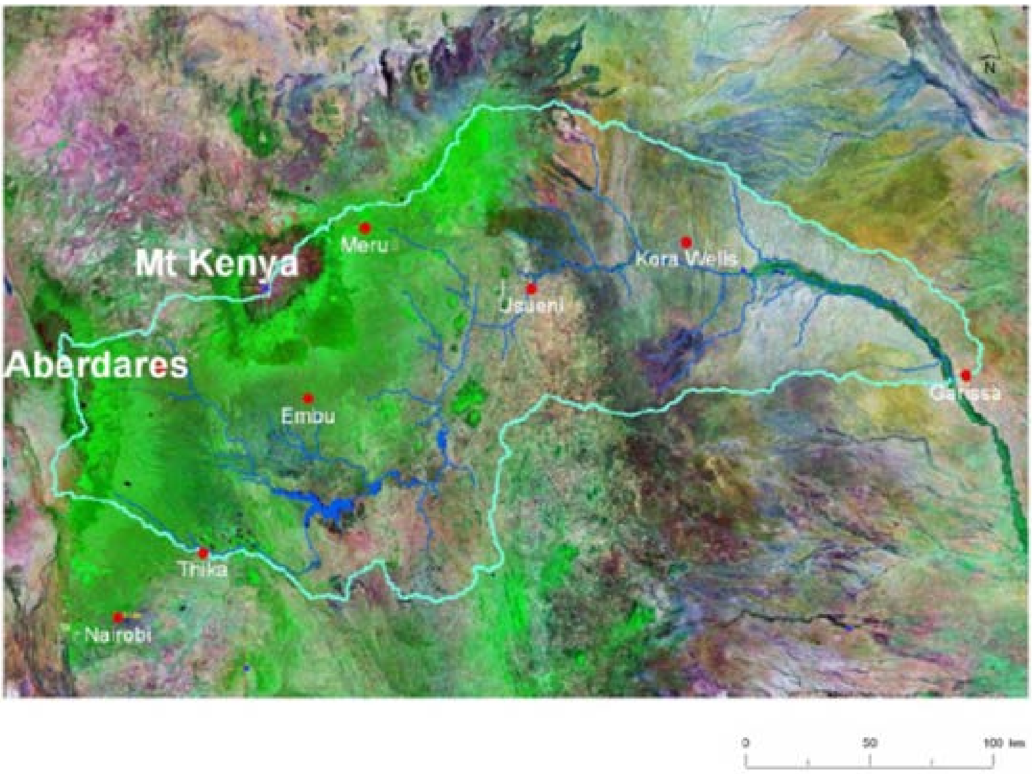


Figure 1
Upper Tana catchment: The Landsat image shows well-vegetated high rainfall areas of Mt Kenya and the Aberdares range. The catchment boundaries are shown in green and streams, reservoirs and other water bodies are shown in blue. Source: Dent and Kauffman 2007

The Mount Kenya catchment in central Kenya contributes up to 49% of the water in the Tana. The Aberdare catchment contributes about 44%, while 7% originates from other catchments (Porras *et al.* 2007). Among the main tributaries of the River Tana within the Mount Kenya catchment are Kathita, Kithinu, Thingithu and Iraru in the larger Meru Central District. In the larger Meru South District are Mutonga, North Maara, South Maara, Nithi, Tungu, Ruguti and Thuchi. River Thanantu is located in the larger Meru North district.

1.2 Agro-ecological zones

Due to the high elevation of Mt Kenya, the agro-ecological zones within the catchment stretch from Tropical Alpine to the Lower Midland zones (Figure 2). The pattern of agro-ecological zones in any particular district in the Upper Tana catchment is typical. It starts from the Tropical Alpine (TA I and II) on the mountain top, which are designated a national reserve. The zones that follow are forest reserves: Upper Highland (UH 0), and Lower Highland (LH 0). These are too wet and steep to be suitable for agricultural use. Agricultural activities are concentrated in the Lower Highland (LH I), Upper Midland (UM 1-4), and Lower Midland (LM 2-5) zones, which descend in altitude towards the footplains (Jaetzold *et al.* 2006).

This vast area is agro-ecologically suitable for a wide range of crops such as temperate fruits and snow peas in LH 1; tea in LH 1 and UM 1; coffee in UM1, 2 and 3; food crops, cotton and ranching in the Lower Midland zones (Table 1). Farming activities in the Upper Tana catchment are largely influenced by altitude. Above 2200 meters it is too cold and wet for crop production while below 550 meters it is too dry for reliable rainfed farming.

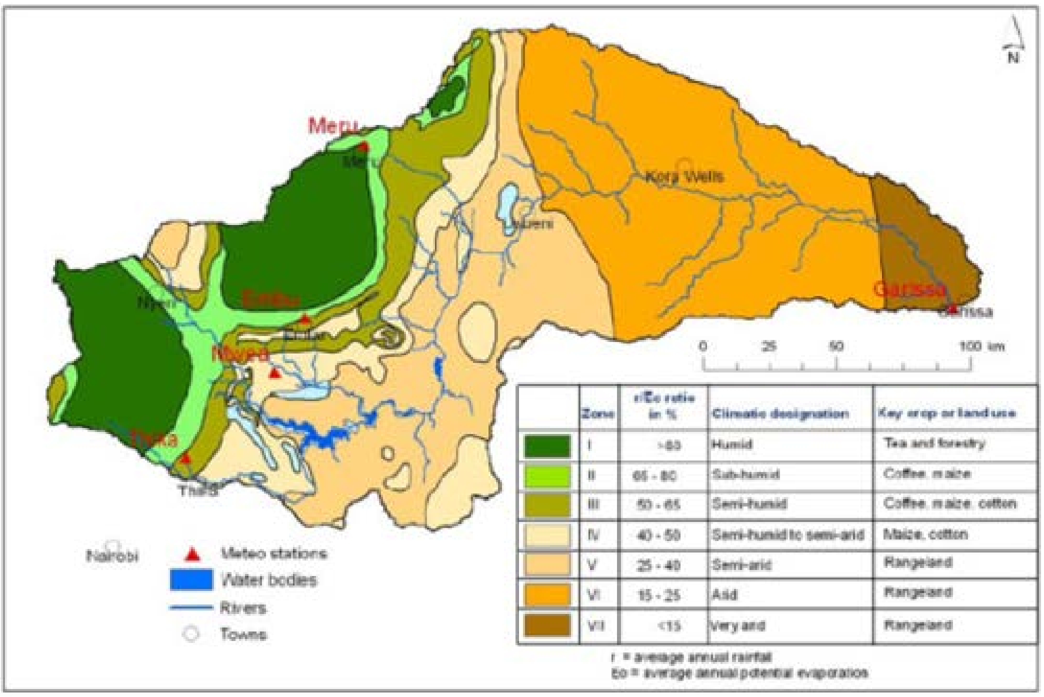


Figure 2
Upper Tana catchment agro-ecological zones
Source: Kauffman et al. 2007, Jaetzold et al. 2006

Table 1
Agro-ecological zones in the Upper Tana catchment

AEZ	Main land use
UH0 (Upper Highland)	Forest reserve
LH0 (Lower Highland)	Forest reserve
LH1 (Tea/Dairy Zone)	Tea, dairy, Irish potatoes
UM1 (Upper Midland/Coffee/Tea zone)	Coffee, tea, dairy, food crops e.g. maize
UM2 (Upper Midland/main coffee zone)	Coffee, dairy, food crops and rainfed horticulture
UM3 (Upper Midland/marginal coffee zone)	Coffee, food crops (e.g. maize, beans) and irrigated horticulture
LM3 (Lower Midland/main cotton zone)	Cotton, food crops and dry land pulses (green grams, cowpeas and pigeon peas)
LM4 (Marginal cotton zone)	Cotton and dry land pulses
LM5 (Livestock/Millet zone)	Millet, sorghum, dry land pulses and local livestock

Source: Jaetzold *et al.* 2006

1.3 Soils

The Mt Kenya region of the Tana catchment is characterised by volcanic soils. In the agriculturally productive upper agro-ecological zones, soils are mainly humic nitisols; thus deep, well-drained with moderate to high inherent fertility. The terrain is characterised by steep slopes especially towards the numerous river valleys. In the lower rangeland zones, the soils are mainly well-drained nito-rhodic ferralsols, deep sandy-clay loams. There are pockets of chromic cambisols (shallow, well-drained stony to rocky-clay loams) and lithosols (well-drained stony-clay loams), both with rock outcrops. In the Lower Midland zones vertisols are found; dark montmorillonite clay rich poorly-drained soils. Histosols are found in the tropical alpine zones; they possess low fertility due to poor drainage (Jaetzold *et al*. 2006).

1.4 History of soil and water conservation

Soil erosion by water affects more than 80% of Kenya's arable land (Violet *et al.* 2010). It was identified as an environmental problem in the 1930s and 1940s, when the colonial government introduced soil and water conservation techniques (Gachene and Mureithi 2004). Widespread soil conservation measures were implemented through village chiefs, headmen and agricultural extension workers through compulsory community work and prohibitory legislation. Some of the techniques developed during this period were effective. However, because the practices were based on forced communal work, soil conservation gained a bad name and the practices were resented by the people (Violet *et al.* 2010; Mutisya *et al.* 2010). The structures thus lacked maintenance, being associated with colonialism, leading to widespread rejection of conservation after independence (Gachene and Mureithi 2004; Okoba and Graaf 2005).

Little happened immediately after independence (1963) until the 1970s, when the Kenyan Government initiated national conservation campaigns through the National Soil and Water Conservation Project (NSWCP) which was supported by the Swedish International Development Cooperation Agency (SIDA: now abbreviated to Sida) (Gachene and Mureithi 2004; Violet *et al.* 2010). A catchment approach was adopted in 1987, with accompanying tools and subsidies to promote individual activities (Okoba *et al.* 2007). This programme was implemented until 2000. NSWCP was a land husbandry programme which reached over 1.5 million smallholder farmers over the years, and was widely perceived to be successful in leading to a considerable decrease of soil erosion and increased productivity in agriculture (Cuellarl *et al.* 2006). In 2000, the National Agriculture and Livestock Extension Programme (NALEP) was launched with support from Sida. The programme employed a shifting “focal area approach”, similar to the catchment approach, but farmers’ advisory services were wider in scope and demand-driven (Cuellarl *et al.* 2006). In order for farmers to practice sustainable agriculture in all zones, concerted efforts have been made to ensure soil and water conservation (SWC). Previous studies have indicated high adoption of SWC within the Upper Tana catchment (Violet *et al.* 2010).

However, despite the successes over the past decades, soil erosion continues in certain areas under particular forms of land use in the Upper Tana catchment, which is testified to by rivers that are richly coloured with sediment during the rainy season leading to a high siltation rate of reservoirs. The main causes of the continued erosion so far identified are:

1. Poor maintenance of established SWC measures[1]. This is in particular the case when the prices of commodities (for example coffee) decrease leading to a loss of economic incentive to maintain proper bench terraces and other SWC measures.
2. Cultivation of riverine areas. Although forbidden by law, extensive tracts along river banks and their many tributaries are used for cultivation of (especially) horticultural crops, leaving the banks vulnerable to erosion during the rainy season.
3. Except for the tea zone, soil and water conservation is often poor - particularly in maize fields. Even erosion-resistant soils like Nitisols exhibit surface runoff and erosion under maize, which is demonstrated by the development of rills and sheet erosion especially during the early rains.
4. The soil and water conservation measures practised by most of the farmers are inadequate.
5. There are isolated hot-spot areas in each catchment where erosion has progressed so much that topsoil has been stripped and the sub-soil is visible. It is not easy to recuperate these areas by normal SWC practices.
6. Overgrazing of common lands is frequent resulting in bare soils and high erosion during rains.
7. Settlement and cultivation in the marginal and semi-arid areas has increased due to population pressure. These areas are highly vulnerable to soil and water erosion (Violet *et al.* 2010). Intensive cultivation on very steep slopes - hitherto recommended for forest cover - has also increased in the upper highlands. In the Upper Tana catchment, settlement has spread both to the marginal zones and the upper highlands. Areas previously used for grazing (rangeland, LM 4-5) have been changed to sedentary agriculture. Soils in these zones are highly erodible due to their structure, rainfall patterns and land use system. Land exceeding a slope of 55% has also seen change in land use from the recommended forest cover to crop production in LH1.

[1] For detailed description of these, and other, SWC measures, visit the World Overview of Conservation Approached and Technologies website: www.WOCAT.net

2 Methodology

The study was carried out in Meru South District (Figure 3). The district was chosen due to the following reasons:

– The NSWCP was implemented in the district, with most locations documented as catchment areas;
– NALEP has been implemented in the entire district, major overlaps existing between the NSWCP catchments and NALEP focal areas;
– The district features all AEZs, from TA1 to the arid lands, providing an ideal site to study and document measures applied since the colonial era to the present; and
– The district has been implementing a project on environmental conservation (Mount Kenya East Pilot Project, MKEPP). The project adopted a river catchment area approach, further increasing farmer coverage to the rangelands.

2.1 Description of study area

2.1.1 Location of Meru South District

Meru South District is one of many districts comprising Eastern Province. The district was created in December 2007 through a sub-division of an existing district into Meru South and Maara Districts. The district lies to the east of Mt Kenya and borders Embu East District to the South, Maara District to the North West and Tharaka District to the East. The district covers an area of 445 km^2, of which 65% is arable and the remaining 35% is made up of forest reserves, roads, urban/market centres and steep/rocky areas. About 40% of the arable land falls under the arid and semi-arid land (ASAL) category. The district has a population of 128,100 persons, which comprise 62,150 males and 65,950 females (numbers rounded). In total, the district has 46,810 farms and 25,095 farm families (GoK 2001). Administratively, the district has three divisions namely Chuka, Magumoni, and Igamba Ng'ombe, 17 locations and 45 sub-locations. Land is demarcated and individually owned under the freehold system of tenure. Holdings average 1.5 ha in the lower zones and 0.5 ha in the upper zones (GoK 2002).

2.1.2 Rainfall and temperature

The rainfall is bimodal, with the March to May rains referred to as the "long rains", though these are normally not reliable. The October to November rains are referred to as the "short rains" and are more dependable. The annual rainfall ranges from 600 mm in the lower semi-arid zones to 2000 mm in the upper highland zones. Temperatures in the midland zones range from 20-30 °C and in the upper highland zone from 14-17 °C.

2.1.3 Altitude

The altitude ranges from 800 metres above sea level (m.a.s.l.) to 5000 m.a.s.l. at the peak of Mt Kenya.

2.2 Data collection

The study was carried out in May 2011 using a transect running from LH1 to LM5. The farms for documentation of the conservation measures were randomly chosen along the transect. The study covered the three administrative divisions of the district: Chuka, Magumoni, and Igamba Ng'ombe. The data collected principally comprised the conservation measures applied, and documentation was effected through photographs and brief discussions with the farmers on each method applied. Secondary data was reviewed to verify farmers' testimonies.

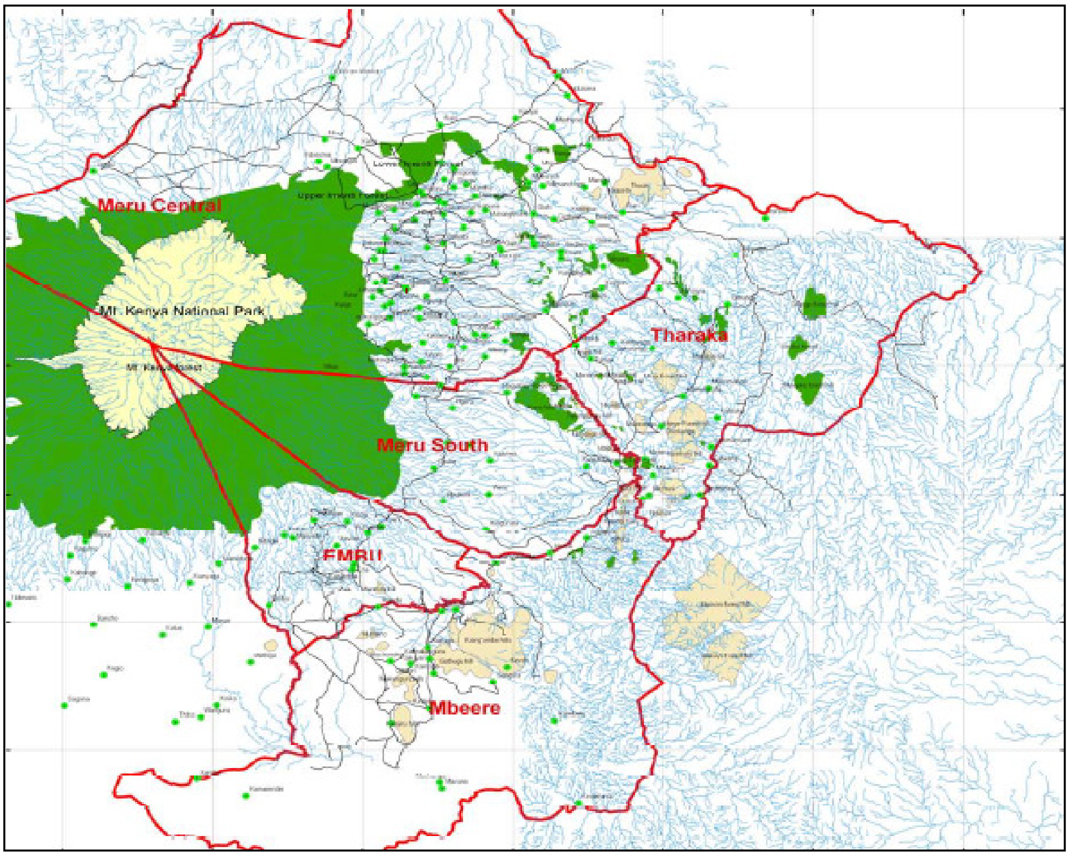


Figure 3

Meru South district within Upper Tana catchment: Forest is shown in green. The district has many rivers, all tributaries of the Tana, shown in light blue. Source: MoA[2].

2.3 Coverage of the study

The study was carried out along a transect and covered farms lying within LH1, UM1-3 and LM3-5. Table 2 summarises the names of the farmers in each AEZ and the SWC measures found in each farm. The documentation was done by taking digital pictures of the structures.

[2] MoA (Ministry of Agriculture), MKEPP project, Meru South District: http://www.mkepp.or.ke

Table 2
Farmers sampled for the study in each AEZ

AEZ (main enterprise)	Farmers Name	SWC Methods
LH1 (Tea)	Mrs Cianjoka Mbungu	Tea cover crop, mulching, cut-off drains, riverine protection (grass and trees), contour cropping
UM1 (Tea and Coffee)	Mr Tartisio Nyamu Mr Christopher Muthee	Cover crops (tea and napier grass), mulching, terraces (bench and *fanya juu*), contour cropping, cut-off drains, retention ditches, agroforestry and riverine protection (trees and grass)
UM2 (Coffee)	Arphaxad Mutegi Gitari Zephania Junius Ruchi Mrs Nyaga Mrs Kiraithe	Cover crops (sweet potatoes, napier grass), ridges, terraces (bench and *fanya juu*), contour cropping, cut-off drains, retention ditches, mulching and agroforestry
UM3 (Coffee, food crops)	Mr Delphino Njagi Charles Mbaya Thomas Mutegi Meru South Union farm	Retention ditches, terraces (*fanya juu* and bench), cover crops (sweet potatoes and napier grass), ridges, contour cropping, grass strips, microcatchments (bananas), agroforestry and riverine protection (trees and grass)
UM/3 LM3 transition sub zone (Maize)	Anthony Andrew Kathanje Gitari, Fredah Kagendo, Lucia Wanyina Mutegi Mbaoni	Contour cropping, grass strips, uncultivated strips, trash lines terraces, agroforestry, microcatchments (bananas)
LM3 Cotton, dryland pulses	Ashford Mbae, Cheria Mbae, Dr Nyaga Octavius Nyaga Winfred Mugambi	Ridges (maize, pigeon peas), furrow planting, minimum tillage, grass strips, stone lines, contour cropping, terraces (*fanya juu*), microcatchments (bananas), retention ditches, and trash lines
LM4-5 (Range lands, livestock, millet, dryland pulses)	Benson Ncuga Esto Mubue Julius Ngai Nelson Kaburu Vangeline Mukwanjeru	Stone lines, ridges, furrow planting, trash lines, grass strips, terraces (*fanya juu*), retention ditches, cut-off drains, water pans for runoff harvesting

3 Findings of the study

The major findings of the study indicated that the farmers sampled (Table 2) applied structural measures, agronomic/vegetative measures and water harvesting techniques to conserve soil and water within their farms. The choice of the measures was determined by the slope (cover crops on very steep slopes and simple trash lines on very gentle slopes), rainfall intensity and amount (stabilised terraces in higher rainfall areas) and soil type (stone line in rocky/stony areas). Some measures, such as terraces, were found in all AEZ. The differences were found in spacing, type of stabilisation and the type of terrace (benches in coffee; *fanya juu* in annual cropland).

3.1 Soil and water conservation measures in smallholder farms

The measures applied by farmers in each agro-ecological zone are presented in Table 3 below. They are categorised into two: agronomic/vegetative measures and structural measures. Agronomic measures are cultural practices that promote soil and water conservation. They are effective in reducing splash erosion, improving soil structure and reducing runoff. These include mixed cropping, intercropping, contour cropping and mulching. Vegetative measures are often associated with perennial crops, grasses or shrubs. They persist for a long time in the field; for example agroforestry technologies. Where these are cross-slope barriers, they result in change in slope profile; terraces eventually develop behind grass strips over time, as soil carried downslope is restrained by the strip established on the contour.

Table 3
SWC methods applied in the AEZ in order of preferences by the farmers

AEZ	AGRONOMIC/VEGETATIVE METHODS	STRUCTURAL METHODS
LH1 (Tea zone)	Cover crops (tea and napier grass) Mulching Contour cropping Agroforestry	Cut-off drains
UM1 (Tea and Coffee zone)	Cover crops (tea and napier grass) Mulching Contour cropping Agroforestry	Bench terraces *Fanya juu* terraces Cut-off drains Retention ditches
UM2 (Coffee zone)	Cover crops (napier grass, sweet potatoes, beans) Contour cropping Agroforestry	*Fanya juu* terraces Bench terraces Cut-off drains Retention ditches
UM3 (Marginal coffee, food crops)	Cover crops (napier grass, sweet potatoes, beans) Grass strips (napier grass) Contour cropping Agroforestry	*Fanya juu* terraces Retention ditches Bench terraces Microcatchments (bananas and fruit trees)
Um3-LM3 transition (Maize belt)	Grass strips (napier and *makarikari* grass) Trash lines Contour cropping Agroforestry	*Fanya juu* terraces Retention ditches Microcatchments (bananas and fruit trees)
LM3 (Cotton and dry land legumes)	Grass strips/unploughed strips Ridges and furrows Contour cropping Minimum tillage Trash lines	Stone lines *Fanya juu* terraces Microcatchments (bananas and fruit trees) Retention ditches
LM4-5 (Range lands)	Ridges and furrows Trash lines Grass strips/unploughed strips Minimum tillage	Stone lines *Fanya juu* terraces Retention ditches

3.2 Most appropriate soil and water conservation measures

The study aimed at identifying the three most suitable soil and water conservation measures in each agro-ecological zone (AEZ). To identify the measures, the following factors were put into consideration:

1. The soil type: of great concern was the erodibility of the soils. Soils in LH1, UM1-3 are characterised by humic nitisols. These are deep, well-drained soils with lower erodibility than chromic cambisols and lithosols found in some sections of LM3-5.
2. Slope: farm land is classified according to the slope and soil and water conservation measures recommended as follows:
   a. Land with slopes of less than 2% is classified as flat. It may be farmed with basic soil and water conservation measures such as contour cropping.
   b. Land with a slope of up to 12% is classified as gently sloping. Measures recommended include terraces - especially on land with highly erodible soils.
   c. Land with slopes between 12% and 55% is classified as having steep – very steep slopes. Terracing is obligatory. The spacing between terraces becomes shorter as the slope increases from 12%. On slopes over 45%, bench terraces are recommended, preferably under coffee, fruit trees, fodder trees or afforestation.

d. Land sloping more than 55% is classified as unsuitable for agricultural production except under permanent grass, tea or forest. Tea provides good soil cover, when well mulched. However, caution should be taken during early stages of tea establishment and with access paths within the tea.
e. Land characterised by shallow, stony soil or rocky terrain should be put under pasture or natural vegetation. Terrace risers should be reinforced with stones.

3. Rainfall: upper zones receive higher rainfall for a comparatively longer period. Lower zones, on the other hand, receive less rainfall in seasonal or annual totals, but the intensity may be relatively high.
4. Land use: climatic suitability of farmers' preferred land use was a major concern. A farmer preferring banana production in lower rainfall AEZ has to invest in water harvesting structural measures. A farmer interested in dairy production, on the other hand, has to invest more in vegetative methods such as cover crops and grass strips to provide fodder.

Based on these considerations, among others, the following were identified as the most appropriate measures of soil and water conservation in each AEZ (Table 4).

Table 4
Most suitable SWC measures in the Upper Tana catchment

AEZ	MOST APPROPRIATE METHODS	
	AGRONOMIC/VEGETATIVE METHODS	STRUCTURAL METHODS
LH1 (Tea zone)	• Cover crops of tea and napier grass on slopes over 30%	• *Fanya juu* terraces • Cut-off drains to safely discharge water to natural waterways
UM1 (Tea and Coffee zone)	• Cover crops of tea and napier grass on slopes over 30%	• *Fanya juu* terraces in crop land and bench terraces in coffee • Cut-off drains to safely discharge water to natural waterways
UM2 (Coffee zone)	• Cover crops of napier grass	• *Fanya juu* terraces in crop land and bench terraces in coffee • Bench terraces in coffee
UM3 (Marginal coffee, food crops)	• Grass strips of napier grass and *makarikari* (*Panicum coloratum var. makarikariensis*) grass	• *Fanya juu* terraces • Retention ditches • Microcatchments for bananas and other fruit trees
UM3-LM3 transition (Maize belt)	• Grass strips of napier grass and/or *makarikari* grass • Ridges and furrows contour cropping	• *Fanya juu* terraces • Retention ditches • Microcatchments for bananas and other fruit trees
LM3 (Cotton and dry land legumes)	• Grass strips of indigenous and /or makarikari grass; • Ridges and furrows contour cropping	• *Fanya juu* terraces • Retention ditches • Microcatchments for bananas and other fruit trees
LM4-5 (Range lands)	• Grass strips of indigenous and /or makarikari grass • Ridges and furrows contour cropping	• Retention ditches • *Fanya juu* terraces • Microcatchments

NB:
1. All structures in all the above-mentioned agro-ecological zones should be complimented or supplemented with agroforestry interventions to be more effective. In the study area, agroforestry practice is a tradition, using indigenous tree species and selected exotic species that have naturalised such as *Grevillea robusta*. There is need to improve availability of exotic multipurpose tree species such as *Calliandra callothyrsus* or *Leucaena leucocephala*.
2. In the LM3-4 and rangeland agro-ecological zones, the most appropriate methods are related to water harvesting.

3.3 Relatively new conservation measures

The relatively new conservation methods in the study area included the use of ridges and furrows for crop production, microcatchments for production of bananas and fruit trees and retention ditches in the Lower Midland zones.

4 Description of soil and water conservation (*green water* management) measures

The Ministry of Agriculture (MoA) recommends various soil and water conservation measures – usually referred to as "*green water* management" measures under GWC - for various soil types and slopes (Thomas *et al.* 1997). All the farmers involved in the study had received information on the measures they had applied on their farms from the extension personnel of the Ministry of Agriculture. The measures are categorised into two: agronomic/vegetative and structural.

4.1 Agronomic and vegetative measures

Agronomic measures are cultural practices that promote soil and water conservation. They are effective in reducing splash erosion, improving soil structure and reducing runoff. Agronomic measures do not lead to change in landscape or slope profile. They are associated with annual crops and are repeated each season. These include mixed cropping, intercropping, contour cropping and mulching. Vegetative measures are similar to agronomic measures except that they are normally associated with perennial crops, grasses or shrubs. They persist in the field; for example agroforestry technologies. Often, when they take the form of cross-slope barriers, they result in change in slope profile; terraces eventually develop on grass strips over time, as soil carried downslope is restrained by the strip established on the contour. They include:

1. Intercropping: This is growing two or more crops simultaneously in the same field and in the same season. Fast growing crops (such as beans or cowpeas) provide cover to the soil early in the season while maize or cotton develops adequate canopy to cover the soil later on during the same season. These crops are distinctly arranged in rows.
2. Mixed cropping differs with intercropping in that there is no distinct arrangement of the crops. If the same crops are grown each year in a mixture, some benefits of rotation may be lost.
3. Cover cropping: a crop that covers the ground protects soil from overland flow and splash erosion. The cover crop also protects the soil from excessive heat from the sun, thereby creating a good environment for soil micro-organisms. Sweet potatoes, tea and napier grass are common cover crops in the district.
4. Contour farming: this involves ploughing, weeding and growing of crops in rows along the contour. The crops may also be grown in alternate strips of similar width - which is then termed "strip cropping". The width of the strips is determined by the slope, soil type, mechanical equipment to be used, and by the climate. Steeper sloping land will have shorter spacing between the strips in strip cropping, the spacing between strips widening as slopes reduces. Contour farming may be practiced in several ways:
    a. Ridges: contour farming may be practiced through planting, for instance, sweet potatoes or Irish potatoes on ridges established on the contour. This is also a very good SWC measure when practicing maize cultivation. It would be an excellent solution to stop erosion in maize fields with poor SWC. However, because it is a labour-intensive method, the introduction will require sensitisation and demonstration of its effectiveness.
    b. Trash lines: these are plant residues that are laid in lines on the contour: these are recommended on soils of gentle slope.
    c. Unploughed strips: these are strips of unploughed land left along the contour. The vegetation on the unploughed strip reduces runoff.
    d. Grass strips: grass is established on the contour. Grass strips, unploughed strips and trash lines are most effective on land not exceeding 30% slope.

5. Mulching: mulch comprises crop residues (stover), weeds, leaves, prunings from crops and other vegetative materials laid on the soil. Mulch provides cover to the soil, reducing impact of raindrop splash, increases water infiltration and eventually, when mulch decomposes, it increases organic matter in the soil. Mulching is also the most effective measure to reduce soil evaporation. In Kenya, several field studies have emphasised the importance of mulch in enhancing infiltration, soil water availability and reduction of evaporation (Gicheru *et al.* 2002) early field trials in Kenya demonstrated large increases in soil moisture and yields when mulch was applied before the rains (Robinson and Hosegood 1965).
6. Multi-storey cropping/agroforestry: this is the practice of growing multipurpose trees (tall crops) and short crops simultaneously. The trees form the top canopy while other shorter crops form lower canopies, the crops growing at different heights. In this system, soil erosion is minimised.

Farmers in the study area applied several agronomic and vegetative measures simultaneously. Such combinations included contour intercropping, contour cover cropping, contour ridge cropping, contour cover cropping with mulching, grass/unploughed strips with contour cropping and agroforestry. Such combinations were more effective in reducing runoff, improving infiltration and improving land productivity.

4.2 Structural measures

These are permanent features formed using soil, stones or masonry, designed to protect soil from uncontrolled runoff, retain water or divert it to crop land (water harvesting). Most common recommended structures on crop land include diversion ditches, cut-off drains, terraces and retention ditches. Some of the structures may develop naturally from vegetative barriers on land with slopes less than 30%, while others are formed by hand. In all cases, construction must be on the contour. Spacing between the structures is determined depending on the slope, soil type and type of structure to be put in place. Selection of the type of structure depends on factors such as:
a. Rainfall amount and distribution, the need to discharge or retain water
b. Cropping pattern (perennial or annual cropping, with or without rotations)
c. Soil characteristics such as erodibility, texture, structure, stoniness, etc.
d. Steepness of the slope

Structural measures recommended on cropland include:
1. Diversion ditches or cut-off drains: these are graded channels with a supporting ridge or bank on the lower side. They are constructed to intercept surface runoff and safely convey it to a waterway, thereby protecting cropland. Grass is established on the upper side to reduce sedimentation and on the lower edge to stabilise the embankment.
2. Retention ditches: these are constructed to harvest and retain water within the crop land to augment water required for the crops. They may be constructed to harness water from farm structures or harvest it from road runoff. They are recommended in the rangelands. In the humid areas, retention ditches are used to retain water in farms where there is no opportunity to discharge it to a waterway.
3. Terraces: these are constructed on the contour as ridges or embankments of stone or earth, with or without a channel. Eventually, the slope on the crop land changes as soil is retained behind the upper ridge. Several types of terraces are common:
   a. Bench terraces: these are constructed as level or near-level steps formed on the contour. The steps may be constructed or formed from grass strips or *fanya juu* terraces. Bench terraces are constructed on land with 30-55% slope. Bench terraces reduce slope of cultivated land, increase infiltration and reduce runoff. They are stabilised with grass and require regular maintenance to prevent erosion. In stony areas, stones are used on the embankment, where stone walls are constructed on near- vertical lay out.

b. *Fanya juu* terraces: these are constructed by digging a trench on the contour and throwing the soil uphill to form an embankment. They are very popular in smallholder farms, especially on farms with slopes below 20%.

4. Microcatchments: These are runoff-collecting pits in which tree crops are planted. The microcatchment may be completely enclosed by bunds or have an open end. The bunds may be V-shaped, semi-circular, crescent shaped, trapezoidal or circular.

The most common structural measures in the study area were *fanya juu* terraces. They were found in all the AEZs. All the structures had been laid out by the MoA extension personnel and excavated by the farmers. The structures were stabilised with napier grass in the upper zones or *makarikari* (*Panicum coloratum var. makarikariensis*) grass in the lower zones.

4.3 Cover crops

Cover cropping is a practise used to provide the crop land with protection by using a crop established primarily to cover the soil surface. The crop covers the ground and protects the soil from overland flow and splash erosion. The cover crop also protects the soil from excessive heat from the sun, thereby creating a good environment for soil micro-organisms to flourish. Cover crops improve soil fertility and crop performance (Thomas *et al.* 1997; Pullaro *et al.* 2006).

4.3.1 Benefits of cover cropping

- The crop protects the soil from erosion by raindrop impact
- It leads to increased infiltration of water into the soil, thereby reducing erosion by runoff
- When ploughed into the soil, herbaceous legume cover crops such as *Mucuna* sp. or *Dolichos* sp. improve soil fertility after decomposition of the residues
- Foliage and roots from cover crops add organic matter to the soil, thereby improving the soil structure and below-ground biodiversity
- Cover crops provide an alternative to bare ground or weed cover
- Cover crops reduce weeds and pests
- Cover crops provide a favourable microhabitat for beneficial insects

4.3.2 Selection of cover crops

Several factors have to be considered when selecting the most appropriate cover crop for each area. These include:

- Slope: on slopes exceeding 55%, establishing a cover crop is mandatory according to the law. On such slopes, natural vegetation such as grassland or forest depending on AEZ is recommended. Farmers may select tree species for establishing woodlots, a source of fuelwood and other tree products. Tea is recommended for areas that are agroclimatically suitable. Soil must be protected before tea fully establishes, through using mulch.
- Agroclimatic suitability of the crops: farmers may choose economical viable crops depending on agroclimatic suitability. These may include tea (LH1, UM1), napier grass (LH1, UM 1/2/3, LM3), *makarikari* grass (UM3, LM3) and sweet potatoes (LH1, UM1/2/3, LM3). These are crops that provide the farmer with either food or income directly or are used to feed livestock, which are a major source of income in all AEZ.

- Soil type: shallow and stony soil types in the rangelands are more appropriate for grass cover crops due to their high erodibility. Trees may be more appropriate for deeper and less erodible soils in LH and UM zones.

4.4 Contour cropping

Contour cropping is practised on all AEZs to reduce runoff and minimise erosion. In LH1 and UM1, tea is established along the contour as a method of contour cropping. Permanent crops such as coffee are also established on the contours in UM1, 2 and 3. It is important to note that even terraces are laid out following the contours and seasonal or permanent crops established between terraces planted following the contour. Contour cropping systems consisting of various combinations of tree, shrub or grass species is used to minimise erosion, restore fertility and improve soil productivity.

4.4.1 Benefits of contour cropping

Contour cropping has many benefits (Young 1997, Angima *et al.* 2002):

- Rows of crops such as maize or hedgerows of pigeon peas or grass strips or hedgerows of shrubs or other agroforestry species established along the contour minimise erosion by slowing down runoff. This increases water infiltration into the soil thus increasing productivity.
- The contour strip becomes a barrier to trap the soil and eventually becomes a terrace. This leads to improved crop productivity due to retention of nutrients that would have been lost through runoff.
- In semi-arid zones (LM3, 4 and 5) hedgerows of pigeon peas are common. These are leguminous shrubs that add nutrients to the soil through nitrogen fixation.
- By integrating (leguminous) calliandra or leucaena shrubs within the contour cropping system, soil fertility restoration of the system is enhanced. Nutrients are retrieved from below the rooting zone of crops by these deep rooted shrubs and deposited on topsoil after litter fall.

4.5 Mulching

Mulch is crop residue (especially stover), weeds, leaves, prunings from crops and other vegetative materials laid on the soil. In LH1, prunings of tea bushes are spread on the soil under the tea thus forming thick mulch. In other zones, mulch of maize stalks is laid on the crop land after farmers have fed the palatable foliage to livestock. The same materials may be alternatively be used as trash lines along the contour.

4.5.1 Benefits of mulch

Mulch provides cover to the soil, reduces impact of raindrop splash, increases infiltration and eventually, when mulch decomposes, it increases organic matter in the soil. The effectiveness of mulch depends on the amount of mulch applied and timing of the application. In a study on leucaena mulch effectiveness in a wheat crop in India, it was found that mulch applied at the rate of 2 t ha^{-1} 30 days after harvest (of the leucaena) was most effective compared to application immediately after harvest. The mulch resulted in higher moisture availability at the time of sowing, leading to higher water extraction and higher water use efficiency (Sharma *et al.* 1998). It has been long known that mulching is the most effective measure to reduce soil evaporation (Kauffman *et al.* 2007). Evaporation reduction is the single largest benefit from *green water* management measures in increasing the amount of *blue water* for downstream users. Each mm of evaporation turned into infiltrated water means 10 m^3 water per hectare, water that potentially may become available as groundwater. However, the best sources of mulch have a high opportunity cost for farmers: they have alternative uses as (for example) feed for livestock. It is one of the great challenges for the Kenya Agricultural Research Institute (KARI) to identify suitable and useful hedges for farmers that also produce slow-decaying mulch to cover bare soils. The search for low-cost artificial mulch should be considered under KARI research.

4.6 Terraces

Terraces are made by digging a trench and throwing the soil uphill (*fanya juu*) to form an embankment. The embankment is stabilised (reinforced) with grass. This creates an embankment to restrict (hold) water and soil, a storage area above to prevent overtopping by runoff, and a ledge to prevent the embankment soil from sliding back into the trench as shown in Figure 4.

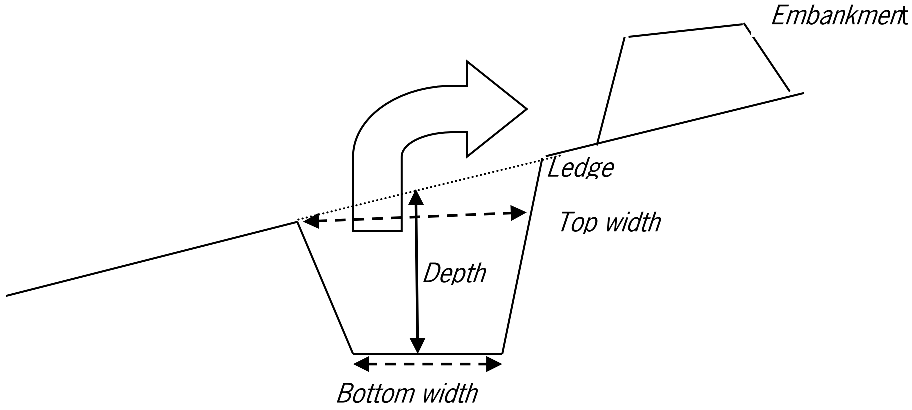


Figure 4
Design of converse terrace (fanya juu). Source: Thomas et al. 1997

Terraces are designed with zero gradients to retain the heaviest storm rainfall, expected in a ten-year period: the "design storm". The design storm is that which leads to the greatest volume of runoff. Normally, short duration storms have a high intensity in terms of mm h^{-1}. They provide a small amount of rainfall, and are thus not likely to produce large volumes of runoff. Storms of lower intensity and longer duration provide more rain, produce large volume of runoff, and allow more time for infiltration. The volume of runoff to be stored depends on duration of the storm, intensity of the storm, infiltration capacity of the soil (both land produce runoff and structure itself). Stabilising the terrace embankment with grass increases its capacity to retain the storm runoff, giving runoff water time to infiltrate in the storage area. Most terrace designs are meant to hold storms of one to three hours depending on the soil factors.

4.6.1 Terrace spacing

Terraces are spaced according to design formulae. One common formula used in Kenya is given in Annex 1. Using the formula described in Annex 1, the following typical dimensions for terraces were established (Table 5).

Table 5
Typical dimensions of fanya juu terraces

Slope (%)	Terrace spacing (m)		Trench excavation (m)		Trench Area	Bund height (m) to retain runoff at infiltration rates		
	VI	HD (	Width	Depth	m^2	Low	Medium	High
5	1	20	0.5	0.50	0.25	0.32	0.29	0.26
10	1.35	14	0.5	0.55	0.28	0.37	0.34	0.30
15	1.73	12	0.6	0.55	0.33	0.41	0.38	0.33
20	1.80	9	0.6	0.6	0.36	0.41	0.37	0.33

Note: VI = vertical interval between terraces and HD = horizontal distance between terraces.
Source: Thomas et al. 1997

Over time, the *fanya juu* terraces develop into benches. Bench terraces may be constructed directly (Figure 6). They may be designed to slope backwards, forward or have level beds (Figure 7).

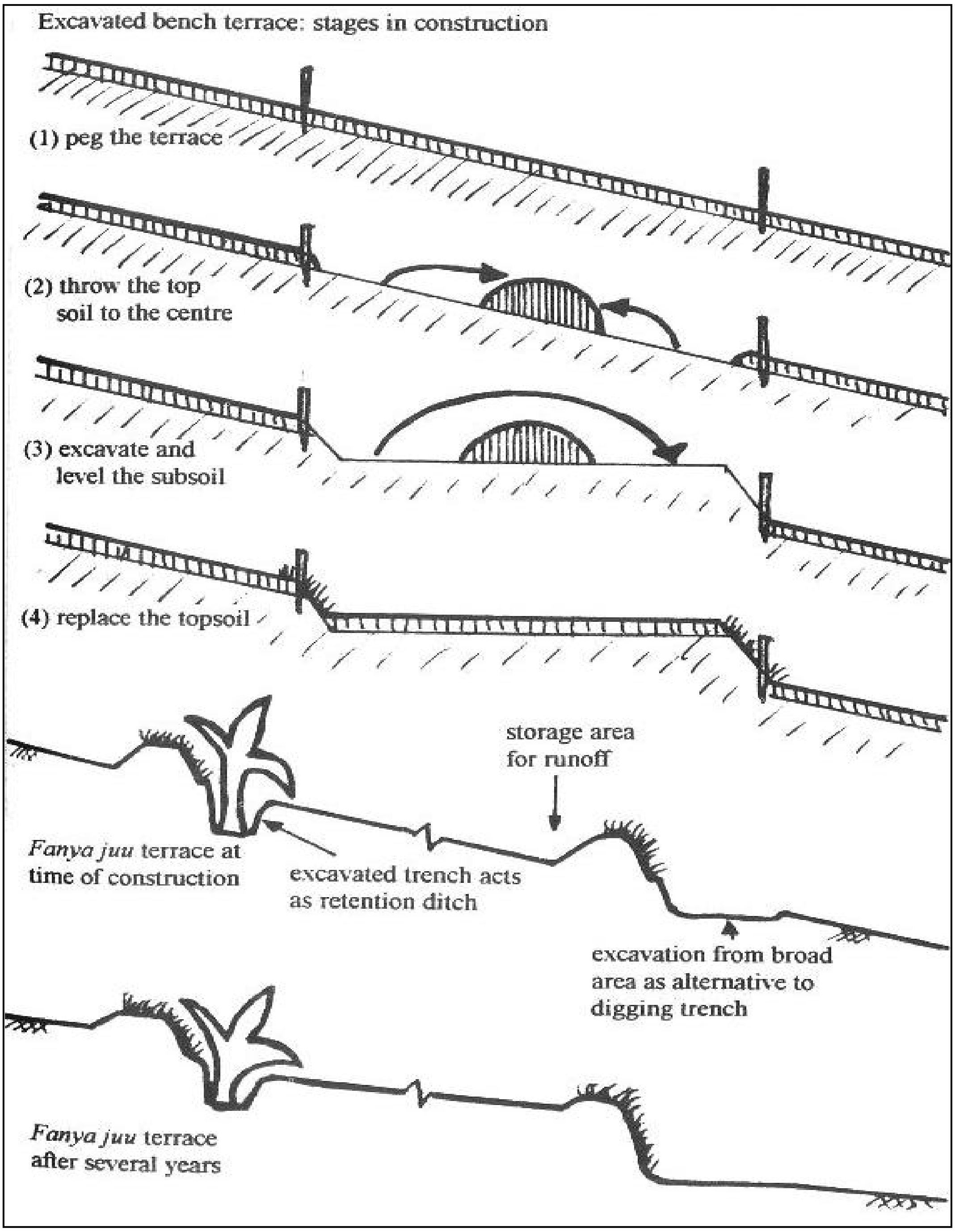


Figure 5

Stages in construction of bench terraces

Source: Thomas et al. 1997

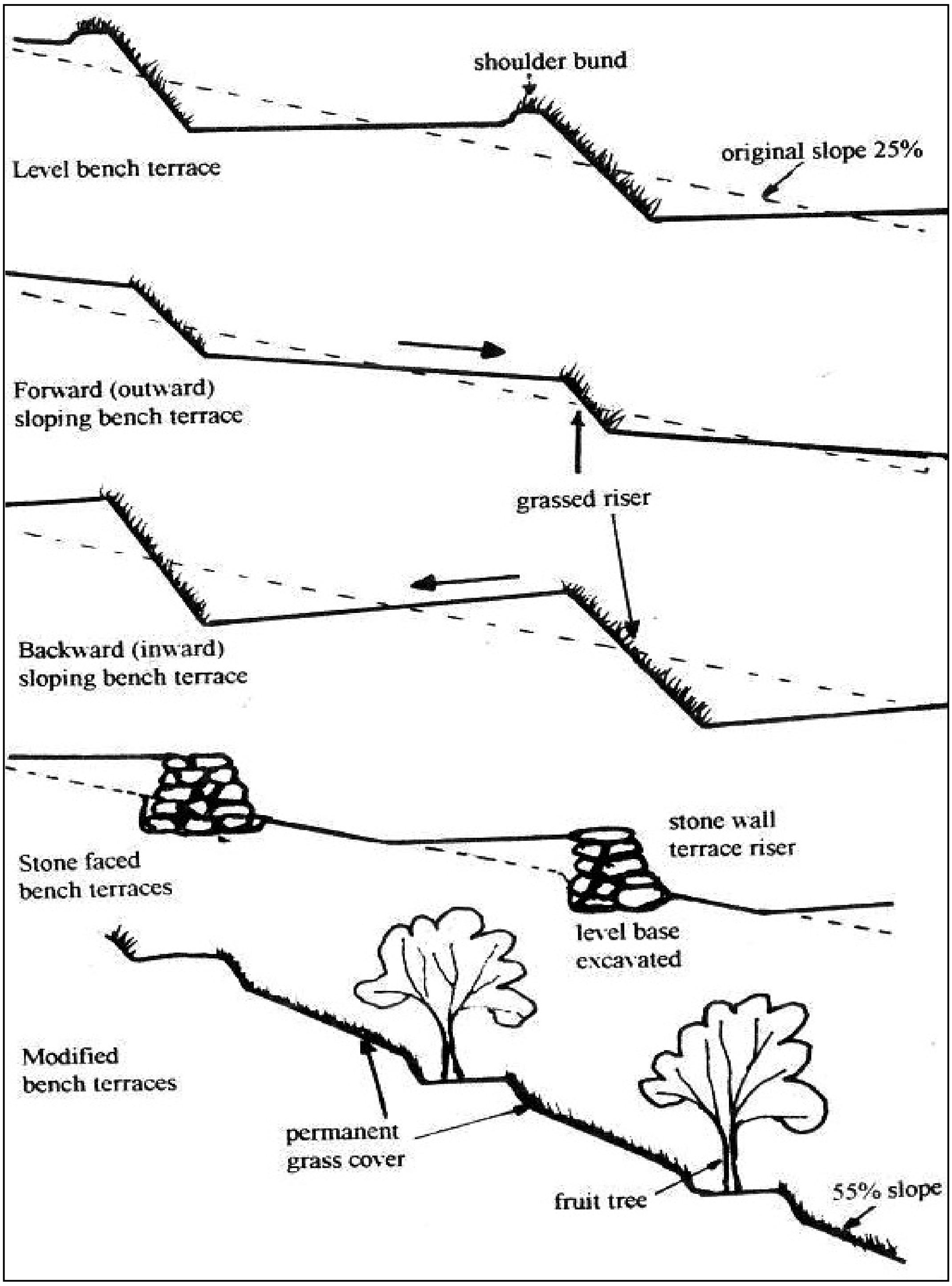


Figure 6
Bench terraces
Source: Thomas et al. 1997

4.6.2 Benefits of terracing

Terraces reduce surface runoff, thereby increasing rainfall infiltration. This leads to an increase in productivity, especially in the semi-arid areas where moisture shortage is a major limitation to crop productivity. Combining terracing, microcatchments and supplemental irrigation where possible, further reduces the risk of crop failure in the rangelands (Barron and Okwach 2005).

4.7 Retention ditches

These are designed to catch and retain all incoming runoff and hold it until it infiltrates into the soil. They are used as alternative to cut-off drains where there is no safe place to discharge the runoff, or there is need to retain the water and use it for crop production. This is becoming common in UM3 to LM4-5. A channel is excavated and the soil is thrown to the lower side to form an embankment. The embankment should be 0.2 meters from the edge of the channel (ledge) to prevent the soil from falling back into the channel. The ends are closed, unlike the open ends of the cut-off drains. *Fanya juu* terraces have channels above the bund that serve as very good retention ditches. The design of terraces and retention ditches is similar. The channel is made wider and/or deeper depending on the amount of runoff to be retained in the ditch.

4.8 Cut-off drains

Cut-off drains are used to divert water coming from outside the farm and safely discharge it to a natural – or artificial - waterway. The water may come from a hill, road runoff or other farms. Cut-off drains should be dug only when there is evidence of heavy water flows, which cannot be stopped through normal terracing. Designs of cut-off drains begin at the outlet point. As in terracing, a cut-off drain should not be longer than 400 meters. A cut-off drain dug by hand is often 1.5 m wide at the top, 0.9 m wide at the bottom and 0.6 m deep, giving a cross-section of 0.7 m^2 as shown in Figure 6 (Jaetzold *et al.* 2006).

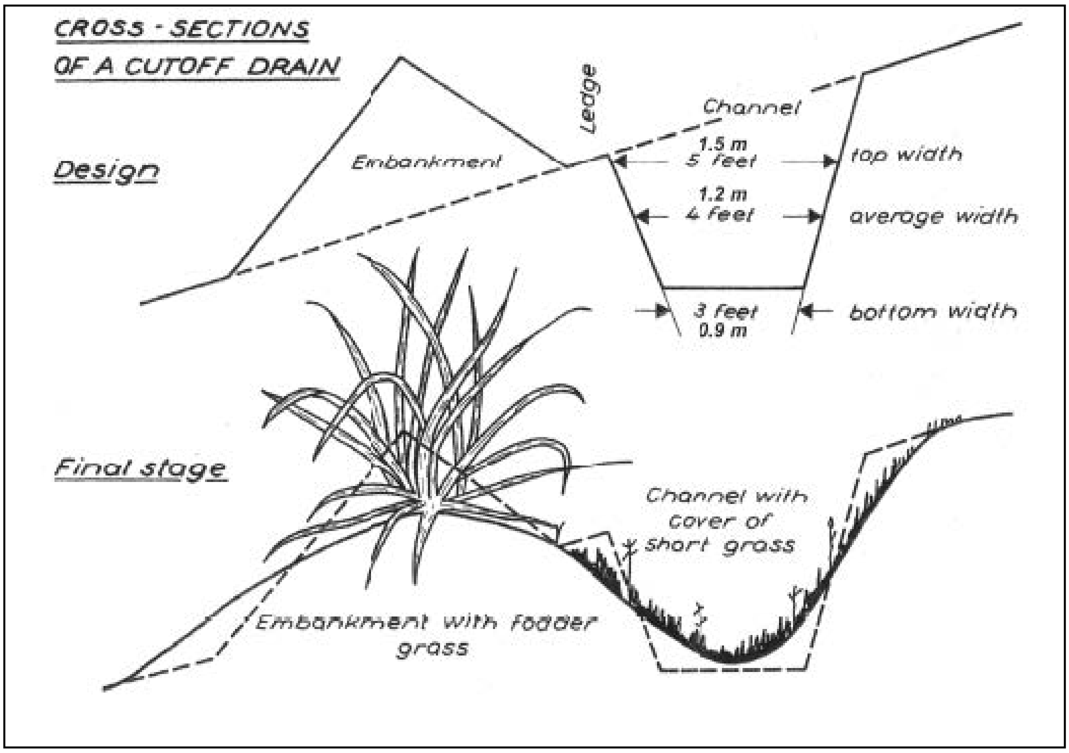


Figure 7

A cross section of a cut-off drain/retention ditch

Source: derived from Thomas et al. 1997 and Jaetzold et al. 2006

5 Photo-Documentation of soil and water conservation (*green water m*anagement) measures

5.1 Lower Highland Zone 1 (Tea Zone)

The Lower Highland zone in Meru South covers a stretch of land neighbouring Embu District. Most farms within the stretch are characterised by high slopes, average 55-60% (Plate 1). Altitude ranges from 1550 to 1800 m.a.s.l. The major economic activity is tea production, favoured by the high altitude, rainfall, soil suitability and the terrain. Most of the land in this zone was initially fallow due to the high slope. The Ministry of Agriculture recommended establishing tea as a cover crop to protect the soil and to earn income for the farmers. Soil and water conservation methods applied on the farms include tea cover crop (Plate 1), cut-off drains (Plate 2) and mulching (Plate 3).

5.1.1 Cover crop of tea

Most of the tea was planted in 1982, at spacing of 0.8 by 1.5 metres, with plant population of 8,500 per hectare. Farmers could not put the land into any agricultural activity before establishing tea due to the high slope.

5.1.2 Mulching under tea bushes

Every three to four years, the tea bush is cut back/pruned to maintain the height of the plucking table, improve productivity by cutting off the old unproductive shoots and to allow regeneration of vigorous shoots. The prunings are spread as mulch under the tea bushes. When the mulch decomposes, it increases the soil organic matter thus improving the soil structure and enriching the soil with nutrients (Plate 3). The mulch may build up to about 5-10 cm thick. Farmers reported one key advantage of mulch is that it conserves soil moisture thus enabling the tea to recover in one year after pruning.

5.1.3 Cut-off drains

These are structures constructed at the upper boundary of the tea farm to collect water from the adjacent forest and safely discharge it to a natural water way. A cut-off drain is stabilised with napier grass on the lower embankment (Plate 4). It frequently fills up with soil and has to be desilted manually. The napier grass provides fodder to stall-fed livestock, a common feature within LH1.

5.1.4 Riverine protection

Riverine protection includes keeping the soil permanently covered along both sides of the river. The Agriculture Act (cap 318) stipulates this. In addition, riverbanks are preserved by planting trees or other deep rooting perennials. Plate 1 and 5 show that the riverbank was planted with trees, although some farmers had planted tea bushes up to ten metres from the bank. Some sections had napier grass to protect the riverbank. However, it was also observed that tracts along the river are used for cultivation. Although this land use is forbidden by law, it still continues to be practiced by many farmers for horticulture and other crops.

Plate 1
A view of LH1
Note the forest in the background to the left, the steep slopes and River Thuchi that serves as boundary with Embu District (across the river to the right)

Plate 2
The tea cover crop in LH1
Viewed from the upper right end of the farms, note the napier grass on the right, on an embankment of the cut-off drain, running along all the farms in view

Plate 3
Thick mulch under tea bushes

Plate 4
The cut-off drain in LH1
Note the path and forest vegetation on the right

Plate 5
Riverbank protection in LH1
Note the trees and napier grass on the right and left bank respectively

5.2 Upper Midland Zone 1 (Tea/Coffee Zone)

The slope within UM1 was comparatively lower than LH1 at 30-45% gradient except on farms on the banks of River Thuchi. The population density within the zone is higher and land holdings average 0.1 to 0.4 hectares in size. Apart from tea and coffee, which are the major cash crops, production of maize and livestock rearing were common economic activities. The conservation methods included cover crops of tea along the contour (Plate 6), mulch within the tea and other crops (Plate 7), cover crop of napier grass (Plate 8), *fanya juu* terraces within seasonal cropland (Plate 9), bench terraces within coffee plots (Plates 10 and 11), contour cropping (Plate 12), *fanya juu* terraces (Plate 13), cut-off drains (Plate 14), and retention ditches (Plate 15) and agroforestry.

5.2.1 Cover crop of tea

The cover crop of tea was found in UM1, similar to LH1. However, plots were smaller, the bushes established on the contour and the pruning period longer comparatively (four years on average). Farmers attributed this to differences in rainfall. The zone had both tea and coffee (Plate 6).

5.2.2 Bench terraces

Bench terraces were found mainly in coffee farms. From the early 1960s to the late 1980s, it was requirement to construct bench terraces on sloping land in order to be allowed to grow coffee. Bench terraces were a common feature in coffee farms both in UM1 (Plate 10) and UM2. A number of farmers neglected maintaining bench terraces especially after the collapse of the coffee industry in the late 1980s. The farmers said they repaired their bench terraces every two years. On a slope of 30%, bench terraces have an average vertical height of 3.0 m and adequate spacing between terrace risers to allow establishment of two or more rows of traditional coffee trees (spaced at 3 m between rows) or three or four rows of Ruiru 11 coffee (spaced 2.5 m between rows). On farms exceeding 40% slope, the contours are closely spaced, allowing only one row of coffee trees (Plate 11).

5.2.3 Retention ditches

Farms in the UM1 zone have problems of controlling fast moving runoff water. Due to climate change, farmers have to contend with long dry spells even in regions that are traditionally wet - such as UM1. Therefore, these farmers have to take measures that will retain water even during the dry season, especially farmers who have dairy cows and need to have a constant supply of fodder. In order to harness free-flowing runoff during the wet season, some farmers have constructed retention ditches to collect and retain water from the farm structures. One of the farmers (Mr Muthee) had constructed a 50 m long retention ditch of 1.5 m top-width, 1.2 m mid-width, 0.9 m bottom-width and 0.9 m deep (Plate 15). Biomass yield from one napier stool near the retention ditch weighed 17 kg compared to the 10 kg from stools away from the retention ditch.

Plate 6

Mulch under tea cover crop in UM1

Note the planting along the contour. Compared with LH1, the mulch cover is less thick. The tea was pruned in late 2010. The farm slopes towards River Thuchi, background to the extreme right

Plate 7

Dried trash from napier grass used as mulch in UM1

Plate 8
Napier grass cover crop in UM1
Note the coffee farm in the background

Plate 9
Fanya juu terraces within seasonal crop land in UM1
Note the napier cover crop on the left and maize on the right, above embankment

Plate 10
Widely spaced bench terraces in UM1
Note the rows of Ruiru 11 coffee trees between the terraces

Plate 11
Side view of closely spaced bench terraces on steep slope in UM1
Note the single row of Ruiru 11 coffee trees (Mr Nyamu's farm)

Plate 12
Maize, bananas, napier planted along contour in UM1

Plate 13
Newly constructed fanya juu terrace in UM1
Note napier grass stabilising the embankment

Plate 14
Cut-off drain in UM1
Note the gentle slope (recommended 0.5%) and grass stabilising the embankment

Plate 15
Retention ditch in UM1
Note bananas on the embankment, and cassava in the drain itself, benefiting from the water held due to the gentle slope designed to minimise erosion within the drain

5.3 Upper Midland Zone 2 (Main Coffee Zone)

In UM2, the land has an average slope of about 30% except in farms with river frontage. The average farm size is about 0.2 – 0.4 hectares. Coffee is the main cash crop in the region. Banana has become a major crop in UM2 since the collapse of the coffee industry in the late 1980s. Dairy is a major enterprise. Most structural soil and water conservation measures combine napier grass which serves two purposes: stabilisation of the structure and a source of fodder for livestock. The soil conservation methods were similar to UM1. Spacing between the structures, however, was comparatively wider due to gentle slopes. Notable among the methods were cover crops under napier grass (Plate 16) or beans (Plate 17) or sweet potatoes (Plate 18). Others included contour intercropping (Plate 19), bench terraces in coffee stabilised with *makarikari* grass (Plate 20) and *fanya juu* terraces stabilised with napier grass and *makarikari* grass (Plate2 1). In UM2, a number of farmers preferred *makarikari* grass for stabilising the bench and *fanya juu* terraces instead of napier grass. This is because it required less moisture to grow and provides fodder for livestock. It has deep fibrous roots that make it drought tolerant.

Cut-off drains and retention ditches gained prominence in the lower AEZ. Farmers use them to discharge water safely to natural water ways, especially from road runoff. Other farmers preferred to harvest water from farm structures and from road runoff using retention ditches. Farmers reported decreasing reliability of rainfall and a major challenge in timing farm operations as a result. They resorted to water harvesting using retention ditches. One of the farmers (Mr Mutegi) excavated retention ditches with the capacity to hold up to 631 m^3 of water within his farm with slopes of 20%. The structures were laid out by MoA extension personnel at 10 metre spacing and support 630 banana stools (Plate 22). Another farmer (Mrs Nyaga) harvests water from about 500 m road runoff length into five lines of retention ditches each about 70 metres long. She has planted pawpaw along the ridges and maize and beans following the contour (Plate 23). The banks have been stabilised with napier grass.

Plate 16

Cover crop of napier grass in UM2

Due to less rainfall, frequency of harvesting is lower compared to UM1 or LH1

Plate 17
Beans in UM2
Beans provide good cover to the soil for one season and are very good in rotations

Plate 18
Sweet potato cover crop established on ridges in UM2
Ridges are not clearly visible due to vigorous vegetative growth of the sweet potatoes

Plate 19
Intercropping along the contour in UM2
Note the fanya juu on the left stabilised with napier grass, beans, rows of maize, sorghum (on the right) and trees in the background

Plate 20
Bench terraces in UM2
Note the stabilising makarikari grass and the neglected coffee in the background

Plate 21
Fanya juu terraces stabilised with makarikari grass in UM2
Note the intercropping on the contour for maize and coffee (cut back through change of cycle)

Plate 22
Retention ditch in UM2
Note the napier on the embankment and the healthy banana crop

Plate 23
Retention ditch supporting pawpaw, maize, beans in UM2
Note the napier grass on the embankment, the pawpaw and row of maize planted along the contour

5.4 Upper Midland 3 AEZ (Marginal Coffee Zone)

Since the collapse of the coffee industry, this zone has become a major maize (and other food crops) belt. In the study area, farmers in this zone plant coffee and other food crops like maize and beans. Land in this agro-ecological zone has an average gradient of about 15%. The average farm size is about 0.4 hectares. Farmers also keep livestock for milk production, mainly crosses of Friesian or Ayrshire and indigenous cattle. Due to the gentle slopes, soil conservation measures are mainly vegetative and agronomic. The structural measures are mainly *fanya juu* terraces (Plate 24), retention ditches (Plate 25) and microcatchments for water harvesting (Plate 28). Vegetative and agronomic measures include cover crop of sweet potatoes (Plate 26), grass strips and contour cropping (Plate 27).

5.4.1 Retention ditches

Slopes in the zone are not very steep but water from the Upper Midland zone 2 tends to flow into this zone. Farmers here harvest the road runoff water and use it for crop production. One of the farmers (Mr. Dephino Njagi) reported that runoff from as far up as one kilometre was flowing into his farm causing massive soil erosion. In 2008, extension officers from the MoA advised him to harvest the water and use it for crop production. Retention ditches were laid out to control and harvest the water. His farm had a double slope creating a very challenging task of designing the structures. The farmer excavated the ditches, harvests water from the runoff and uses it for crop production. The improvement in his farm motivated other farmers to construct such retention ditches within the AEZ (Plate 25).

Plate 24
Fanya juu structure constructed the previous year in UM3

Plate 25
Retention ditches in UM3
Note the napier stabilising the embankment and the V-design due to the slope

Plate 26
Sweet potato cover crop in UM3

Plate 27
Grass strips of napier in UM3
Note the bean cover crop (major food crop) and contour cropping of maize

Plate 28
Bananas planted in microcatchments in UM3
Note the trunk of a young Grevillea robusta tree in the foreground and other agroforestry trees in the background

5.5 Upper Midland Zone 3-Lower Midland Zone 3-Transition (Maize Zone)

This is a transition zone, between UM3 and LM3 and is unique. Land is almost flat with very gentle slopes of 5-8%. Land holdings are also comparatively large (0.8 – 1.2 hectares). The zone is the main maize producing belt of the district.

The soil conservation structures were very similar to those in UM3, except that grass strips and trash were more popular due to the gentle slopes. In most farms, old grass strips (Plate 29) and trash lines (Plate 30) were common. Retention ditches and *fanya juu* terraces were also found within the zone. *Fanya juu* terraces were common and widely spaced due to the gentle slope (Plate 31). The farmers practiced contour cropping i.e. planting crops following the contours. Farmers in this zone have preserved many indigenous trees on their farms, unlike other zones where exotic species such as *Grevillea robusta* are the most common (Plate 32). Farmers in the transition zone use microcatchments to grow bananas. The spacing is wider than UM 3 (4x4 m) and most common banana varieties were local. Farmers said tissue culture did not do well even under microcatchment technology (Plate 33).

Plate 29
A mature strip of makarikari grass in UM3/LM3 transition zone
Note it has formed a terrace over time, easily mistaken for a fanya juu terrace. Indigenous trees are seen in the background

Plate 30
An old trash line, also forming a terrace over time in UM3/LM3 transition
Note in the background, makarikari grass on the strip

Plate 31
Fanya juu terraces in UM3/LM3 transition zone
Note the makarikari grass and the wide spacing between terraces

Plate 32
Newly constructed fanya juu terrace in UM3/LM3 transition
Note the grass stabilising the terrace has not fully established. Maize is planted along the contour. Indigenous agroforestry trees are scattered in the background

Plate 33
Microcatchment for banana production in UM3/LM3 transition belt
Note the spacing is wider, up to 4 m and microcatchment pits bigger

5.6 Lower Midland 3 (Cotton, Dry-Land Legumes Zone)

The LM3 zone is characterised by gentle slopes of 3-5% except on hills where gradients of up to 30% are found. The main economic activity in the zone is production of cotton and dryland legumes (pigeon peas, green grams and cowpeas). Farmers also keep livestock for meat. Local cattle (zebu) and goats (gala) are kept. The greatest challenge that farmers face is the low rainfall amount and distribution. Most methods for soil and water conservation are either to ensure retention of almost all the rainwater on the farm, or harvest and deliver runoff water to the crop land to support crop production.

5.6.1 Ridge and furrow planting

Water availability in this AEZ is a big challenge. Crops are planted on ridges and furrows made to hold water. MoA and KARI have carried out demonstrations on ridge and furrow technology in LM3. Many farmers in the zone have adopted the technology and are able to produce maize (dryland varieties) and pigeon peas. One farmer had 0.8 hectares of maize grown in furrows (Plate 34). The farmer admitted that before the introduction of the technology, she never used to harvest much from her plot.

5.6.2 Minimum tillage

Rains in Meru South district are bimodal. The short rains are received from October to December while the long rains fall from March to May. Farmers in the lower dry zone practice minimum tillage with respect to land preparation before the long rains. The farmers noted that the dry period between the seasons (i.e. December to March) was short and the long rains had become unreliable. Through experience, farmers noticed that by not disturbing the soil during land preparation in January-February, the crop performance was better during the

March to May long rains season. During this period, the farmers now tend to use alternative tools for land preparation: for example a machete (*panga*) that does not dig deep into the soil.

5.6.3 Grass strips / unploughed strips

Farmers in LM3 use grass strips as the most common method of soil and water conservation on gentle slopes. Apart from establishing perennial grasses like napier and *makarikari* grasses in UM3 and above, some farmers in LM3 preferred strips of indigenous grasses. Some strips were narrower than the recommended 1.2 m width while other farmers were able to establish standard strips (Plate 35). The strips are established along the contour.

5.6.4 Stone lines

Some sections of LM3 are characterised by shallow, well drained stony to rocky clay loams both with rock outcrops (chromic cambisols and lithosols). Farmers whose land falls in this category use stones within the farm for soil and water conservation purposes. The stones are collected and meticulously arranged along the laid-out contour, forming a bench over time (Plate 36). The upper embankment of the stone lines is reinforced with napier grass, *makarikari* grass - or indigenous grass species which establish naturally.

5.6.5 Contour cropping

Contour cropping is common practise in LM3, purposely to control erosion and retain all moisture within the farm. Farmers use combinations of vegetative and agronomic methods for soil and water conservation to maximise available rainwater. It is common to see pigeon peas, maize, beans and other crops planted on ridges between the stone lines, both ridges and stone lines laid along the contour (Plate 37).

5.6.6 Fanya juu

Fanya juu terraces in LM3 were stabilised with napier grass or stones in farms with stones (Plate 38).

5.6.7 Microcatchments for bananas

Though the altitude and soils of LM3 are suitable for banana production, availability of water for bananas is a challenge to the farmers. However, by harvesting water through microcatchments, they have been able to grow bananas (Plate 39). Some farmers augment the water supply by using retention ditches used to harvest water from road runoff.

5.6.8 Retention ditches

In order to support crop production in the semi-arid environment of LM3, farmers harvest water from runoff using ditches. Water is diverted from the road and retained in ditches within the farm. Some of the water is harvested from roof catchments from farm structures (Plate 40). For example, Dr. Nyaga a farmer within the region, constructed five lines of retention ditches each about 70-80 m long that “walk the water” in his farm.

He then planted the tissue culture bananas in microcatchments (Plate 39). The success of Dr Nyaga motivated other farmers within the region to adopt water harvesting technologies.

5.6.9 Trash lines

Trash lines are very common in this zone especially in farms with fairly flat slopes. During harvesting, the crop stover and other trash are arranged along contour lines to form the trash lines. However, the trash lines are attacked by termites especially during dry weather and have to be reconstructed frequently (Plate 41).

Plate 34
Ridge and furrow technology in LM3
Note the robust pigeon pea crop on ridges and maize planted in furrows

Plate 35
Grass strips in LM3
Note the farmer standing next to her narrow grass strip and the healthy maize crop planted on the contour (left) The photo on the right shows a standard grass strip of 1.2 m width

Plate 36

Stone lines in LM3

Note the stone lines are laid out along the contour. A young mango tree is seen on the left and a healthy maize crop on the right, planted along the contour

Plate 37

Contour cropping in LM3

Note the rows of maize (left) and mango trees (right), both established along the contour; An old fanya juu terrace is visible on the right

Plate 38
Fanya juu terrace in LM3 (stabilised with stones)

Plate 39
Microcatchment technology in LM3
Note the healthy banana suckers

Plate 40
A retention ditch in LM3
It collects water from roof catchment of the farm structures. Note the sweet potatoes on the embankment

Plate 41
Trash line in LM3
Note it has formed a ridge over time due to retention of soil and water running along the farm

5.7 Lower Midland 4/5 Range Lands

The economic activities in LM 4 and 5 are limited by availability of water. The zone receives less than 600 mm rainfall annually, which in most cases is unreliable. Farmers initially reared beef cattle and goats, but due to population pressure, most of them started crop production. The crops grown are dryland species, mostly sorghum, millet, pigeon peas and cowpeas. Land in this agroecological zone has an average gradient of 3 - 5% except on rocky out crops and river valleys. The average farm size is about 0.8 – 1.2 hectares.

The soil and water conservation methods within the farms are very similar to LM3. These include stone lines (Plate 42), ridge and furrow cropping (Plate 43), trash lines (Plate 44), grass strips (Plate 45) and *fanya juu* terraces (Plate 46).

5.7.1 Stone lines

Soils in the rangeland are rocky. Farmers arrange the stones in lines to conserve the soil. Other farmers mark boundaries with stone lines that do not follow the contour, hence confer little conservation advantage.

5.7.2 Ridge and furrow planting

A good number of farmers have taken up planting their crops on ridges comprising small mounds measuring about 10 cm wide by 5 cm high. The ridges, though small, collect some rainwater to support the crop. Farmers practicing this say it assists in harnessing the little water that comes their way as rain. Farmers in this zone do not position the ridges in a strict pattern or spacing. The crop is planted on top of the ridge.

5.7.3 Trash lines

Trash lines are very common in this zone especially in farms that have a fairly flat slope.
Often, the weather is extremely harsh and termites destroy the trash lines. The farmers said this was the greatest disadvantage of using trash lines in dry environments.

5.7.4 Grass strips/unploughed strips

Grass strips are the most common method of soil and water conservation in the rangelands. Most of the farmers leave an unploughed strip that becomes colonized by local natural vegetation, eventually forming a terrace. Some farmers establish grass strips of napier, which sometimes dries during drought periods.

5.7.5 *Fanya juu* terrace

These terraces were found in farms with slopes exceeding 5 - 7%. Farmers in the AEZ said that labour to construct terraces was the most limiting factor. The traditional economic activity used to be livestock rearing, which does not necessitate digging of terraces. Crop production on farms with terraces was higher, mostly due to extra soil moisture conserved within the farm.

Plate 42
Stone lines in LM rangeland
Workload to arrange the stones is massive

Plate 43
Ridges and furrow technology in rangeland
Note the dryland maize and pigeon peas

Plate 44
Trash line in rangeland

Plate 45
Grass strip in rangeland
Note the stones in the foreground, a common feature on the soil in the zone

Plate 46
Fanya juu terraces in rangeland
These are found on the rather sloping terrain in the AEZ

6 Conclusions

Soil erosion by water has been recognised as a major problem impeding productivity of farmlands. Considerable resources have been invested in soil and water management since the colonial days. However, the approaches used were top down during the pre-and post-colonial days. This led to farmer apathy. A change to a more participatory approach in the 1980s led to wide acceptance of soil and water conservation among small holder farmers. Studies carried out in the Upper Tana catchment reported adoption of soil and water conservation measures – or "*green water* management" measures - of over 80%. This study has established wide acceptance and adoption of structural, vegetative and agronomic measures across all AEZ within the catchment as useful technologies to enhance availability of *green water* for crop production. These include terracing (bench and *fanya juu*), cut-off drains, retention ditches and microcatchments. These are practiced in combination with agronomic and vegetative measures such as contour cropping, grass strips, cover cropping and mulching.

However, despite the successes over the past decades soil erosion continues for specific land uses in the Upper Tana catchment. The main causes of the continued erosion are:

1. Poor maintenance of established soil and water conservation (SWC) measures. When prices of commodities are low, motivation of investment in maintenance decreases.
2. Continued cultivation of riverine areas.
3. Soil and water conservation in maize fields is often below par.
4. A number of the farmers do not yet practice adequate SWC measures.
5. Isolated hotspot areas where erosion has progressed too far and it is not easy to recuperate by normal agricultural practices.
6. Overgrazing in the common lands is very frequent resulting in bare soils and high erosion during rains. Due to population pressure in the upper zones, there was high migration and settlement in the lower zones, where migrants changed to sedentary farming in the fragile environment.

All this indicates that there is still need to intensify farmer education in the heart land of the Upper Tana catchment, but with particular focus on water harvesting in lower zones, promoting microcatchments, ridging and tied ridging technologies that were not found to be widely adopted.

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Annex 1 Design of terrace spacing and height

The design of terraces in Kenya has evolved of years of scientific trials and farmer modification. While design varies from place to place, depending on many factors, the standard specifications are given in Thomas and colleagues' excellent soil conservation manual (Thomas *et al.*, 1997) as follows:

Terrace spacing in Kenya is determined by using the formula:

$$VI = \left(\frac{\%\, slope + 2}{4}\right) \text{ x } 0.3$$

The horizontal interval (*HI*, in meters) between terraces is determined by the formula:

$$HI = \left(\frac{VIx100}{\%slope}\right)$$

The depth of the storage (d) d) above the embankment (Figure 5) is calculated using the following equation:

$$d = \sqrt{\left[\frac{2A}{(\cot)(\alpha + 1)}\right]}$$

$$d = \sqrt{\left[\frac{2A}{Cot\alpha + 1}\right]}$$

Where, d = depth of the storage area above the embankment (m)
A = cross section area of storage required (m^2)
α = the slope of the ground in degrees (^{0})
Cot α = the cotangent of the slope (reciprocal of the tangent)

The area of storage, A = (R - I) x L

Where, R = maximum depth of rainfall in one hour for a ten-year period (m)
I = maximum depth of infiltration between terraces in one hour (m)
L = spacing between the terraces

Example: A farmer with land estimated to have infiltration rate of 20 $mmhr^{-1}$ wants to install terraces at 14 m spacing. The slope of the ground is 10% (5.7^0) and the ten year one hour storm return period of 65 mm.

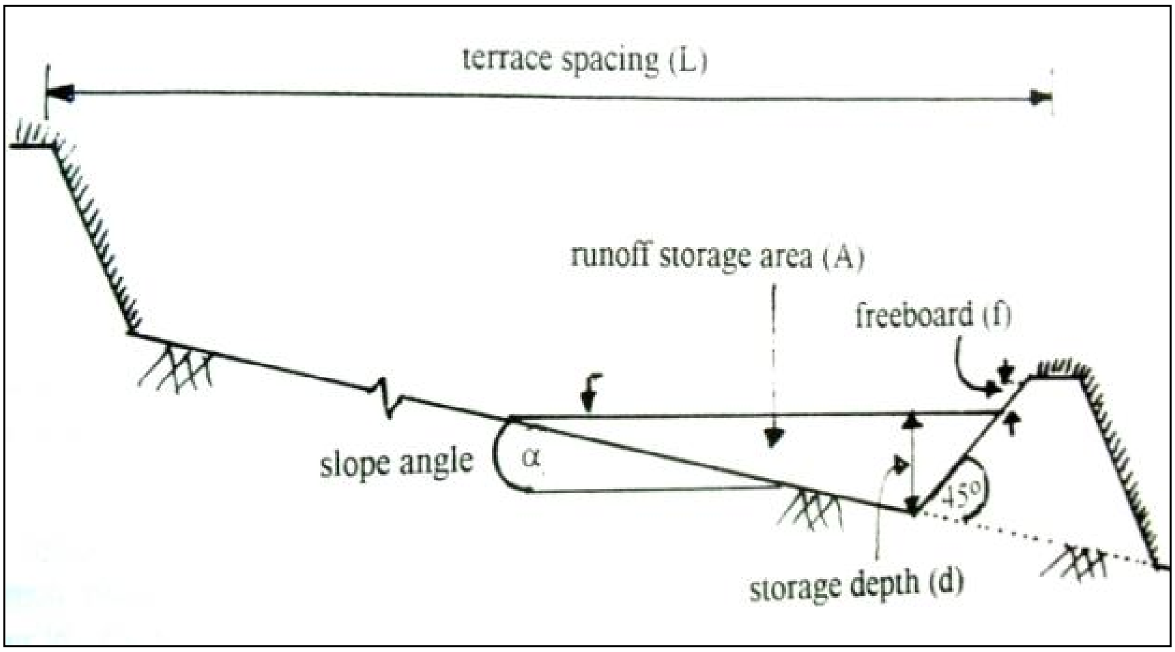
The area of storage (A) = (0.065 - 0.020) x 14 = 0.63 m^2

The depth of storage required, *d*, will be found by substituting these variables in the formula above:

$$(\tan 5.7^0 = 0.0998, \text{ reciprocal is } 10.01)$$

$$d = [(2 \times 0.63)/(10 + 1)]^{0.5}$$

$$d = 0.34 \text{ m}$$



Fanya juu terrace for rainfall/runoff retention

GWC Reports Kenya

GWC K1	*Basin identification*	Droogers P and others 2006
GWC K2	*Lessons learned from payments for environmental services*	Grieg Gran M and others 2006
GWC K3	*Green and blue water resources and assessment of improved soil and water management scenarios using an integrated modelling framework.*	Kauffman JH and others 2007
GWC K4	*Quantifying water usage and demand in the Tana River basin: an analysis using the Water and Evaluation and Planning Tool (WEAP)*	Hoff H and Noel S 2007
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GWC K6	*Political, institutional and financial framework for Green Water Credits in Kenya*	Meijerink GW and others 2007
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GWC K9	*Land Use Map of the Upper Tana, Kenya: Based on Remote Sensing*	Wilschut LI 2010
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