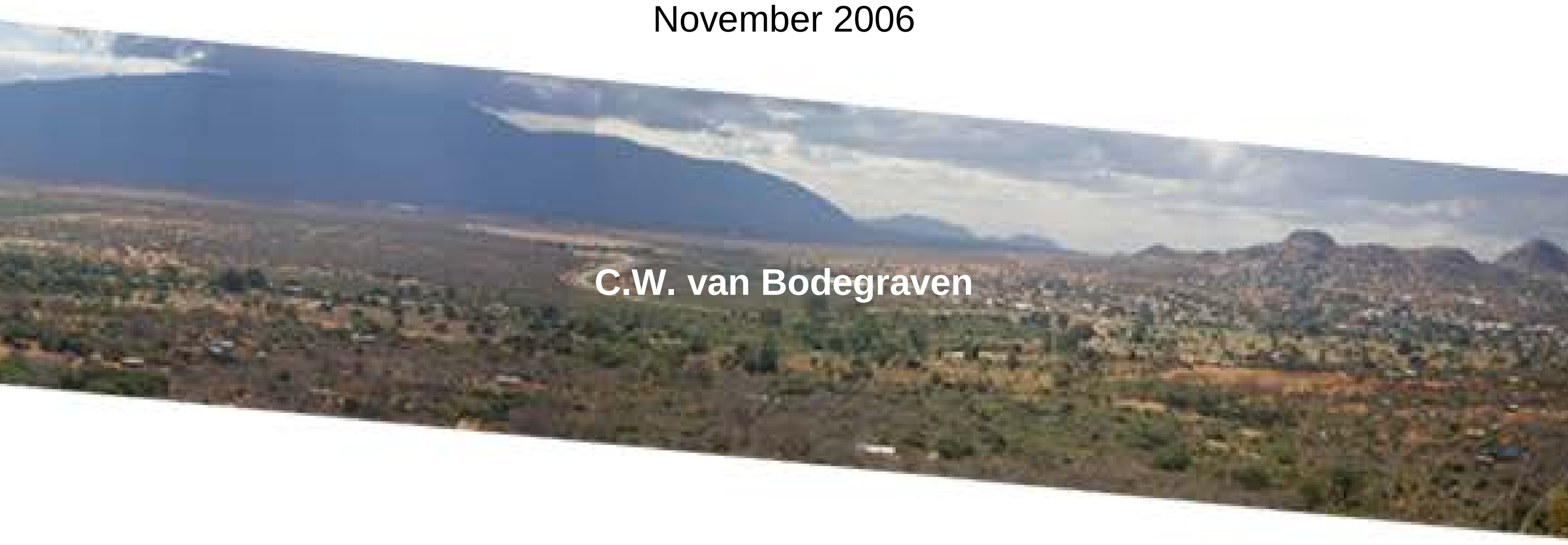
Realising an evergreen dream?!

A master plan for re-hydration of a part of Voi River basin, Southeast Kenya

Panorama photo of the research area

November 2006



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HEIJMANS

Universiteit Twente
de ondernemende universiteit

Realising an evergreen dream?

A master plan for re-hydration of a part of Voi River basin, Southeast Kenya

Nairobi, November 2006

Report about re-hydration in the Voi River basin, Kenya for the Bachelor-thesis of Civil Engineering (& Management) and the minor Sustainable Development in a North-South Perspective, "As the world turns" of TDG, University of Twente, The Netherlands. Internship is carried out at Westerveld Conservation Trust (Dutch-Kenyan NGO) in Voi, Kenya from 11th of July till 11th of November 2006.

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Summary

Introduction

In the Voi River basin, a problematic situation has been occurred with decreasing of the vegetation cover and amount of water storage and increasing of soil erosion. Several factors have a role in this process. Firstly, the morphology of the basin defines the hydrologic cycle with unequal dividing of the rainfall in the basin, which means much rainfall in the mountain ranges Taita Hills and Sagala Hills and little rainfall on the plains. Secondly, the historical regional developments caused decreasing of the vegetation cover in the area by various forms of human activity.

The report provides a contribution for changing the problematic situation in the basin by development of a master plan to implement small water-retaining structures for realising re-hydration in a part of the Voi River basin. Re-hydration should lead to evergreen forests in the basin.

Methodology

In the field, various local social-economical and physical data was collected using the method Rapid Rural Appraisal. This is a widely used method for exploratory work in developing countries and it provides both social and physical information in a limited time. Some other methods were used for analysing various data. Firstly, Land Capability Classification was applied to define the suitable land for trenching. Secondly, the social-economical data is analysed with use of the Triade-model leading to an estimation of the will to participate of local farmers in the trenching project. Thirdly, a Multi-Criteria Analysis was executed to assess the suitability of the five sub-areas for trenching. Also, a quick scan to suitable locations for sand storage dams was done with use of criteria provided by Westerveld Conservation Trust. Finally, recommendations were done based on the output of the Multi-Criteria Analysis, the recommendations for soil conservation from Kort (2006) and insight from the field.

Conclusions

- The suitable area for application of trenching consists of the foothills of Mwakingali Hills, Sagala Hills, Small Taita Hills, the plains and the area along the Voi River, and was divided in five sub-areas.
- The will of the local farmers to participate in the trenching project by digging of trenches is estimated as low in the sub-areas Mwakingali Hills and Voi town and Voi Sisal Estates, moderate in Voi River and Plains and high in the Small Taita Hills.
- The five sub-areas were assessed on five criteria, namely stability of soil, will to participate, effectiveness for water storage, effectiveness for erosion prevention and suitability of land use. The suitability of the sub-areas is from most suitable to least suitable: Small Taita Hills, Voi River, Plains, Mwakingali Hills and Voi town and Voi Sisal Estates.
- Six locations were found as suitable for building of sand storage dams in the Eastern part of the research area.
- Recommendations were done about the applications of measures in the research area to increase water storage and prevent also soil erosion. The measures consist of technical-agronomical measures, divided in mechanical and re-vegetation measures, and measures to improve practices of local farmers. Those recommendations form a master plan for the research area.

Recommendations

- Research to the implementation of the trenching technique in various situations and especially in critical situations with steep slopes and (very) soft soils.

- Thinking about how the project could be a project of the local farmers. Practical ideas are good information, involvement of local farmers in the decision-making process and set the local people central in the project.
- Charting of the water supply and water demand in the Voi River basin for well-argued decisions of areas for trenching and locations for building dams with estimation of their effects.
- Research to possibilities for selling crops at local market and access to bigger markets.
- Doing the same research for the other part of the Voi River basin.
- Execution of trenching has to done more carefully and precisely.
- Developing of action plans per sub-area for specification of needed measures.

Preface

Some people have ideals to improve the world. People, who cannot be content with a world in which many people suffer, live in poverty and are hungry. The undersigned is one of those people. During the study was given the possibility to look in a developing country and to see with own eyes and experience how people live in worse circumstances.
This report is a part of the Bachelor thesis of the study ‘Civil Engineering (& Management)’ and the minor ‘Sustainable Development in North-South Perspective, As the World turns’ of the Technology Development Group, both part of the University of Twente in the Netherlands. The Bachelor thesis was executed by Westerveld Conservation Trust (WCT) from 11th of July until 11th of November 2006 together with Bert Kort. WCT is a Dutch/Kenyan Non Government Organisation that tries to re-hydrate some areas in East-Africa by building of sand storage dams and digging of trenches.
During the internship a preparatory study was done to the suitability of a part of the Voi River catchment area for trenching and building dam. Based on this study and the preparatory study to soil erosion of Bert Kort recommendations were done for re-hydration of the research area.

I would like to thank various people, who contribute with finishing of this report. The first persons are my supervisor’s Dr. ir. D.M.C. Augustijn and Dr. J.S. Clancy of University of Twente. I thank them for their guidance. Secondly, I would like to thank Westerveld Conservation Trust for the opportunity to do my Bachelor thesis and I thank especially my supervisors of the organisation, Mrs. M.G van Westerop and Mr J. Mukusya for guiding me in the Netherlands and in Kenya. Thirdly, I thank Heijmans in Roosendaal in the Netherlands for sponsoring my internship and I would like to thank especially Mrs. M. van Tiel of Heijmans for her help for getting the valuable slope measurement tool.
My thanks also go to the people of Amani Guesthouse in Voi for sharing their knowledge about the surroundings and the several local people for their co-operation during our fieldwork by guiding and providing of important information. I would like to thank my family for their support in the preparation and during the internship.
Finally, my big thanks go to Bert Kort, my colleague student and friend. Together wit him I lived for a long period in a strange country and did my Bachelor thesis. I thank him for the good cooperation and discussions about the things we saw and experienced everyday.

I hope that this research contributes to better life-circumstances for the local people in the future, because the area becomes wetter, greener and poverty will be reduced!

Nairobi, November 2006

Wilco van Bodegraven

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Abbreviations of acronyms

ED	Excellent Development
FDA	Federal Department of Agriculture
KSh	Kenyan Shilling
LCC	Land Capability Classification
MCA	Multi-Criteria Analysis
REAL	Re-hydrating the Earth in Arid Lands
RRA	Rapid Rural Appraisal
WCT	Westerveld Conservation Trust

List of Swahili terms

Matatu	Public transport, mini bus for officially 14 passengers
Shamba	Agricultural plot

1. Introduction

1.1 Background

“Climate changes and population growth cause increasing pressure on the East African highlands. The results of the pressure are manifold: urban growth, intensified agriculture, decrease of forested areas, loss of biodiversity, accelerated land degradation and soil erosion. The consequences introduce great demands on land use planning.” (Pellikka et al.; 2005)

This quote gives an impression of the problematic situation in the Voi River basin in Kenya. Human interference leads to destruction of the environment and drying out of the area. To oppose this process, the Re-hydrating the Earth in Arid Lands (REAL) project has been started in which several NGOs and universities from Kenya, Tanzania, Belgium and The Netherlands work together to stabilize and humidify the environment again in a sustainable way.
The general objective of the REAL project is: “to clarify the relations between local practices and theoretical approaches, by focusing on the design, management and performance of small groundwater retaining structures on a communal level in semi-arid regions in two African countries, Kenya and Tanzania, linking both the individual and the community as theory and practice, resulting in guidelines for participatory design of small water retaining structures in semi-arid regions world-wide” (Westerveld & Van Westerop, 2005).

Westerveld Conservation Trust (WCT), an NGO, participates in the REAL-project. It has projects in various areas in Kenya and Tanzania to restore the environment by constructing small water retaining structures, which are trenches and sand storage dams to increase water storage and prevent soil erosion. Groups of students from several universities did research for WCT, concerning several aspects of sand storage dams and trenches.
WCT has a project in the Voi River basin in Southeast Kenya. The purpose of the project is to re-hydrate and stabilize the environment in that basin. Figure 1.1 shows the current situation and problems leading to desertification of the basin and the desired situation of WCT with enough water and restoration of vegetation resulting in evergreen forests.

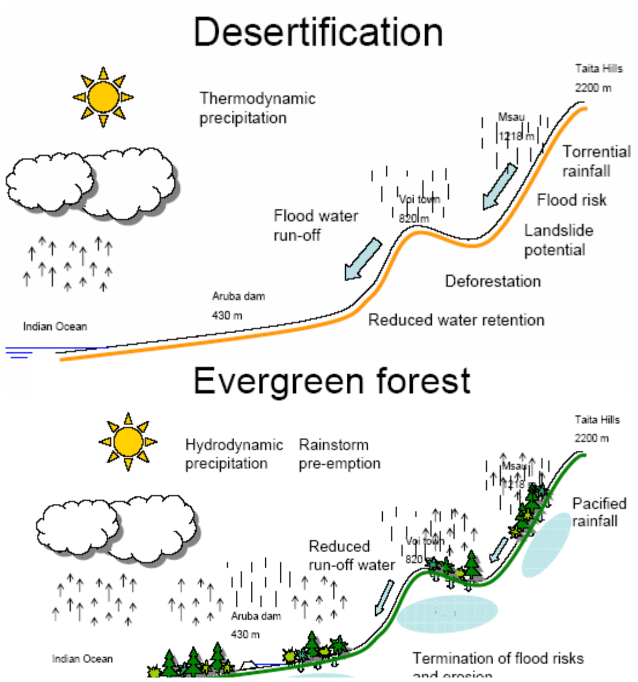


Figure 1.1: Current and desired situation of the Voi River basin (Westerveld Conservation Trust (2002).

WCT has already built four sand storage dams in the surroundings of Voi town and dug trenches on a few plots along the Voi River near one sand storage dam. The NGO wants to apply the trenching technique and sand storage dams at large scale in the whole basin to realise the ultimate project aim: evergreen forests. Before starting the application, a plan has to be worked out for the basin.

The task given by Westerveld Conservation Trust was to work out a master plan for application of sand storage dams and especially trenches in the Voi River basin.
The next paragraph gives the geographical position of the Voi River basin in Kenya and the researched area in the basin as to understand the geographical situation.

1.2 Geography

The Voi River basin lies in the Taita-Taveta District, which is part of the Coast Province in Southeast Kenya. It reaches from the Taita Hills (Latitude 3º25´ S, longitude 38º20´ E) to the Indian Ocean (Latitude 3º38´ S, longitude 39º52´ E). Figure 1.2 shows the positioning of the Voi River basin on the map of Kenya.

Figure 1.2: Positioning of the Voi River basin in Kenya

Figure 1.3 shows a map of the west part of the Voi River basin. The red line gives an indication of the western watershed. In addition, the research area is positioned on the map. The research area was divided in eight 4 by 4 km squares to make things workable. The green boxes show the areas and numbers of the squares, treated as separate maps.

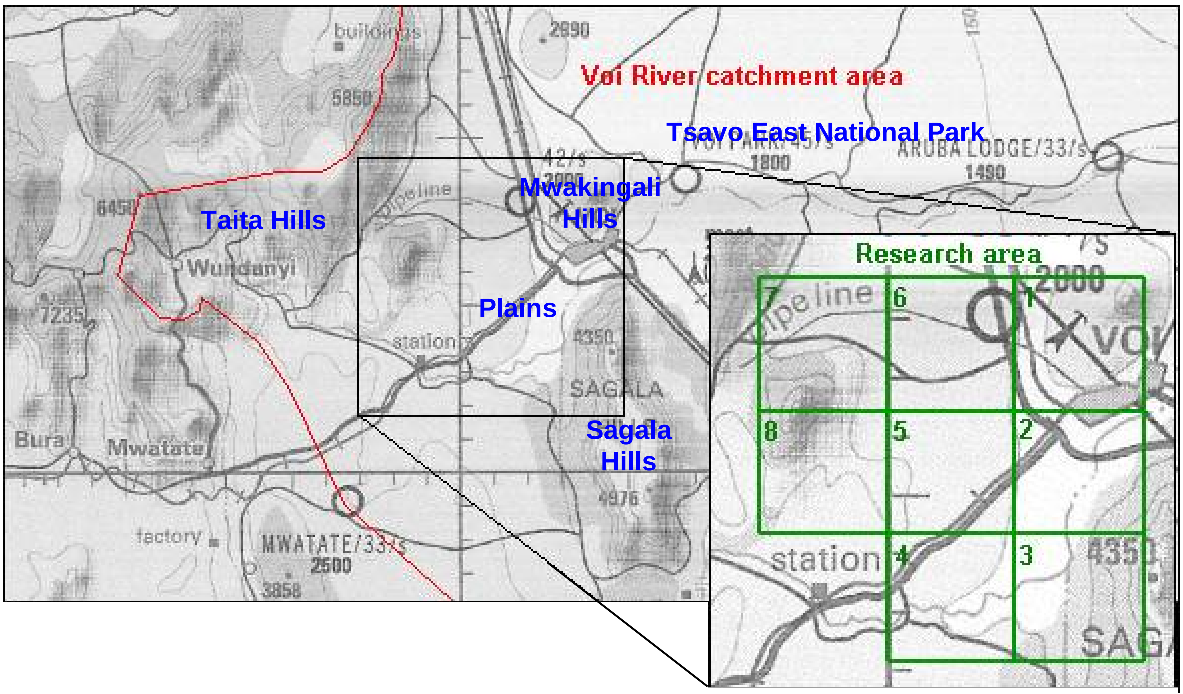


Figure 1.3: A map of the Western part of the Voi River basin (the red line is the western watershed) and positioning of the research area in the Voi River basin.

To gain insight into the local situation and problems in the Voi river basin a problem analysis will be given. The problems result especially from the hydrological cycle in the basin and the historical regional developments. For this reason, these two aspects are described firstly in the next two paragraphs.

1.3 Hydrological cycle in the Voi River basin

The morphology of the landscape of the river basin defines its hydrological cycle. The amount of precipitation and the temperature influencing the evaporation depend on the altitude. They are classified in six agricultural zones showing in table 1.1 (see Annex V for justification of the shown data). The morphology is given in 1.3.1 firstly, followed by the description of the hydrologic cycle.

Table 1.1: Climate information of the Voi river basin. (Soini, 2005; Bindloss et al., 2003; FAO-SDRN Agrometeorology Group, 1997; Floor, n.d)

Zone	Altitude (m)	Precipitation (mm)	Temperature (min and max) (ºC)	Climatologic class
Pasture/plain zone	<790	250-500	20-40	BSh
Livestock-Millet zone (Hills)	790-980	480-700	18.7-38.7	Am
Marginal cotton zone (Hills)	910-1,220	600-800	17.4-37	Am
Sunflower-Maize zone (Hills)	1,220-1,520	700-900	16.5-36	Am
Marginal coffee zone (Hills)	1,370-1,680	900-1.200	15.5-34	Am
Wheat/Maize-Pyrethrum zone (Hills)	>1,680	1,200-1,500	13.5-30	Am

1.3.1 Morphology

The landscape consists of different characteristic areas. The Voi River streaming from West to East passes the following areas: from the spring in the Taita Hills, it streams through the plains, between the Mwakingali Hills and Sagala Hills and through Tsavo East National Park (TENP) to the Indian

Ocean. The different characteristic areas are described below and figure 1.3 shows their positioning in the basin.

- The Taita Hills are situated about 170 km from the Indian Ocean with an average altitude of about 1,500 m and the highest top Vuria is 2,208 m above sea level. Also, other rivers originate from the hills to the other direction. Taita Hills is the habitat of the Taita tribe.
- The plains around the different hills are relatively flat areas with an average altitude of about 700 m. It is bare and dry land, only a narrow strip along the meandering Voi River consists of green vegetation during the whole year.The Sagala Hills are a rough massive mountain range with an average altitude of about 1,150 m and the highest top is 1,518 m above sea level. A part in the midst of the range is suitable for cultivation, the habitat of the Sagala tribe.
- The Mwakingali Hills are some small hills with its highest top at about 1,000 m above sea level. At the foot, the slopes are gentle. They change into steep slopes near the rocky tops. The slopes are mostly bare and arid. These hills lie in a straight line from North to South with Sagala Hills with a valley between them.
- The large plains easterly of the Sagala Hills and Mwakingali Hills with the TENP descend from 700 m to sea level. Within the park, there is a dam in the river, the Aruba dam, with a mainly dry lake.

1.3.2 Hydrological cycle

The hydrological cycle in the Voi river basin starts with winds, which move the clouds from the Indian Ocean in the Western direction inland before and during the rainy seasons. The first barriers are the Sagala Hills and Mwakingali Hills. Strong winds drive up the clouds along and through the valley between the two mountain ranges to the plains. After the plains rise the Taita Hills and the clouds are driven up to above the Taita hills.

The data in table 1.1 shows that how higher the altitude, how more precipitation. The rainfall in the Taita Hills, Sagala Hills, Mwakingali Hills and on the plains is respectively 1,200-1,500 mm, 900-1,200 mm, 600-800 mm and 250-500 mm per year. The precipitation falls in two rainy seasons. The first one with the short rains is from October until December and the second one with the long rains is from March until June.

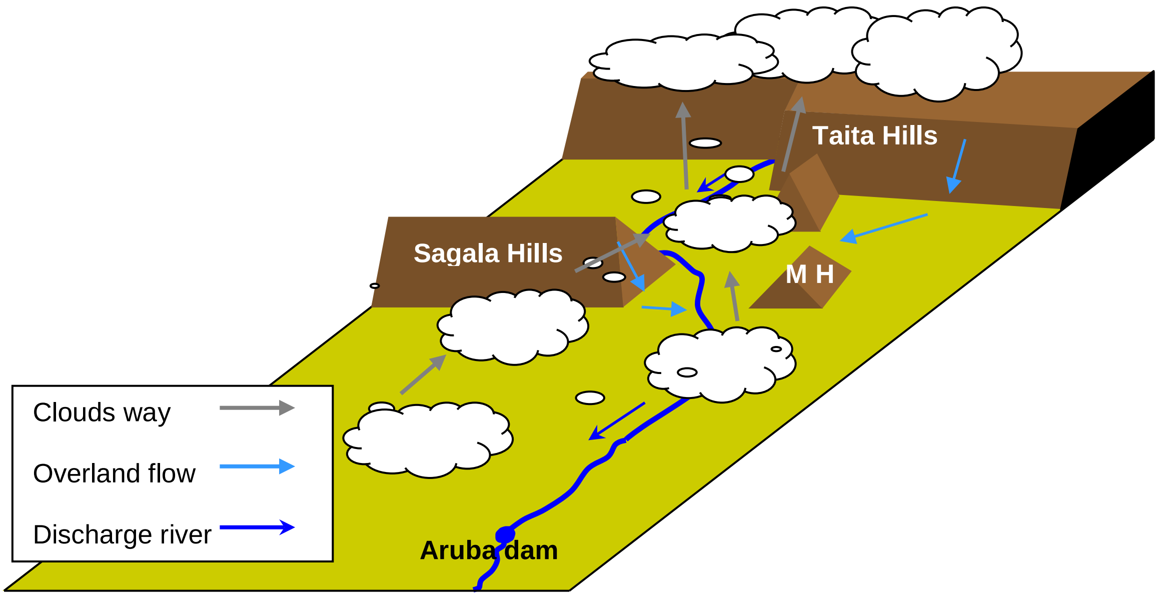


Figure 1.4: Schematic drawing of the Voi River basin system with the hydrological process.

After the rainfall, a small part of the water infiltrates into the ground, but the biggest part flows from the Taita Hills and Sagala Hills downwards to the Voi River. A big part of that water evaporates. Data is not available, but the potential evaporation is 1,500 mm per year (Pellikka et al, 2005). Also, water from the river and subsurface water are used by man, animal and vegetation. A part of that water is also lost by evapo-transpiration of vegetation.
All the rainwater that has fallen in the river basin and that is not evaporated or used is carried off via the Voi River in the direction of the Indian Ocean. Because of much human use and evaporatn the river streams maximal some times a year to the ocean, but it is already dried up in the par most of the time. During the dry season, the biggest part of the river is often dry for some months per year.

1.4 Historical regional developments

Big sisal estates were established in the end of the 19th and beginning of the 20th century. They cultivate of large parts of the plains around Taita Hills and for getting agricultural land, forests on the plains were cut, which decreased the vegetation cover.
At the beginning of the 20th century, the *Uganda railway* from Mombasa to Kampala was constructed by the Britons. Large forests in the Taita Hills were cut for providing construction wood; the consequence was decreasing vegetation cover. Because of attainability and work by the railway, more people settled in the fertile Taita Hills and Sagala Hills.
By construction of the *highway from Nairobi to Mombasa* more people moved to the area, especially to *Voi town* situated at the junction of the highway and the important road to Moshi in Tanzania. This transport and trade town has grown very fast from a small village to the current town with a population of almost 40,000 (Hurskainen & Pellikka, 2004; Msagha, 2004).
In 1948, *Tsavo National Parks* were founded. People living in the parks were moved outside to the Taita Hills causing increase of population pressure. Another cause was strong decrease of available pastureland, while the land-animal ratio had become lower and pressure on pasture had increased by getting bigger herds. This resulted in overgrazing of the area (Soini, 2005).

Since the beginning of the 20th century, the *population* of the Taita Hills and the area around Voi has *grown* rapidly by natural growth and above described reasons. The total population of the Taita-Taveta district has grown from 90,146 in 1962 to more 300,000 persons nowadays. Of these people around 42,000 (including almost 40,000 in Voi) live in urban centres. In the Taita Hills, population density has followed the climatological and ecological conditions. In the upper highlands, the agricultural natural circumstances are much better than downhill. As a result, that the upper highlands have a population density of 150 persons per km^2, while downhill 45 persons per km^2 live (Pellikka et al, 2005; Soini, 2005). The consequence of the population growth during the century is an increased need of income, food, water, firewood, timber and houses. To fulfil these need four developments occurred with *deforestation* as result:

1. Getting agricultural land, because agriculture is the biggest source of income and food.
2. Growing domestic use, like building of houses, furniture and firewood.
3. Commercial production of timber wood for selling outside the area. Hardwood from the Taita Hills is wanted and yields a lot of money.
4. Charcoal burning for domestic use and commercial production in the 1960s and the 1970s. This part of Kenya was one of the biggest exporters of charcoal. Nowadays charcoal is still produced, but only on small scale.

Despite the reforestation programmes in the 1920s, the 1970s and the 1980s, the total area of forest still decreases. In the past large cloud-forests were situated on the Taita Hills, but today only 400 hectares of indigenous forest are retained. Decrease of the (permanent) vegetation cover

causes increase of soil erosion and decrease of water storage, which results in land degradation. The consequence is lower yields and because of that more agricultural land is needed to get enough income and food. Which results again in deforestation and the cycle goes on.
The pressure is so high that people have used the marginal places and looking for non-used land Taita people have been moving from the fertile Taita Hills to the less fertile and dry plains, because there is still land available. Trees and vegetation cut for agriculture has also been the result on the plains. (Soini, 2005)

1.5 Problem analysis

From the analysis of the hydrological cycle of the Voi River basin becomes clear that the rain mainly falls in the Taita Hills and Sagala Hills. Rainwater infiltrates partly or flows over the drier plains to the Voi River. Because of various developments in the past, the vegetation cover has been reduced a lot in the river basin. Nowadays this process is still continuing.

1.5.1 Functions of vegetation

A decreasing vegetation cover causes problems, because it has some important functions. Those functions are discussed firstly. During rainfall, vegetation stores water in the stems, branches and leafs. Another function is that the roots make the soil loose and the thrums protect the soil against the burning sun preventing a hard crust, so that the rainwater can infiltrate easily into the ground near the vegetation. The roots also hold the surrounded soil when water flows overland downhill. Besides these, the plants and their roots also ensure seed supply and seed growth needed for increasing the vegetation. (Sirviö et al., 2004)
Because of these functions the consequences of less vegetation is that soils become bare, because the soils are very hard by the hot sun and are susceptible for erosion. During the rains the land suffers rain splash erosion, soil compaction and the overland flow remove the fertile organic topsoil. In case of soil compaction the water cannot infiltrate fast into the ground. That decreases water storage and increases the overland flow causing soil erosion.

1.5.2 Flow diagram

In figure 1.3, a flow diagram shows the relations between the various important factors influencing each other within the river basin system and two factors from outside the river basin. When beside an arrow is standing (+) it means that increasing of the origin variable lead to an increase of the destination variable, while a (-) means that when the origin variable increases, the destination variable decreases.

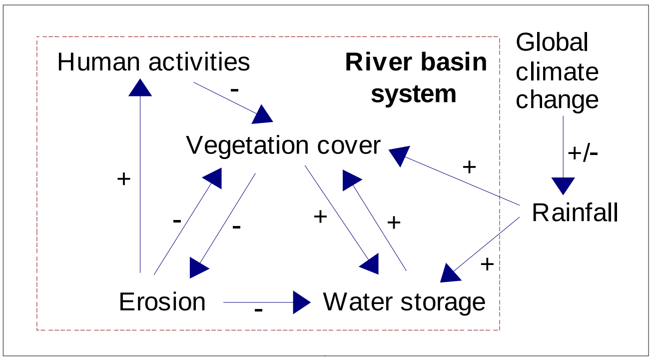


Figure 1.5: Flow diagram with important factors and influence of each other.

In the flow diagram has been made a distinction between the factors inside and outside the Voi River basin system. The two factors outside the system (global climate change and rainfall) also lie outside the influences of anybody in the river basin. The water storage and vegetation cover factors inside the system are influenced directly by rainfall. Last called depends on the global climate change.

1.5.3 Global climate change

Worldwide the climate is changing. Nowadays, much research on these changes and the effects of them is carried out. Predictions for East Africa and in particularly Kenya are that precipitation will change. By influences of El Niño the chance of occurrence of droughts increases in Somalia and southeast Kenya by less rainfall. During the short rainy season from October to December, the rainfall in Kenya will be more heavily. (Sample, 2003; Burgers & Oldenborgh, 1999) El Niña, which is almost the opposite of El Niño, seems to have almost no influence for southeast Kenya (Burgers & Oldenborgh, 1999). Thus in southeast Kenya, during the year the rainfall amount decreases (-), but during a shower the rainfall intensity increases (+) as a result of global climate change.

1.5.4 Processes in the Voi River basin

A smaller amount of rainfall per year and heavier showers when it rains means reduction of water storage, because less water is available for infiltration. That is a result of increasing soil compaction during heavy showers and a simple principle: less rain means less water on the ground. The latter also reduces the available water for vegetation leading to less vegetation. Besides this, heavier showers cause more rain splash erosion and less water infiltration into the ground. More overland flow is the result with the consequence increase of soil erosion.
Less water storage in the river basin means that less water is available for vegetation, especially in the dry season. The effect is that plants will die, because of lack of water in that period. In the next rainy season, this effect causes that again less water will infiltrate into the ground, because more soil in the river basin is compacted.
Reduction of the vegetation increases soil erosion, because the soil lacks the tying of the roots leading to erosion types as rills, gullies and landslides. Extension of, for example a gully, during and after a heavy shower leads to destruction of everything in its way. Therefore, the vegetation cover decreases because of erosion. The latter also destroys the soil layer reducing the infiltration capacity of an area, which leads to less water storage.
Human activities, like woodcut, charcoal burning and cutting forest for agricultural land also result in reduction of the vegetation cover. An increase of the activities means decrease of the vegetation cover in the river basin. The latter leads to soil erosion. Rills, gullies and landslides destroy agricultural plots and houses. Getting new houses and agricultural plots local people cut more forests. Thus, more erosion leads to more human activities, which reduce the vegetation cover.

The three physical main problems in the basin are reduction of vegetation cover, decreasing water storage and increasing soil erosion. These processes reinforce each other, leading to degradation of the liveability of the Voi River basin.

Problem definition:

> *The problem in the Voi River basin is that the water storage and the vegetation cover have been decreasing and soil erosion has been increasing.*

1.6 Research objective and question

In the problem analysis was discussed that the human activities leads to reduction of the vegetation cover and via that way to increase erosion and decrease of water storage. Certain human activities however can also result in increase of water storage and reduction of erosion. When people intervene in the processes causing the problems by use of various technical and social-economical techniques to store water and control erosion. WCT has executed this by application of trenching and sand storage dams for some years.

Research objective

> *To develop a master plan to implement small water-retaining structures for realising re-hydration in a part of the Voi River basin. Based on a preparatory study by doing field research to suitable area for trenching and locations for building sand storage dams, assessment of the suitability of various sub-areas for trenching, and giving recommendations to apply water storage increasing measures taken in consideration soil erosion and social-economical characteristics.*

To reach the research objective the following research question is defined:

Research question

> *What are the recommendations to increase water storage by trenching and construction of sand storage dams taking in consideration soil erosion and social-economical characteristics?*

Sub-questions:

1. What are the suitable sub-areas for trenching?
2. In which extent will the local farmer participate[1] in the trenching project?
    a. Do local farmers regard water shortage as a problem?
    b. What is the motivation to increase water availability by trenching?
    c. What is the capacity of local farmers to dig trenches?
3. What are the criteria assessing of the suitability various sub-areas for trenching?
4. What is the suitability of various sub-areas for trenching?
5. What are the suitable locations for building of dams?

1.7 Reading guide

This report consists of two documents with appendixes. The first one are the appendixes enclosed behind this report and the other document is the Collective Appendix. This document consists of the collected data during the field study, which is also the basis of the report: Dangerous soil erosion!? of A.J.K. Kort.

All the theoretical and practical methods used in this research study are discussed in the second chapter, Methodology. Followed by, a description of the two small water-retaining structures of issue, the trenching technique and sand storage dams. The results and answers on the five sub-questions are discussed in respectively the chapters four to eight. The fourth chapter deal with the results of the social-economical analysis. The analyses can be found in Appendix II. The criteria are described in chapter five, following by the results of the assessment of suitability in chapter six. The

[1] Participation: the act of taking part or sharing in something

execution of the assessment and the used data are discussed in Appendix II. The seventh and eighth chapter deal with respectively the suitable location for sand storage dams and the application of measures in the research area. The data collected at the suitable dam locations are shown in Appendix III. Recommendations to increase water storage and prevent also soil erosion are done in chapter nine. Finally, the conclusions of this report and some recommendations are given.

The Collective Appendix consists of the next kind of data:

- Maps for the eight grids with land use, slope and land capability classification, gullies and water flows
- Interviews
- Land capability classification tables
- Soil data
- Photo gallery from the research area

2. Methodology

2.1 Introduction

The objective of this research study is to work out a master plan for application of small water-retaining structures for the defined research area within the Voi River basin. A matching research question and six sub-questions were formulated.
The sub-questions 1, 3, 4 and 5 are focussed on the application of trenches and sand storage dams to increase water storage (and reduce soil erosion). Firstly, sub-question 1 and 3 had to answer, before that it was possible to answer question 4. The second sub-question is meant to analyse the current human activity and to estimate the future human activity needed for the application of trenches and sand storage dams. The latter was necessary to verifier one of the criteria found in sub-question 3. To answer the research question, research was done to recommend and combine measures for increasing of water storage, erosion control, the vegetation cover and improving practices of local people.
Below, the applied methods to answer the six sub-questions are discussed. Firstly, however the data collection method, Rapid Rural Appraisal is explained in the second paragraph. The used RRA-techniques are mentioned per sub-question.
A master plan gives comprehensive guidance and that means non-detailed planning at headlines. To work out the master plan a preparatory study was done. To found a particular plan rough data is sufficient. Therefore, the method Rapid Rural Appraisal (RRA) was used to collect this rough data. For the research various local data was needed, but those were not available. A field study was necessary to collect the local data.

2.2 Data collection

2.2.1 Method: Rapid Rural Appraisal

Rapid Rural Appraisal (RRA) is a semi-structured activity carried out in the field by a multi-disciplinary team and designed to acquire quickly new information on rural life in developing countries according to McCracken et al (1988). It consists of a series of techniques for quick research that are claimed to generate results of less apparent precision, but greater evidential value, than classic quantitative survey techniques (IISD, 1995).
Most information collected by RRA is qualitative in a limited time, which matches well with the nature of this research: non-detailed and planning at headlines. While, quantitative techniques should cost too much time and they were too detailed for a master plan for a large area. In addition, the various RRA-techniques were useful for collection and mapping of data necessary for answering the sub-questions.
RRA was developed from origin for social research, but it has also been used for physical/technical research. I.M. Crawford (1997) wrote that the application of RRA has been quite wide as regards rural development, for example in health, nutrition, emergencies and disasters, agro-forestry, natural resource assessment and sociology approaches. This research also matches with the application range, because data was collected about the morphology and physical processes of the landscape, land use and social-economical aspects. A disadvantage of this method is that the local people are not involved with the research, but that they are only a source of information for the researchers. Other disadvantages of this method can be imprecisely and that it only gives indications, but those were not a problem, because this research is a preparatory study. RRA is also susceptible for bias (McCracken et al, 1988). By the use of indicators and collection of overall data,

there is a big chance that very essential details are overlooked. That is a risk, which has to be taken into account.

2.2.2 Application

Various data gathering techniques of RRA are used to collect data for answering the sub-questions. The mainly utilized techniques are secondary data analysis, direct observation, physical mapping, semi-structured interviews and use of indicators. The practical application of the diverse techniques is discussed by every sub-question, but a definition of the techniques follows firstly:

- *Secondary data* is published and unpublished data, acquired by other people at an earlier time (McCracken et al, 1988).
- *Direct observation* means a relatively straightforward and encompasses any direct observation of field objects, processes or people that is recorded by the team in note or diagrammatic form (McCracken et al, 1988).
- *Physical mapping* is defined as a technique to map physical elements and objects in the area.
- *Semi-structured interviews* take place in informal, guided interview sessions where only some of the questions are predetermined and new questions or lines of questioning arise during the interview, in response to answers from those interviewed (McCracken et al, 1988).
- An *indicator* is defined as a variable or component used to infer the status of a particular criterion or condition according to Mendoza and Macoun (1999).

2.2.3 Field practices

The first weeks were used to explore the river basin by doing some field trips through the area to define the research area, and to set up and improve measurements, way of mapping and interviews. The research area was defined by starting with randomly dividing the river basin in squares of four by four km in the first week to make it workable, following by estimation of what was possible by available transport and time. As a result, eight blocks forming the research area were chosen.

The other two months in Voi, field trips were done to gather needed data through the research area. During a field trip by bicycle or at feet, a selected part of the area was crossed and land use, water flow, land capability classification, roads, and so on were mapped. The steepness of slopes were measured during the whole trips and also, research was done to suitable location for sand storage dams. Infiltration and soil samples were done at random selected locations and when a farmer was passed, he or she was interviewed. Some days per week during the field study, collected data was processed by drawing various maps, execution of the soil texture and stiffness analysis, and structuring interviews and observations.

2.3 Sub-question 1: Definition of suitable sub-areas for trenching

2.3.1 Method: Land Capability Classification

To define the suitable area for trenching the method Land Capability Classification (LCC) was applied. It was developed as a method of assessing the extent to which limitations hinder the agricultural use of land. Limitations can be erosion risk, soil depth, wetness and climate. The objective of LCC is to regionalize an area of land into units with similar kinds and degrees of limitation (Morgan, 1986).

The United States system consists of eight classes arranged from, no or slight risk of damage to land when used for cultivation (Class I), to very rough land which can be safely used only for wildlife, limited recreation and watershed conservation (Class VIII). Classes I up to and including IV are designed as suitable for arable farming (Morgan, 1986). The criteria used for classification are the effective depth of the soil layer, steepness of the slope and extent of erosion. The exact description of the eight classes can be found in Collective Appendix, LCC tables, table 1.

The reason for choosing this method is that it combines diverse factors, which influence the thickness of the soil layer. When for example, the slope is moderate, but erosion moved away the biggest part of the soil layer it is unusable or in many cases a steep slope also means a low effective depth. In addition, the descriptions of the eight classes are easy and quick to use in the field. The classification can be done by observing and comparing the observation with the description. A disadvantage is that it depends on the estimation capacity of the researcher and that it is not very precise. However, it is precise enough for a rough study like this.

2.3.2 Application

Translating the classes to the partitioning between suitable and unsuitable area, the area assessed as class I up to and including class IV are suitable for trenching. While area assessed as class V through VIII are not suitable for trenching, because they lack a reasonable soil layer and are too stony or rocky.

2.3.3 Dividing in sub-areas

After definition of suitable area, this area was divided in five sub-areas based on morphological and social-economical characteristics. The dividing was necessary to assess the suitability of the various sub-areas. There is chosen for five, because this number kept the situation workable and the sub-areas are ‘natural’ areas. An alternative was dividing the sub-areas in more areas, but they should give a too complex situation for this rough study.

2.3.4 Data gathering techniques

The used technique is direct observation for presence of rock surface, estimation of the thickness of the soil layer and tillage conditions. The classifications are mapped in the maps Slope and Land Capability Classification. Those can be found in Collective Appendix, Maps.

2.4 Sub-question 2: Estimation of the will to participate

Success and sustainability in development projects depends greatly on building bridges between the technical and social dimensions of project-impacted communities according to Euroconsult B.V. & WAPCOS (1996). To match this important principle, the question “In which extent will the local farmer participate in the trenches project?” was made. To answer this second sub-question a social-economical analysis was done. The *purpose* of this *social-economical analysis* was to estimate the extent of participation of the local farmers in the trenching project by doing interviews and observations through the research area about water harvesting.
In the research area, the two major types of land use are agriculture and bush. Agricultural land is land that is used by local people to do small-scale agriculture to get income and food. They have directly big disadvantage of erosion and low water storage for their life. Because of that, this group will also have direct advantage of trenches. Therefore, local farmers doing small-scale agriculture were chosen as *purpose group*. To analyse the social-economical data collected the Triade-model of Poiesz is used.

WCT would like that the local farmers are going to dig trenches on their plots by themselves without payment. Therefore, the way of participating of local farmers meant in this study is taking part in the trenching project by digging of trenches.

2.4.1 Method: Poiesz' Triade-model

This model is a thinking model that offers a simple, practical and widely applicable system for the declaration, influence and forecast of behaviour. The user defines which behaviour. The Triade-model assumes behaviour of one person, but the behaviour of a group can be analysed by adding up the individual scores (Poiesz, 1999). The model assumes three fixed, necessary causes of behaviour:

- Motivation: the extent in which a person has interest for (the result of) this behaviour.
- Capacity: the extent in which a person has the properties, power, skills and instruments to do this behaviour.
- Opportunity: the extent in which time and the circumstances stimulate or hinder this behaviour.

An assumption of this model is that those factors consist of all possible causes. According to Poiesz, 1999) behaviour can be quantified by giving the three causes a score (0 - 1.0) and multiplying those according to this formula: T=M*C*(O)[2] [0-1.0]. That the causes are multiplying related means that one low factor gives a much lower score for behaviour.

Participating (digging of trenches) is behaviour. The way of thinking of the model is that behaviour is caused by the motivation, capacity and opportunity of a person. Analysing the mainly qualitative social-economical data this idea was used to give structure to the analysis, so that an estimation could be given of the will to do the behaviour participating.
The model has been intended for behaviour of individual persons, but the behaviour of individuals defines the behaviour of a group. Assumed is that the information of individual farmers compared with observation gives a reasonable impression of a group farmers in an area.

2.4.2 Application

Per defined sub-area, the motivation, capacity and opportunity were analysed of local farmers. The analysis starts with opportunity, because that influences the other two factors. For example, when the perception is lacked that something is a problem, then people will not be motivated to solve the problem.
The collected data was analysed and based on its results an estimation of the cause per sub-area was made. According to the way of thinking of the model, the qualitative estimations of the causes were 'multiplied' and an estimation of the will to participate was done.

The three lower-sub-questions of sub-question 2 to are:

a. *Do local farmers regard water shortage as an important problem?*
b. *What is the motivation to increase water availability by trenching?*
c. *What is the capacity of local farmers to dig trenches?*

They are related to respectively opportunity, motivation and capacity. Indicators were used to make the questions operational. Question 2a asks if water shortage is a problem and how important it is for male and female farmers. As indicators were used "perception of water shortage as problem" and "ranking of water shortage among other problems".
Question 2b asks if the local farmers are motivated to get help with use of trenching. That depends on their focus on various water sources, do they want help and do they own their land? Those factors were indicated by "focus on which water sources", "demand for help" and "land ownership".
Capacity to dig trenches is the core term in question 2c. The extent of "self-initiative of local farmers" indicated the current possibilities of the farmers. The "organisation rate" of the communities

[2] The origin symbol is "G" from the Dutch word "Gelegenheid"

defines partly the labour capacity and knowledge of farmers. The labour capacity also depends on the “labour division between men and women”.

2.4.3 Data gathering techniques

The data for the social-economical analysis was collected by doing semi-structured interviews and direct observation. Observations about the amount of available water, the used water storage techniques and living conditions of local farmers were done during the field trips and the interviews.
Three male persons of WCT, five female and fourteen male local farmers were interviewed including the male directors of Sisal Estates and orange estate. The reason for a majority of men is that it was more difficult to interview women, because more men worked on the plots and when both presented, the men talked to the interviewers. In addition, many women do not speak English well. Sometimes it was a search to get women for interviewing.
It was tried to get three respondents per map of 16 km^2, but some maps has less, because the area was thinly populated. In Voi town and Mwakingali Hills, farmers were not interviewed, because they were not available.
A questionnaire with twelve basic questions was prepared and informal interviews without papers and fixed sequences were done to get fair answers (See Collective Appendix, Interviews). One male farmer is interviewed with help of two translators, namely two teacher of the nearby school. The other 21 interviewed persons spoke English. Other farmers, who could not speak English, were not interviewed, because it was not possible to communicate well with them.

2.5 Sub-question 3: Criteria for assessment of suitability

The assessment of suitability of the sub-area was done by use of Multi-Criteria Analysis. In the next paragraph, this method is discussed. The method to define the criteria for the assessment matches with the Multi-Criteria Analysis.

2.5.1 Method

In a MCA criteria and/or indicators represent goals and relevant aspects in a project (Krol, 2006). According to Mendoza and Macoun (1999) the conceptual tools criteria and indicators can be structured in a hierarchy of elements, namely from high to low; principles, criteria, indicators and verifiers.
Principles are defined as “a fundamental truth or law as the basis of reasoning or action” Mendoza and Macoun (1999). In this research, four principles were found. Minimal one criterion per principle was defined to meet the principles. The criteria were made operational by indicators and matching verifiers.
The reason for choosing this method was that it helps the researcher to think about the important aspects in this assessment and how to make it operational. In addition, it was the only available method for definition of criteria in Kenya.

2.5.2 Application

The found principles, which are important for assessment of the suitability, are:

1. Practising functions
2. Technical feasibility
3. Social feasibility
4. Easy implementation

The principle “costs” was not used as criterion, because in the case that the local people dig the trenches by themselves: the purpose of WCT and the costs are low.

2.6 Sub-question 4: Assessment of suitability of the sub-areas

2.6.1 Method: Multi-Criteria Analysis

Multi-Criteria Analysis (MCA) is defined by Mendoza and Macoun (1999) as "a decision-making tool developed for complex multi-criteria problems that includes qualitative and/or quantitative aspects of the problem in the decision-making process."
The reason for using was that the result, after application of this tool, is assessment of the alternatives. In this case, the alternatives were the five sub-areas and the suitability of them for implementation of trenching was assessed. The result is a list with ranked sub-areas from most suitable to least suitable. Based on that, a priority can be made among the sub-areas to start the implementation. Another benefit of assessment of the suitability of the five sub-areas was that it gave insight in the technical and social-economical situation and the possibilities in the various sub-areas. Thus, MCA is used as a consideration tool and as indirect information gathering method.
For ranking and rating of the criteria the methods 'ordinal ranking' and 'rating' described in Mendoza and Macoun (1999) were followed. Ordinal ranking is a technique where the list of decision elements is ordered to importance. Rating is a technique where each decision element is given a rating between 0 and 100, and the sum is 100 (Mendoza and Macoun, 1999). The reason for using these ranking and rating techniques was that it was the only available method in Kenya and useful in this study.

2.6.2 Application

The five sub-areas could score at the five criteria minimal 1.0 point and maximal 3.0 points. When a criterion has more indicators, the maximum score of 3.0 points was divided over the indicators. The exact definition of the score per criterion and indicator can be found in Appendix II. The assessment of the sub-areas was done by giving a score and justification of the score per indicator per sub-area. The scores were multiplied with the rating and these numbers were counted per sub-area to get the total score per sub-area.

2.6.3 Data gathering techniques

Some techniques are applied to collect data for the verifiers. Direct observation in combination with physical mapping was used to get data about land use and water flow. In addition, the tillage condition was defined by observation of soil after the infiltration sample. The latter was used forty times as indication to measure the infiltration velocity. At the same locations the soil samples were taken for analysing the soil texture and stiffness. Those locations were selected randomly with minimum of three samples per 16 km^2. The infiltration capacity is estimated based on an analysis of the infiltration velocity, soil texture and stiffness, which can be found in Appendix II.2.5. Secondary data about rainfall per attitude and attitude maps are used to draw the rainfall per attitude map.

2.7 Sub-question 5: Definition of suitable locations for sand storage dams

Research to suitable locations for sand storage dams had less priority than the research about application of trenches. In addition, the researchers had little experiences and feeling with research to suitable locations for dams. Therefore, a quick scan was made along the part of the Voi River streaming through the research area.

2.7.1 Method

WCT use two lists with criteria for dam locations with some different criteria, which are reported in the REAL-manual of WCT (Westerveld and van Westerop, 2005). The two lists were developed based on experiences of people of WCT. Those lists were combined in this study to get an assessment of wider aspects. Some criteria of the lists were combined to formulate an easier criterion for in the field. In paragraph 8.1, an overview of the used criteria in this study is given with discussion of the changed criteria. Because working criteria of WCT were used and this is a less important part of the research study, those are not discussed as deep as the criteria for the assessment of the suitability for trenches.

2.7.2 Application

In the field, the research is done as followed. An important and clearly to observe criterion is: “presence of hard rock basement, which is not porous and fluctuated”. Walking along the river was looked firstly to hard rock basement, which is not porous and fluctuated. In the case that this one was presented, estimation was made if a sand storage dam could be possible in the morphology of the river and the other criteria were worked out. This way of working means that the found locations are probably discussable. Therefore, only data was collected about those locations and conclusions have not been drawn.

2.7.3 Data gathering techniques

The used RRA-tools were direct observation and indicator. The topographical gradient was measured roughly with the slope measure tool and the data for the other criteria were observed and estimated.

2.8 Research question: Recommendations to apply measures

“What are the recommendations to increase water storage by trenching and construction of sand storage dams taking in consideration soil erosion and social-economical characteristics?” This is the final question that has to be answered.

2.8.1 Method

The followed method was assessment of the recommendations for erosion prevention in the research area done in Kort (2006) through the eye of water storage. When the measures are positive or are not an obstacle for water storage, they were taken over. Besides this, other recommendations were done for water storage, including the results of the assessment of suitability of the sub-areas for trenching. Finally, all the measures are presented per area in one master plan.

3. Small water-retaining structures

This research study is dealt with two small water-retaining structures, namely contour trenching and sand storage dams. Below the two techniques are described. Contour trenching get the most attention in this study. Therefore, trenching is discussed deeper than sand storage dams.

3.1 Contour trenching technique

Contour trenching is a small water-retaining structure technique with the function of water retention and erosion control. It combines two traditional techniques, namely terracing with surface irrigation from ditches and (erosion) pits. Last one is built in line with interspaces. Dig the ditches of terraces deeper and the pits uninterrupted, more water can infiltrate to the subsurface for perennial use for vegetation (Westerop, 2006). Contour trenches are deeper ditches dug some distance from each other. The part between the trenches is levelled by excavated soil. They have to be dig along the contour lines of a slope, so that they catch the water as much as possible.

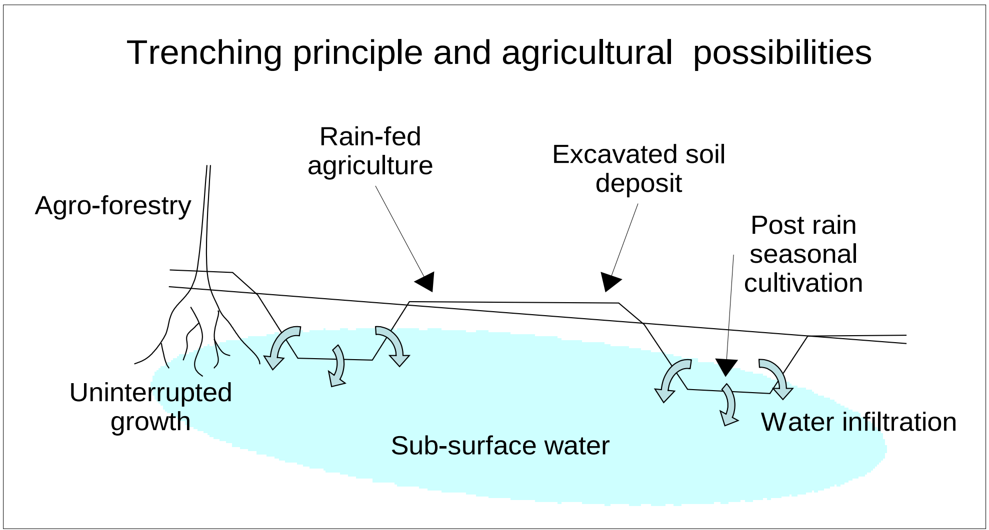


Figure 3.1: Principle and utilisation of trenching.

3.1.1 Principle

The principle of trenching is that precipitation fallen between the trenches flows into the lower trench, which hold the rainwater inside. Therefore, the water gets time to infiltrate into the ground and by gravity it streams as groundwater downhill. This technique diminishes overland flow and with that floods and erosion. In addition, more water is stored under ground level. Because of stored water, rain-fed agriculture and agro-forestry is (better) possible by uninterrupted growth during the year and after the rains, the trenches are useful for seasonal cultivation. The available water can be also used as drinking water for cattle, wildlife and for people. Another application of trenching along a river is that a system of trenches is connected with the river, so that during floods in the river, the trenches-system can be filled with water by another way.

3.1.2 Design

The design and functions of trenching depend on the steepness of slope. The main function of trenches on slopes with low steepness is water storage by infiltration of rainfall and overland flow. Therefore, the trenches can be designed according to the average volume of water that falls in one shower under regular circumstances (Westerveld, 2005). The distance and depth between trenches can be respectively bigger and deeper. Steeper slopes need trenches for water storage and erosion control. Trenches with these functions are defined as bench terraces (recommended for slopes from 7º to 30º) in Morgan (1986). Trenches on these slopes have to be dug on smaller distance from each other, because increases in slope steepness and slope length result in increasing velocity and volume of surface runoff, which cause erosion (Morgan, 1986). Also, the depth has to be lower, because the soil layer above the rock layer is often thinner on steeper slopes, so deep trenches are not possible.

3.1.3 Application area

An essential condition for the application of the trenching technique is the availability of a soil layer of minimal about a half meter, so that it is possible to dig trenches. In addition, the cohesion of the soil must be strong enough, so that the trenches do not collapse after infiltration of rainwater.

3.2 Sand storage dams

A sand storage dams is an artificial barrier constructed inside the river. Behind the dam, a reservoir is created. The river fills up the reservoir with sand from upstream during the rainy seasons. This way a sand layer is deposited behind the dam on the rock layer, which increases the infiltration capacity of the riverbank. Therefore, water can be stored in the sand layer during and after the rainy season. That stored water can be extracted in the dry season when the river is dry. (Hut, Joeman and Vergeer; 2005)
"The purpose of the construction of small groundwater dams will be to supply water –generally untreated- to public water point to serve the local population" according to Westerveld and van Westerop (2005).

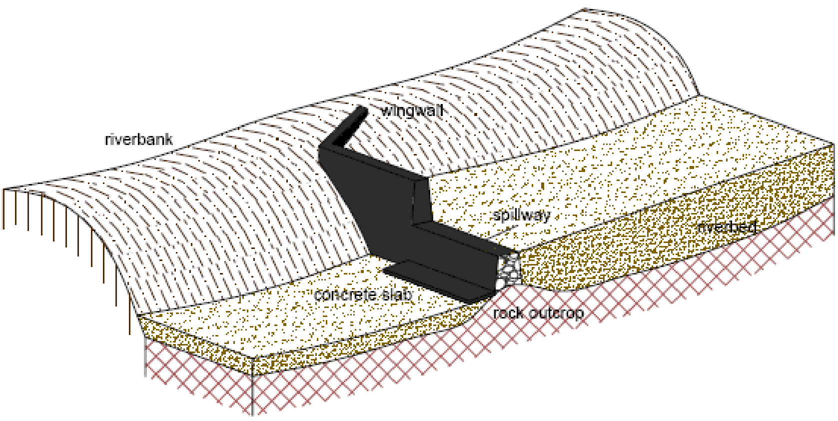


Figure 3.2 Different aspects of an effective sand storage dam (Borst & de Haas, 2006).

Figure 3.2 shows a cross-section of sand storage dam in a riverbank. The dams are built on a rock basement, and have wings inside the river walls at both sides to prevent water flow along the dam and so erosion. In the midst of the dam, a spillway is constructed to channel the river.

4. Definition of suitable area for trenching

The suitable area was defined by using the method Land Capability Classification, which was discussed in paragraph 2.3. The classification data, obtained during the field study are shown in Collective Appendix, Maps. The result of the classification is presented in the first paragraph. A description of the five sub-areas follows.

4.1 Suitable area for trenching

Figure 3.2 shows an indication of the suitable and unsuitable areas. The red-coloured area is classified as class V up to and including class VIII is unsuitable for trenching. It consists of the higher parts of the Small Taita Hills, Sagala Hills and Mwakingali Hills, and the low rocky hills of the Small Taita Hills and the hilly rocky part of the plain Southern of the Voi River.
The white-coloured area falls in the classes III and IV and is suitable for trenching. The research area does not consist of areas of classes I and II. In the next paragraph the suitable area is divided in sub-areas. These are necessary for comparison of the various characteristic sub-areas in the research area.

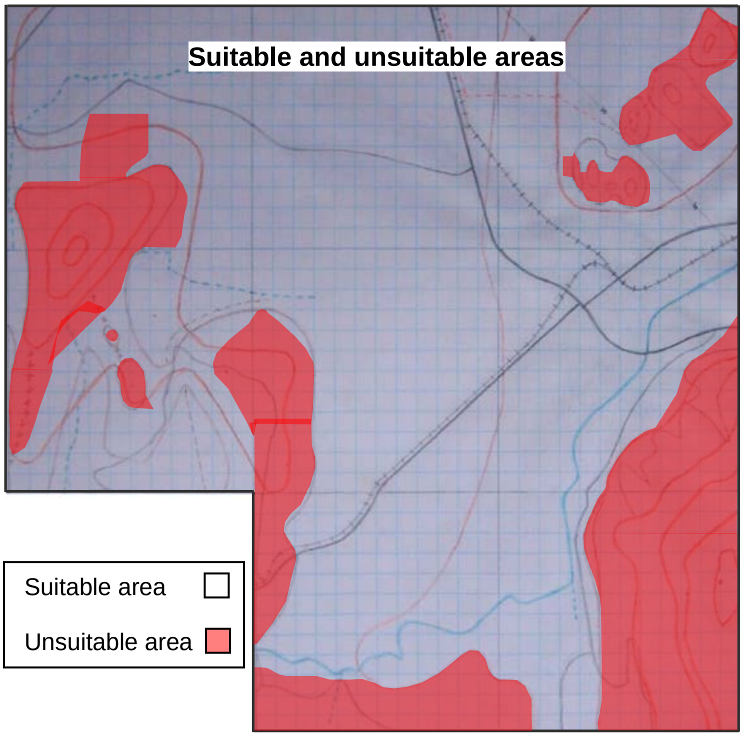


Figure 4.1: Indication of suitable and unsuitable area for trenching.

4.2 Description of sub-areas

Based on the morphology and social-economical aspects the suitable area is divided in five sub-areas. The sub-areas are Voi town and Mwakingali Hills, Sisal Estates, Voi River, Plains and Small Taita Hills. The photos in Collective Appendix, Photo gallery, give an impression of the three mountain ranges, the plains and the river. Below, a description of the sub-areas follows.

4.2.1 Voi town and Mwakingali Hills.

The first sub-areas consists two parts, Voi town and the Mwakingali Hills. Voi town is the largest urban area in the surroundings and its outskirts are built on the foot of Mwakingali Hills. Excepted of the outskirts the Mwakingali Hills are uninhabited, because it is rough and bare terrain. Between the railway and the Voi River lies some government land, which is used illegally for agriculture. There is also some pastureland on the north foot of the Hills, but that is property of the Voi Sisal Estates. Characteristic of this sub-area is urban area, rough and bare hills and a little agriculture and pastureland.

4.2.2 Voi Sisal Estates

Voi Sisal Estates is a commercial company that consists of sisal estates and an orange estate. The estates cover an area of 2.800 ha, a considerable part of the research area. The company use the largest part for cultivation of sisal and the orange estate is 200 ha.
Because of the large-scale production of sisal and oranges, this actor is very different from the small-scale farmers. The policy and will of the management influence big part of the area.

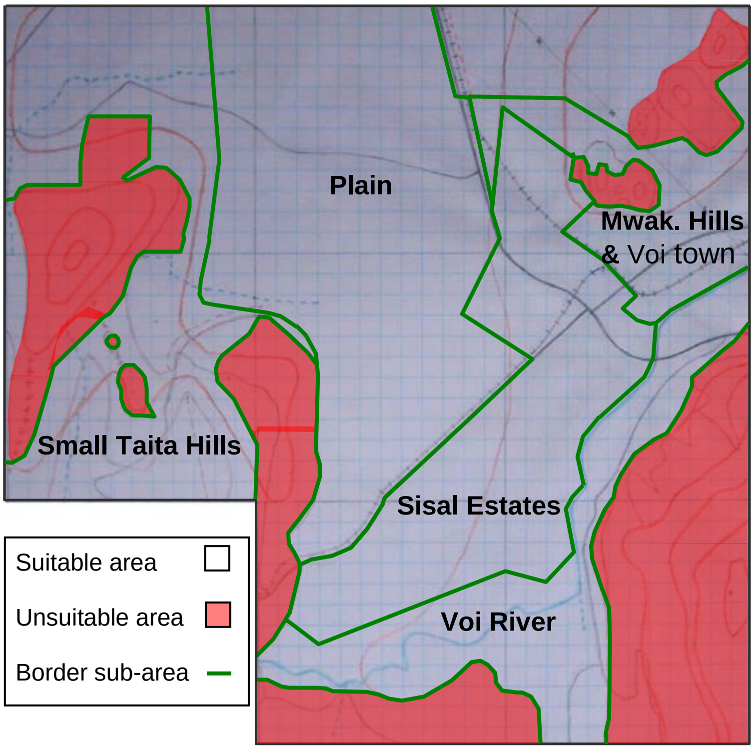


Figure 4.2: Suitable area divided in five sub-areas.

4.2.3 Voi River

The Voi River meanders from the Taita Hills through the plains. In the research area, it is the only source of surface water. Along the river lies an agricultural strip of 100-300 m. The way of farming is different from other places in the research area, because the farmers on these plots use river water for irrigation, so that they can cultivate almost the whole year. Besides this, the river streams along the foot of the Sagala Hills and Sagala people live there near the river.

4.2.4 Plains

The characteristic of the plains is that it has a low gradient, it is dry and only rain-fed agriculture is possible. The land use mainly consists of agriculture and bush existing of acacia trees and grasses. At the plains, a mix of people live and there is almost no community-structure. Another feature is that the farmers are not very active in use of erosion prevention and water harvesting techniques.

4.2.5 Small Taita Hills

This sub-area is specific by its morphology. It consists of the foothills of the first mountain of the Taita Hills from the ocean side. The higher parts of the Small Taita Hills are classified as unsuitable for trenching. In addition, Taita people live here and there are more community-structures. The farmers are also more active in use of techniques to prevent erosion and harvest water. On the hill slopes, more vegetation grows than on the plains, but at the feet, erosion is a big problem.

5. Estimation of the will to participate

After definition of the sub-areas, in this chapter the results of the social-economical analysis to human activity and possibilities are presented. The analysis is executed in Appendix I. The estimation of the will of local farmers to participate in the trenching project was used to match the principle social-economical feasibility, which will be discussed in chapter six.

5.1 Results

5.1.1 Opportunity

The definition of opportunity is the extent in which time and the circumstances stimulate or hinder this behaviour. In this case, the most important conditional circumstance is that water availability is a problem. A problem can be defined as an obstacle, which makes it difficult to achieve a desired purpose. It depends on the person if something is a problem or not. Therefore, the perception of the farmers about the availability of water was measured. In addition, the perception of the farmers were compared and completed with field observations. The results of the analysis are:

- When local farmers were asked to mention their five major problems in farming, the farmers in the sub-areas Voi River, Plains and Small Taita Hills said that water shortage and drought are their biggest problem. This means that local farmers have the perception that water shortage is a problem and that they rank it as their most important problem.
- Observation shows that drought is also a problem in the sub-area Mwakingali Hills and Voi town.
- Voi Sisal Estates including the orange estate have as commercial company more important problems than water shortage, like problems with politician, competition and soil erosion. Increasing of the water availability does not have a high priority.
- Other major problems are plant diseases, erosion and destruction by wild life and cattle.
- The local farmers focus on different sources of water per sub-area. The farmers along the Voi River focus especially on irrigation water, while their colleagues at the Plains and Small Taita Hills have only one source of water, rainfall.
- There are no big differences between men and women in perception of availability of water.

<u>Regarding water shortage as a problem</u>
The local farmers with a small-scale farm regard water shortage as their biggest problem. Those farmers live in the sub-areas Voi River, Plains and Small Taita Hills. The two directors of the both estates have other priorities than increasing water availability. The last sub-area, Mwakingali Hills and Voi town consists of dry terrain, but the perception is not measured. The opportunities of the sub-areas are estimated as high, except the Voi Sisal Estates. The latter is probably low.

5.1.2 Motivation

Motivation is defined as the extent in which a person has interest for (the result of) this behaviour. The issue of this sub-paragraph is increasing water availability by trenching. The behaviour is participation by digging trenches and its result is that the amount of harvested water increases. Local farmers' interest is defined by the focus on rainwater harvesting, if they need and want help and if they own their land, so that they are sure that they work for their family's future. The results of the analysis are:

- The farmers from the sub-areas Small Taita Hills and Plain only practice rain-fed agriculture and they focus on rainfall as water source.

- Along the Voi River, the farmers focus mainly on irrigation water from the river. The interest in a trenches system, which trenches are filled with water during a river flood, depends on the access and successful application of irrigation pumps.
- 88% of the interviewees want help with water harvesting. This percentage is including the directors of the estates. They focus on drilled wells as water source and the prime director said that he has no interest in application of trenches.
- The farmers living Southern of the river near Voi rent their land from a big landowner, while farmers on the northern riverbank live there illegally. Voi Sisal Estates rent every 30 year their land from the local government and the remaining area is officially community land ‘owned’ by local families.
- There are a few measured differences between the motivations of both genders. Little differences are that all the women asked help and when the men asked help, they asked more specific help than women.

Motivation to increase water availability by trenching
The motivation varies per sub-area. The current motivation of the Voi Sisal Estates is low. Because the dependent on rain-fed agriculture, the high demand of help and that the farmers ‘own’ their family land, the motivation of farmers from the Plain and Small Taita Hills is estimated as high. The motivation of farmers along the Voi River is probable moderate, because they mainly focus on irrigation and farmers near Voi rent their plots. The motivation in sub-area Mwakingali Hills and Voi town is probably low, because the land users and landowners are different persons.

5.1.3 Capacity

The definition of capacity is the extent in which a person has the properties, power, skills and instruments to do this behaviour. Capacity is changeable. The current capacity can be increased when instruments are purchased, farmers are learnt new skills or farmers are organised to work together. The current capacity and potential labour force for digging of trenches is analysed. The results are:

- The farmers in the Small Taita Hills are more active in application of water harvesting and erosion control techniques than Plains, Voi River and Mwakingali Hills and Voi town.
- Applied water harvesting techniques are terraces, small earth walls, trenches, water pumps and boreholes.
- Voi Sisal Estates uses five boreholes to irrigate the orange trees and provide processing water for the factory. In Voi River water pumps are mainly used.
- There are no big different between the answers of men and women in use of water harvesting techniques.
- Some communities are organised in the Small Taita Hills and in Voi River. The Plains, Makingali Hills and Voi town and Voi Sisal Estates have a low or no organisation rate with surrounded farmers.
- Generally, men and women do the same work in farming. Only the women are also busy with domestic work and men do some heavy jobs.
- The local farmers do not have much money, therefore it is important that they get the possibility to lent or buy for little money tools needed for digging trenches.

Capacity of local farmers to dig trenches
The capacity per sub-area is as following. Voi Sisal Estates has experiences with drilled boreholes, can get easily knowledge as commercial company and employs many people. Therefore, its capacity is estimated as high. In Mwakingali Hills and Voi town the capacity is low, because people do not use water harvesting techniques and the organisation rate is low. The capacity of Plain is

low, because the organisation rate is low and local farmers do not have many experiences with water harvesting techniques. The organisation rate in the Small Taita Hills is moderate, but the Taita people are active in use of techniques generally. Therefore, the capacity is classified as high. The capacity of Voi River is moderate, because the organisation rate is high, but people use less water harvesting techniques than in Small Taita Hills and the farmers lack knowledge.

5.2 Estimation of participation

The will of the local farmers to participate in the trenching project is estimated per sub-area. Below, a discussion of the will to participate per sub-area follows.
The motivation and capacity in Mwakingali Hills and Voi town is low, therefore the will to participate is estimated as low. The estimation for Voi Sisal Estates is also low, because the opportunity is low and there is a lack of motivation.
The opportunity of the other three sub-areas is high, but the motivation and capacity is different. These two are moderate in Voi River, which lead to an estimation of moderate. The motivation will be probably increased when farmers see good results of the already dug trenches. In Plains the motivation is high, but the capacity is low. Therefore, the will to participate is estimated as moderate. One condition is that the capacity will be increased by organisation of the individual farmers or education to get skills and knowledge. In Small Taita Hills the people are more active and the will to dig trenches is probably high, because the motivation and capacity of its local farmers are both estimated as high.
The answer on the sub-question is that the will of local farmers to participation in the trenching project is low in Mwakingali Hills and Voi town, and Voi Sisal Estates, moderate in Voi River and Plains, and high in Small Taita Hills.

5.3 Discussion

This social study is based on a low number of respondents, what increases the chance of biases. Respondents are mainly random selected, except selection of some women, but only farmers working on their plots are interviewed. Farmers, which are ill or busy with other activities, are not represented. As a result, that the interviewed group is perhaps unrepresentative.
In addition, it is hard to define and describe the real situation of the farmers and to estimate the three causes, because of the low number of respondents and differences in culture. Western researchers can interpret some cultural aspects different from the African farmers.
Another factor is that interview questions could consider better. It is a disadvantage to do firstly the whole field study without computer and to finish with writing the report. During the analysis of the output of the questions, it turns out that there is a lack of some data.
Besides those reasons, it is very hard to estimate behaviour of people and therefore, this study only gives an indication of the will of local farmers to participate.

5.4 Reflection on use of Triade-model

According to Poiesz (1999), the Triade-model can be applied at various behaviour situations and he does not mention restrictions about use in a particular culture. In addition, during the use of the model in this study no problems about this aspect were encountered.
A problem, which was encountered, is that it was very difficult to keep the causes separated. For example, a particular factor of opportunity can influence a particular factor of motivation. Should that factor divided at opportunity or motivation. This was many times a dilemma. A reason for this can be

that the Triade-model is more suitable for analysis of simple behaviour and it is not very suitable for the analysis of complex behaviour.
Another disadvantage was that estimation based on this model needs information that is detailed. To estimate accurately behaviour, information about the motivation, capacity and opportunity is necessary that is as detailed as possible.
Despite those disadvantages, the way of thinking that behaviour exists of motivation, capacity and opportunity gave a good frame to do the social-economical analysis. The model helped to arrange the needed social-economical data.

6. Criteria for assessment of suitability

The suitability for trenching is defined as the quality of being appropriate to apply the trenching technique. The principles with matching criteria, indicators and verifiers for assessment of the suitability for trenching are discussed below.

6.1 Principle 1: Practising functions

The functions of trenches are to store more water by infiltration and prevention of soil erosion. The effectiveness of application of this technique depends on the extent of functioning of it, because well functioning trenches cause (much) more water storage than in the current situation at local scale and prevent erosion. It is a demand that the trenches function moderate too very well.
To match this principle the two functions were separated in two criteria:

1. Effectiveness for local water storage
2. Effectiveness for erosion prevention

6.1.1 Criterion 1.1 Effectiveness for water storage

A trench is effective for local water storage when it functions well. Functioning well occurs in the situations when sufficient water is available to store and when a trench causes (big) change between the current amount of stored water without trenches and the situation with trenches.
The last situation is when the infiltration capacity is low in the current situation. Infiltration capacity is defined as “the maximum sustained rate at which soil can absorb water” in Morgan (1986). It is influenced by pore size, pore stability, form of the soil profile and the tillage conditions. However, infiltration behaviour on many soils is rather complex, because the soil profiles are characterized by two or more layers with different hydraulic conductivities. “Local variability in infiltration rates can be quite high because of differences in the structure, compaction, initial moisture content and profile form of the soil and vegetation density” (Morgan, 1986). In spite of the complexity of soil is tried to determine the infiltration capacity (indicator C1.1.2) by measuring the infiltration rate and observing the extent of compaction and sealing of the surface soil (see Appendix II). The output the analysis of the infiltration capacity is the verifier of indicator C1.1.2.
The amount of available water depends on the amount of rainfall at a particular location and the overland flow from uphill at same location (indicator C1.1.1). The verifier of this indicator is rainfall data per altitude and water flow data based on the morphology of the landscape. A rainfall map is made by using data from the classification of rainfall per agricultural zone (see Appendix V).

6.1.2 Criterion 1.2 Effectiveness for erosion prevention

Overland flow causes erosion, like gullies, rills and overland flow erosion. Decreasing of the cause leads to less erosion. Therefore, trenches can prevent erosion downhill of the trench by storing more water to decrease overland flow. When an area has an high erosion risk, trenches can fulfil its function of erosion prevention better than in areas with an low erosion risk. As a result, that effectiveness of erosion prevention depends on the erosion risk of a sub-area. Erosion risk is also the indicator, and the verifier is the erosion risk data per location presented at the erosion risk map of Kort (2006).

6.2 Principle 2: Technical feasibility

Technical feasibility is defined as the technical quality of being capable to accomplish the objectives. The objective is in this case functioning for a long period to get a sustainable application of the trenching technique. It is essential that trenches are dug well, so that they can continue working well during the time. That can be threatened by low stability of the soil. An unstable soil can cause total collapsing of the trench walls by erode of the upstream soil during rain showers. For implementation of trenching technical feasibility is an essential condition. To judge the technical feasibility, soil stability was as a criterion. When the soil is less stable the design of trenches have to adjust and extra measures are needed to vouch the stability of the trenches.

6.2.1 Criteria 2.1 Stability of soil

Stability of soil means the same as erodibility, “resistance of the soil to detachment and transport”, discussed in Morgan (1986). Erodibility varies with the soil properties; soil texture, aggregate stability, shear strength, infiltration capacity, and organic and chemical content. Soil resistance to eroding also depends on steepness of slope, topographic position and the amount of disturbance created by man. (Morgan, 1986)
Soils saturated after infiltration with a low erodibility can be flushed away by overland flow. Because infiltrated water changes the cohesion among the soil particles. According to Craig (2004) the failure of soil will occur at any point on a layer within a soil mass where the shear stress becomes equal to the shear strength of the soil. Morgan (1986) uses for assessing the stability of the soil mass in respect to mass movement a safety factor (F). It is defined as “the ratio between the total shear strength (s) along a given shear surface and the amount of shear stress (τ) developed along this surface”:

$F = s / \tau$ (if $F > 1$ the slope is stable and if $F \leq 1$ occurs failure)

Above written shows that erodibility is very complex with a lot of factors. Shear strength plays an important role and depends on the cohesion in the soil. It lay outside the possibilities to investigate all factors. Therefore, the ‘physical behaviour of soil under wet conditions’ is determined as indicator of the cohesion of the soil with verifier; the classification during the soil tests, described in Kort (2006; paragraph 4.1.2).
This criterion focuses on the physical stability of the soil, while the criterion erosion risk also includes erosion caused by human inferences and so on. At a particular location with a high erosion risk caused by men, the soil stability can be good, because instability was not the cause of erosion.

6.3 Principle 3: Social-economical feasibility

Socio-economic feasibility is defined as the socio-economic quality of being capable to accomplish a successful and sustainable implementation of trenching. The environmental, economic, social and institutional patterns and their linkages in the area influence the sustainability of implementation of trenching. To match this principle the next criteria was formulated: will of local farmers to participate.

6.3.1 Criterion 3.1 Will of local farmers to participate

Because of the importance and difficulty of inferring this criterion, extra attention was given to the social and economical aspects of the implementation of trenching. In chapter 5, the results of the social-economical study are discussed. The indicator of this criterion is the estimation per sub-area of the will to participate in the trenching project. The verifiers are the results of the analysis of the causes opportunity, motivation and capacity.

6.4 Principle 4: Easy implementation

Generally, easy implementation of something is preferred above a difficult implementation with the same results. Implementation is easier when allowance is made for the current structures. This means for implementation of trenching that allowances are made for current land use. Some land uses lent themselves better for trenching than others. Because ground is available for trenches and there is relative equal overland flow, so trenches can function better. The matching criteria for principle 5 is; suitability of current land use

6.4.1 Criteria 4.1 Suitability of current land use

Land uses like agriculture, bush and pasture are more suitable than urban area, because urban area consists many building, roads, and goes on. Therefore, it is more difficult to dig long trenches and to make the system ‘closed’ and it is a generally known phenomenon that water always chooses the way with the least resistance. So, the type of land use is used as indicator with as verifier, data about land use.

6.5 Summary of criteria and matching indicators and verifiers

A survey of the criteria and the matching indicators and verifiers is given in table 5.1. The scoring per indicator is discussed in Appendix II. A code-system is used for criteria and indicators, C1.1.1 means criterion 1 of principle 1, indicator 1.

Table 6.1: Summary of criteria with matching indicators and verifiers.

Criterion		**Indicator**		**Verifier**
C1.1	Effectiveness for local water storage	1	Amount of rainfall and overland flow	Rainfall per altitude and water flows
		2	Infiltration capacity	Data from analysis infiltration capacity
C1.2	Effectiveness for erosion prevention	1	Erosion risk	Erosion risk per location
C2.1	Stability of soil	1	Physical behaviour of soil under wet condition	Classification during soil test
C3.1	Will to participation	1	Estimation of will to participate	Results of social-economical analysis
C4.1	Suitability of current land use	1	Type of land use	Data about land use

7. Assessment of suitability of the sub-areas

After definition of five criteria for assessment of the suitability of the five sub-areas, the assessment is executed by application of a Multi-Criteria Analysis. Firstly, the ranking and rating is discussed, following by the results.

7.1 Ranking and rating

7.1.1 Ordinal ranking

The list with criteria is ordered to importance as shown in figure 7.1. The stability of soil was ranked as most important, because the stability of soil defines the possibilities for digging of trenches. Unstable soils are less or even not suited and trenches need special design and construction in these soils. Mistakes in wrong assessment of the soil can cause severe erosion and landslides and prevention is better than healing.
Will to participate is also very important, because support and belief in trenching of local farmers is essential for a successful implementation. The principles of those criteria were mentioned essential conditions, because they are the key-factors in success or failure of the project.
Effectiveness for both local water storage and erosion prevention has the same importance, because they represent the two functions of trenches. Well-functioning of the trenches is more important than as easy as possible implementation at locations with a particular land use, because when trenches do not functioned well the aim do not obtained. Land use can also change more easily.

Table 7.1: Ranking of the five criteria

Most important	
	Stability of soil
↑	Will to participate
	Effectiveness for water storage
	Effectiveness for erosion prevention
↓	Suitability of land use
Least important	

Table 7.2: Rating of the five criteria

Criteria	**Rating**
Stability of soil	25
Will to participate	23
Effectiveness for water storage	19
Effectiveness for erosion prevention	19
Suitability of current land use	14
Total	*100*

7.1.2 Rating

The five criteria were given a rating between 0 and 100 mainly based on the argumentation of ranking. Stability of soil was rated with 25 and will to participate with 23. The reason for the difference is that the technical factor is a more constant and reliable than the social-economical factor. The third and fourth ranked criteria both were rated with 19 and Suitability of current land use with 14, because this criterion is less important than the others are.
The results however are not sensitively for the rating. In the case of equal rating, this means all criteria are rated with 20, the sequence from high to low scored was almost the same with very little changes in total score. Only, Mwakingali Hills and Voi town and Sisal Estates should turn.

7.2 Results

Table 7.3 shows the results of the Multi-Criteria Analysis executed in Appendix II. The score per criterion was multiplied with the rating and the sum gives the total score per sub-area.

The sub-areas Voi River, Plain and Small Taita Hills have scored the highest with respectively 210, 194 and 254 points, while Mwakingali Hills and Voi town, and Sisal Estates scored lower with respectively 182 and 181 points.

Table 7.3: Results of Multi-Criteria Analysis.

Criteria / *Sub-areas*	Rating	Mwakingali Hills and Voi town	Voi Sisal Estates	Voi River	Plains	Small Taita Hills
Stability of soil	25	3,00	2,00	2,00	2,00	2,00
Willingness of participation	23	1,00	1,00	2,00	2,00	3,00
Effectiveness for local water storage	19	2,50	2,25	2,00	1,75	2,50
Effectiveness for erosion prevention	19	1,20	1,20	1,80	1,20	2,40
Suitability of current land use	14	1,00	3,00	3,00	3,00	3,00
Total score	100	**182**	**181**	**210**	**194**	**254**

The three highest scored sub-areas differ at three criteria. Small Taita Hills has a higher erosion risk and effectiveness for local water storage, because of the high rainfall. The will to participate in the Small Taita Hills is estimated as high, while in Plains and Voi River as moderate. That is also an important difference with the lowest two sub-areas having a low will to participate in the trenching project.
The stability of the soil is the highest in Mwakingali Hills and Voi town. The other sub-areas score moderate, because they consist of 'very soft' soil besides 'soft' and 'firm' soil. The Mwakingali Hills and Voi town and Small Taita Hills are averagely the most effective for local water storage. The erosion risk is the highest in the Small Taita Hills and Sagala Hills, which are situated in sub-area Voi River. Therefore, trenches are most effective in those sub-areas for erosion prevention. Except Mwakingali Hills and Voi town, all the sub-areas score high at the criterion Suitability of current land use.

The five sub-areas are from most suitable to least suitable:

Most suitable	⟷			Least suitable
Small Taita Hills	*Voi River*	*Plains*	*Mwakingali Hills and Voi town*	*Voi Sisal Estates*

5.5 Discussion

The advantage of MCA is that it is a tool used for structural assessment and comparing of various alternatives, in this case sub-areas. However, using a MCA also has some disadvantages for assessment of areas. A balance had to be found between the amount of sub-areas for detailed assessment and feasibility. In this analysis is chosen for five sub-areas. Therefore, it was necessary to use average assessment per indicator for getting a general impression, so that the sub-areas could be compared. The disadvantage is that many data is lost by this manner and the averages are not always representative for the measured situations in a sub-area.
In addition, input of the MCA was gathered by rough measurements, estimations and methods to get an impression of the area. Because of that, a large area could be investigated, but the disadvantage is that it is not very accurate. Locally, there can be large differences from the overall impression based on rough indications. As a result, the defined suitability of the sub-area can differ

from the real situation. Therefore, detailed investigation is necessary in smaller areas to gather more detailed data of the local situations.
In the case of using smaller sub-areas in this research, the same criteria could be applied, because those criteria match with the rough character of this research. However, when a smaller area have to be investigated other and more specific criteria should be used, because then a can get a more realistic impression of the local situation

8. Definition of suitable locations for sand storage dams

In paragraph 2.7, the applied method of research to suitable locations of sand storage dams was discussed. Below, the used list of criteria and the results are described.

8.1 Criteria

Table 8.1 shows the used criteria for suitable locations. The most criteria were taken over from the REAL-manual of WCT. Some criteria were combined, which are the criteria 1 and 4. Criterion 1 is a combination of the criteria “Then locations are sought out with a solid rock foundation”, “The rock at the base should not be porous” and “Rock basements which are suspicious of fluctuation have to avoid”. Criterion 4 is a combination of the criteria of WCT “The site should be at least some reasonable distance from main road” and “The site must be easily accessible. Mostly a dam downstream, close to a road is best”.

Table 8.1: Used criteria for investigation to suitable locations for building of sand storage dams and used gathering technique in the field.

Criteria	Formulation	Technique
1	Presence of hard rock basement, which is not porous and fluctuated	Field observation
2	Topographical gradient: [0.2% - 16%]	Field measurement
3	High of the riverbanks (at least 1.5 m high)	Field observation
4	Accessibility of the site by presence of roads or distance to main road	Field observation or map measurement
5	Type of soil riverbank	Field observation
6	Type of soil of surrounding is not black cotton soil	Field observation
7	Volume of reservoir:	
a	Wide	Field estimations
b	Length	Field estimations
c	Depth of rock layer	Field estimations
8	Indicator: presence of scoop holes	Field observation
9	Presence of local materials:	
a	Non porous stones	Field observation
b	Clear sand or pure sand	Field observation
c	Water	Field observation
10	Social criteria:	
a	Location is on individual land or near a number of plots	Field observation
b	Land use	Field observation
11	Kinds of vegetation along and on the river walls (grass, plants, small trees (< 2 m), moderate trees (2 m – 8 m) and high trees (> 8 m)	Field observation

The range of the topographical gradient of criterion 2 was also taken over from Westerveld and van Westerop (2005). Criterion 11 is added, because the extent and kind of vegetation on and along the river walls influence the erosivity of these walls.
The criterion “Water should not be very saline” is not used, because it was assumed that the salinity of the Voi River is reasonable constant. The value of salinity of water in the Voi River was low enough to decide to build the current four dams in the river.

Data about the size of the reservoir is interesting, because extent of being economical of a sand storage dam depends on the size of the reservoir and the needed high and breadth of the dam. When for example for a small reservoir, a small dam is needed then it can be economical.
Accessibility of the location and presences of building materials are criteria, because they are relevant for a successful building process. The social criterion defines who or what can get profit of the sand storage dam. For example, a location with eight small-scale farmers gets more priority then a location with big commercial landowner of company like the estates. Two sub-criteria are shown in the table. When there could not identify landowners/users, the land use was written.

8.2 Suitable locations

During the trips along the river are found six locations, which are perhaps suitable as dam location. Those locations consist of a hard rock basement situated above the riverbank and mainly small natural barriers with water flow on the lowest point. Figure 8.1 gives an indication of the estimated places of the suitable locations.
The other parts of the river do not have a rock basement or this one is porous and fluctuated. The part between the western sand storage dam and the ‘small bridge’ are not found suited locations, because the riverbank is a thick sand layer and the rock layer is at the most places deep under the riverbank. The rocks lying at the surface resemble to stab sloping into the ground, a big part under the riverbank. Nearby and under the bridge are some rocks above the riverbank for the first time since the sand storage dam. The bridge is constructed on these rocks; therefore, it is not reasonable to construct a dam on these rocks, because the dam increases the water level. That water can maybe undermine the stability of the bridge. There is observed that river water has already swept away a part of the road and slopes of both sides of the bridge in downstream direction.

8.3 Discussion

Because of lack of a detailed map and position-finding tools, it was impossible to determine the exact places of the suitable location. Therefore, estimations had to be done with result that the chance of deviations like few hundreds meters is presented.
The investigation to dam locations was less relevant than the research to areas for trenching according to WCT. The accent of this fieldwork lay at the research to trenching and little time was spent to deepen in exactly investigation to dam locations. In addition, the researchers had very little field experiences of investigation to dam locations. Because of these reasons, it was hard to assess the suitability of the six found locations. Only an inventory of data of the locations was made and it is necessary that a more experienced person assess the six locations.

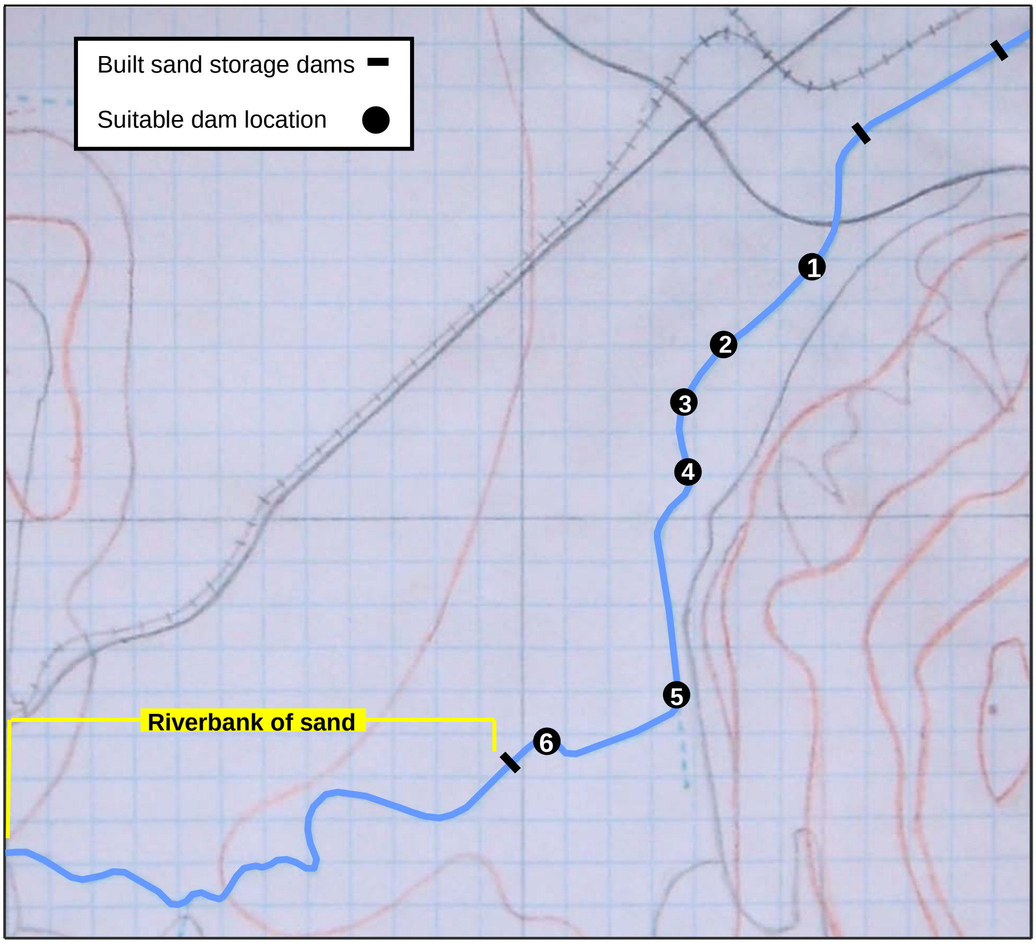


Figure 8.1: Map with six suitable locations.

9. Recommendations of measures in the research area

The sub-areas were assessed on suitability for application of trenches, some suitable locations for sand storage dams were found and research was done to social-economical aspects influencing the implementation of trenches. At the same time, recommendations for soil conservation were done in Kort (2006). In this chapter, all those results are combined and the various measures are listed and discussed.

9.1 Technical-agronomic measures

To increase the infiltration possibilities and capacity two general techniques are available: increasing of the vegetation cover and artificial influencing of the infiltration capacity of the ground by mechanical measures. The latter one consists of trenching and sand storage dams, which is a mechanical measure to store water in a sand reservoir in the river. Besides water storage, controlled drainage of excess water is also important.

9.1.1 Mechanical measures

Trenching

Based on the results of the MCA, it is recommended to start with the implementation of trenching at the foothills of the Sagala Hills, along the Voi River, at the plains (except the area of Voi Sisal Estates) and at the foothills of Small Taita Hills.
This technique is also recommended for soil conservation for the Southern foot of Mwakingali Hills, foothills of Sagala Hills, along the river and on the plains. The assessment of the first mentioned location is less suitable, mainly caused by the low estimated will of local people to participate and according to Kort (2006) co-operation with the municipal county of Voi is needed.
The soil stability of these grounds is firm, mainly soft and a small part very soft. It is important to determine the capacity of the soils to store water and prevent collapsing (see sub-paragraph 6.2). The distance between the trenches and their depth has to be designed based on that capacity.
In the Small Taita Hills construction of ladder terraces are recommended in Kort (2006). Ladder terraces are trenches with a sloping surface between them (see for a picture in Kort (2006), Appendix VII), but this technique has no large water storage capacity. Therefore, other bench terraces, trenches with a flat surface between them, are a better alternative, because these have a higher water storage capacity. However, Kort (2006) described the bad experiences on comparing slopes. Because of that, extra research to design and application of bench terraces in the research area is recommended. Sure is that the trenches at the steeper slopes have to be designed less deep and with a shorter distance between them, because of the higher risk of land sliding (Morgan, 1986).

It is also important that soon after digging of trenches the walls are planted with grass to stabilize them and when possible with planting of (fruit) trees for increasing of the stability and infiltration capacity of the soil.
The best way to trench an (sub-)area is starting with all agricultural plots, because farmers have the highest willingness of participation. Followed by, trenching and re-vegetation of the bushy area to realise evergreen forest.

Construction of waterways

Kort (2006) recommended construction of waterways to carry the excess water in a controlled way. In spite of the infiltration increasing measure, runoff will remain, especially on the foothills. It is important to manage runoff by using waterways for leading the water to the Voi River or other waterways in the direction of the river. Therefore, some gullies at the foothills of the three mountain ranges have to channel into a waterway. In combination with trenches, a water drainage scheme can be made. For a well-designed scheme, it is necessary to estimate the infiltration capacity upstream (after taking of measures) and to calculate the maximum amount of excess water per location that has to be carried away to the river.

Construction of check-dams
Prevention of expansion of the gullies is also necessary by construction of check-dams in combination with planting of grass and trees in the gullies, which are not used for channelled waterway according to Kort (2006). This measure is favourable for water storage, because gullies cause a decreasing of the infiltration capacity.

Furrows along the roads
Kort (2006) also recommended digging furrows along the roads and planting grass on their verges to stop expansion of gullies along the road. The strips along the roads can store little water. The water drained by the furrows is water that runs of from the roads and boarding areas. To a certain extent, this prevents roads from flooding and becoming impassable for transport.

Sand storage dams
Trenching enhances water storage on land and subsequently decreases floods in the river, while the function of sand storage dams is to store water in the river. Well re-hydration of the river basin need probably many more dams, because the floods are big and much water has to be stored, before the floods are controlled (Chun-Tian and Chau, 2004). Now sand storage dams are constructed at rock basements, but it is also possible to build dams on sand, when they have a good foundation and the seepage way under the dam is long enough, so that the dam is not going to force up. The disadvantage is that it is more expensive than building on rock basements, but when more dams are desired for re-hydration of the Voi River basin it may be necessary to use sandy locations.

9.1.2 Re-vegetation measures

Kort (2006) recommended the next measures, which lead to increasing of the vegetation cover. Vegetation cover increases the infiltration capacity and the measures are recommended at locations, which are not suitable for trenching or in combination with trenches. The suggestions are:

- Planting of mixture of trees, when possible in combination with construction of small terraces, shrubs and grasses on the hilltops and slopes of Mwakingali Hills, Sagala Hills and Small Taita Hills
- Planting of trees for sustainable firewood production at southern foothill of Mwakingali, Hills and the foothills of the other two mountain ranges.
- Planting of napier or vertive grass and trees at the foothills of Sagala Hills and Taita Hills.
- Planting of shrubs and trees with a lateral system of roots in the area with gullies caused by piping on the plain in grid 6.
- Planting of napier or vertive grass on the riverbanks for stabilisation.

9.2 Measures to improve practices

It is observed and some farmers mentioned it during the interviews that lack of knowledge is a big problem and it leads to bad farming and wood collection practices causing erosion and lower water storage. In Kort (2006) some social measures are recommended, which have good effect for both erosion control and water storage, because they increase the infiltration capacity. Measures for the whole area are:

- Teach farmers about good farming practises, like use of mulch, manure, fertilizers, crop rotation, mixed crops and giving land rest and irrigation practices.
- Teaching about and practise of (re)planting of trees profiting of timber and fruits.
- Teaching about sustainable forestry management.

Measures for specific areas are:

- Teaching of sustainable firewood collection by planting, cutting and replanting of trees in area of Mwakingali Hills, Sagala Hills and Taita Hills.
- Closing of land classified as VIII for animals and men in Sagala Hills and Taita Hills in co-operation with the local government.

<u>Teaching and support with digging trenches</u>
The lack of knowledge also applies for the theoretical and practical knowledge trenches. Therefore, good teaching about the relevant aspects of digging trenches and adequate support for farmers during digging of trenches is demanded for a successful implementation.

<u>Organisation of individual farmers</u>
The organisation rate on the plains is low and in the Small Taita Hills moderate, which give local farmers a low potential capacity to dig trenches. A solution of this problem is organisation of the individual farmers. This can be very difficult, but the possible result is worth trying. During the interviews became apparent that the farmers were organised more in the past. These structures could perhaps be used for re-organisation, so that the farmers work together with trenching of their plots.

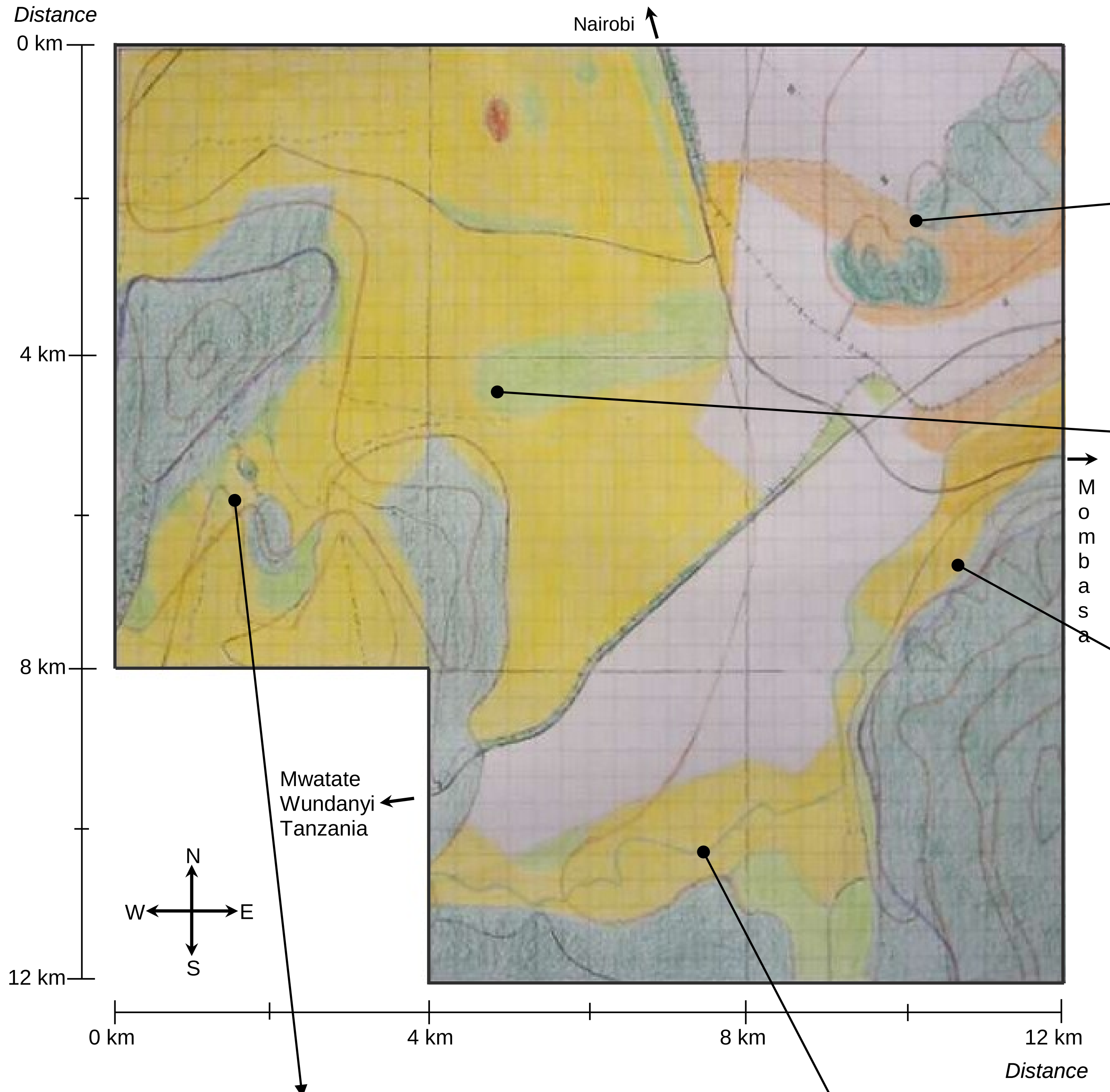
9.3 Master plan

At page 38 the master plan is presented consisting of the recommended measures per area discussed in paragraph 9.1 and 9.2. A map is drawn with the various technical-agronomic measures and in boxes, all the measures are mentioned per characteristic area.

9.4 Discussion master plan

The master plan consists of the measures, which should have to apply to solve the problem: continuing decrease of water storage and the vegetation cover and increase of soil erosion in a river basin. An interesting and important question is if all the measures are feasible, because the execution of the measures ask much effort, time and money. It is also questionable if it is possible to change the way of thinking and living of the local people (easily), so that they also do sustainable forestry or maintain their water harvesting techniques at long term.
Another issue is the market of crops. When local farmers can harvest more water by trenches, so that they can cultivate more crops, they also need the possibility to sell their yields for a good price. The small-scale farmers can probably sell only at the local market in Voi. This master plan does not take into account the space of the market of crops.

Master plan for re-hydration of a part of the Voi River basin



Mwakingali Hills
- Construction of waterways
- Construction of check-dams
- Trenching in outskirts and pastureland north side
- Planting mixture of trees, shrubs and grass on hills
- Planting of trees in outskirts for sustainable firewood production
- Teaching of sustainable firewood collection

Plain
- Trenching of area and planting of profitable trees on plots
- Construction of waterways from three seasonal rivers
- Planting of scrubs and trees with a lateral system of roots in area with gullies caused by piping
- Planting mixture of trees, shrubs and grass
- Organisation of individual farmers

Sagala Hills
- Closing of land classified as VIII for cattle and men
- Planting of napier or vertive grass and trees at the foothill
- Planting mixture of trees, shrubs and grass on hills
- Construction of waterways
- Construction of check-dams
- Trenching of foothills planting of profitable trees on plots
- Teaching of sustainable firewood collection

Whole area (excepted Voi Sisal Estates)
- Teaching farmers about good farming practises
- Teaching about and practise of (re)planting of profitable trees
- Teaching about and accompanying of digging trenches
- Teaching of sustainable forestry management
- Digging of furrows along the roads and planting grass in verges

Small Taita Hills
- Closing of land classified as VIII for cattle and men
- Planting of napier or vertive grass and trees at the foothill
- Planting mixture of trees, shrubs and grass on hills
- Construction of waterways
- Construction of check-dams
- Construction of ladder terraces: trenches with sloping area between them planting of profitable trees on plots
- Teaching of sustainable firewood collection

Voi River
- Planting of napier and vertive grass for riverbank stabilisation
- Building of sand storage dams
- Trenching and planting of profitable trees on plots

Legend
- Planting of trees, scrubs and grass
- Trenching of agriculture land and bush:
  - Priority 1
  - Priority 2
  - Priority 3
- Trenching of bush and Planting of trees, scrubs and grass
- Border area classified as VIII
- Planting of trees and grass with lateral roots system
- No measures recommended

10. Conclusion and recommendations

10.1 Conclusion

The suitable area for application of the trenching technique is the area classified as classes III and IV according to the Land Capability Classification, which consist of the foothills of Mwakingali Hills, Sagala Hills and Small Taita Hills, the plain and the area along the Voi River. The suitable area was divided in five sub-areas.

The will of the local farmers in the research area to participate in the trenching project by digging of trenches is estimated per sub-area as low in the sub-areas Mwakingali Hills and Voi town and Voi Sisal Estates, moderate in Voi River and Plains and high in the Small Taita Hills.

Five criteria were found and used in a MCA for assessment of the suitability of the five sub-areas for implementation of trenches. Those criteria are: stability of soil, will to participate, effectiveness for local water storage, effectiveness for erosion prevention and suitability of land use. The results of execution of the MCA are that the five sub-areas assessed from most suitable to least suitable: Small Taita Hills, Voi River, Plains, Mwakingali Hills and Voi town and Voi Sisal Estates.

Six locations in the part of the Voi River within the research area were found as suitable for building of sand storage dams. The Western part of the riverbank consists of a thick sand layer and is therefore unsuitable.

Recommendations were done about the applications of measures in the research area to increase water storage and prevent also soil erosion. The measures consist of technical-agronomical measures, divided in mechanical and re-vegetation measures, and measures to improve practices of local farmers. Mechanical measures include trenching, construction of waterways and check-dams, digging of furrows along the roads and building of sand storage dams. Re-vegetation measures consist of planting of mixtures of trees, shrubs and grasses on the hill slopes, foothills and on the plain, while human behaviour measures include teaching and support of farmers, closing of risky land and organisation of individuals.

The recommendations form the master plan for implementation of small water-retaining structures and added measures to re-hydrate the Voi River basin to realise a dream: evergreen forests.

10.2 Recommendations

Based on this study some recommendations are given for further research:

1. Research is necessary for the application of the trenching technique in various situations and especially in critical situations with steep slopes and (very) soft soils. It is important to know in which soil trenching is possible, so that the trench walls do not collapse and do not cause land slides during and after rain showers. Interesting to know is the required design of trenches in different soils. When trenching will be applied at large scale, research to this subject is very relevant for successful results.
2. The water supply and especially the water demand in the Voi River basin have to be investigated, because those have to be taken in consideration when the places where trenches and sand storage dams are necessary will be defined. This prevents that too much water is stored upstream, while downstream a shortage of water arises. Therefore, the exact water

supply consisting of the amount of rainfall per location per period and the water demand have to be known. The latter includes demand of vegetation, agriculture, animals and domestic use per location in the whole area. When such an inventory is made, well-considered decisions can be taken.

3. Experiences with projects in developing countries shows that participation of the local people defines extent of success and sustainability of a project. (Euroconsult B.V. & WAPCOS, 1996). Therefore, it is important to think about how the re-hydration project in the Voi River basin could be a project of the local farmers. So that they are motivated to dig trenches, stop gullies, take over the good farming practices, etcetera.
   Some practical ideas are: involving local farmers in the decision-making process and good information of the farmers about the steps in the process and the measures. Another idea is to take the problems of the farmers serious and help them to solve their problems, this increases commitment with the project. It is important to set the local farmers central and not the re-hydration of the Voi River basin, because local farmers have to do the work and it is about their life. Their co-operation is also essential for obtaining the goal: re-hydration of the Voi River basin.
4. In the discussion of the master plan is mentioned that the master plan does not take into account the space for higher supply of crops at the local market. Positive results of digging of trenches for the income of the local farmers, needs possibilities for selling of their crops. Research is necessary to possibilities for selling at local market and access to bigger markets.

Recommendations for (further) project performances

5. In this study, a part of the total Voi River basin is investigated. The same research has to be done for the other part of the river basin. Because that area mainly consists of the Taita Hills, it will cost more time, therefore it is reasonable that the other area is split up in two parts for two groups of students.
6. Observed is that digging of trenches does not occur precisely. After digging of trenches and levelling of the soil the steepness of the slopes were higher than before, while the area between the trenches must be as flat as possible. This means that the situation is worse than before. Therefore, more care should be taken during execution of the work.
7. A preparatory study is done and a master plan with overall measures is developed. The next step is to do a detail-study (for example an Environmental Impact Assessment) per small area and work out an action plan with feasible measures at short and long term.

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Glossary of key terms

Agronomic measures	“Measures that utilize the role of vegetation in helping to minimize erosion.” (Morgan, 1986: p. 164)
Catchment area	An drainage area bordered by hill or mountain ranges that catch precipitation streaming to one river.
Criterion	“A principle or standard that a thing is judged by.” Mendoza and Macoun (1999)
Effectiveness	The contribution made by something’s results to the achievement of its purpose. (European Commission, 2004)
Erosion	A three-phase process consisting of the detachment of individual particles from the soil mass and their transport by erosive agents such as running water and wind and the sedimentation of those soil particles. (Morgan, 1986)
Feasibility	The quality of being capable to accomplish the objectives. (Answers Corporation, 2006)
Foothill	The lowest parts of a hill near the base, where the hill passes off in plain by decreasing steepness of its slopes.
Indicator	Any variable or component used to infer the status of a particular criterion or condition. Mendoza and Macoun (1999)
Hill/Mountain	A well-defined natural elevation. (Answers Corporation, 2006)
Master plan	A plan giving comprehensive guidance (Answers Corporation, 2006)
Multi-Criteria Analysis	“A decision-making tool developed for complex multi-criteria problems that include qualitative and/or quantitative aspects of the problem in the decision-making process.” Mendoza and Macoun (1999)
Physical	Relating to material things: our physical environment. (Answers Corporation, 2006)
Plain	An extensive, level area of land. (Answers Corporation, 2006)
Principle	“A fundamental truth or law as the basis of reasoning or action”. Mendoza and Macoun (1999)
Project	“A series of activities aimed at bringing about clearly specified objectives within a defined time-period and with a defined budget.” (European Commission, 2004)
Re-hydration	Make an area wetter again during the whole year by storing (more) precipitation.
Sand storage dam	A small-retaining structure consisted of an artificial barrier constructed inside the river creating a reservoir for sand carried by the river during the rainy seasons.
Slope	Numerical measure of a line’s inclination relative to the horizontal, expressed in degree or percentage. (Encyclopaedia Britannica, Inc, 2006)
Socio-economic	Referring to environmental, economic, social and institutional patterns, and their linkages that compose the context of development.

Sub-area	This is an (small) area consisting the same characteristics on which the research area is assessed.
Suitability	The quality of being appropriate to a purpose or an occasion.
Suitable area/location	Area/location meeting the requisite conditions for trenching or building dams.
Sustainable	Sustainable water resource systems are those designed and managed to meet the needs of people living in the future as well as those of us living today. (Loucks & Gladwell, 1999)
Trenching	A small-retaining structure technique consisted of ditches at particular distance from each other with as functions increase water retention and erosion control.
Verifier	“Data or information that enhance the specificity or the ease of assessment of an indicator.” Mendoza and Macoun (1999)
Water storage	Storing of water for a particular period in a physical object.

Appendices

Appendix I Analysis social-economical aspects

I.1 Introduction

In this appendix, the social-economical aspects are analysed based on interviews and observations in the field. The output of the interviews can be found in Collective Appendix, Interviews. Table I1 shows in short the answers given by the interviewed farmers on various questions per sub-area. From left to right questions 3, 4, 7, 8, 10, 11, 12 of the questionnaire are answered. The questionnaire is worked out in Collective Appendix, Interviews. The analysis of the opportunity, motivation and capacity follows in the next three paragraphs.

Table I.1: Survey of number of answers per sub-area.

Sub-area	*Farmer*	**Problems with water availability**	**Used water storage technique**	**Projects in past or today**	**Want help and kind of help**	**Community organisation**	**Land ownership**	**Labour division between men and women**
Sisal Estate	5	Irrigation	Irrigation	Dam,pipeline	Borehole/dam	No	Yes	Yes
	6	No	Irrigation,borehole	Noting	Borehole/dam	No	Yes	?
Voi River	3	No	Irrigation	Dam	No	No	No	No
	17	Irrigation	Irrigation	Dam	Yes	Yes	No	No
	7	Irrigation	Irrigation,terraces	Dam,trenches,pump	Others	Yes	No	No
	8	Irrigation	Irrigation	Dam,trenches,pump	Knowledge	Yes	Yes	No
	18	Rainfall	Irrigation	Dam,trenches,pump	Yes	Yes	Yes	Yes
	19	Irrigation rainfall	Irrigation,trenches	Dam,trenches	No	No	Yes	No
Plain	1	Rainfall	(Small earth walls)	Nothing	Borehole	No	Yes	No
	2	Rainfall	Small earth walls,trenches	Nothing	?	No	Yes	No
	15	Rainfall	Nothing	Borehole	Yes	No	Yes	No
	16	Rainfall	(Terraces)	Borehole,pipeline	Borehole	No	Yes	No
Small Taita Hills	9	Rainfall	Noting	Seminar	Knowledge	Yes	Yes	No
	10	Rainfall	Terraces	Seminar	Yes	No	Yes	No
	11	Rainfall	Nothing	Nothing	Borehole	No	Yes	Yes
	12	Rainfall	Nothing	Noting	Yes	Yes	Yes	No
	13	Rainfall	Other	Noting	Yes	Yes	Yes	No
	14	No	Nothing	Noting	Borehole	No	Yes	No

I.2 Opportunity

To indicate the opportunity of local farmers the indicators "perception of water shortage as problem" and "ranking of water shortage among other problems" are used. These indicators are discussed at the same time, because they are indicated by the same results. Also, a discussion about the other mentioned major problems and differences in perception between men and women is done.

I.2.1 Major problems for local farmers

During the interviews, the farmers were asked to mention the five major problems in farming from the biggest to the smallest. In table I.3, the rated output of this question is shown per sub-area and of the total area. The ranking was done as following. The problem ranked as number one got six points; number two got five points and so on. The sum of those points defines the rates of the problems per sub-area and of the total area. The weights are taken linear, because the ranking is not very precisely and depends on the perception of the farmers. “Other problems” consist of politics, closed market of the USA and Europe for agricultural products, competition, availability of water tanks, lack of knowledge of modern farming practices and rent of irrigation pump and tubes.

Table I.2: Mentioned and rated major problems in farming.

	Sisal Estate	*Rate*	**Voi River**	*Rate*	**Plain**	*Rate*	Taita Hills	*Rate*	**Total area**	*Total rate*
1	Other	13	Water, drought	28	Water, drought	23	Water, drought	36	Water, drought	93
2	Erosion	9	Erosion	19	Plant disease	13	Plant disease	22	Plant disease	51
3	Water, dry	6	Other	15	Poor harvest	6	Erosion	17	Erosion	47
4	Plant disease	6	Plant disease	10	Wildlife&cattle	4	Wildlife&cattle	12	Other	31
5	Theft	6	Price fuel	9	Erosion	2	Animal disease	9	Wildlife&cattle	24
6			Poor harvest	8			Other	9	Animal disease	15
7			Good seeds	8			Bad fertility	6	Poor harvest	14
8			Wildlife&cattle	8			Good seeds	4	Good seeds	12
9			Animal disease	6					Bad fertility	10
10			Bad fertility	4					Price fuel	9
11			Theft	1					Theft	7

Table I.3 shows that farmers said generally that water shortage and drought are their biggest problems, except the directors of Voi Sisal Estates. Per sub-area, people however have different causes of water problems. Along the Voi River, river water is used for irrigation of crops, when the rainwater in the ground is finished. The majority of the farmers living in this sub-area mentioned shortage of irrigation water as major cause. While, the farmers living on the plains and in the Small Taita Hills mentioned shortage of rainfall as only cause, because that is their only source of water is observed.
The majority of interviewed farmers said that shortage of water is a problem, but the place in the landscape of the research area defines the access and as a result the focus on different sources of water. Observed is that a strip along the Voi River is permanent green and that the farmers can cultivate almost the whole year round, while the farmers on the plains and in the Small Taita Hills can harvest one times a year. The rest of the year the hills and the plain are too dry for cultivation, only some arid-resistant trees survive the drought.
Another observation is that the hills are greener than the plains. The reason is that in the hills is more rainfall (see the analysis of climate data per attitude in Appendix V). Nevertheless, that makes no big difference for good yields, because some farmers both on the plain and in the hills said that they can only harvest when the rains are good, bad rains means low yields.
Observation in sub-area Mwakingali Hills and Voi showed that this area depends on rainfall, except along the river and in Voi town. The latter has pipelines from the Taita Hills to provide water in the town. The hills are dry and bare and only the Northern foothill consists of pastureland.
The directors of the sisal estate and the orange estate are managers in a commercial company. (The director of the sisal estate is the boss of the director of the orange estate.) They set water shortage and drought as problem average at the third place. The sisal plant does not need much water, because the plant needs one rain per year. However, observed is that the sisal plants of another sisal estate near Mwatate, an area with more rainfall, are two times bigger. Therefore, when sisal gets more water the plant grows better and that means higher production. Now sufficient water is available for irrigation of the orange trees on the estate according to its director. Interesting is that

Voi Sisal Estates as commercial company has other problems than the small-scale farmers in the area, like problems with politicians and competition with other companies.

Plant diseases are a problem in all the sub-areas. Along the Voi River is a relation between plant diseases and way of irrigation according to J. Mukusya (see Collective Appendix Interviews). The farmers pump river water to their boxes with crops for flood irrigation. So, the crops stand a long time in water and that cause plant diseases. Another wrong farming practise is cultivation during the whole year, because land needs rest and this leads to infertility.
Erosion is also a high rated problem, except on the plains. The reason is that the plain have mainly overland flow erosion on low slopes. This kind of erosion is less problematic than riverbank erosion caused by floods or gully erosion and landslides in the Small Taita Hills caused by overland flow on steep slopes during the rainy season.
In the total area, damage of crops and destruction of plots by wild life and cattle is also a problem. In the Small Taita Hills, baboons living in the hills give troubles, while near the river elephants looking to water in the dry season and on the plain cattle herds grazing by other people are the problem.

It is difficult to say something about differences in perception of major problems of gender, because the number of respondents is small and the genders are disproportionably divided. Two interesting differences however are that relative more women than men mentioned water shortage as biggest problem and the majority of the women said that plant diseases are their second biggest problem, while men have more diversity as second problem. Generally, for the answer of the research question are there not big differences between the perception of men and women.

I.3 Motivation

Indicators, to make this factor operational are the “focus on water sources”, “demand for help” and “landownership”. Those indicators are discussed below in the same sequence.

I.3.1 Focus on water sources

The different focus on diverse kinds of water sources is already mentioned in paragraph I.2.1. A particular focus depends on the availability of the water sources and defines partly the motivation to use the trenching technique.
Farmers in the Small Taita Hills and on the plain focus on rainwater, because that is their only source of water for their crops. While the farmers along the Voi River focus mainly on irrigation, because that is their constant source of water during almost the whole year, while rainwater is seasonal. These people mentioned problems like high price of fuel for the pump and broken pumps. They have seen that the built sand storage dams provide more water for irrigation. Therefore, it happened some times that local farmers asked the researchers to build a sand storage dam.
Rainwater is less important for the farmers living along the river. This could give a lower motivation for trenching, but there is also an application of trenching that water from the floods in the river is used to fill the trenches. The motivation to use such a trenches system depends probably on the successfulness of using irrigation pump. When this is successful the motivation of farmers will be lower than when farmers do not have access to or problems with application of irrigation.
In the sub-areas Small Taita Hills and Plains the motivation to increase the water availability by trenching will be higher based on this indicator, because it is a method to increase the water harvesting of the only source of water.
The sisal estates focus on rainfall as source of water and water from a drilled well has been used for the processing of sisal in the sisal factory. The focus on a particular kind of water source of the

orange estate is also the drilled wells. Water from five wells has been used for irrigation of the orange trees. Because sisal does not need much water and the focus on drilled wells, the motivation of Voi Sisal Estates based on this indicator will be low.

I.3.3 Demand for help

The interviewed farmers were directly asked if the want help to solve their water problems. Before asking this questions was known that the most farmers would say; yes, but in the first weeks various people asked us for help to get more water. By asking this question the people could answer honestly and they could say what kind of help they need. The majority said that they need help. In figure I.1 is shown a diagram with answers and see table I.1 for dividing per sub-area.

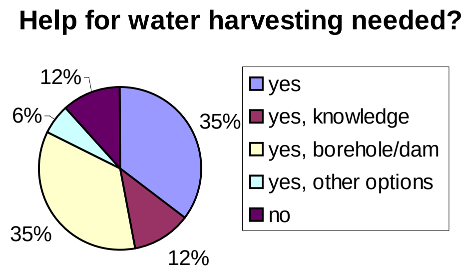

Figure I.1: Diagram with the answers on the question if they want help for water harvesting

The two directors of the estates said that they can use help for construction of boreholes and dams for irrigation of the orange trees and processing of sisal in the factory. Therefore, they need point sources of water. The prime director said that he does not need trenches, because it rains too little on the estates and sisal does not need much water.

The farmers along the river would also like to get help for harvesting more water. Tole Bula (F3) said ‘no’, because he has sufficient by his pump and Josua Msoke (F19) already has trenches. Charles Devei (F8) would like to get knowledge about how to dig trenches or terraces.

On the plain and in the hills the farmers also want help. Farmer 1 on the plain asked help to drill a boreholes, but he also want trenches. Farmer 2 has already dug a kind of trenches along his plot.

In the hills two times were mentioned specifically that farmers would like to get help with a borehole and one time help with knowledge by a woman. She has a lack of knowledge about digging of terraces and she is looking for someone who can explain that.

Men often knew the kind of help they can use. They asked help for drilling of boreholes or construction of dams. While, women said that they want help with water harvesting, but they did not mention specific help. All the women also said that they want help, while the two interviewees who said that they do not need help are men.

I.3.4 Landownership

“The communal land tenure system, which allows free grazing and accumulation of livestock, undermines the concept of land carrying capacity and promotes environmental deterioration,” wrote Rwelamira (n.d), is one of the key factors affecting sustainability in Africa. During the interviews was asked if a farmer was landowner. This gives the following results.

Voi Sisal Estates rent the estates’ land for 30 years from the local government. It also ‘owns’ the pastureland on the foothill of Mwakingali Hills, but they permit that it is used for grazing of cattle, because it lies beside Tsavo East National Park. That piece of land has a high risk for damage of

sisal according to its director. The land along the river at the Northern riverbank near Voi town is government's land and poor people live on and cultivate illegally that land.
The land, South of the river near Voi is property of a big landowner based on the fact that there a lot of farmers "rent their land from a big land owner". Southern of the river more westwards, the plots are officially community land, because there are not spread title deeds, but the people still have their own parts of land. The farmers at this locations said that they own their land. Probably, the Plains and Small Taita Hills are also divided according to that principle, but exact information is not known. There, all the farmers said that they 'own' their land. One woman said that she also rent a plot.
Above is discussed that a large part of the area consists of community land, because the government has not spread title deeds in these surroundings. Families use the agricultural plots, but everybody with cattle uses the bush and pasture. The beginning phrase of this sub-paragraph implies that people do not take care for the land when it is not theirs. The consequence is that farmers do not will to invest in their plots, like digging of trenches. This is especially applied for the people around Voi, because near the river they are tenant or illegal and the pastureland is marginal land with different users and owner. In the other area along the Voi River, the Plains and Small Taita Hills the farmers are 'owners' of their family part of the community land. As a result, that the motivation of these farmers will probably be higher.

I.4 Capacity

Indicators to define the capacity are "self-initiative of local farmers" to solve their water availability problems, "the organisation rate" and "the labour division between men and women".

I.4.1 Self-initiative of local farmers

Definition of the qualities, skills and knowledge of local farmers can be done well by looking to what they do to solve their water problems by themselves. In figure I.2 and table I.1 are shown respectively the used water harvesting techniques in the total area and per sub-area.
In Voi town and Mwakingali Hills was observed that people do not use water harvesting techniques. It is only questionable if the cause is a lack of capacity or motivation in this sub-area, because the farmers live there illegally or used someone else land for grazing cattle. That results in a low motivation to use water harvesting techniques, because a farmer is not sure that he or she can harvest.

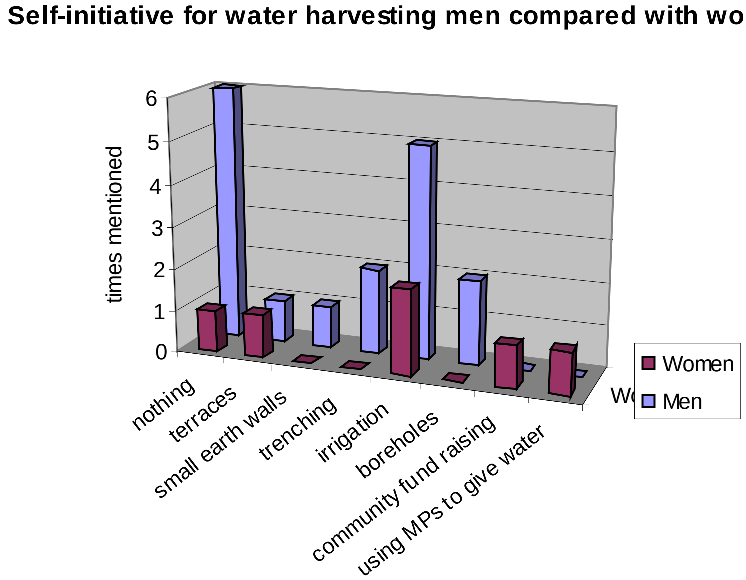

Figure I.2: Mentioned self-initiative for water harvesting of men and women.

Voi Sisal Estates have five boreholes, three along the Voi River and two in the Taita Hills. These boreholes provide water to the sisal factory and the orange trees. They have tried to found more good locations for boreholes, because they drilled holes along the river, but many of them were not suitable.
All farmers along the Voi River (try to) use irrigation pump for water harvesting from the river. Those pumps were bought or given conditionally by World Vision. This organisation also told that the farmers have to dig a kind of trenches, but they do not know how to dig according to Charles Devei (F8). He said that when someone explain them how to dig trenches, the farmers can help each other with trenching. Lack of knowledge is a big problem. This is also told by Paul Mwadime (F7), who already uses terraces.
Farmers living at the plains apply some water harvesting techniques. One farmer let dig two trenches and earth walls, while two others dig respectively earth walls and terraces with as purpose erosion prevention, but those techniques also increase water storage. It is observed that farmers do not use many water harvesting techniques. Many plots look flat and bare, without any sign about using of particular techniques, while the measured slope is 2-4%. In that case, some small techniques like earth walls are minimal to prevent erosion and store water.
Observations show that in general the Taita people in the Small Taita Hills are more active in use of water harvesting and especially erosion prevention techniques. They have more knowledge of those issues than on the plain and along the Voi River. The majority use terraces of a kind of trenches for water storage and erosion control. This is in contrast with the answers of the interviewed farmers, which are not very active with water harvesting techniques. One interviewee uses terraces and one community in the Small Taita Hills tried to get a pipeline from the (big) Taita Hills, but it failed by politics.

Generally, there were little differences between the answers of men and women. That means that they think relatively the same about farming and especially about water storage. In figure I.2 is shown a diagram with the mentioned water harvesting techniques of men compared with women. However, it shows that there are not very big differences. Men are more active in boreholes and trenches than women, while relative more men do nothing. It is difficult to say the influence on the capacity of families and communities.

I.4.2 Organisation rate

The organisation rate of a sub-area defines the potential labour force for digging trenches. A well-organised community can help each other, while an individual farmer has to dig everything by himself.
44% of the small-scale farmers is organised in the research area. The estates directors said that they are not organised, because they are the only sisal estate and orange estate in the surroundings. In addition, it is a commercial company, which cannot compare with the small-scale farmers. The estates employs together about 700 people.
The sub-area with Voi town is probably organised badly, because in Voi town various tribes live in a heap and Voi has got the character of a town and that means many individuals.
Along the river, the organisation rate is higher. A women self-help group operate Southern of the river near Voi. They have a collective plot and they use its yield for renting and using of a pump for irrigation together. Besides this, they help each other with farming. The other organised farmers also live Southern of the river, but more westwards. World Vision organised the community in the village Kalambe to work together in farming.
The organisation rate on the plain is very low. All the farmers said that they do not cooperate with other farmers. They cultivate crops with their family. According to the farmers 1 and 2, labourers has to employ for application of bigger techniques, like trenches. For that money is needed.

Half of the farmers in the Small Taita Hills said that they are organised with the community to help each other. In the Small Taita Hills are probably more community-structures than on the plain. One woman said that there is a community project to make terraces on each plots. The other farmers cultivate crops and apply water-harvesting techniques with their family.

I.4.3 Labour division between men and women

A cultural factor influencing the labour capacity of farmers is the cultural accepted labour division between men and women. The majority of the respondents through the whole research area said that there is no or almost no different in farming work between men and women, except in the sisal factory (see table I.2). There the women put the sisal over lines to dry, while men cut and process the sisal leafs and packs the sisal in sacks. That is confirmed by observations in the factory and on the estates. Differences mentioned by interviewees are that women do also domestic work like cooking and washing. Men do the heavy work like prevention of diseases and inoculation of cattle. In practice, it often means that men spent more time on the plots, while women spent part of the day in the house for domestic work. Leah Mcharo in the sub-area Voi River however told that men work in the towns or are lazy and that women do more work. Observation shows that cattle raising is done by boys and men. Only, one time a girl was seen with cattle.
Generally, women and men do the same work in farming and especially in digging of water harvesting and erosion prevention techniques. That means a bigger labour force per family and per community.

I.4.4 Financial capacity

There is a different is extent of poverty caused by amount of family land, extern jobs and yields, but generally the people in the rural area little money. Therefore, people do not mainly have much money for expensive measures, employing of labourer, expensive tools and expensive sources of water, like drilled wells.
It is important for sufficient capacity of local farmers that they can lent of buy for little money tools for digging of trenches, because this can be a bottleneck for the capacity of local farmers.

I.5 General information

In this paragraph, two interested subjects are discussed, but those do not match exactly with the sub-questions 2a, 2b and 2c.

I.5.1 Projects in research area

In the area were some projects for water harvesting (see table I.2), but the results were moderate. Mentioned projects are construction of dams and trenching (by WCT) and an irrigation pump project in de Voi River, construction of boreholes at the plain, water pipeline and seminars and in the Small Taita Hills.
The people were positive about the sand storage dams, because they provide irrigation water. World Vision gave the farmers along the river irrigation pumps per some farmers and had organised the community for cooperation of farmers. Federal Department of Agriculture (FDA) has given some seminars about water harvesting and other farming practises, but the effects are unclear. The borehole and pipeline projects failed, because of siltation of the borehole and lack of money for the pipeline.

I.5.2 How local people handle pipelines with water

During the field trips, some things were observed about use of water by local people. Various pipelines lie from the Taita Hills to Voi, Mombasa and the Small Taita Hills. The latter consists of

many smaller pipelines to different locations with houses. Those pipelines lie bare and are broken or the connection is bad at some places, so that much water is lost, but the people do nothing to repair it. In Voi town the same happens, there sagged pipelines also lie bare caused by gully erosion.
During the field study the next paragraph in a Kenyan newspaper was read:

Kenyan newspaper 'Standard' of Friday 21st of July, 2006

Loss deplored
"More than half of piped water supplied to Mombasa Town is lost due to leakage and illegal connections. The Coast Water Service Board CEO, Eng Iddi Mwasina, said over half of 71,000 cubic litres of water meant for Mombasa was wasted daily. Mwasina made the remark at his office yesterday when speaking to Supreme Council of Kenya Muslims Mombasa branch officials, who wanted to know why there was persistent shortage of water in the town."

Taita Hills is one of three catchment areas of water for Mombasa (population: 1 million) according to local people. In the area, some pipelines lie in the ground through the research area, but the pipes are bare at some places and observation shows that water streams outside the pipes. That agrees with the paragraph of the newspaper.
During the interviews and observations in the field was gotten the impression that people mainly take measures for water harvesting when they get profit from it short-term, but that they do nothing to prevent land degradation at long-term.
All those things do not give the impression that the local people use the scarce water economically and that they really take care about the available water both in the current situation and in the future.

I.5.3 Cultivated crops by interviewees

Ten farmers were asked what kind of crops they cultivate. In table I.3, the output is shown divided in tree, scrubs and plant crops. Farmers cultivate mostly plant crops. Everybody cultivate maize, the basic food in the area. Cassava and cow peas are also much cultivated crops. People do not use many trees and those are together with scrubs the permanent vegetation on a plot, what is important for erosion prevention and water storage.

Table I.3: The number of mentioned crops during the interviews

Trees	Mentioned number	**Plants**	Mentioned number
Fruit trees	3	Maize	10
Papayas	3	Local crops	5
Bananas	2	Beans	4
Coconuts	1	Tomatoes	4
Shrubs		Peppers	3
Cassava	8	Pumpkins	1
Cow peas	6	Water melons	1
Green peas	2	Sweet potatoes	1
Pigeon peas	1	Cabbage	1
		Kale	1
		Spinach	1
		Sisal	1

Appendix II Multi-Criteria Analysis

II.1 Scoring of indicators

The principles with matching criteria, indicators and verifiers are discussed in paragraph 5.2. Verifiers are presented and analysed in the next paragraph. The scoring of the indicators is discussed in this paragraph. The scores per indicator are also shown in table II.1. Every criterion can score minimal one point and maximal three points. The same apply for the criteria consisting of two or three indicators. So, these indicators can score respectively maximal 1 and 1.5 point.

Table II.1: Definition of scoring per indicator.

Criteria		Indicator		Verifier	Scores
C3.1	Stability of soil	1	Physical behaviour of soil under wet condition	Classification during soil test	Very soft (1.00) Soft (2.00) Firm (3.00)
C4.1	Will to participate	1	Estimation of will to participate	Results of social-economical analysis	Low (1.00) Moderate (3.00) High (3.00)
C1.1	Effectiveness for local water storage	1	Amount of rainfall and overland flow	Rainfall per altitude and water flows	Low (0.5) Moderate (1.00) High (1.50)
		2	Infiltration capacity	Data from analysis infiltration capacity	Low (0.50) Moderate (1.00) High (1.50)
C1.2	Effectiveness for erosion prevention	1	Erosion risk	Erosion risk per location	Low (0.50) Below moderate (1.00) Moderate (1.50) Above moderate (2.00) High (2.50) Very high (3.00)
C5.1	Suitability of current land use	1	Type of land use	Data about land use	Urban area (1.00) Bush and pasture (2.00) Agriculture/bush (2.50) Agriculture (3.00)

II.1.1 Explanation

C2.1.1 The ‘physical behaviour of soil under wet condition’ of the 40 soil samples was classified in very soft, soft and firm. The most ideal soil is firm and the least ideal soil is very soft, therefore, those get respectively 3.00 and 1.00 point. Soft soil is moderate ideal and it gets 2.00 point.

C3.1.1 Estimation of the will to participate is divided in three classes: low, moderate and high, because this is the minimal number and the estimations are rough, so more classes was too detailed. The three points were divided equally in low 1.00, moderate 2.00 and high 3.00 point.

C1.1.1 The amount of rainfall is divided in three occurred amounts of rainfall in the area: low (250-500 mm, below 763 m), moderate (480-700 mm, between 763 and 915) and high (600-800 mm, between 915 m and 1220 m). The altitudes of the agricultural zones are adapted a little bit to the contour lines of the used map. Estimations are done based on the ways of water from the hills to the river. Rainfall creates better infiltration water than overland flow, because rainfall is without horizontal velocity,

while overland flow can have a high horizontal velocity. The latter decrease the amount of water available for infiltration.
Therefore, rainfall gives relatively more available water than overland flow and so, it is valued double. The amount of available water is classified according to the next calculation

	Hill	**1.17**	**Foothill**	**1.00**	**Plain**	**0.83**
Rainfall	Much	1.00	Moderate	0.67	Little	0.33
Overland flow	Little	0.17	Moderate	0.33	Much	0.50

C1.1.2 The infiltration capacity is analysed and divided in three classes: low (0.33), moderate (0.67) and high (1.00). Because of the rough determining of the infiltration capacity is chosen fore three classes.

C1.2.1 The six classes of erosion risk were taken from Kort (2006) and the three points are divided through six.

C4.1.1 The types of land use are roughly divided in three classes from unsuited to suited: urban (1.00), pasture and bush (2.00) and agriculture (3.00). The class agriculture/bush is a combination of the last two, therefore this one is scored with 2.50.

II.2 Data gathering

II.2.1 Map physical behaviour under wet conditions

The way of determining the physical behaviour is done, like described in Kort (2006; paragraph 4.1.2). The soils of 40 measurement points through the research area are classified as very soft, soft or firm. A map is made by drawing the borders between the points of with different physical behaviour to give an indication through the area. Figure II.1 shows the map. The different colours mean, white: firm, yellow: soft, red: very soft,

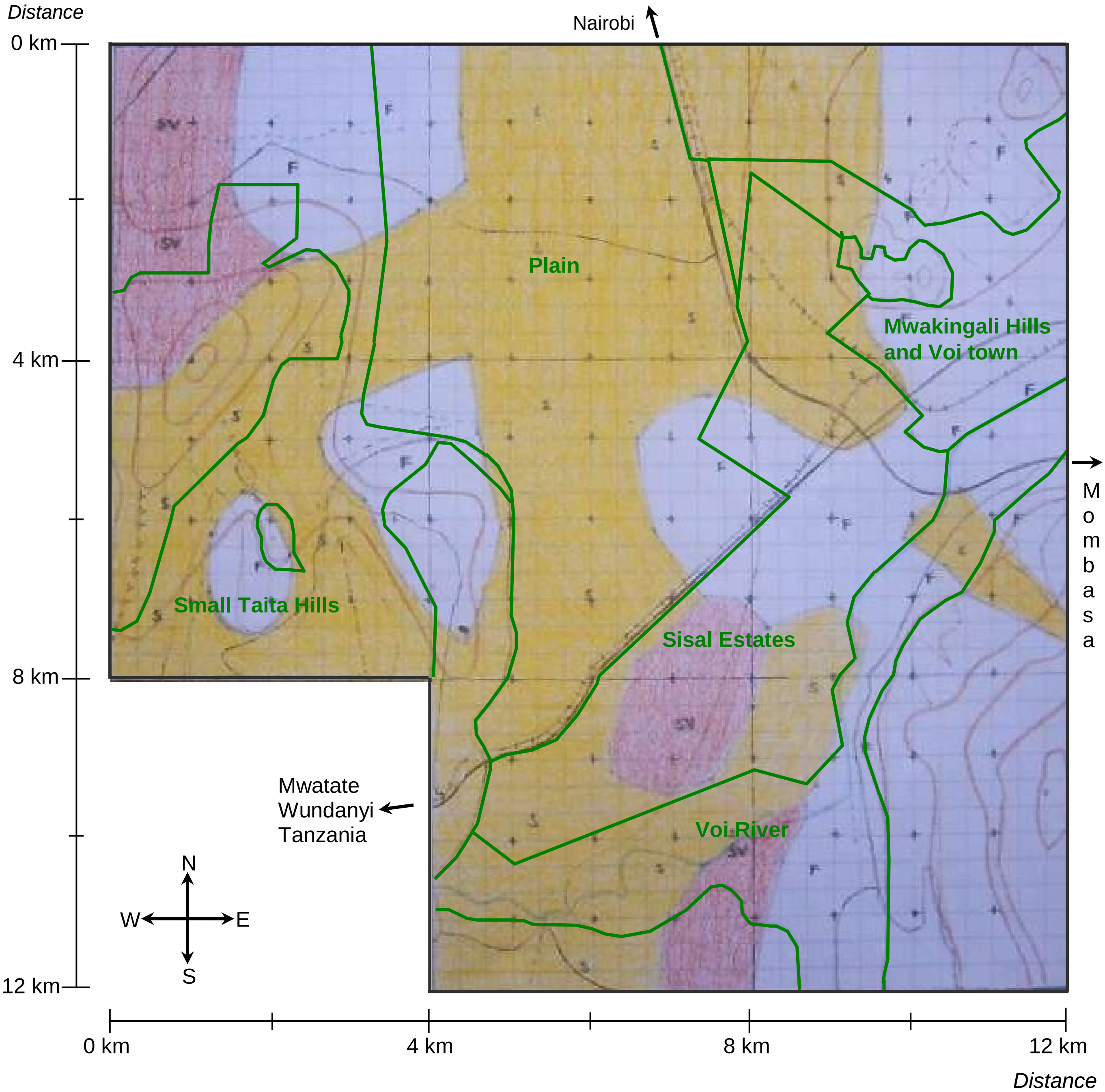

Figure II.1: Map physical behaviour of soil under wet conditions.

II.2.2 Map rainfall based on agricultural zones

Based on the different agricultural zones, described in Appendix V the areas between the contour lines are classified. The contour lines of the map correspond reasonably with the altitudes, which border the agricultural zones. A rainfall map of the Western basin is shown in figure II.2 with the rainfall in mm per year per altitude. The non-squared numbers presented at the matching altitude.

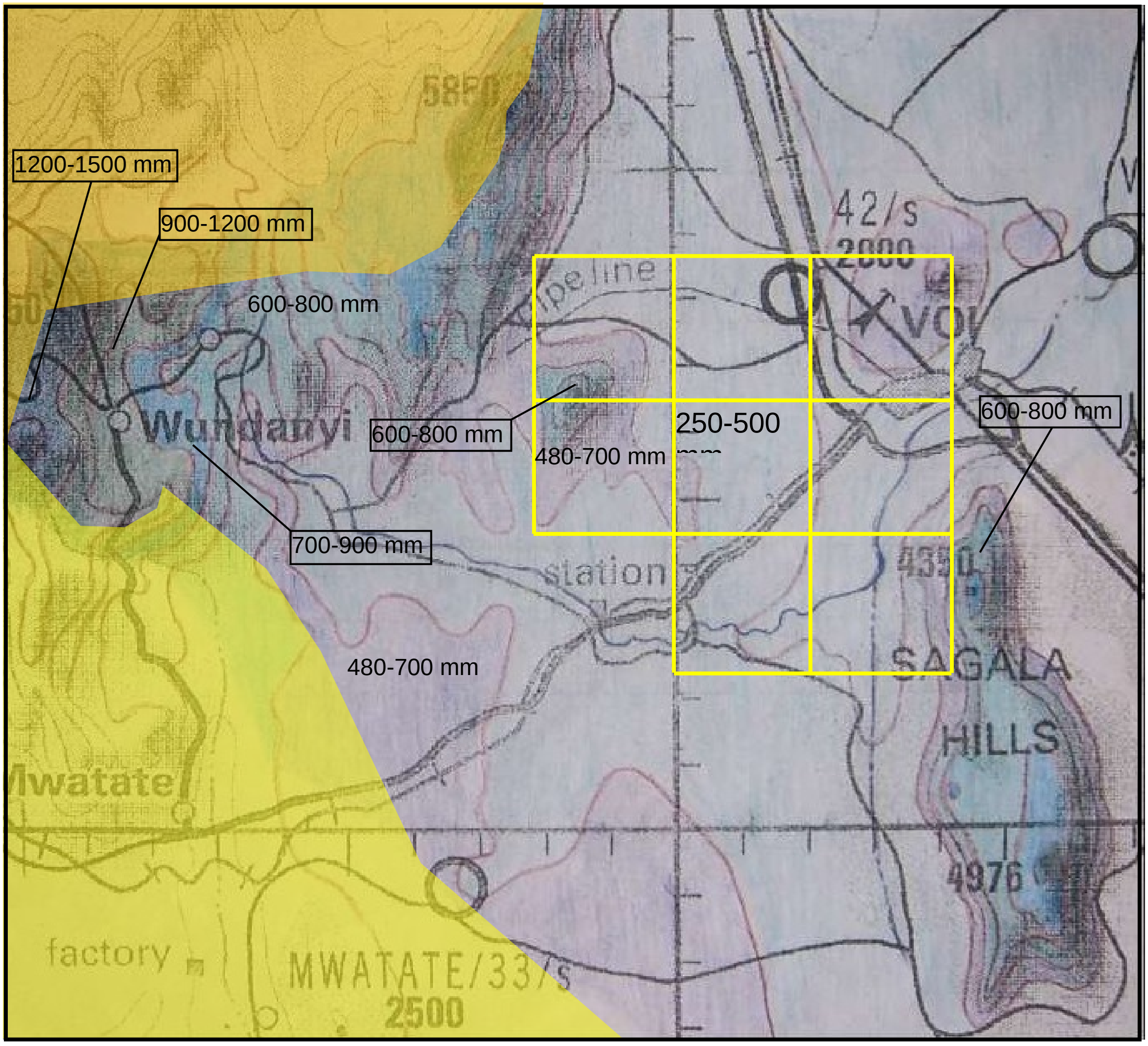

Figure II.2: Map with rainfall per altitude in mm per year.

II.2.3 Map erosion risk

Map with erosion risk taken over from Kort (2006). The map with six different classes is shown in figure II.3. The colours mean light yellow: low risk, yellow: below moderate, light orange: moderate, violet: above moderate, red: high risk and grey: very high.

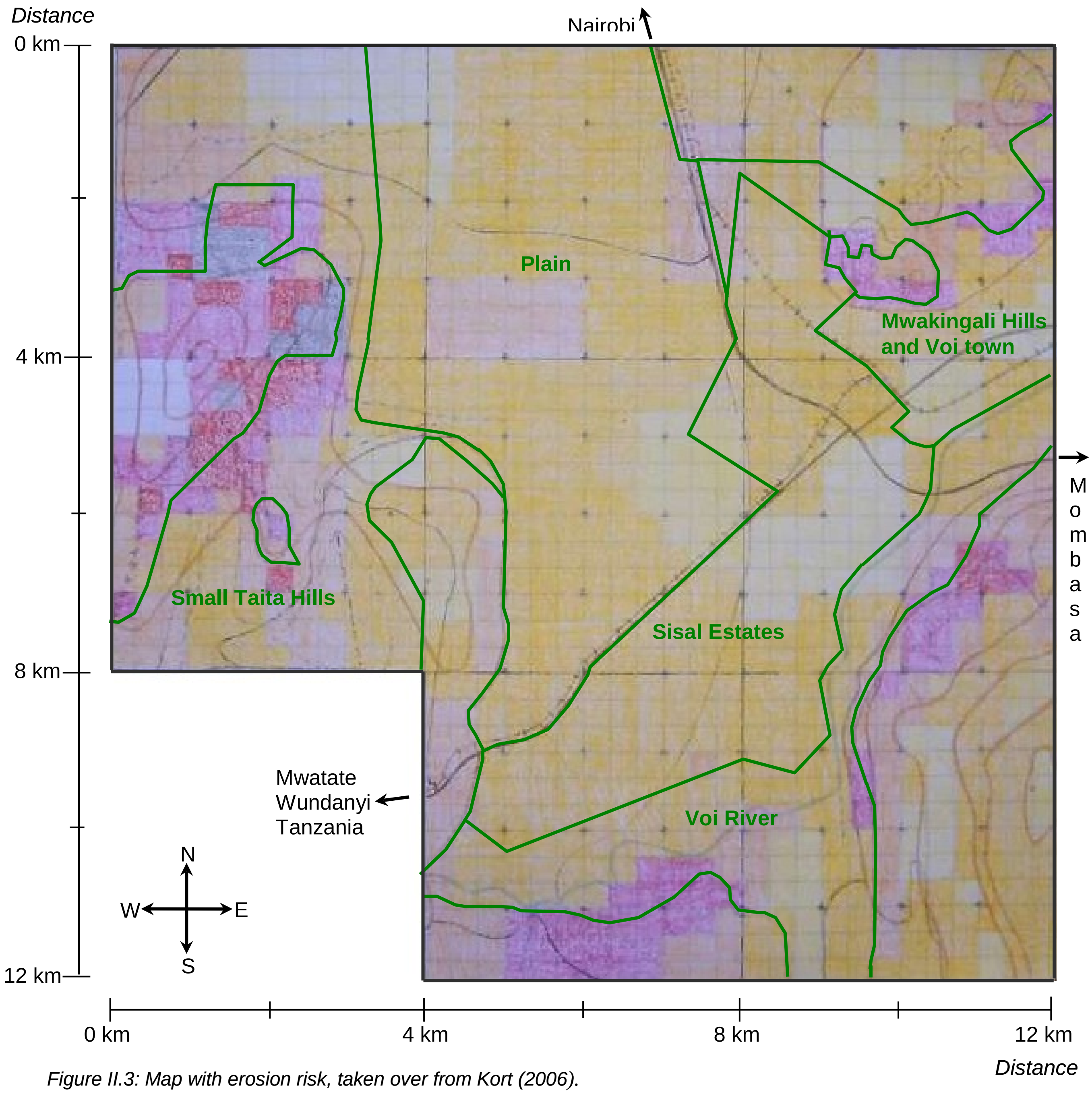

Figure II.3: Map with erosion risk, taken over from Kort (2006).

II.2.4 Map current land use

In figure II.4, the land use map is shown. Detailed versions of the land use maps and extensive legend are presented in Collective Appendix Maps.

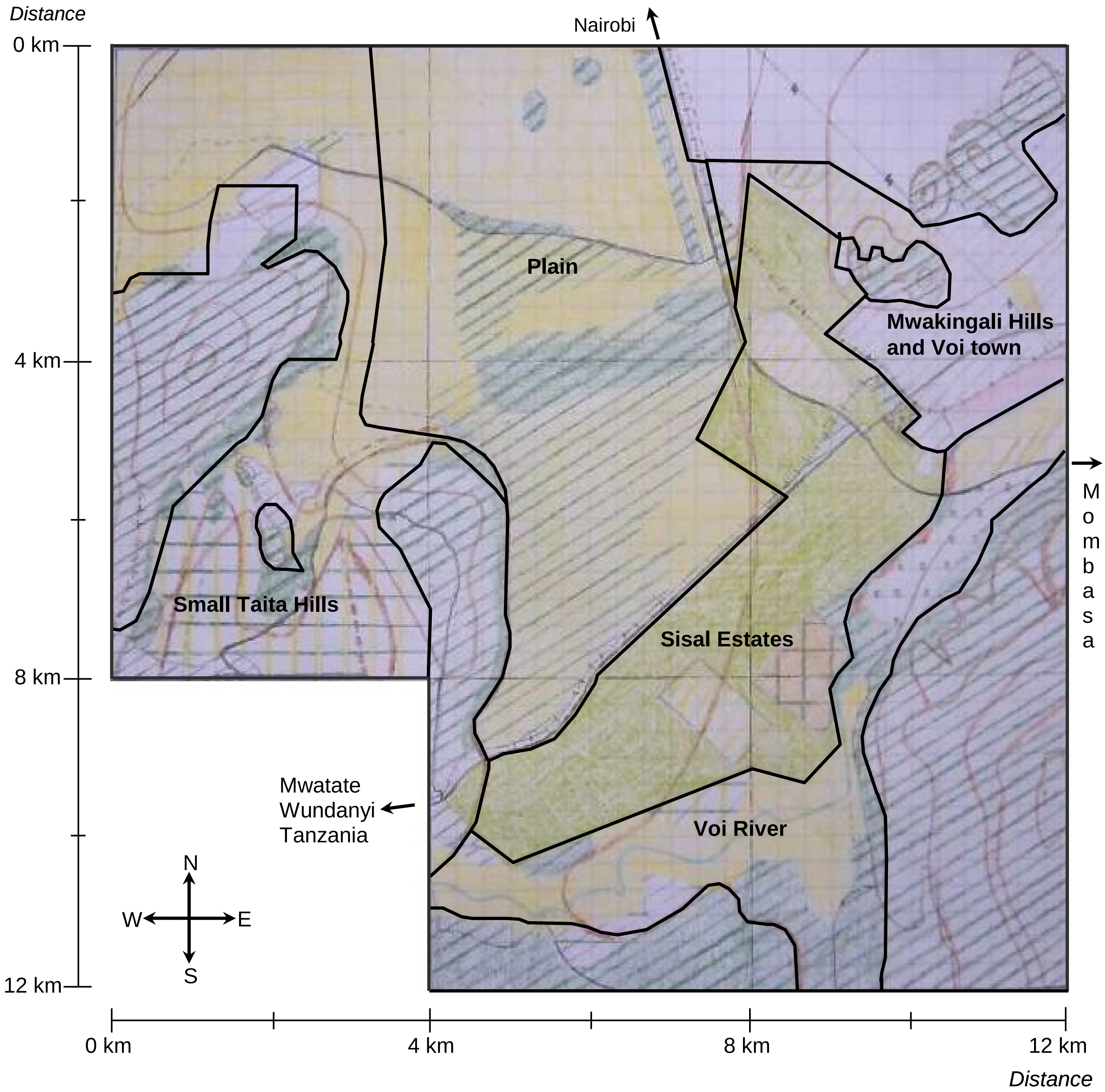

Figure II.4: Map with land use.

II.2.5 Estimation of infiltration capacity

Infiltration capacity depends on many local factors, which can be different per location, like discussed in paragraph 6.1. Therefore, it was not possible to use the measured infiltration rates as ‘truth’. Two other factors, tillage conditions and soil samples were used to estimate the infiltration capacity better. The infiltration rate was measured at 40 measurement points, meanwhile were the tillage conditions determined and soil samples are taken for soil analysis.
As infiltration test was used a bottle without a bottom. The process bottle was put down on the ground and the bottle was filled with a water layer of about 15 mm thick. Meanwhile, the time recording was started to record the time the water had needed for infiltrating into the ground. The

thickness of the water layer and the recorded time were exactly calculated to 15 mm for estimation of infiltration velocity. The infiltration can be compared with overland flow and heavy rain showers, because the soil had to process a lot of water in one time and that is the same during these events. The infiltration rates were classified per class of 50 seconds with matching scores: 0-50 (3.0), 51-100 (2.5), 101-150 (2.0), 151-200 (1.5), 201-250 (1.0) and > 250 (0.5). Hereby is noted that the infiltration rates were not compared with extern rates, but they were only compared by each other, because there were not suitable rates of comparing methods.
The tillage conditions are the extent of compaction and sealing of the surface soil. This factor is important because crusts of surface soil formed during infiltration reduce the infiltration capacity. Infiltration points were estimated based on comparing of observations and the definitions for tillage conditions of Morgan (1986). Those are *'no t'*, *'t_1'* ("Slightly unfavourable physical conditions. The soil has a tendency to compact and seal at the surface and a good tilth is not easily obtained") and *'t_2'* ("Unfavourable physical conditions. Compaction and sealing of the surface soil are more severe. A hard crust forms when the bare soil is exposed to rain and sun (…)"). 'No t' was assessed with 3 points, 't_1' with 2 points and 't_2' with 1 point.
Soil texture also influences the infiltration capacity. Morgan (1986) said "generally, coarse textured soils such as sands and sandy loams have higher infiltration rates then clay soils because of the larger spaces between the soil particles". So, sand has a higher infiltration rate than silt, because sand consists of larger soil particles than silt. Because of the local situation is often more complex than this general rule, soil texture was used, but with lower rating. Therefore, the sandy soils were assessed with 1 point and the silty soils with 0.5 point.
In table II.2 the scoring per factor per measurement point and the total score for the infiltration capacity ranked per sub-area are presented. The classes are:

- Scoring 2 and 3 low capacity red
- Scoring 4 and 5 moderate capacity orange
- Scoring 6 and 7 high capacity yellow
-

Table II.2: Analysis of infiltration capacity with scoring and ranked per sub-area.

Measurement point	Infiltration		Tillage conditions		Soil texture		Total	
	Time (sec)	*Score*	Assessment	*Score*	*Soil name*	*Score*	*Total score*	*Sub-area*
I28	237	1.00	t2	1	sandy SILT	0.5	3	PL
I36	539	0.50	-	3	organic sandy SILT	0.5	4	PL
I37	184	1.50	t1	2	organic sandy SILT	0.5	4	PL
I38	191	1.50	t1	2	sandy SILT	0.5	4	PL
I30	43	3.00	t2	1	sandy SILT	0.5	5	PL
I31	99	2.50	t1	2	organic sandy SILT	0.5	5	PL
I35	189	1.50	t1	2	organic very silty SAND	1	5	PL
I32	177	1.50	-	3	sandy SILT	0.5	5	PL
I19	351	0.50	t2	1	organic sandy SILT	0.5	2	SE
I20	230	1.00	t2	1	organic sandy SILT	0.5	3	SE
I8	133	2.00	t1	2	organic very silty SAND	1	5	SE
I14	155	1.50	-	3	organic very silty SAND	1	6	SE
I23	151	1.50	t2	1	very silty SAND	1	4	TH
I25	143	2.00	t2	1	organic very silty SAND	1	4	TH
I26	145	2.00	t2	1	organic very silty SAND	1	4	TH
I27	99	2.50	-	3	organic sandy SILT	0.5	6	TH
I22	151	1.50	t1	2	very silty SAND	1	5	TH
I29	37	3.00	t1	2	sandy SILT	0.5	6	TH
I21	106	2.00	t1	2	organic very silty SAND	1	5	TH
I24	138	2.00	-	3	organic silty SAND	1	6	TH
I34	45	3.00	-	3	organic sandy SILT	0.5	7	TH
I33	73	2.50	-	3	organic silty SAND	1	7	TH
I10	220	1.00	t2	1	sandy SILT	0.5	3	VR
I18	250	0.50	t2	1	organic sandy SILT	0.5	2	VR
I7	90	2.50	t2	1	sandy SILT	0.5	4	VR
I11 eroded	165	1.50	t2	1	organic very silty SAND	1	4	VR
I6	127	2.00	t2	1	organic very silty SAND	1	4	VR
I15	136	2.00	-	3	organic sandy SILT	0.5	6	VR
I4	43	3.00	t1	2	organic sandy SILT	0.5	6	VR
I5	50	3.00	t1	2	organic sandy SILT	0.5	6	VR
I16	59	3.00	-	3	organic sandy SILT	0.5	7	VR
I17	57	2.50	-	3	organic silty SAND	1	7	VR
I39	52	2.50	-	3	very silty SAND	1	7	VR
I40	55	2.50	-	3	very silty SAND	1	7	VR
I2	85	2.50	t2	1	very silty SAND	1	5	VT
I3	30	3.00	t2	1	very silty SAND	1	5	VT
I1	60	2.50	t1	2	organic sandy SILT	0.5	5	VT
I12	133	2.00	-	3	organic very silty SAND	1	6	VT
I13	88	2.50	-	3	organic very silty SAND	1	7	VT

II.3 Analysis per sub-areas

Within the sub-areas some indicators can consist of different classes. To get an impression of these indicators in a sub-area an average was calculated by multiplying the surface of a particular class with the score of the class (see for scores table II.1). The calculated average score per sub-area is rounded for the score in the calculation. Some indicators are not well represented by this manner, therefore per sub-area the scores are discussed at application and representative.

II.3.1 Mwakingali Hills and Voi town

Table II.3: Scoring per indicator of Mwakingali Hills and Voi town.

Indicator		Assessment	Comments	Points
C2.1.1	Physical behaviour soil under wet condition	Soft: 30% Firm: 70%	Average is firm (2.70 point)	3.00
C3.1.1	Estimation of will to participate	Low	See paragraph 5.3	1.00
C1.1.1	Amount of rainfall and overland flow	Moderate		1.00
C1.1.2	Infiltration capacity	Moderate	(Scale infiltration capacity: 5.40)	1.00
C1.2.1	Erosion risk	Low: 30% Below moderate: 50% Moderate: 10% Above moderate: 10%	Average risk is below moderate (1.00 point)	1.00
C4.1.1	Type of land use	Agriculture: 10% Pasture: 20% Urban area: 70%	Majority is urban area, average is 1.4 point	1.00

<u>Analysis and discussion</u>

C2.1.1 The eastern and biggest part consists of firm soil, while the western part consists of soft soil

C4.1.1 The estimated will to participation is low.

C1.1.1 About 30% of the area is higher than 763 m, while the other 70% lies below the 763 m above sea level, but the foothill is large and almost lies up to the river. Therefore was chosen for moderate.

C1.1.2 The average infiltration capacity is the highest in the research area. In the western part is the infiltration capacity classified as moderate, while in the eastern part as high.

C1.2.1 The erosion risk at the southern hill foot at higher level is moderate to above moderate. For the whole hill feet apply that the erosion risk decrease with the lower steepness of the slopes.

C4.1.1 In this sub-area Voi town is situated, the biggest town in the surroundings. Because of that, about 70% of the area is urban area. The other parts are agriculture along the river and pasture in the northern part of Mwakingali Hills.

II.3.2 Sisal Estates

Table II.4: Scoring per indicator of Sisal Estates.

Indicator		Assessment	Comments	Points
C2.1.1	Physical behaviour soil under wet condition	Soft: 30% Firm: 70%	Average is firm (2.70 point)	3.00
C3.1.1	Estimation of will to participate	Low	See paragraph 5.3	1.00
C1.1.1	Amount of rainfall and overland flow	Low		0.83
C1.1.2	Infiltration capacity	Moderate	(Scale infiltration capacity: 5.40)	1.00
C1.2.1	Erosion risk	Low: 30% Below moderate: 50% Moderate: 10% Above moderate: 10%	Average risk is below moderate (1.00 point)	1.00
C4.1.1	Type of land use	Agriculture: 10% Pasture: 20% Urban area: 70%	Majority is urban area, average is 1.4 point	1.00

Analysis and discussion

C2.1.1 The eastern parts of the sisal estate consists of soft and firm soils, while the physical behaviour of soil under wet conditions of the western part are soft and very soft. The orange estate lies on soft soil

C3.1.1 In paragraph 5.2 was discussed that the will to participate of Voi Sisal estate is estimated as low.

C1.1.1 99% of the total area lies below 763 m above sea level, but there is much overland flow from the Taita Hills and Mwakingali Hills.

C1.1.2 The rounded average score of the infiltration capacity is 4 and that score is classified as moderate. The soils of the western part have low capacity and the eastern soils have moderate and high infiltration capacity.

C1.2.1 The estates area has an erosion risk of low to below moderate. The low classified parts lie in the eastern parts of the sisal estate.

C4.1.1 The land use of the estates is total agriculture with only some office and factory buildings.

II.3.3 Voi River

Table II.5: Scoring per indicator of Voi River.

Indicator		Assessment	Comments	Points
C2.1.1	Physical behaviour soil under wet condition	Very soft: 20%, soft: 30%, firm: 50%	Average is soft (2.30 point)	2.00
C3.1.1	Estimation of will to participate	Moderate	See paragraph 5.3	2.00
C1.1.1	Amount of rainfall and overland flow	Low		0.83
C1.1.2	Infiltration capacity	Moderate	(Scale infiltration capacity: 4.88)	1.00
C1.2.1	Erosion risk	Low: 10% Below moderate: 60%, Moderate: 20% Above moderate: 10%	Average risk is below moderate (1.15 point)	1.00
C4.1.1	Type of land use	Agriculture: 60%, Bush and pasture: 35%, Urban area: 5%	Majority is agriculture, but average is 2.45 point	3.00

<u>Analysis and discussion</u>

C2.1.1 The ‘physical behaviour soil under wet conditions’ is diverse in this sub-area. From East to West it consists of firm, soft, firm, very soft and soft soils.

C3.1.1 The will to participate of the farmers along the Voi River is estimated generally as moderate. There could be a difference between the eastern (tenants) and western (landowners) part of the sub-area.

C1.1.1 This whole sub-area lies below 763 m above sea level. Therefore, it is classified as area with low rainfall. In this area is however little difference in amount of overland flow between foothills and plain. Because of this, the amount of the plain is used for whole area.

C1.1.2 The infiltration capacity is average moderate, but it consist a wide range from low to high. Some are low and moderate and these are mostly situated in the part between the river and the hills southerly of Voi. The majority is high is lies westerly of the Sagala Hills.

C1.2.1 A majority of 60% of the area has erosion risk below moderate and that is mainly in the area northerly of the river. The erosion risk is higher at the hill feet of the Sagala Hills and a part westerly of the hills (see paragraph II.2.3).

C4.1.1 At the most places along the Voi River, both sides of the river have a strip of 200-300 m agriculture. At the locations H9 to F11 the northern side consist a strip bush between the estates and the river. The people live concentrated in Kalambe and two other urban locations. Because of the strips very suited strips agriculture along the river and the score 2.00 is not representative for those; the score is increased to 3.00.

II.3.4 Plains

Table II.6: Scoring per indicator of Plains.

Indicator		Assessment	Comments	Points
C2.1.1	Physical behaviour soil under wet condition	Soft: 80% Firm 20%	Average is soft (2.20 point)	2.00
C3.1.1	Estimation of will to participate	Moderate	See paragraph 5.3	2.00
C1.1.1	Amount of rainfall and overland flow	Low		0.83
C1.1.2	Infiltration capacity	Moderate	(Scale infiltration capacity: 4.19)	1.00
C1.2.1	Erosion risk	Low: 10% Below moderate: 80%, Moderate: 10%	Average risk is below moderate (1.00 point)	1.00
C4.1.1	Type of land use	Agriculture: 50%, Agriculture/bush: 40% Bush: 10%	Majority is agriculture, average is 2.70 point	3.00

<u>Analysis and discussion</u>

C2.1.1 The physical behaviour of soil under wet condition is mainly soft, while about 20% is firm lying in the border areas.

C3.1.1 The will to participate of the farmers on the plains is estimated as moderate.

C1.1.1 The whole plain is situated under 763 m above sea level and the plain lies between the Taita Hills and the Voi River. Because of that, there is a lot of overland flow.

C1.1.2 The average infiltration capacity is classified as moderate and almost the whole area has a moderate infiltration capacity.

C1.2.1 Big majority of the area has an erosion risk classified as below moderate. Two locations have a moderate risk, while also two locations at the borders of the sub-area have a low risk.

C4.1.1 Agriculture is the biggest land use on the plain. Some parts are bush, while about 40% of the surface has a varied land use of bush and agriculture.

II.3.5 Small Taita Hills

Table II.7: Scoring per indicator of Small Taita Hills.

Indicator		Assessment	Comments	Points
C2.1.1	Physical behaviour soil under wet condition	Very soft: 25% Soft 65% Firm: 10%	Average is soft (1.85 point)	2.00
C3.1.1	Estimation of will to participate	High	See paragraph 4.3	3.00
C1.1.1	Amount of rainfall and overland flow	Moderate		1.00
C1.1.2	Infiltration capacity	Moderate	(Scale infiltration capacity: 5.15)	1.00
C1.2.1	Erosion risk	Low: 10% Below moderate: 40%, Moderate: 30% Above moderate: 15%, High: 5%	Average risk moderate (1.33 point)	1.50
C4.1.1	Type of land use	Agriculture: 60%, Agriculture/bush: 30%, Bush: 5% Urban area: 5%	Majority is agriculture, average is 2.70 point	3.00

<u>Analysis and discussion</u>

C2.1.1 The northern parts of Small Taita Hills consist of both very soft and firm soils. The soil of the middle part is soft and the southern parts consist of soft and firm soils.

C4.1.1 In this area, the will to participate is estimated as high.

C1.1.1 About 35% of the area lies above 763 m and the rest lies below this altitude, but a large part of the hills lies higher and there is the amount of rainfall higher. The foothills take up about 65% of the surface and the rest is plain. The overland flow from the various foothills streams over the plains in the direction of the river. Therefore, moderate represents this best.

C1.1.2 The infiltration capacity is average classified as moderate. The sub-area consists of soils with moderate and high capacity. The northern soils have mainly a high infiltration capacity, while the southern soil have a mixed of moderate and high.

C1.2.1 The average erosion risk is moderate, but there the risk of the hill feet at higher altitude is from above moderate to high in the sub-area and it can be very high at the hill outside. The erosion risk decrease when the slopes are less steep changing into the plains. There is the risk low or below moderate.

C4.1.1 The major land use is agriculture. A part of 30% of the area is mixed agriculture and bush and a small part is urban area.

Appendix III Data dam locations

Table III.1: Data of the six suitable dam locations.

Criteria		Location 1	Location 2[3]	Location 3	Location 4	Location 5	Location 6
1		Basement: 40 m long with 4 rapids, 75 m farther another basement	Basement from East to West side; natural barrier with rapid; length 30 m	2 basements near each other; northern one is most suitable	Basement with 3 small rapids	Basement with 4 rapids, most upstream one is most equal	Basement with 1 rapid
2		11%	4%	2%	Varies: 1% - 4%	Between 1e and 4e rapid: 20%, in front of 1e: 8%	5%
3		Both sides: 3 m high	Both sides: varies 2 m - 3 m high	Both sides: varies 2.5 m - 3.5 m high	Both sides: 1.5 m - 2 m high	Western side: 3 m high, eastern side: 1.5 m high	Northern side: 4.5 m high, southern side; 2.5 high
4		Main road about 250 m	Main road about 700 m	Nearest road estimated at 150 m	Road near orange estate	Some roads to farms	Some roads to farms
5		Brown-grey clayey sand	Dark grey clayey sand	Red clayey sand	Red clayey sand	Red clayey sand	Grey brown clayey sand
6		Absent	Lays in riverbank	Lays in riverbank	Lays in riverbank	Lays in riverbank	Lays in riverbank
7	**a**	30 m	12 m	25 m	12 m	14 m	11 m
	b	75 m	About 150 m	>100 m	> 50 m	> 50 m	>50 m
	c	About 1 m	About 1 m	About 1 m	About 1 m	About 1 m	About 1 m
8		Absent	Absent	Absent	Wells of orange estate	Absent	Absent
9	**a**	Rock for chipping stones	Rock in river for chipping stones	Unnoticed	Rock in river for chipping stones	Unnoticed	200 m from sand storage dam, same sources
	b	Western direction clean sand	Clean sand from river walls upstream	Clean sand from river walls	Clean sand downstream	Clean sand from river walls upstream	Idem
	c	Water only in Voi River	Water only in Voi River	Water in wells of orange estate	Wells of orange estate	Wells of orange estate	Idem
10	**a**	Farms unobserved, only some houses	No indication about landownership	No indication about landownership	Western side: orange estate+ some farms	Western side: some farms, eastern side more farms	Both sides: some farms,
	b	Western side: bush and sisal estate, eastern side bush and pasture	Eastern side: bush and sisal estate, western side: agriculture and pasture	Western side: bush and sisal estate, eastern side: bush	Western side: orange estate + bush + agriculture, eastern side: bush.	Both sides: agriculture	Western side: agriculture + bush, eastern side: agriculture
11		Moderate trees, small trees, plants and grass on river walls	Moderate trees, small trees, plants and grass on river walls	Some high trees, small trees, plants and grass on river walls	Some high trees, small trees, plants on river walls	Couple of high trees, moderate trees, small trees, plants and grass on river walls	High brownish trees, brownish trees, small brownish trees and plants on river wall

[3] People dig construction sand from the river walls. When a dam is constructed on this location, then this part of river become reservoir. These people could not be glad with a dam, because digging sand is their way of getting income. Besides this notice, here riverbank and walls are used for grazing and drinking place for cattle.

Appendix IV Flow diagram

A Flow Diagram, showed in figure IV.1, was made about the relevant relations between different variables in the system, Voi River catchment. The factors mentioned in the research context (chapter 1) are accented. Those are the human acts divided in population growth and inappropriate farming techniques, erosion, water storage, vegetation cover and global climate change. When beside an arrow standing (+) is means that increasing of the origin variable lead to increasing of the destination variable, while a (-) means that when the origin variable increase, the destination variable decrease..

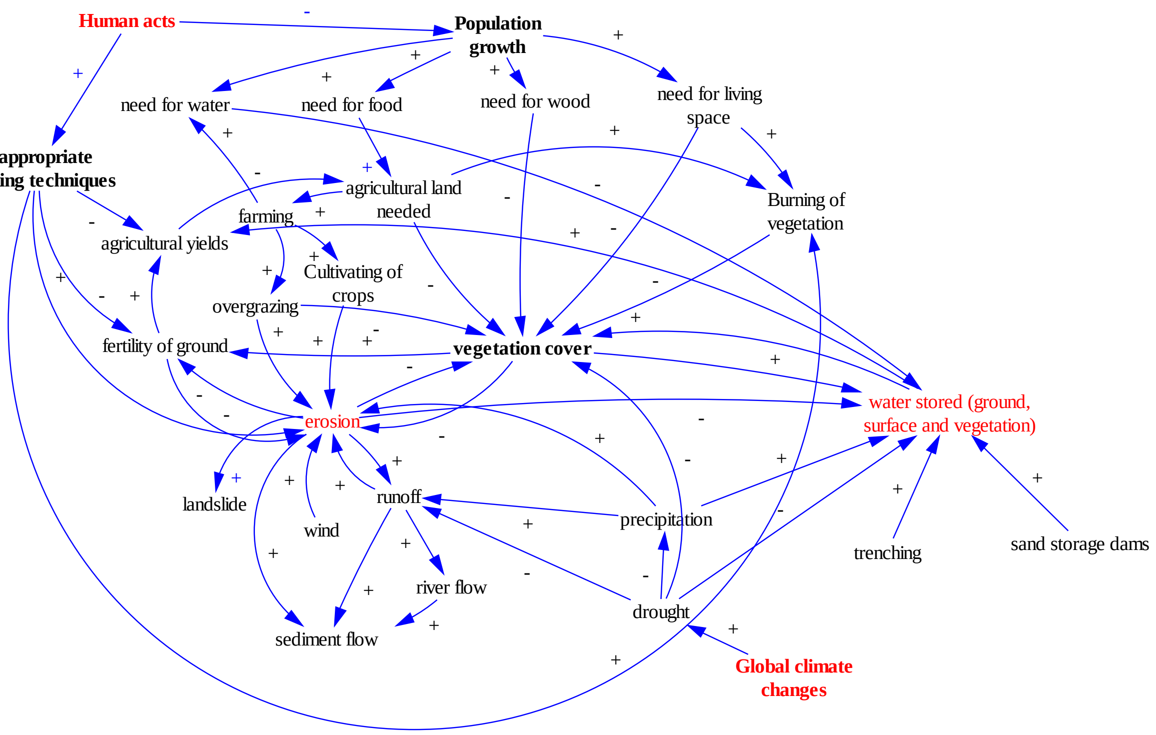

Figure IV.1: Flow diagram of variables in the Voi River basin system.

Appendix V Agricultural zones

The mountain area and plains can be divided in six agricultural zones, with different height, precipitation and temperature, according to Soini (2005). The plains around Voi belong to the semi-arid zone of East Kenya in which temperature ranges between 20 to 40 ºC (Bindloss et al., 2003). In the mountains the temperature decreases with increasing height. A fist rule can be taken of 6.5 ºC per 1,000 m (Floor, n.d.). In table V.1 the six zones are presented and also the climate class is given.

Table V.1: Climate information of the Voi River basin. (Soini, 2005; Bindloss et al., 2003; FAO-SDRN Agrometeorology Group, 1997; Floor, n.d)

Zone	Height (m)	Precipitation (mm)	Temperature (min and max) (ºC)	Climatologic class
Pasture/plain zone	<790	250-500	20-40	BSh
Livestock-Millet zone (Hills)	790-980	480-700	18.7-38.7*	Am
Marginal cotton zone (Hills)	910-1220	600-800	17.4-37*	Am
Sunflower-Maize zone (Hills)	1220-1520	700-900	16.5-36*	Am
Marginal coffee zone (Hills)	1370-1680	900-1200	15.5-34*	Am
Wheat/Maize-Pyrethrum zone (Hills)	>1680	1200-1500	13.5-30*	Am

**Temperatures are estimated, because there is not much data available on temperature.*

The climate class given to the zone is based on Koeppen's Climate Classification consisting five climate zones: A (Tropical), B (Dry), C (Temperate), D (Cold) and E (Pole). The semi-arid plains with rainfall around 250 mm belong to the dry climate zone (B) and biome is savannah. The subgroup for the plain zone's dry climate is S, semi-arid. The mean annual temperature is above 18ºC, so the subcode h is added. The climate zone is BSh. (FAO-SDRN Agrometeorology Group, 1997) The hills belong to a more tropical zone (A) with more rainfall, cooler temperatures and endemic forests. It is not a real tropical climate, but this gets the most near the climate. Furthermore it is a kind of rainforest/more temperate climate that is influenced by a dry season in the monsoon cycle, which results in the code m. So the hills belong most probably to the Am climate zone. (FAO-SDRN Agrometeorology Group, 1997)