CURRENT WATER DEMAND FOR SMALLHOLDER IRRIGATION IN THE MESSICA CATCHMENT, MOZAMBIQUE

Master Thesis

Jan-Willem Moerman

MSc Sustainable Development Global Change and Ecosystems

Supervisors: Dr. P. P. Schot (Utrecht University), A. L. Oord, MSc. (Oord Water Services) and ir. W. Beekman (Resilience BV)
Date: August 2013
Email: j.moerman@students.uu.nl

RESILIENCE BV Oord Water Services Universiteit Utrecht

Preface

This document contains the findings of a master thesis study in the Messica catchment, in the Manica province in Mozambique. The research is conducted by a student as a Master Thesis Research for the Master Sustainable Development Global Change and Ecosystems in collaboration with Resilience BV, Oord Water Services and under supervision of University Utrecht. Furthermore, this study forms an integral part of a comprehensive hydrological research of the Messica catchment, which was conducted in the period 2012 – 2013.

Goal of the study is to get insight in current water demand for smallholder irrigation in the Messica Catchment and the factors that affect current water demand for smallholder irrigation. The study included several months of fieldwork in the catchment to determine the size of irrigated farmland and to interview local farmers about land use and the limitations they experience that affect current water demand for irrigation.

During the study several people assisted me, which I would like to thank for their help, insights, motivational support and knowledge. I would like to thank Wouter Beekman for all his help with practical things in Mozambique, including local transport, housing, visa papers and an interpreter. During fieldwork I was grateful to have David Muchenga to guide me through the catchment, interpreting interviews and walking lots of kilometers with me and of course all farmers that took time to cooperate.

During the whole study Arjen Oord and Paul Schot assisted me when I got stuck, with their positive critique and thoughts it became possible to improve this study severe.

Lastly, I would like to speak out my hope that this research can contribute to sustainable development of smallholder irrigation in the Messica catchment and the work of Oord Water Services and Resilience BV and their project to assist these smallholders.

Jan-Willem Moerman, 16 August 2013

David and me conducting an interview with a farmer in the Messica catchment before measuring his irrigated farmland

Table of Contents

Preface ... 1

Table of Contents ... 2

1. Introduction ... 4
1.1 State of the art ... 4
1.2 Problem definition ... 5
1.3 Aim ... 6
1.4 Research questions ... 6

2. The Messica catchment ... 7
2.1 The Messica catchment ... 7
2.1.1 Location and geology ... 7
2.1.2 Climate and vegetation ... 8
2.1.3 Land use and agriculture development ... 9

3. Methodology ... 11
3.1 Outline ... 11
3.2 Research question 1: Current water demand for irrigation ... 11
3.2.1 Introduction ... 11
3.2.2 Selecting satellite imagery ... 12
3.2.3 Fieldwork: Identifying land use types and measuring ground truth training sites. 13
3.2.4 Land use classification using Erdass Imagine ... 14
3.2.5 Crop water demand ... 15
3.2.6 Reference evapotranspiration ... 15
3.2.7 Local crop water demand ... 16
3.2.8 Effective precipitation ... 17
3.2.9 Water demand for irrigation ... 17
3.3 Research question 2: Limitations that affect current water demand ... 17
3.3.1 Introduction ... 17
3.3.2 Interviews ... 18
3.3.3 Observations ... 18
3.3.4 Data analysis ... 18

4. Results ... 19
4.1 Outline ... 19
4.2 Research question 1: Current water demand for irrigation ... 19
4.2.1 Fieldwork: ground truthing points and land use types ... 19
4.2.2 Land use classification of 7 April 2013 ... 22
4.2.3 Land use classification of 8 June 2013 ... 25
4.2.4 Land use classification of 26 July 2013 ... 26
4.2.5 Evaluation of the land use classification ... 28
4.3 Water demand for irrigation ... 31
4.3.1 Determining reference evapotranspiration ... 31
4.3.2 Determining local crop water demand ... 31
4.3.3 Effective precipitation ... 33
4.3.4 Water demand for irrigation ... 33
4.4 Research question 2: Limitations that affect current water demand ... 35
4.4.1 Introduction ... 35
4.4.2 Environmental limitations ... 35
4.4.3 Economic limitations ... 36
4.4.4 Social limitations ... 38
4.4.5 Analysis of the found limitations ... 39

5. Discussion 42
5.1 Introduction.. 42
5.2 Water demand for irrigation 42
5.2.1 Selection of satellite imagery 42
5.2.2 Fieldwork...42
5.2.3 Land use classification 42
5.2.4 Water demand for crops (Reference evapotranspiration, crop factor and effective precipitation)..43
5.2.5 Water demand for irrigation 44
5.3 Limitations that affect current water demand.. 44
5.3.1 Limitations that affect current water demand for irrigated agriculture 44

6. Conclusion 45
6.1 Research question 1: Water demand for irrigation 45
6.2 Research question 2: limitations that effect current water demand 45

6. References 47

Appendix 1: Questionnaire.. 50
Part 1: Land use...50
Part 2: Limitations 50

Appendix 2: Visited irrigated farmland 51

1. Introduction

1.1 State of the art

Mozambique is one of the world's poorest countries with a Gross National Income (GNI) per capita of US$470 and 54.7% of its citizens living below the poverty line (Alfani et al., 2012). Poverty in Mozambique is predominantly rural (56,9%) as for eastern and southern Africa (IFAD, 2012 and Alfani et al., 2012). Often governments underestimate the importance of rural poverty and invest more heavily in industry and in physical and social infrastructure than in agriculture (Tschirley and Benfica, 2001).

Rural households in developing countries that cultivate 0.5 to 10 hectare of land for subsistence or production of cash crops are referred to as smallholder farmers (Goodbody et al., 2010, Reumkens and de Boer, 2012 and Morton, 2007). Smallholder farmers are vulnerable to natural and economic disasters such as crop and animal diseases droughts, floods and market shocks (IFAD, 2012 and Morton, 2007).

The Mozambican government started to invest seriously in agriculture after the end of the civil war in 1992. The state-led socialist models, including fixed prices, state farms and restrictions on external trade were abandoned, leading to some of the highest economic growth rates in Africa (Tschirley and Benfica, 2001). During the abandonment of socialist plan economy large-scale state farms were closed and replaced by development of the agricultural and smallholder sector in Mozambique (Tschirley and Benfica, 2001). Nevertheless, since 2007 rural poverty remained stable (IFAD, 2012).

For smallholder farmers in Mozambique, farming is the main source of food and income, but agricultural production is low (IFAD, 2012). Low agricultural productivity is the result of a lack of appropriate technologies and support services. It can also be attributed to the fact that produce markets are distant, unreliable and uncompetitive. Furthermore, smallholders depend on traditional farming methods, low-yield seed varieties and manual cultivation techniques. An example is the use of purchased inputs; according to a national survey conducted in 2007, only 4 percent of the smallholders use fertilizers (Goodbody et al., 2010). Alternative sources of income outside agriculture are few. Therefore, the rural poor are vulnerable to the effects of natural disasters on agriculture. In times of scarcity they have little to buffer them from food insecurity (IFAD, 2012 and Morton, 2007). Moreover, an estimated 45% of Mozambique's total land area is suitable for agriculture, but only 11% is currently cultivated (Goodbody et al., 2010). Since 1983 NGO's (Non-Governmental Organizations), developed countries and the International Fund for Agricultural Development (IFAD) provided funding and loans to the Mozambican government to combat rural poverty by improving the situation of smallholders and initiatives to cultivate more arable land, examples of projects are the Strategic Plan for Agricultural Development (PEDSA 2010-2019) (Goodbody, 2010 and IFAD, 2012), Building Commodity Value Chains, Market Linkages for Farmers' Associations and the World Bank funded PROIRRI program (Oord, 2012 and IFAD, 2012).

Irrigated production is known to expand in Africa mainly through an increase in irrigated farmland developed by smallholder farmers, with annual growth rates as high as 3.8% in some parts of Tanzania (Lankford, 2005). Furthermore, the growth of the informal irrigation sector in and the production per hectare compares favorably to annual growth rates in overall irrigation expansion (including government and donor funded projects) (Lankford, 2005). An example of this trend is the Messica catchment in the Manica Province which hosts a large community of smallholders that independently developed irrigation schemes on the eastern and northwestern slopes of the catchment (Oord, 2012). Irrigation in the Messica catchment increased increased from none in 2003 to 340 ha in 2010 and 1000 ha in 2012 (ibid). An increase of irrigated land will lead to an increase in water demand for irrigation in the Messica catchment. But currently, the water availability and water demand for irrigation are unknown. Insight in the water availability of the catchment and water demand for irrigation is paramount for the successful implementation of sustainable irrigation development.

Not only water availability determines successful development of smallholder irrigation. Projects and studies by Tafesse (2003), Kortenhorst (1980) and Mujere (2005) categorized several other limitations than water availability that determine successful smallholder irrigation development. The first category consists of environmental problems like water availability, diseases, soil quality and climatic variation (ibid). The second category is related with the economic situation of farmers. Problems found are infrastructural problems limiting the access of farmers to a market to sell their crops or other services e.g. credit, seeds or fertilizer. Another problem is price instability of the sale market that pressures the profit margins (ibid). The category social limitation is the third category. The main problems are related with the knowledge and motivation for farmers to develop their irrigated agriculture business. Examples are motivation to do extra labor related with maintaining irrigated farmland, irrigating crops, saving money to invest in inputs and take risks related with producing irrigated crops. Other constraints are found within the community of the farmer about boundaries of plots, irrigation times and other community problems (ibid).

A comprehensive hydrological research of the Messica catchment was conducted in the period 2012 – 2013 and split up in two studies. Goal was to estimate 1) the available water resources for irrigation and 2) the current water demand for irrigation and an assessment of the limitations that affect current water demand for irrigation in the Messica catchment. A hydrology student of the Vrije Universiteit Amsterdam conducted the first part of the hydrological research by conducting a water balance study (Weemstra, forthcoming). The combined outcome of study (1) and (2) will result in a projection of water demand in relation to the available water resources leading to insight of the sustainability of irrigation development and outlining current other limitations that affect current water demand for irrigation in the Messica catchment.

1.2 Problem definition

In the last ten years the area of smallholder irrigated land in the Messica catchment increased from none in 2003 to 1000 hectare in 2012 with increased economic resilience and prosperity as a result. Irrigation development success is determined by the availability of water and abundance of other limitations that prevent farmers in the catchment from further development of irrigation potential. Currently water availability, water demand for irrigation and the current limitations that affect water demand for irrigation in the Messica catchment are unknown.

1.3 Aim

This study aims to provide insight in the current water demand for irrigation and possible limiting factors that affect current water demand for irrigation other than available water resources.
The second aim of this study is that if the results are combined with the results of the catchment water balance study of Weemstra (forthcoming). Water availability and current water demand can be compared in order to check if sustainable growth of smallholder irrigation in the Messica catchment is possible.

1.4 Research questions

1. What is the current water demand for irrigation in the Messica catchment?
2. What are the current limitations that smallholders experience in the Messica catchment and do they affect current water demand?

2. The Messica catchment

2.1 The Messica catchment

2.1.1 Location and geology

The Messica catchment is situated in the Manica Province in western Mozambique. The Messica River is a perennial, North-South oriented river located between longitude 32° 59' 17" to 33° 13' 30" E and latitude -18° 43' 51" to -19° 2' 30 S that covers an area of approximately 220 km². The river catchment is mostly characterized by gentle sloping landscape with a combination of rain fed agricultural land cultivated by smallholders and woodlands (Oord, 2012 and Burgess et al., 2007).
The geology of the study area is formed by an extension of the Zimbabwean Craton and consists of Achaean and Paleoproterozoic rocks referred to as crystalline basement. The geology is made up of granitoids and gneisses, the higher situated inselbergs consist of rocks from the Gairezi Group. In the east the craton terminates against the younger Mozambique belt (Koistinen et al, 2008).
The Achaean and Paleoproterozoic rocks found in Africa have an age of more than 550 ma, prolonged weathering resulted in the formation of an on average 10m thick regolith layer (Chilton and Foster, 1995). The weathering process has spanned numerous climatic and tectonic cycles that determined the relative depth of the regolith layer, height of the water table, the frequency and scale of surface runoff and erosion causing inselberg formation (Figure 1) (ibid). Inselbergs are steep-sided mountains, ridges, or isolated hills that rise abruptly from adjoining plains or gently sloping areas. Inselbergs are a common feature in settings with a tectonically stable crystalline basement geology, which is widely found in southern and eastern Africa (Koistinen et al, 2008 and Chilton and Foster, 1995). Generally, the regolith layer consists of a top layer (0.5 – 5 m) of red silty quartz sand with basal lateritic concentrations while deeper in the regolith layer (5 – 10m) accumulation of mainly secondary clay minerals with silty sand and occasional weather rock fragments are found. The top of the bedrock consists of deeply weathered and partly decomposed rocks with fractures filled with clay with underneath unweathered bedrock (Chilton and Foster, 1995). More precise data about the exact depth of the regolith, saprock and bedrock layers in the Messica catchment is unavailable.

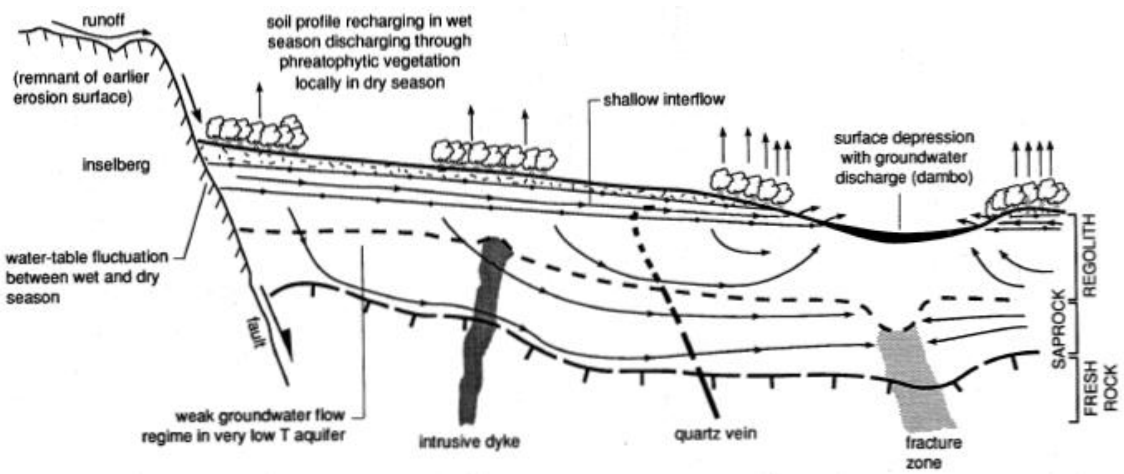

Figure 1: Generalized section of the geology in the weathered crystalline-basements in eastern Africa, horizontal lines indicate the thickness of regolith, saprock and fresh rock layers (Chilton and Foster, 1995)

In the Messica catchment an Inselberg is found on the eastern border. The height of the inselberg is approximately 1450 meter above sea level and covered with deciduous miombo woodlands while the Messica River is found around 650 meter above sea level. The Messica River discharges into the artificial Chicamba Lake south of the road from Manica to Chimoio EN6 (Figure 2).

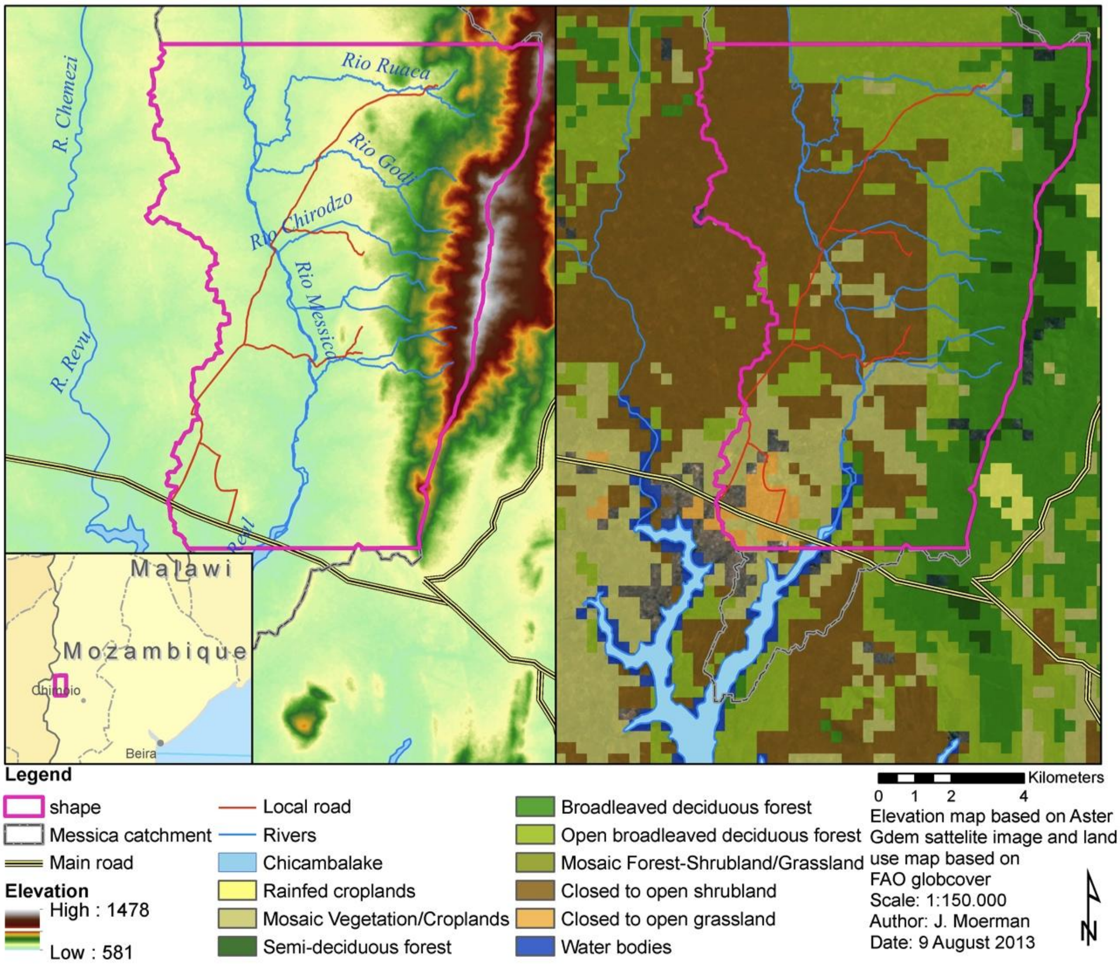

Figure 2: On the left an overview of the Messica Catchment with a digital elevation map based on AsterGdem stereo paired satellite imagery to calculate elevation (AsterGdem, 2013). On the right a land use map made by FAO (FAO, 2000)

2.1.2 Climate and vegetation

Climate and vegetation are closely related to one another, key elements of any climate are temperature and moisture (Burgess et al., 2000). The research area is located in south-eastern Africa between 20° and 35° S which is classified as a humid subtropical climate with dry winters (Cw) according to the Kọ̈ppen Classification (Burgess et al., 2007 and Strahler and Archibold, 2004). Average annual rainfall in the most nearby weather station (25 kilometer west of the catchment in the city Manica) is 1014 mm, while the average annual temperatures fluctuate between 15 °C and 24 °C and evapotranspiration potential is 1307 mm from 1961 to 1990 (FAOclim-net, 2013) (Figure 3).

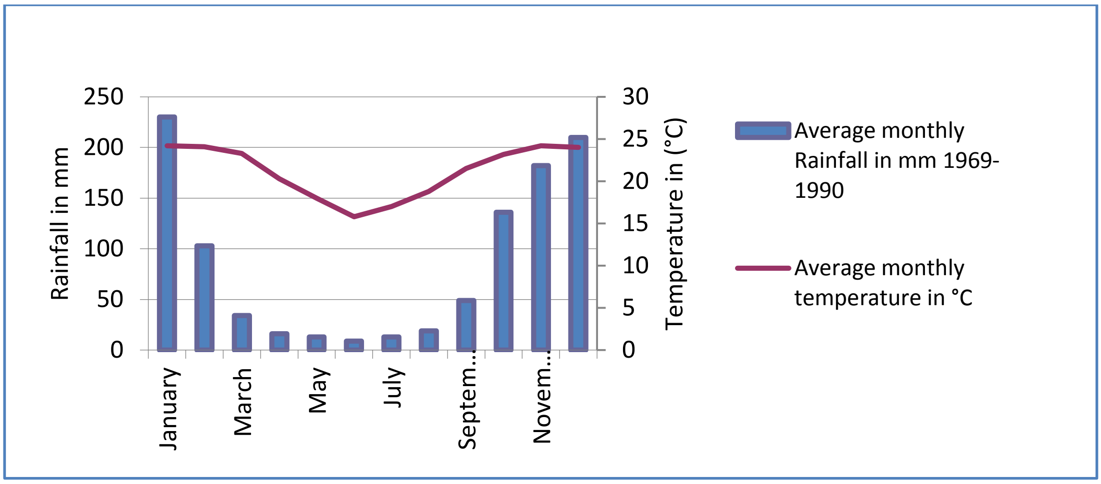

Figure 3: Average monthly rainfall (mm) and temperature (°C) from the Manica weather station from 1961-1990 (FAOclim-net, 2013)

Rainfall is not evenly spread over the year as a result of the seasonal movement of the Inter Tropical Convergence Zone (ITCZ) (Burgess et al., 2007). During spring and summer (October to March) 85% of yearly precipitation occurs when the ITCZ passes through the area while during the winter months precipitation is sparse (Figure 3). The wet season with heavy precipitation starts around the end of October and last until the end of February (Goodbody et al., 2010 and Burgess et al., 2007). Local floods often occur during the wet season (ibid). During the winter from March until September rainfall is sparse averagely less than 50 mm per month (Figure 3) (FAOclim-net, 2013). Precipitation patterns and quantities also fluctuate heavily between years in Mozambique causing droughts or floods (Goodbody et al., 2010). Local data of floods and dry years for the Messica catchment is not available.
In the Messica catchment measurements indicate that the baseflow of the Messica River is small but constant, and varies between 70l/s in the summer and 40l/s in the winter (Oord, 2012). Water in the Messica originates from tributaries that flow from the inselberg into the Messica. Smallholders use these tributaries e.g. Rio Godi, Rio Ruaca and Rio Chirodzo during the dry winter months as water supply for their irrigated farmland (Figure 2) (Oord, 2012).

The natural vegetation in the area consists of miombo woodlands, the most extensive tropical seasonal woodland an dry forest formation in Africa covering an estimated 2.7 million km² in regions receiving over 700 mm mean annual rainfall in Angola, Democratic Republic of Congo, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe (Chirwa et al., 2008). The woodlands cover a rich number of species and widespread occurrence of the Brachystegia, Julbernadia and Isoberlinia (Nhantumbo et al., 2001). Miombo woodlands offer a variety of forestry and wildlife products and are used by rural communities for agricultural production. Examples of forestry and wildlife products are edible fruits, mushrooms, animals, firewood, construction material and medicinal plants (Chirwa et al., 2008). Agricultural practices in Miombo forests consist of shifting cultivation (ibid).

2.1.3 Land use and agriculture development

According to the FAO\UNEP land cover classification system (LCCS) (FAO, 2000), the area consists of rain fed croplands, croplands, (deciduous) broadleaf forests, scrubland and grassland (Figure 2), however the data is coarse with a resolution of 1 km². Throughout the catchment small settlements consisting of some small houses and communities are found surrounded by their small agricultural fields. The different communities are connected by dirt roads. Field observations from (Reumkens 2011 and de Boer 2011) divide land use in four classes: rain fed agriculture, natural vegetation (Miombo woodlands) and irrigated agricultural fields in the headwater areas on the eastern slopes of the catchment. Rain fed agriculture is practised during summer. On farmlands maize is grown, while small fields close to the houses are used for the production of cabbages, beans, pumpkins, cassava and cabbages (van den Pol, 2012).

In the headwater areas on the eastern higher slopes of the catchment smallholders autonomously constructed small channels by hand to transport water from tributaries of the Messica to their agricultural fields (from 0.5 up to 5 ha) using gravity to produce crops outside the wet season. Unused water, deep percolation and leakages from the channels eventually flow back to the streams, the Messica River or evaporate (Reumkens and de Boer, 2011). The area of irrigated farmland increased from none in 2003 to 340 ha in 2010 and 1000 ha in 2012 (Oord, 2012). The irrigated plots are used to grow commercial crops such as tomatoes, covo, maize, sorghum, beans, sweet potatoes, cassava and cabbages (Reumkens and de Boer, 2011). Water supply depends on small streams that flow throughout the year connected with irrigation channels managed by the local community (Reumkens and de Boer, 2011). During the year three different crop growing seasons are identified, 1) from October until March the wet season, 2) April until July the dry season and 3) the August until October the dry where only farmers with water left irrigate (Van den Pol, 2012). Farmers downstream are only able to produce during the wet season while farmers that built irrigation canals from streams to their fields are able to sew crops during the dry season.

3. Methodology

3.1 Outline

The study is split up in two parts based on the research questions 1 and 2. Research question 1 aims to determine current water demand for irrigation in 2 steps: 1) determine irrigated farmland (1), 2) determine water demand of crops on irrigated farmland (2) that lead to current water demand for irrigation (6) (Figure 4).
The second part of the research is focused on the second research question. Interviews with farmers in the following categories: environmental (3), economic (4) and social limitations (5) are used to determine possible limiting factors that affect current water demand for irrigation (7) (Figure 4).

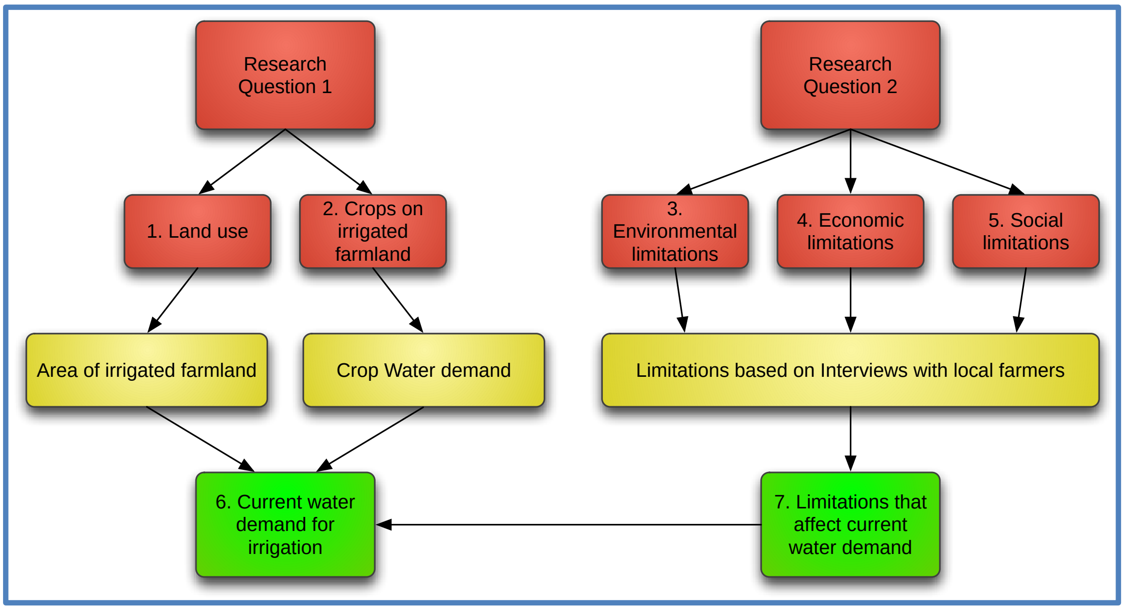

Figure 4: Schematic overview of the research methodology

3.2 Research question 1: Current water demand for irrigation

3.2.1 Introduction

The Messica catchment is approximately 220km² big, the focus of this study is on the southern half of the catchment which includes the eastern slopes of the Inselberg where most irrigated farmland is found (2.1.3). The selected area is around 110 km² big. Because of the size not all irrigated fields can be visited. Chosen is to utilise satellite imagery and remote sensing land classification techniques with fieldwork to collect ground truthing sites that are used to identify irrigated farmland (3.2.2 to 3.2.4).
Secondly it is impossible to measure for every irrigated farmland individual water demand for irrigation. Therefor a methodology developed by Brouwer and Heibloem (1986) is applied. The method is focused on the crop, by defining crop water demand as the amount of water needed to meet water loss trough evapotranspiration (ibid) (3.2.5. to 3.2.8). The combination of these techniques was used to estimate current water demand for irrigation in the Messica catchment (3.2.9):

$$Water\ demand\ for\ irrigation = Area\ of\ irrigated\ farmland * Cropwater\ demand$$

Calculation of water demand for irrigation (m^3 per month) by combining irrigated farmland (m^2 per month) derived from remote sensing land use classification and crop water demand (mm per month) estimated by the methodology of Brouwer and Heibloem (1986).

The land use calculation consists of 3 steps (3.2.2 to 3.2.4). In the first step satellite imagery was chosen that is used for the classification. The second part consisted of fieldwork in the Messica catchment in order to collect land use classes and corresponding ground truth points needed for the classification. Lastly, the land use classification was conducted for the selected satellite images using a geographic information system (GIS) (Figure 5).

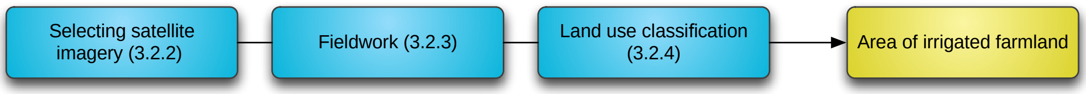

Figure 5: Schematic overview of the land use classification methodology. Satellite imagery, fieldwork and remote sensing techniques are used to estimate the area of irrigated farmland

Water demand was estimated with the methodology of Heibloem and Brouwer (1986) and consisted of 3 steps (3.2.5 to 3.2.8). First local climatic influence on evapotranspiration was calculated. Secondly, the crop water demand is calculated by combining crop properties of local grown crops with local growth times of these crops. Lastly average monthly effective precipitation is deducted from crop water demand to get crop water demand per month (Figure 6).

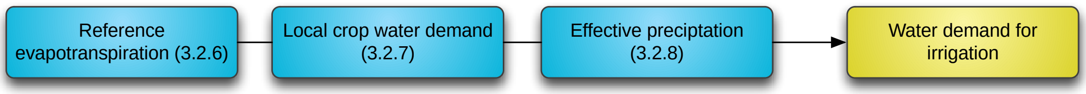

Figure 6: Schematic overview of the methodology of Heibloem and Brouwer (1986) to calculate water demand of irrigated crops

3.2.2 Selecting satellite imagery

Satellite imagery is used to determine land use and land cover change since the launch of the Landsat imagery platform in 1972, followed by others such as SPOT and ASTER (Burrough et al., 1998). The satellite imagery used in this research is from the Landsat 8 satellite because the images are recent and available without a charge. The Landsat 8 provides images of 185 km^2 with a pixel size of 30 by 30 meters in 11 spectral bands (USGS, 2013). The spectral bands are sensitive for obtaining reflections from visible light to long-wave infrared. These different bands have variable properties that can be used to identify phenomena on earth (Table 1) (De Jong et al., 2009). For land use classification the recorded bands are often combined to fully utilise the different reflections of land use classes in the different bands. For this study band combinations that highlight differences between vegetation types are most useful therefor band 2 – 7 and band 10 and 11 are used. Band 1 and 8 have similar wave length with band 2, 3 and 4 and are therefore not used while band 9 is not used because it can only detect cirrus clouds (Table 1).

Wavelength (µm)	Band name	Application
1. 0.43-0.45	Coastal	Band aimed to register shallow coastal water and dust and smoke
2. 0.45-0.52	Blue	Designed for water body penetration (coastal waters)
3. 0.52-0.60	Green	Designed to measure green reflectance peak of vegetation for crop and vegetation discrimination
4. 0.63-0.68	Red	Designed to sense in chlorophyll absorption bands for species differentiation.
5. 0.85-0.89	Near infrared	Near infrared: useful for determining vegetation types, vigour and biomass content and for delineating water bodies
6. 1.56-1.66	Short-wave infrared 1	Short-wave infrared: Indicative of vegetation moisture content and soil moisture. Useful to discriminate clouds from snow.
7. 2.10-2.30	Short wave infrared 2	Short-wave infrared: Useful for discrimination of mineral and rock types. Also sensitive for vegetation moisture content.
8. 0.50-0.68	Panchromatic	Panchromatic band is mostly used for resolution improvement for the other bands
9. 1.36-1.39	Cirrus	Cirrus: To detect cirrus clouds
10. 10.30-11.30	Long-wave infrared 1	Thermal infrared: Useful in vegetation stress analysis, soil moisture mapping and thermal mapping.
11. 11.50-12.50	Long-wave infrared 2	Thermal infrared: Useful in vegetation stress analysis, soil moisture mapping and thermal mapping.

Table 1: Description of the Landsat 8 Thematic Mapper spectral bands (USGS, 2013)

Because of the different growth seasons (see 2.1.3) found in the Messica catchment multi-temporal satellite images are used to include changes in land use. Furthermore, Turker and Arikan (2005) and Guerschman et al. (2003) emphasize the value of using multi-temporal satellite images to increase the accuracy of the land use classification, especially images that embrace the shift between summer and winter crops. This is particularly true for this study area; the change from wet to dry regulates seasonal changes of land use and vegetation e.g. start of irrigation in autumn and winter and changes in natural vegetation due to water shortages in winter (2.1.2). In order to incorporate these changes land use in the study area is classified in 3 different images acquired in April, June and July. Landsat 8 images are acquired every 16 days for the research area; the availability of cloud free images determined the choice for the images of 7 April 2013, 8 June 2013 and 26 July 2013. In order to classify the Landsat 8 satellite images local data of land use in the Messica catchment is required that can be used to determine land use classes for the image classification and as ground truth training sites.

3.2.3 Fieldwork: Identifying land use types and measuring ground truth training sites

Fieldwork took place during the shift between summer and winter from 11 March until 15 May 2013 and led to an overview of all major land use classes in the Messica catchment and corresponding ground truth training sites. Fieldwork was prepared with the most recent cloud free Landsat 5 satellite image taken on 10 November 2011 because the Landsat 8 satellite was not yet launched (USGS, 2013). The preparation consisted of marking easily distinguishable and remarkable points on the satellite image in order to visit them during fieldwork. The predefined points were located with a GPS device and consequently mapped by walking around them with a GPS. The found land use types were categorised in the land use categories natural vegetation, agricultural land and other. Not only the predefined points were visited, also other distinguishable or remarkable land use found during fieldwork were mapped and categorised. Additional information about the land use of the visited land was gathered by interviews with the owners of lands (see 3.3.2 and 7.1).

The mapped and categorised land use types were divided into land use classes (e.g. bedrock, grassland, farmland, irrigated farmland, water and forest) and combined with the information gathered by interviews in order to use them as ground truth training sites during the land use classification of the Landsat 8 satellite images. The information from the interviews consisted of question about when farmers plan to plant and harvest their irrigated crops and how much of the visited irrigated farmland they plan to use in 2013 (Appendix 1). Lastly for, places that were had to visit georeferenced photos were taken instead of mapped training sites.

3.2.4 Land use classification using Erdass Imagine

Land use is classified by the supervised land use classification tool of Erdass Imagine, a Geographic Information System (GIS), where local ground truth land use data is used to classify land use (Burrough et al., 1998). The overall objective of the image classification is to automatically categorize all pixels in an image into land use classes (ibid). The Landsat 8 images of April, June and July, the mapped ground truthing points, georeferenced photos, and information from the interviews during fieldwork are used to train the GIS to classify land use. The land use classification is conducted in 4 steps for the three different images.

First the ground truth training sites found during fieldwork were categorised and divided into land use classes and subsequently projected on the Landsat 8 satellite images. Secondly, the ground truth sites are used as training samples by assigning clusters of ground truthed cells with pixels from the 8 bands of the satellite image. These so called training sites are made for every identified land use class and should at least consist of 40 pixels that are spread out over the satellite image (Pouncey et al., 1999). The measured fields during fieldwork formed the basis for the training sites. Additional training sites were added based on the georeferenced photos and observations to get enough pixels in each class, especially for classes that were hard to visit (e.g. bedrock or forest on hilltops).

Secondly, different tools in Erdass Imagine are available to test the training sites for their suitability by calculating average reflection per band, continuity and separability. Average reflection per band is used to select training sites for similar reflections. This is a visual and fast method based on a graph to do a fast interpretation of selected training sites. Continuity and separability are more precise methods to check the assigned training sites afterwards.

In the contingency matrix the different land use classes are classified according to the reflectance of the corresponding training sites. After the classification a matrix is computed that indicates what percent of the training sites corresponds with their trained land use class. A percentage of +80% is considered as sufficient.

Lastly, the separability tool calculates the distance between training sites by evaluating the Euclidean spectral distance between the means of the training sites (Pouncy et al., 1999). The outcome is used to check whether training sites have similarities in reflectance over the 8 bands with one another (ibid). The outcome of the separability index is dimensionless; in order to check if the separability is appropriate, the outcome is compared with the average separability of all training sites and the importance of the land use class for this particular study. In this study the

class irrigated farmland is most important since this class is needed for the water demand for irrigation calculation.
In the third step the satellite image was classified by Erdass Imagine that uses a Maximum likelihood classification based on the variances and covariance of the trained land use classes. Lastly, the classified land use map is tested for accuracy by creating 200 random points on the map that are checked for their land use by the georeferenced photographs taken during fieldwork and an high resolution aerial photograph of Digital Globe (2010).
The end product is a land use map for April, June and July 2013 and a table with the analogous amount of hectares of the different land use classes in the Messica catchment. Subsequently, in the results of the land use classification of the April, June and July are evaluated to determine the total area of irrigated farmland that is used to estimate total water demand for irrigation (3.2.5).

3.2.5 Crop water demand

As for the total area of irrigated farmland in the Messica catchment also every farmer's water use for irrigation is impossible to measure. Therefore the methodology developed by Brouwer and Heibloem (1986) is used. The method is focussed on crop water demand defined as the amount of water needed to meet water loss through evapotranspiration per month instead of actual water supplied to a crop (ibid). The method consists of 3 steps that were also mentioned in the introduction and Figure 6. Firstly, the influence of local climate on evapotranspiration is estimated for the reference crop grass with a length of 8 to 15 centimetres (Et_0). Secondly, Et_0 is corrected to take into account other crop types than grass with the crop factor $K_{c\,month}$. Whereby crop type, growth stage and time on the field determine $K_{c\,month}$. Lastly, precipitation is subtracted from water demand in P_{eff} (mm/month) (ibid). This can be described in the following formula:

$$Crop\ water\ demand = (Et_0 * K_{c\,month}) - P_{eff}$$

Whereby crop water demand is in mm per month, Et_0 in (mm per month) and considers climatic influences on evapotranspiration, $K_{c\,month}$ (dimensionless per month) corrects Et_0 for other crop types, growth stages and time on the field. P_{eff} considers the amount of precipitation that contributes to the water demand of the irrigated crops in (mm per month). In the following paragraphs the acquisition and method to calculate Et_0, $K_{c\,month}$ and P_{eff} is described.

3.2.6 Reference evapotranspiration

Climatic influences on evapotranspiration are estimated in Et_0 (Brouwer and Heibloem, 1986). Et_0 is an estimation for the reference evapotranspiration of grass with a length of 8 to 15 centimetre. There are several ways to estimate Et_0, in this case chosen is to use the Blaney-Criddle method because data for more precise methods to estimate reference evapotranspiration like the Modified Penman or Makkink is not available. Blaney-Criddle uses average daily temperature per month and hours of daylight (p) to calculate reference crop evapotranspiration (Et_0).

$$Et_0 = p(0{,}46 * (T_{mean} + 8))$$

Where Et_0 is the reference evapotranspiration in (mm/month), T_{mean} is the mean daily temperature per month in degrees Celsius (°C), p (dimensionless) is defined as mean daily percentage of annual daytime hours and found in a table of Brouwer and Heibloem (1986). T_{mean} is calculated with FAO data collected from the Manica weather data collection station from 1961 until 1990 (FAOclim-net, 2013).

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
p for Latitude (20° S)	0,30	0,29	0,28	0,26	0,25	0,25	0,25	0,26	0,27	0,28	0,29	0,30

3.2.7 Local crop water demand

Next is determination of crop factor (K_c) that adjusts the reference evapotranspiration to fit local crops. Hereby, type of crop, plant time and growth stage (initial, crop development, mid-season and late season) have to be determined. Lastly, K_c is transposed to a monthly value $K_{c\ month}$ and corrected for wind and humidity.
In order to determine which crops farmers plant during the year, visits are planned to ask farmers which crops they plant at what time of the year and for how long these crops are on the field for each growth stage (Appendix 2: Visited irrigated farmland). Subsequently per crop and per growth stage a corresponding crop factor is appointed from Brouwer and Heibloem (1986) (Table 2).

Crop	Initial stage		Crop development		Mid-season stage		Late season stage		
	K_c	days	K_c	days	K_c	days	K_c	days	total
Maize	0.40	30	0.80	50	1.15	60	0.70	40	180
Tomato	0.45	35	0.75	45	1.15	70	0.80	30	180
Potato	0.45	30	0.75	35	1.15	50	0.85	30	145
Cabbage	0.45	25	0.75	30	1.05	65	0.90	20	140

Table 2: Example of crop factor values (K_c), and days per growth stage for 4 crops derived from Brouwer and Heibloem (1986). During fieldwork growth days per stage and crop type were determined by interviews.

In order to transpose the crop factor to the same dimension as Et_0, K_c is divided by the total days of a crop in a growth stage per month ($K_{c\ month}$). Crop type, plant and harvest time and growth stage were verified during fieldwork with interviews. Based on the interviews the two most common planting schemes in 2013 were used for the calculation of $K_{c\ month}$.

$$K_{c\ month} = \frac{\sum days\ initial\ stage}{30} * \mathrm{K_{c\ initial}} + \frac{\sum days\ crop\ development}{30} * \mathrm{K_{c\ crop\ development}}$$

$$+ \frac{\sum days\ mid\text{-}season\ stage}{30} * \mathrm{K_{c\ mid\text{-}season}} + \frac{\sum days\ late\ season\ stage}{30} * \mathrm{K_{c\ late\ season\ stage}}$$

$K_{c\ month}$ is adapted for humidity and wind speed (Brouwer and Heibloem 1986). If humidity is above 80% or wind speed is low (2 < m/s) $K_{c\ month}$ is reduced with 0.05 while if humidity is below 50% and wind speed is high (5 > m/s) $K_{c\ month}$ is increased with 0.05 as can be found in Brouwer and Heibloem (1986). For the correction of $K_{c\ month}$ average wind speed per month from 1961-1990 from

FAOclim-net (2013) is used and average monthly relative humidity in (% per month) from MyWeather (2013) is used because the humidity data was unavailable from FAOclim-net.

3.2.8 Effective precipitation

Lastly effective monthly precipitation (P_{eff}) is determined. Effective precipitation is defined as the water that retains in the root zone after precipitation (Brouwer and Heibloem, 1986). Hereby evaporation, surface runoff, deep percolation are subtracted from rainfall (*P)* to obtain P_{eff} (ibid). High values of P_{eff} during the summer will lead to a lower crop water demand while in the dry winter P_{eff} has to be supplemented with water from streams.

$$P_{eff} = 0{,}8 * P_{mean} - 25 \;\; if\ preciptation > 75\ mm/month$$
$$P_{eff} = 0{,}6 * P_{mean} - 10\ if\ preciptation < 75\ mm/month$$

P_{mean} and P_{eff} are in mm per month. Data from the Manica weather station of FAO is used for monthly average rainfall (1961-1990).

3.2.9 Water demand for irrigation

Calculation of reference evapotranspiration, the crop factor and effective precipitation per month allows for the estimation of water demand for irrigation by filling in the formula of Brouwer and Heibloem (1986). The formula is filled in twice for the two most common found planting schemes.

$$Crop\ water\ demand = (Et_0 * K_{c\ month\ scheme\ 1}) - P_{eff} + (Et_0 * K_{c\ month\ scheme\ 2}) - P_{eff}$$

Whereby crop water demand is in mm per month, Et_0 in mm per month, $K_{c\ month}$ dimensionless per month and P_{eff} in mm per month.
By combining crop water demand for the two most common found planting schemes in the catchment with the total area of irrigated land total water demand for irrigation can be calculated.

$$Water\ demand\ for\ irrigation = Area\ of\ irrigated\ land * Crop\ water\ demand$$

Water demand for irrigation is in m³ per month, Area of irrigated land in m² per month and Crop water demand in mm per month.

3.3 Research question 2: Limitations that affect current water demand

3.3.1 Introduction

The interviews conducted with the farmers about their land use are combined with the possible limiting factors of farmers that affect current water demand for irrigation. But not only interviews are used; also observations done during fieldwork are incorporated (3.3.3). In the last paragraph the method of how the interviews and observations are analysed to answer research question 2 is described in 3.3.4.

3.3.2 Interviews

The interviews took place in the same area as the ground truth sampling. Farmers are selected by GPS locations that were based on remarkable points found in satellite imagery from the Landsat 5 satellite (3.2.2) or by the expertise of the guide, since he also knew has knowledge where for example farmers with large irrigated fields are found.

The questionnaire was made in a semi-structured way, in the sense that the different topics that are addressed are determined but with room for the farmer and the interviewer to discuss the topics in a broader context. In this way the farmer is able to describe his problems and experiences. While for the interviewer there is space to adjust, extend or change the sequence of questions.

According to Pile (1999) the power relation between the researcher and the researched is a key factor to keep in mind during an interview (Pile, 1999). This is especially true for this type of research, since cultural differences are vast and farmers could be tempted to exaggerate or change their stories considering possible aid coming into their direction. Therefore it is important to explain what the aim of the questionnaire is and to ask some questions in multiple ways. Additionally, Pile (1999) names two other notions which are important conducting an interview, the researcher nor the subject is passive, emotions during the interview have an influence on the other participant and their answers. Lastly, experiences from the researcher will be reflected in the interviews and affect the research (ibid).

The interviews were divided in two parts: part one consisted of questions about land use of the visited site (Appendix 1) to determine the land use classes (3.2.3) and the calculation of the crop factor K_c (3.2.7). The second part of the research is about the limitations smallholders experience with their irrigated agriculture.

The statements of farmers during the interviews are divided in the categories social, economic and environmental limitations according to Tafesse (2003), Kortenhorst (1980) and Mujere (2005) and subsequently grouped with similar statements of other farmers. See Appendix 1 for the used questionnaire.

3.3.3 Observations

During the visit of farmers observations of the local circumstances could add to the understanding of the researcher. Since observations are not limited to language, behaviour, natural phenomena and other settings can in this way get a place in a research (Green and Thorogood, 2009). An example could be a farmer stating lack of money to invest in inputs while he has relative welfare seen by clothing, housing or other goods. Most likely then his limits are not money but lack of knowledge or motivation to plan his budgets. By using these observations during interviews better insight of the real limitations of the farmers should become apparent. Therefore, the observations are used during the categorisation of the different statements from the farmers to place the mentioned problems under the right category of limitations.

3.3.4 Data analysis

The statements of farmers collected during interviews are described and combined with observations made in the catchment. The combination of the interviews and observations led to a list of problems per category of limitations and a qualitative analysis of the found limitations.

4. Results

4.1 Outline

This chapter is organized similar to the methodology chapter. First the results of research question 1 are presented followed by research question 2. Thus for research question 1, first the amount irrigated land is estimated for April, June and July based on satellite imagery (4.2). Secondly, based on the methodology of Brouwer and Heibloem (1986) crop water demand for irrigation is calculated (4.3). In paragraph 4.3.4 total water demand for irrigation is calculated by combining irrigated farmland and crop water demand.

Research question two deals with the current limitations that farmers experience and their effect on current water demand for irrigation (4.4).

4.2 Research question 1: Current water demand for irrigation

4.2.1 Fieldwork: ground truthing points and land use types

Based on the Landsat 5 image, 90 points were selected as ground truth points that had to be visited to interview the owner about land use and to map with a GPS device. From 11 March 2013 until 14 May 2013, 29 interviews and 99 areas of different land use have been visited and mapped (Figure 7).

There were problems to find all of the 90 selected ground truth points because of restricted access e.g. vast vegetation, steep terrain, the owner living outside the catchment or places were sacred for the community (e.g. a burial ground). From the mapped points during fieldwork 15 visited locations corresponded with pre-identified ground truthing points. During fieldwork more of the 15 selected points were visited but the above mentioned constraints made it impossible to walk around them with a GPS. Alternatively georeferenced photographs were made this led to another 34 predefined visited ground truthing points. These sites were not walked around by GPS but just mapped by 1 georeferenced coordinate and a corresponding photograph. During the classification these points gave information about land use on that particular point.

The other 84 mapped sites with a GPS were found based on local knowledge of the interpreter, own observations and interviewed farmers that advised to visit neighbouring farmers or other remarkable sites. Second goal of fieldwork was to identify land use categories and corresponding classes. During fieldwork in the catchment different land use types have been identified and divided in the following land use classes (Table 3).

Category	Land use classes
Agricultural fields	Farmland Irrigated farmland
Natural vegetation	Forest Grassland Bush
Other	Bare soil Towns and houses Bedrock Water

Table 3: Land use categories and the corresponding land use classes found in the Messica catchment

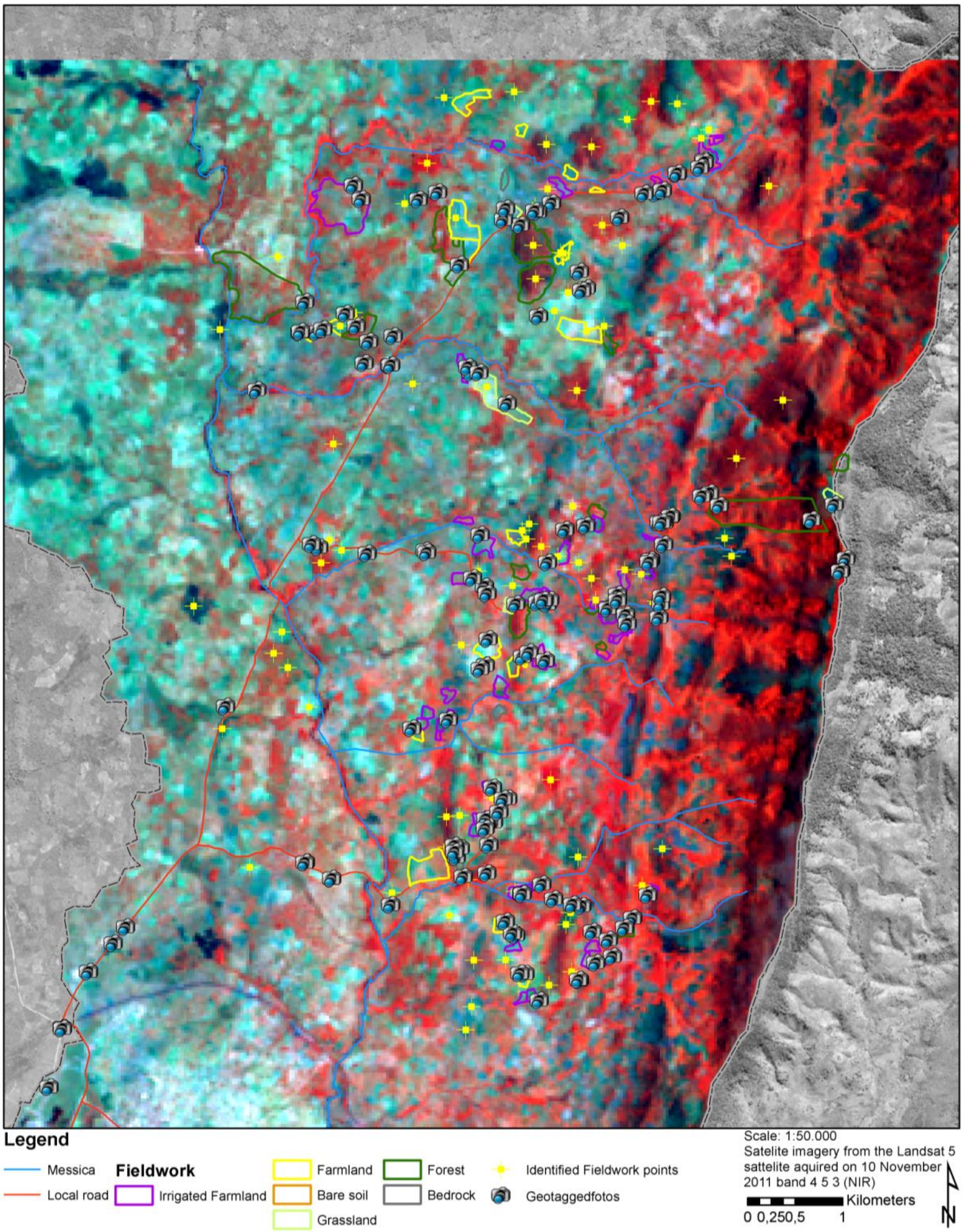

Figure 7: Identified ground truthing points and the results of fieldwork. The satellite image on the background was used to identify the ground truthing sites (white). Shades of red indicate natural vegetation, shades of green agriculture, shades of blue water and wet soils and shades of white indicate bare soil, towns, bedrock or houses.

The category agricultural fields is divided in the land use classes farmland and irrigated farmland. On farmland maize and sorghum are the main planted crops in summer with sometimes pumpkins, cucumbers and beans underneath it. In autumn the maize dries on the field before harvest, after harvest from end of April until begin

July cows graze the leftovers of the maize and meanwhile natural vegetation starts to grow until October (Figure 8a and 8d). In October the field is plowed in order to plant maize after the first rain in October or November.
The irrigated fields are mostly found on the higher parts of the catchment where it is possible to construct an irrigation canal. The fields are relatively small and used intensively throughout the year mainly for maize, tomatoes, beans and covo (Figure 8e and 5f).

There were 3 different categories found of natural vegetation, forest is found on the eastern slopes of the inselberg and on the small hills found throughout the catchment (Figure 8a and 8b), while Bushes and grasslands with trees are found throughout the catchment on old unused agricultural fields, sandy soils and near streams (Figure 8b and 8c). The land use classes found in the category natural vegetation show few variations during the year and mainly used for wood gathering and cow grazing.

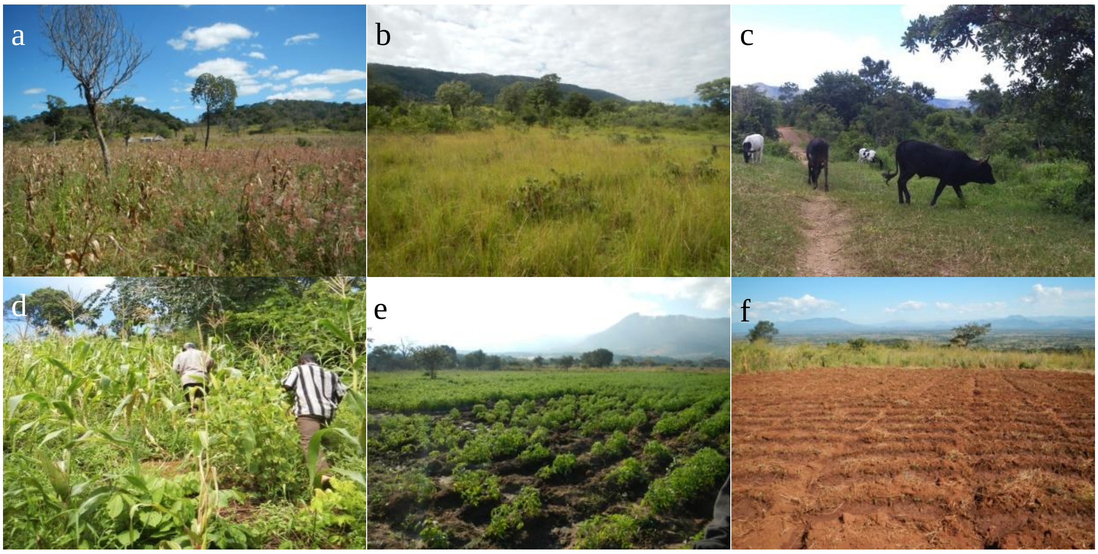

Figure 8a: Forest on small hills, in front a harvested maize field, 8b: Old unused field with small bushes and grassland in the back the inselberg covered with forest, 8c: Grassland surrounded by bush, 8d: Maize field in March, 8e: Irrigated covo and 8f: plowed irrigated field (photographs taken during fieldwork)

The category other consists of bedrock, open water, bare soils and towns and villages. Bedrock is found on multiple places in the catchment, the biggest parts are found on top of the inselberg and other smaller hills in the catchment and often surrounded by natural vegetation (Figure 9a). Towns, houses and bare soils are found in the southwest of the catchment where the only town is situated; bare soils are found around houses throughout the catchment and on plowed fields (Figure 8e and Figure 9c). Open water is found in the south of the catchment where the Messica flows into Lake Chicamba. Rio Messica and the streams in the catchment are small and often surrounded by dense natural vegetation (Figure 9b).

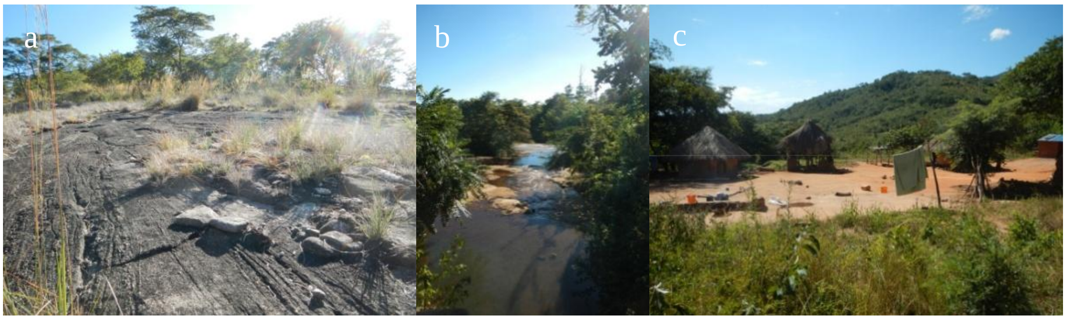

Figure 9a: Bedrock found on a small hill, 9b: Rio Messica surrounded by bushes 9c: Bare soil found around houses (Photographs taken during fieldwork)

4.2.2 Land use classification of 7 April 2013

The land use classification is based on the land use classes (Table 3) and corresponding training sites from fieldwork. In order to perform the land use classification a combination is made between satellite images of April, June and July and the fieldwork data. For every land use class training sites were made based on the mapped sites with the GPS and the georeferenced photographs. During the classification of satellite image of April the sufficient amount of minimum 40 pixels per class was classified. Pixels that corresponded with the classes' bare soil and irrigated farmland were hard to find because most farmers still used their irrigated plots for maize (Table 4 and Figure 10).

Classes	Total pixels
Bush	396
Forest	362
Grassland	128
Bedrock	118
Water	108
Bare soil	66
Farmland	361
Irrigated Farmland	73
Towns and houses	184

Table 4: Amount of classified pixels on a Landsat 8 satellite image on 7 April 2013

The average reflection per band was used by the selection of suitable training sites for all classes and showed that the classes bare soil and towns and houses and bush and forest have almost similar reflectance's in all 8 bands (Figure 10). The figure shows that in the bands 4, 5 and 6 the reflectance of the land use categories are most different from one another.

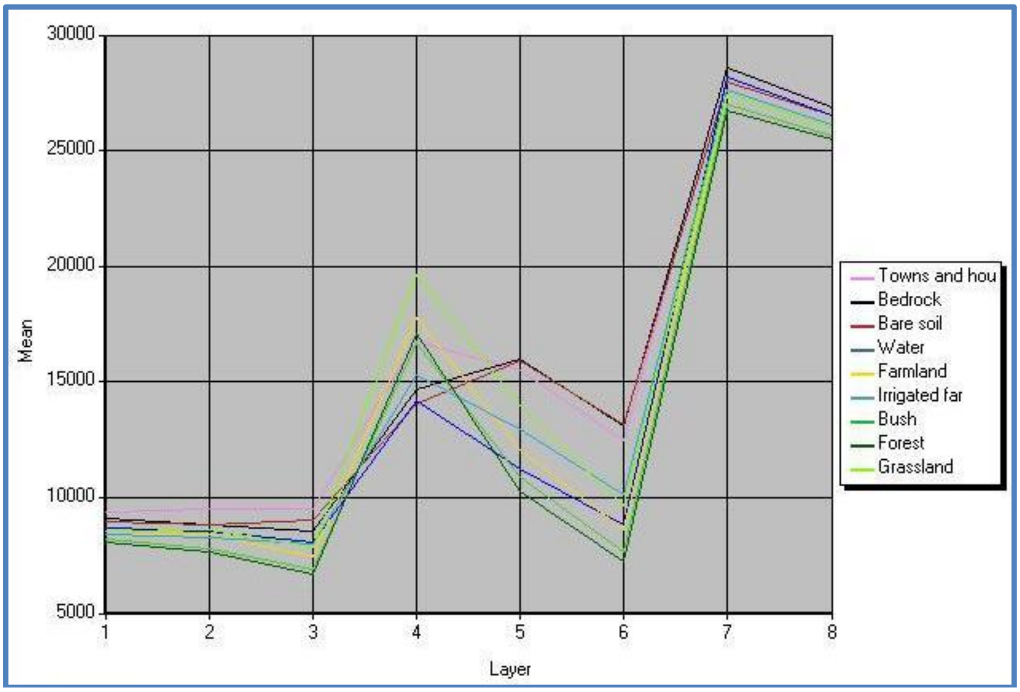

Figure 10: Average reflection per band of the training sites for the 9 land use classes based on the Landsat 8 satellite image of 7 April 2013

Separability and continuity are used to test the training samples more precise. According to the separability matrix the classes bush and forest have most similar training sites while towns and houses and vegetation have the highest difference in reflection (Table 5). For this research the separability of irrigated farmland with all other classes is most important, the lowest separability found is 2588 with bedrock. The separability index indicates that the classes' the classes bush and forest and bedrock and bare soil have a highest overlap this corresponds with in Figure 10.

Best Average Separability

Bands	AVE	MIN	Class Pairs:						
1 2 3 4	5415	1082	1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8
5 6 7 8			1: 9	2: 3	2: 4	2: 5	2: 6	2: 7	2: 8
Classes			2: 9	3: 4	3: 5	3: 6	3: 7	3: 8	3: 9
1 Bush			4: 5	4: 6	4: 7	4: 8	4: 9	5: 6	5: 7
2 Forest			5: 8	5: 9	6: 7	6: 8	6: 9	7: 8	7: 9
3 Grassland			8: 9						
4 Bedrock			1082	4635	7507	2727	8719	2226	5124
5 Water			10248	5612	8533	3389	9705	3137	6108
6 Bare soil			11262	4423	5001	5676	2542	3294	6077
7 Farmland			6348	1626	6159	2588	3952	7369	3511
8 Irrigated Farmland			3912	9318	7436	3619	3692	4117	8390
9 Towns and houses			5859						

Table 5: Erdass Imagine Separability matrix calculated for the training sites of the 9 classes found in the Messica catchment on a Landsat 8 satellite image of 7 April 2013

Lastly, the contingency matrix results show the accuracy of the training sites. Overall 7 out of 9 classes have 85% of the training samples classified according to the assigned class and most overlap can be explained by land use that is closely related to each other like bush and forest (Table 6). But for the class irrigated farmland a lot of pixels in the training sites are classified as another class e.g. 30% of the pixels is classified as bare soil. This indicates that the training sites found for irrigated farmland are not very good. An explanation could be that the early growth stage of crops causes that the crops are too small to be noticeable for Landsat 8 or that maize is still on found on irrigated farmland.

Classes	Bush	Forest	Grass land	Bedroc k	Water	Bare soil	Farm land	Irrigated farmland	Towns and houses
Bush	91,97	5,77	0,77	0,00	3,81	0,00	3,88	0,00	0,00
Forest	2,59	91,34	2,31	0,00	0,00	0,00	0,28	0,00	0,00
Grassland	0,26	0,26	86,92	0,00	2,86	0,00	2,49	1,19	0,00
Bedrock	0,26	0,00	0,00	88,28	1,90	0,00	0,00	1,19	0,54
Water	0,78	1,31	2,31	1,56	82,86	0,00	1,11	4,76	0,00
Bare soil	0,00	0,00	0,00	2,34	0,00	94,59	0,83	29,76	0,00
Farmland	3,37	1,31	5,38	0,00	6,67	0,00	88,09	13,10	0,00
Irrigated farmland	0,78	0,00	2,31	7,81	0,95	5,41	3,32	50,00	0,00
Towns and houses	0,00	0,00	0,00	0,00	0,95	0,00	0,00	0,00	99,46

Table 6: Contingency matrix of the land use classes for the Landsat 8 image of 7 April 2013

The satellite image is classified based on the training sites with a maximum likelihood calculation. The biggest classified class in the catchment is agriculture (27%), which is found throughout the catchment. The classes bush, forest and grassland nearly cover 50% of total land use. On the flanks of the inselberg most forest is found, bush vegetation on smaller mountains and near streams while grassland is found on dryer places and on clear cut places on the inselberg (Figure 14). The accuracy assessment of the classified image indicates an overall accuracy of 73% based on 192 sampled pixels but for the class irrigated farmland the accuracy is lower 52% (Table 7). Also the classes water, grassland and bedrock score low. West of the local road and near the town Messica the classification does not match own observations; too much water, irrigated farmland and towns and houses are found (Figure 14).

April	# Pixels	Percent	Hectare	Accuracy
Towns and houses	5786	4,59%	521	84%
Bedrock	2358	1,87%	212	65%
Bare soil	4713	3,74%	424	80%
Water	4795	3,80%	432	54%
Farmland	34557	27,39%	3110	82%
Irrigated farmland	12081	9,57%	1087	52%
Bush	26132	20,71%	2352	84%
Forest	20667	16,38%	1860	92%
Grassland	15084	11,96%	1358	63%
Total	126173	100%	11356	73%

Table 7: Classified land use for 7 April 2013 and corresponding accuracy per land use class

4.2.3 Land use classification of 8 June 2013

For the classification of the image of 8 June the training samples were checked for average reflectance per band and separability. For most classes the same training samples were used for the classification. But for bare soil and irrigated farmland the training samples were edited because the average reflectance per band graph indicated more overlap in the training samples compared to the satellite image of April. Natural vegetation and farmland classes show a lower reflectance in band 4 compared to April (Figure 11).

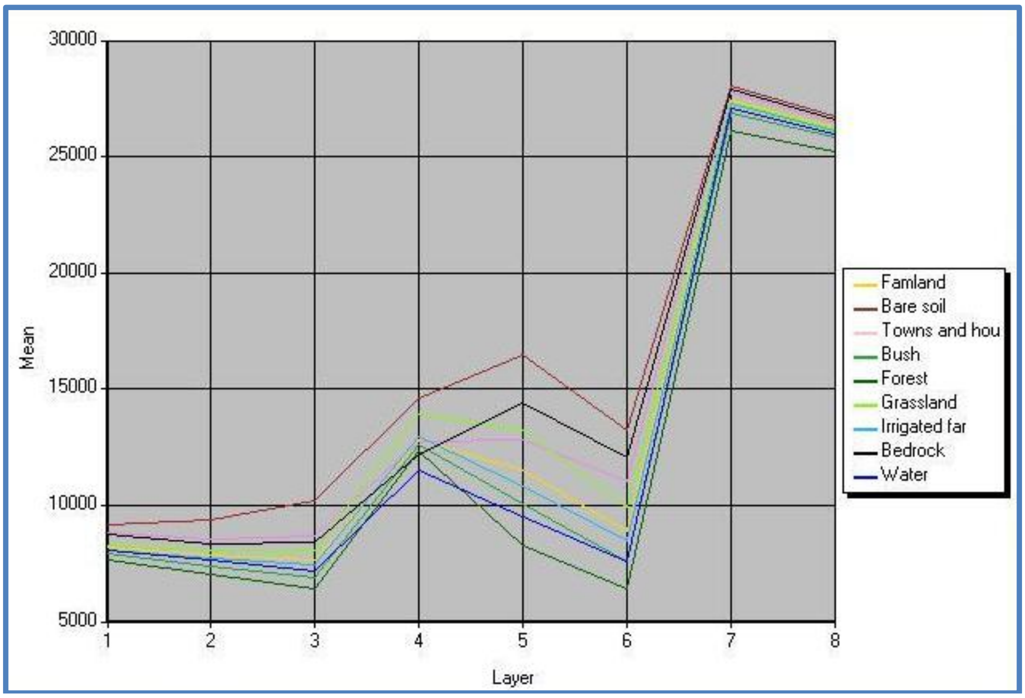

Figure 11: Average reflection per band of the training sites for the 9 land use classes based on the Landsat 8 satellite image of 8 June

The separability index shows that in June the overall separability increased compared to April (Table 8). But other training sites have low separability including the most important one; irrigated farmland that has a lowest separability score of 893 with farmland. Other classes with high overlap are towns and houses with bedrock, bush with water, towns and houses with grassland and bush with irrigated farmland.

Best Average Separability

Bands	AVE	MIN	Class Pairs:						
1 2 3 4	8401	893	1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8
5 6 7 8			1: 9	2: 3	2: 4	2: 5	2: 6	2: 7	2: 8
Classes			2: 9	3: 4	3: 5	3: 6	3: 7	3: 8	3: 9
1 Farmland			4: 5	4: 6	4: 7	4: 8	4: 9	5: 6	5: 7
2 Bare soil			5: 8	5: 9	6: 7	6: 8	6: 9	7: 8	7: 9
3 Towns and houses			8: 9						
4 Bush			7540	2920	2255	4707	2343	893	4520
5 Forest			2816	4962	9737	12127	5429	8352	3955
6 Grassland			10240	5103	7465	1980	3727	1994	5392
7 Irrigated farmland			2477	4403	1442	6674	1339	6809	3868
8 Bedrock			9055	2486	3084	3123	5140	5370	2165
9 Water			6962						

Table 8: Erdass Imagine Separability matrix calculated for the training sites of the 9 classes found in the Messica catchment on a Landsat 8 satellite image of 8 June 2013

The overall accuracy of the classified image is 87% with an accuracy of 73% for the irrigated agriculture class based on 178 test sample points. In June the amount of irrigated agriculture found in the catchment increased from 1087 to 1389 hectare and the amount of natural vegetation is still the largest class with 46% (Table 9). In the western and eastern parts of the catchment more irrigated agriculture is classified compared to the classification in April. In the west pixels that were classified as water changed to irrigated agriculture which does not match observations (Figure 14).

June	# Pixels	Percent	Hectare	Accuracy
Towns and houses	3755	2,98%	338	100%
Bedrock	4894	3,88%	440	100%
Bare soil	1562	1,24%	141	83%
Water	5221	4,14%	470	63%
Farmland	35762	28,34%	3.219	89%
Irrigated farmland	15436	12,23%	1.389	73%
Bush	23229	18,41%	2.091	92%
Forest	19978	15,83%	1.798	95%
Grassland	16336	12,95%	1.470	88%
Total	126173	100%	11.356	87%

Table 9: Classified land use for 8 June 2013

4.2.4 Land use classification of 26 July 2013

The training samples of July are again slightly edited to get more accurate training sites; especially the classes water and irrigated agriculture needed adjustment to get the most representative pixels. The average band reflections trend seen in June continuous, average reflection in band 4 decreased and more overlap between classes becomes visible. Examples are the classes rock with grass and towns and houses with farmland.

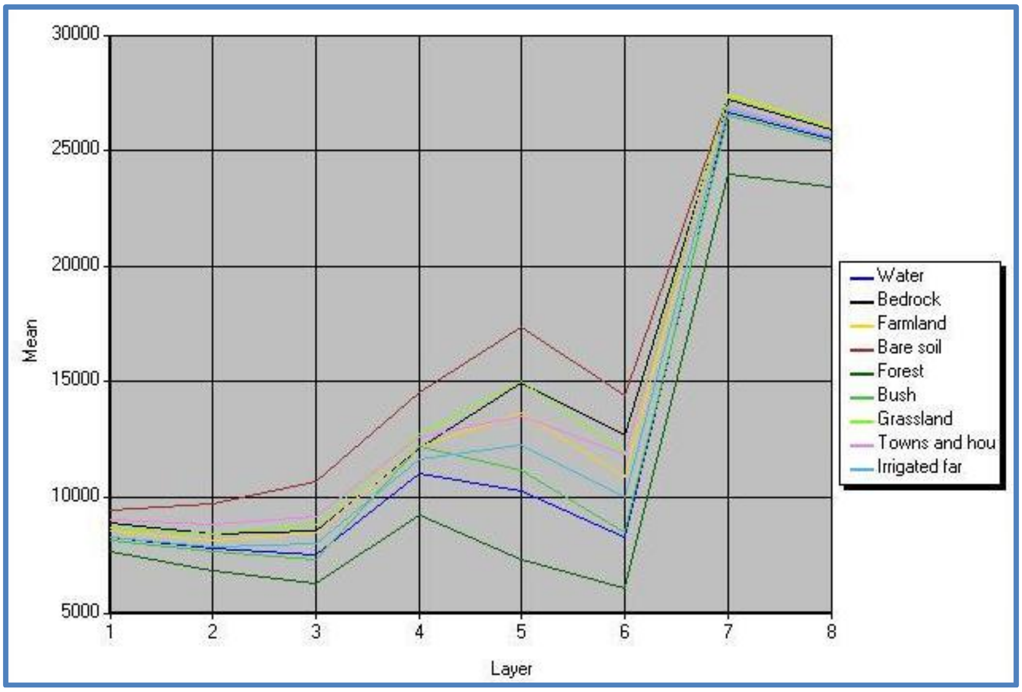

Figure 12: Average reflection per band of the training sites for the 9 land use classes based on the Landsat 8 satellite image of 26 July

The average separability is comparable with April but more classes have low separability scores especially the classes' bedrock with grassland (Table 10). The class irrigated farmland scores better than June for separability, most overlap is found with farmland but the value is 2017.

Best Average Separability

Bands	AVE	MIN	Class Pairs:						
1 2 3 4	5675	1105	1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8
5 6 7 8			1: 9	2: 3	2: 4	2: 5	2: 6	2: 7	2: 8
Classes			2: 9	3: 4	3: 5	3: 6	3: 7	3: 8	3: 9
1 Water			4: 5	4: 6	4: 7	4: 8	4: 9	5: 6	5: 7
2 Bedrock			5: 8	5: 9	6: 7	6: 8	6: 9	7: 8	7: 9
3 Farmland			8: 9						
4 Bare soil			6684	4647	10747	5572	6452	5491	2726
5 Forest			1635	2286	4604	11649	1105	1922	4006
6 Grassland			6388	6295	9908	1850	1661	2017	4332
7 Towns and houses			15700	4549	5339	8139	10198	11563	10520
8 Irrigated Farmland			7904	6159	1777	3769	5998	2981	5172
9 Bush			2558						

Table 10: Erdass Imagine Separability matrix calculated for the training sites of the 9 classes found in the Messica catchment on a Landsat 8 satellite image of 26 July 2013

In July the area of irrigated agriculture increased to 1609 hectare but again the places where the irrigated agriculture is found changed (Table 11 and Figure 14). Nearly all irrigated agriculture is found on the eastern slope of the inselberg, which matches observations. The overall accuracy of the classified image is 79% based on 193 control points. The accuracy for irrigated agriculture is 68% (Table 11).

July	# Pixels	Percent	Hectare	Accuracy
Towns and houses	3549	2,81%	319	79%
Bedrock	24870	4,08%	463	63%
Bare soil	909	0,72%	82	28%
Water	5149	4,08%	463	75%
Farmland	5141	19,71%	2238	79%
Irrigated Farmland	17873	14,17%	1609	68%
Bush	48493	38,43%	4364	84%
Forest	9610	7,62%	865	96%
Grassland	10579	8,38%	952	85%
Total	126173	100,00%	11356	73%

Table 11: Classified land use for 26 July 2013

4.2.5 Evaluation of the land use classification

The classification of the satellite images of April, June and July gave a wide variety in both the locations where the different land use classes were found and the total amount of hectares per land use class (Table 12 and Figure 14). The land use classes in the category other (bedrock, bare soil and towns and houses), decreased slowly from 1157 in April to 865 in July (Table 12 and Figure 13) but the internal variation shows more change e.g. bedrock from 232 hectare in April to 464 hectare in July and bare soil the opposite. Some of this variation is explained by the overlap in reflection of these classes as seen in the separability matrixes that led to errors in the land use classification that caused pixels to be classified in the class bare soil in April, in the class towns and houses in June and bedrock in July.

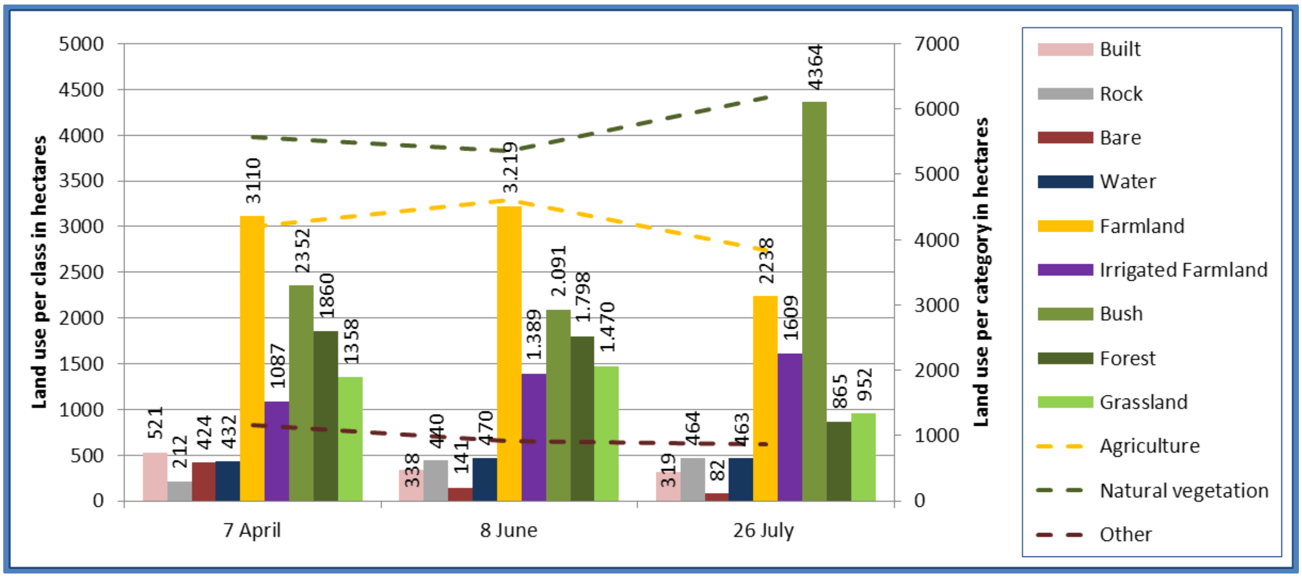

Figure 13: Land use in hectares per class in (bars) and pet category (dashed line)

In the category natural vegetation some changes per month were also found. In April and June big parts of natural vegetation on the eastern slope are classified as forest and grassland while in July land use classified as bush increased from 2091 hectare to 4364 hectare (Figure 13 and Table 12). Additionally the total area of natural vegetation increased from around 5400 hectares in April and June to 6181 while agriculture decreased from 3150 hectares to 2238 in July (Table 12 and Figure 13). A possible explanation is that the farmland without irrigation is not used from June until the end of October, during these months weed and bushes grow on these fields causing more overlap with the natural vegetation.

Land use Categories	April	June	July	Land use classes	April	June	July
Natural vegetation	5570	5359	6181	Forest	1860	1798	865
				Grassland	1358	1470	952
				Bush	2352	2091	4364
Agricultural land	4197	4608	3847	Farmland	3110	3219	2238
				Irrigated farmland	1087	1389	1609
Other	1157	919	865	Bare soil	424	141	82
				Towns and houses	521	338	319
				Rock	212	440	464
				Water	432	470	463

Table 12: Land use in hectares per categories and per class based on Landsat 8 satellite images of 7 April, 8 June and 26 July 2013

For the class irrigated farmland two clear trends became visible from April to July. Namely, the increase in size of total irrigated farmland from 1087 hectare in April to 1609 hectare in July and additionally the location of where irrigated farmland is found (Table 12 and Figure 14). In April irrigated farmland is found both in the western and eastern parts of the catchment while in July most irrigated farmland is found in the east (Figure 14). The classification of July fits best with observed land use during fieldwork and with reports of (Oord, 2012 and Reumkens and De Boer, 2011) that state that most irrigated farmlands are found on the eastern slopes of the inselberg. The total area of irrigated farmland is higher than estimations of Oord (2012) and observed values. Oord (2012) estimated 1000 hectares of irrigated farmland in 2012 and during field work only 882 hectares of irrigated farmland is visited. Moreover, farmers indicated that due to financial limitations (see 4.4), they do not always use their whole field for irrigated crops. Farmers were asked to indicate how much of their irrigated farmland they planned to use in 2013. From the 882 measured hectares the questionnaire indicated that 388 hectares will be used in 2013 as irrigated farmland (Appendix 2: Visited irrigated farmland).

Unless the high value, chosen is to use the outcome of the satellite imagery of July because the locations of the class irrigated agriculture are represented best and the evaluation tools of Erdass give the same or better outcome for separability, overall accuracy and the accuracy of irrigated agriculture compared to the other classified images.

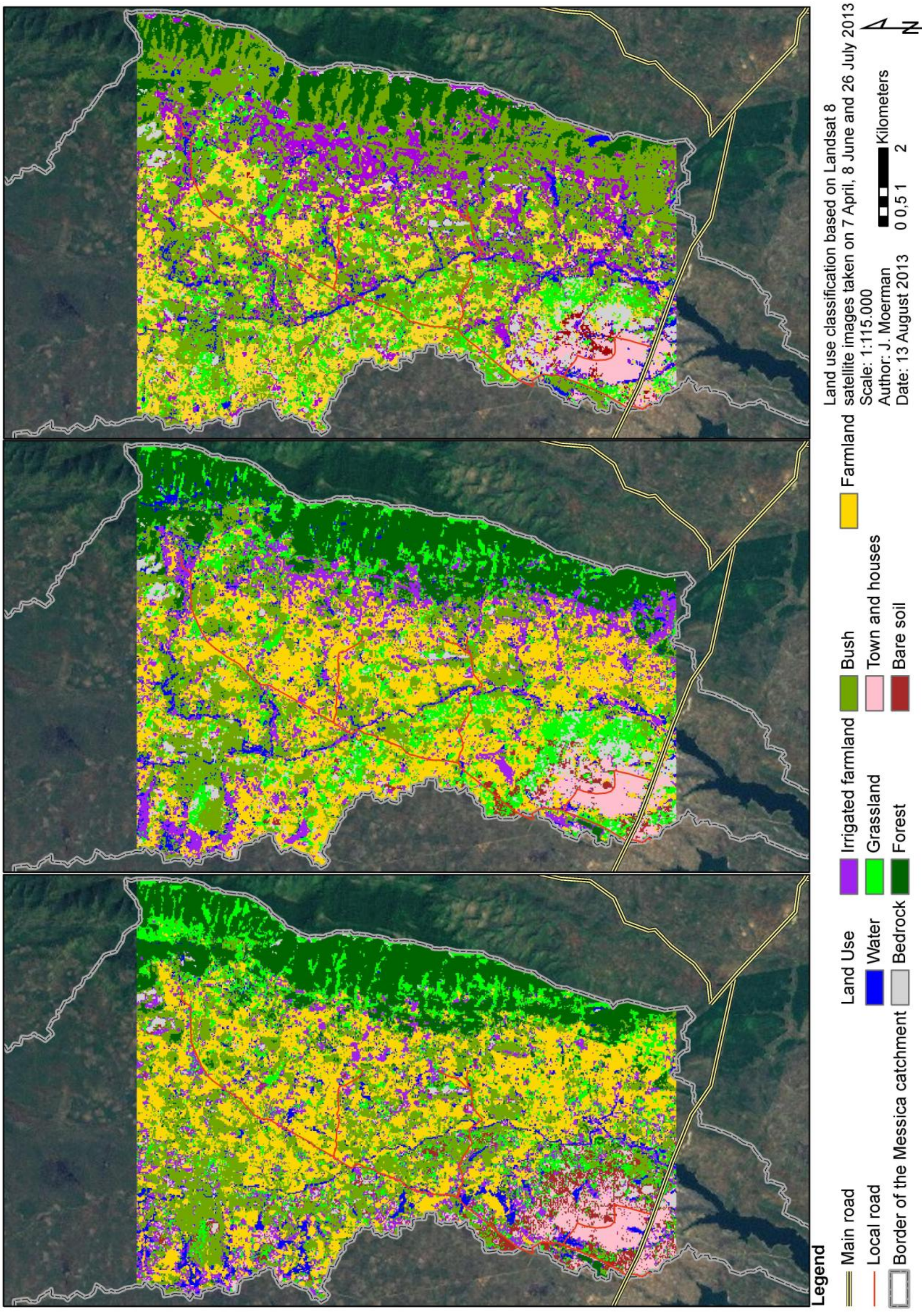

Figure 14: Land use classification maps of 7 April, 8 June and 26 July based on Landsat 8 satellite imagery

4.3 Water demand for irrigation

4.3.1 Determining reference evapotranspiration

Reference evapotranspiration is calculated with Blaney-Criddle method which uses mean monthly temperature (T_{mean}) and the mean daily percentage of annual daytime hours (p). Values for p are found in the paper of Brouwer and Heibloem (1986) for different latitudes and average monthly temperature data is used from a weather station in Manica, 25 kilometers west of the Messica catchment (Table 13) (FAOclim-net, 2013).

$$Et_0 = p(0{,}46 * (T_{mean} + 8))$$

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
p for Latitude (20° S)	0,30	0,29	0,28	0,26	0,25	0,25	0,25	0,26	0,27	0,28	0,29	0,30
T_{mean}	24,2	24,2	23,2	21,5	18,8	17,0	15,8	18,0	20,3	23,3	24,1	24,0
Et_0	4,4	4,3	4,0	3,5	3,1	2,9	2,7	3,1	3,5	4,0	4,3	4,4

Table 13: Reference crop evapotranspiration Et_0 in mm per month as a function of mean daily percentage (p) of annual daytime hours for 20° S (Brouwer and Heibloem, 1986) and Mean monthly temperature in °C (FAOclim-net, 2013)

4.3.2 Determining local crop water demand

Reference crop evapotranspiration is adjusted with crop factor (K_c). In order to determine the crop factor interviews about land use indicated which crops are planted and how long these crops are on irrigated farmland in 2013. The interviews indicated the main crops planted on irrigated farmland namely; maize by all farmers, tomatoes (64% of all farmers), covo (61% of all farmers) and beans (58% of all farmers) (Table 14 and Appendix 2: Visited irrigated farmland).

Crop	# of farmers	Percentage	Crop	# of farmers	Percentage
Maize	32	100	Soy Beans	2	6
Tomato	23	64	Wheat	2	6
Covo	22	64	Green Beans	1	3
Beans	21	58	Tobacco	1	3
Onion	12	33	Garlic	1	3
Sorghum	6	17	Carrots	1	3
green pepper	6	17	Nuts	1	3
Cabbage	5	14	Pumpkin	1	3
Potato	3	8	Nyimo	1	3
Yam	3	8	Sesame	1	3
Lettuce	2	6	Rice	1	3
Peanuts	2	6	Okra	1	3

Table 14: Most named sown crops in the Messica catchment by the 32 interviewed farmers with irrigated agricultural fields

In Table 15 the crop factors for the most common grown crops in the catchment and corresponding days per growth stage are described. The table consists of data from Brouwer and Heibloem (1986) with the K_c factors while the growth stages of the crops are based on interviews with farmers (Appendix 2: Visited irrigated farmland).

Crop	Initial stage		Crop development		Mid-season stage		Late season stage		
	K_c	days	K_c	days	K_c	days	K_c	days	total
Maize	0.40	30	0.80	50	1.15	60	0.70	50	185
Tomato	0.45	20	0.75	30	1.15	30	0.80	20	100
Covo	0.45	10	0.75	20	1.05	35	0.90	10	75
Beans	0.35	20	0.70	25	1.10	35	0.30	20	100

Table 15: Growth times derived from interviews and crop factor (K_c) for the different growth stages from Brouwer and Heibloem (1986).

Lastly the crop factors are corrected for influences of wind and relative humidity. Average wind speed per month is throughout the year lower than 2 m/s therefor K_c is not corrected for wind speed (Table 16). Relative humidity is only in February eligible for correction. But because but both wind speed and relative humidity have to exceed the limits defined by Heibloem and Brouwer the crop factor is not corrected (Table 16).

Months	Average Wind speed (m/s)	Relative Humidity (%)	Months	Average Wind speed (m/s)	Relative Humidity (%)
Jan	1,1	78	July	0,7	67
Feb	1	80	Aug	1,1	60
Mar	0,7	79	Sept	1,4	59
Apr	0,7	74	Oct	1,7	64
May	0,8	67	Nov	1,5	69
June	0,7	67	Dec	1,2	75

Table 16: Average monthly wind speed (m/s per month) and relative humidity in (% per month) (FAOclim-net, 2013) and (Myweather, 2013)

Based on the interviews the two most found planting schemes were used to calculate $K_{c\,month}$. During the interviews it became clear that there are several factors that influence the choice of crops on irrigated farmland. Firstly, in order to prevent the field from exhaustion maize or sorghum is planted every year. Most maize is planted in spring from October until half November and harvested in April or the beginning of May. After maize or sorghum farmers mainly chose to sow beans, covo or tomatoes on their fields, the choice depends on seed availability, money and custom habits.

Most farmers rather plant tomatoes in autumn (May) than in winter (July) because low winter temperatures and water shortages affect tomatoes more than beans and covo. Some farmers act contrary to evade the drop of tomato prices due to a surplus of ripe tomatoes in June and July. At the end of July or in the beginning of August farmers that have sufficient money to buy inputs and water in their canal plant a new field that is harvested in October just before the wet season starts (Table 17).

This leads to two major growth schedules: one consists of tomato and covo while the other includes beans and covo (Table 17).

$$K_{c\,month} = \frac{\sum days\ initial\ stage}{30} * \mathrm{K}_{\mathrm{c\ initial}} + \frac{\sum days\ crop\ development}{30} * \mathrm{K}_{\mathrm{c\ crop\ development}}$$

$$+ \frac{\sum days\ mid\text{-}season\ stage}{30} * \mathrm{K}_{\mathrm{c\ mid\text{-}season\ stage}} + \frac{\sum days\ late\ season\ stage}{30} * \mathrm{K}_{\mathrm{c\ late\ season}}$$

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Crop	Maize				Tomato			Tomato / Covo	Covo	Covo / Maize	Maize	
Days	30	30	30	30	30	30	30	10 / 20	30	25 / 5	30	30
$K_{c\,month}$	0.98	1.15	0.93	0.70	0.55	0.77	1.03	0.67	0.95	0.87	0.47	0.80
Crop	Maize				Covo		Covo / Beans	Beans		Beans / Maize	Maize	
Days	30	30	30	30	30	30	15 / 15	30	30	25 / 5	30	30
$K_{c\,month}$	0.98	1.15	0.93	0.70	0.65	1.05	0.65	0.64	1.10	0.45	0.47	0.80

Table 17: Most found growth schedules in the Messica catchment on irrigated plots and corresponding $K_{c\,month}$

4.3.3 Effective precipitation

Effective precipitation (P_{eff})is calculated from FAOclim-net average precipitation data from 1961 to 1990. In fall and winter the average monthly rainfall is low leading to a negative sum of effective precipitation in April, May, June and July while in the other months effective precipitation is positive (Table 18).

$$P_{eff} = 0{,}8 * P_{mean} - 25\ \ if\ preciptation > 75\ mm/month$$
$$P_{eff} = 0{,}6 * P_{mean} - 10\ if\ preciptation < 75\ mm/month$$

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
P_{mean}	230	103	34	16	13	9	13	19	49	136	182	210
P_{eff}	159	57,4	10,4	-0,4	-2,2	-4,6	-2,2	1,4	19,4	83,8	120,6	143

Table 18: Effective precipitation (P_{eff}) in mm per month based on average monthly precipitation (P_{mean}) from FAOclim-net (1961-1990)

4.3.4 Water demand for irrigation

With the methodology of Brouwer and Heibloem (1986) water demand for the most found planting schemes is estimated. The results show that in the months April to August there is a water demand for irrigation. Depending per planting scheme water demand fluctuates during the autumn and winter months. For both schemes water demand in June is highest with 6,8 mm per month shortage for tomatoes and 7,6 mm per month shortage for covo (Table 19).

$$Crop\ water\ demand\ scheme\ 1 = (Et_0 * K_{c\ month\ scheme\ 1}) - P_{eff}$$
$$Crop\ water\ demand\ scheme\ 2 = (Et_0 * K_{c\ month\ scheme\ 2}) - P_{eff}$$

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
$K_{c\ tomato/covo}$	1,0	1,2	0,9	0,7	0,6	0,8	1,0	0,7	1,0	0,9	0,5	0,8
$K_{c\ covo/beans}$	1,0	1,2	0,9	0,7	0,7	1,1	0,7	0,6	1,1	0,5	0,5	0,8
Et_0	4,4	4,3	4,0	3,5	3,1	2,9	2,7	3,1	3,5	4,0	4,3	4,4
P_{eff}	159,0	57,4	10,4	0,4	2,2	4,6	2,2	1,4	19,4	83,8	120,6	143,0
Water demand tomato covo	154,7	52,5	6,7	-2,9	-3,9	-6,8	-5,0	-0,7	16,1	80,3	118,6	139,5
Water demand covo beans	154,7	52,5	6,7	-2,9	-4,2	-7,6	-4,0	-0,6	15,6	82,0	118,6	139,5

Table 19: Estimated water demand for the two most found planting schemes during fieldwork in 2013. Et_0(mm per month), $K_{c\ month}$ (dimensionless per month), P_{eff} (mm per month) and water demand in (mm per month)

Finally, based on the Area of irrigated land found with remote sensing techniques and Crop water demand for the two planting schemes water demand for irrigation can be estimated.
The two planting schemes are assigned to the found Area of irrigated farmland from the remote sensing classification. Chosen is to assign 60% of total land use with the planting scheme tomato and covo and 40% with covo and beans based on Table 14 and observations. The water demand for irrigation based on the land use classification of July; total water demand for irrigation is highest in June namely 114561 m³ per month which corresponds with around 45 liter per second. Lowest Water demand for irrigation is found in August; 4 liter per second.

$$Water\ demand\ for\ irrigation = (Area\ of\ irrigated\ farmland * Cropwater\ demand\ scheme\ 1) * 0{,}6 + (Area\ of\ irrigated\ farmland * Cropwater\ demand\ scheme\ 2) * 0{,}4$$

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Water demand scheme 1	154,7	52,5	6,7	-2,9	-3,9	-6,8	-5,0	-0,7	16,1	80,3	118,6	139,5
Water demand scheme 2	154,7	52,5	6,7	-2,9	-4,2	-7,6	-4,0	-0,6	15,6	82,0	118,6	139,5
Irrigated farmland	0	0	0	1609	1609	1609	1609	1609	0	0	0	0
Water demand per month in m³	0	0	0	46661	64682	114561	74014	10619	0	0	0	0
Water demand per second in liters	0	0	0	18	25	44	29	4	0	0	0	0

Table 20: Calculated water demand for irrigation (m³ per month) for 2013. Water demand for grow scheme 1 and scheme 2 in mm/per month and irrigated farmland in m³

4.4 Research question 2: Limitations that affect current water demand

4.4.1 Introduction

During fieldwork 47 semi-structured interviews were conducted to determine limitations that smallholder farmers currently experience. In total the farmers mentioned 19 different limitations that were mentioned 197 times as a problem. The paragraphs organized per limitation category of Tafesse (2003), Kortenhorst (1980) and Mujere (2005) and the limitations are illustrated by a quote of a farmer. In 4.4.2 the environmental limitations, 4.4.3 the economic limitations and 4.4.4 the social limitations are described. In 4.4.5 the results of the interviews are combined with observations during fieldwork and analysed for their consequences on current water demand for irrigation

4.4.2 Environmental limitations

Farmers named 7 different limitations related to the environment, which were mentioned 58 times. Most mentioned are problems related to climate variability (Figure 15). Other environmental limitations mentioned by Tafesse (2003), Kortenhorst (1980) and Mujere (2005) like diseases and lack of knowledge were rarely mentioned as a limitation. Four farmers mentioned no problems at all.

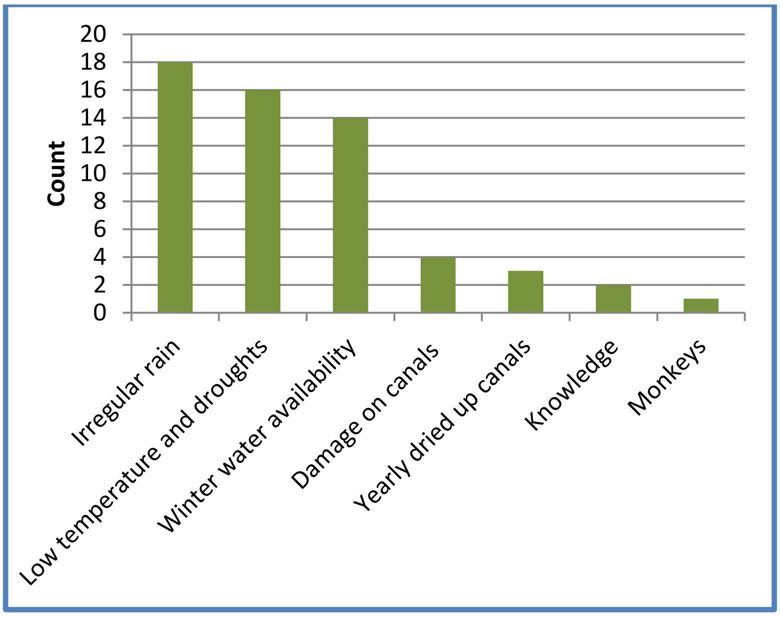

Figure 15: Categorized environmental limitations derived from interviews with 47 farmers in the Messica catchment

Irregular rain at the start and the end of the wet season is mentioned by 18 out of 47 farmers. This problem is mostly related to non-irrigated fields in the research area although irregular rain causes farmers to plant their maize later which effects the planting time of other crops.

> *'My maize did not grow well this year because after good rains in the beginning of November the rain stopped until December which caused that the sun burned my maize.'*

A second problem mentioned is that dry years give problems with water availability in the winter causing farmers to plant less crops and to irrigate during night (14 out of 47).

> *'The years 1992, 2002, 2008 and 2012 had less rain. If the rain during summer is low, I plant fewer crops because the streams also have less water during the winter'*

Additionally, 3 farmers mentioned that every year during August and September their canal dries up. This made it for them impossible to use their fields.

> *'The water or my irrigated crops is behind my own dam, every year in August and September the water dries up. During those months I cannot use my irrigated farmland'*

During winter farmers have problems with irrigated crops, especially tomatoes. Low temperatures and droughts cause need for pesticides against spiders and phytophthora (16 out of 47).

> *'During June and July the temperatures are too low. I use pesticides to prevent tomatoes from illnesses caused by low temperatures and spiders. Shortages of money to buy pesticides sometimes prevent me to plant tomatoes In these months'*

Lastly, there are some local problems mentioned by just a few farmers. Four farmers mention that floods and heavy rains in the summer damage their crops, irrigation canals and inlets. Two farmers have problems with their knowledge about the application of pesticides and fertilizers and one farmer has problems with monkeys that eat and damage his crops.

4.4.3 Economic limitations

The category economic limitations scored 6 problems that were mentioned 93 times in total (Figure 16). Hereby the economic limitations are mentioned most. Often during the explanation of the goal of the interviews farmers directly mentioned that their biggest problem is shortages of money to buy inputs (e.g. fertilizer, seeds and pesticides).

36 farmers mentioned that a shortage of money to buy inputs resulted in lower usage of irrigated farmland.

> *'I do not have enough money to buy all the inputs for my field. This year I try to plant more maize. By selling maize I want to buy more inputs for my irrigated farmland.'*
>
> *'For me it's hard to get money and save money to invest in my irrigated farmland, once I earned some money after selling covo and tomato we need to buy medicine, cloths and cooking oil.'*

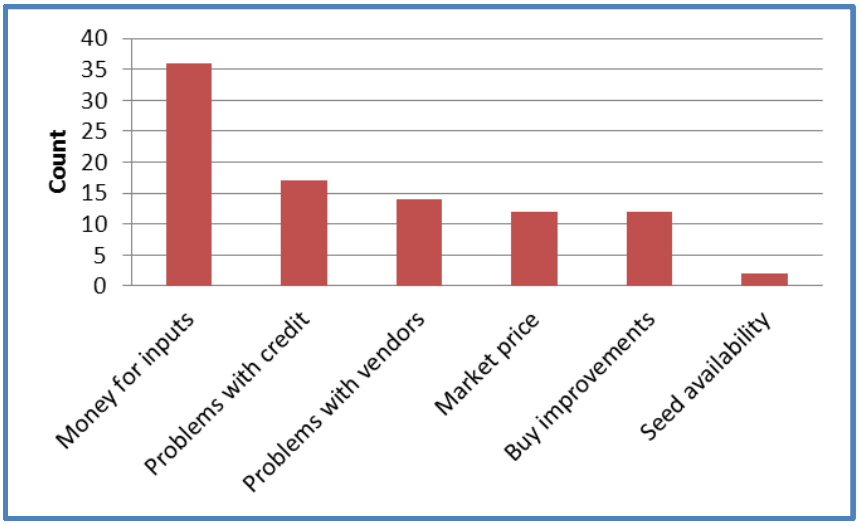

Figure 16: Categorized economic limitations derived from interviews with 47 farmers in the Messica catchment

The problem of insufficient money to buy inputs is found in several other problems. 17 farmers mentioned that they do not know or have the possibility to get a credit. They state that credit from the bank has payback times that do not correspond with the timespan to grow crops and the interest rates are high.

> *'The payback time of credits from the bank is to short. I have to pay interest and a part of my loan before my harvest is ready to sell'*

> *'I head that the government also has options to get a credit, but I don't know how to apply for it'*

Another problem is that some farmers are not eligible for a credit because farmers lack a pawn or are scared that they lose their belongings if they do not manage to pay back credit.

> *'For me it's not easy to get a credit because the bank needs to be sure that you can payback the credit'*

> *'I do not want to get a credit from the bank because of the high interest and the pawn on my belongings. I am scared that I cannot pay back the credit in time and that the bank takes my house or other belongings'*

Some farmers stated that they work with vendors to get inputs and sell their crops. Vendors buy tomatoes directly from the farmer at the field and supply inputs as a credit. When the next harvest is ready the farmer is obligatory to sell the harvest to the same vendor. 14 farmers stated that they have problems with the lower price they get from the vendor after he supplied the inputs. Farmers that do not use vendors for inputs also mentioned the danger of working with the inputs from vendors.

> *'The vendor bought my box of tomatoes only for 200 Metical while my neighbour sold his tomatoes for 300 Metical per box. The profit on my tomatoes is too low, now I have to use the same vendor again to get inputs'*

'Taking a credit from vendors is dangerous, because they buy your tomatoes for a lower price. If you don't watch out you will become an employee of the vendor instead of an independent farmer'

12 farmers mentioned problems with the ability to sell their harvest with a good price on the market, especially in August prices can be low compared to the investment made. During these months vendors buy for low prices or do not come at all and if the tomatoes are brought to the market by the farmer the prices are also low.

'Sometimes there are too much tomatoes, even if I bring the tomatoes myself to the market the prices are low.'

A problem less mentioned is the lack of money to invest in field improvements, 12 out of 47 farmers mentioned that they lack money to invest in field improvements like sprinklers, tubes, transport improvements, specific seeds, labour to assist with weeding and irrigated canal improvements.

'It's hard for me to improve my irrigated agriculture because I lack money to invest in people to help me weeding and to fix my canal after heavy rains'

Lastly 2 farmers mentioned that it is hard to get specific seeds, especially potato seeds are mentioned.

'In the past a NGO helped me to get diverse seeds that spread the risk of low prices and diseases. But since their help stopped it's hard for me to get the different seeds I want'

4.4.4 Social limitations

The problems that fall under the category social limitations were mentioned the least. Farmers often needed an explanation about what is considered as a social problem before they answered the questions. In total 27 problems were mentioned in this category divided in 6 categories. Subsequently, twenty farmers did not mention any social problems at all (Figure 17).

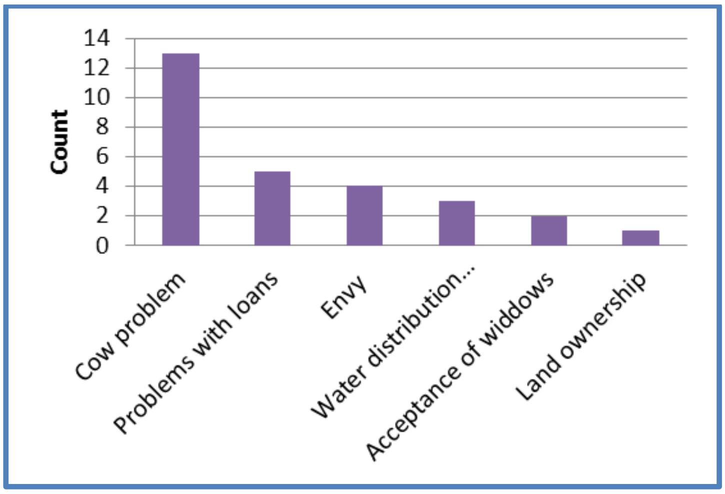

Figure 17: Categorized social limitations derived from interviews with 47 farmers in the Messica catchment

Problems with cows are mentioned most; cows of fellow community members eat and or damage crops during grazing (13 out of 47). Cows are held near the houses of farmers but grazing takes place in communal bushes and grasslands in the catchment. Children of the farmer supervise and bring the cows to these places to graze and to take care of the cows. But during transport to the grazing grounds and during grazing cows also eat crops from agricultural land if the supervisor pays no attention.

> *'Sometimes my children forget to take care of our cows and I have to arrange something with my neighbours sometimes the same thing happens to me, that just the way it goes'*

The cow problem is often related to other problems mentioned like envy (4 out of 47) and the position of widows (2 out of 47) (Figure 17). These both groups state that fellow community members lack respect to them and that cows of other farmers accidently come to their places. The farmers that mentioned envy or problems with widows stated that envy is related to farmers that own more land or money while the widows suffer from the less respected position of single women.

The farmers that didn't mention any social problems they often knew the problems related to cows but stated that the rules set by local leaders solved the problem for them. The rules consist of paying compensation for the made damage or by accepting that the next your own cows damage the crops of others.

Other social problems are discussions about), problems with loans in the community (5), water distribution during droughts (3) and land ownership (1).

4.4.5 Analysis of the found limitations

The interviews show that the category economic limitations scored highest. In total 6 different problems were mentioned 93 times compared to 7 problems mentioned 58 times and 5 problems mentioned 27 times for the categories environmental and social limitations (Figure 18).

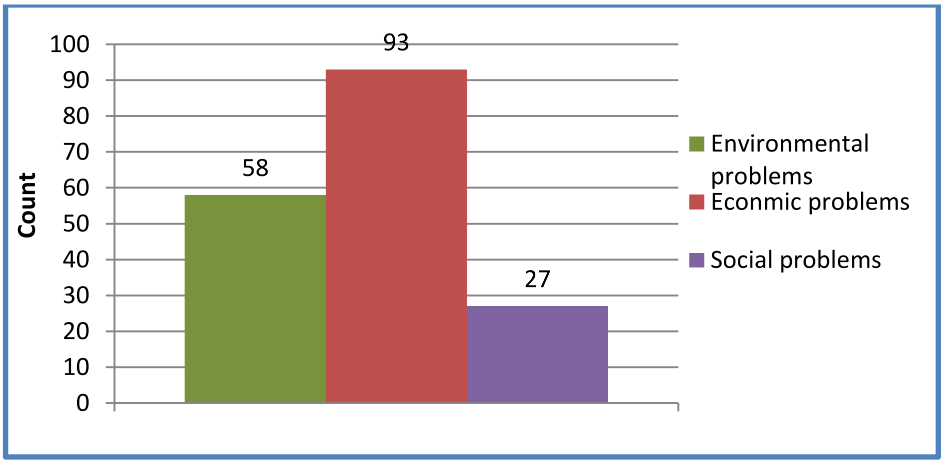

Figure 18: Number of problems mentioned per limitation during interviews with smallholder farmers in the Messica catchment

The most mentioned problem is the lack of inputs due to money constraints (36) (Figure 19). In several other problems the lack of money is also found. Examples are the problems: low temperatures during winter (16) (can be solved buying with pesticides), problems with vendors (14), lack of money to invest in agricultural improvements (12), the market price (12) and problems with loans (5). In total 95 out of the 178 mentioned problems are related with lack of money.

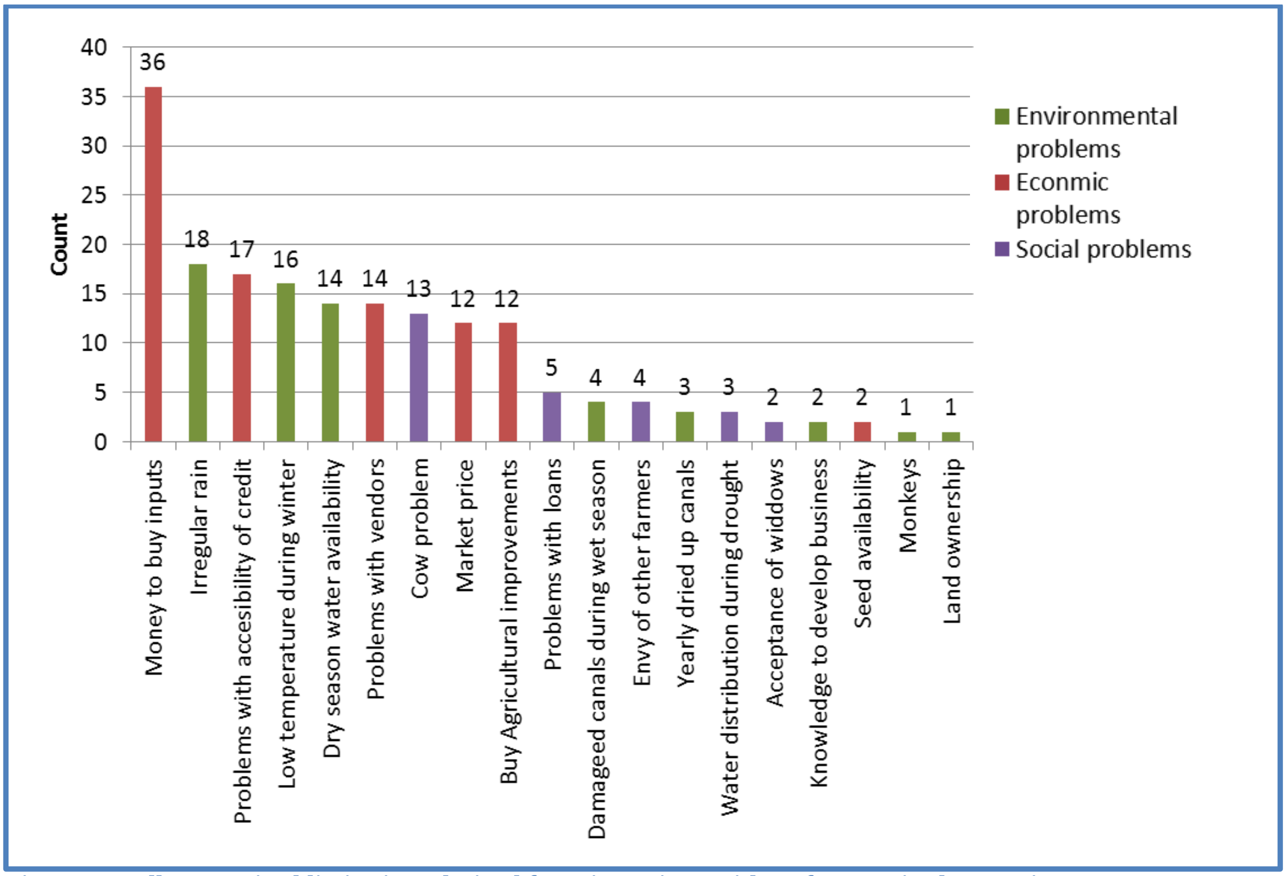

Figure 19: All categorized limitations derived from interviews with 47 farmers in the Messica catchment per category and total (upper right)

Subsequently, farmers also have problems by obtaining or saving money: access to a bank savings account (17), lack of knowledge about options to save money and fear to pay back loans and unsuitable loans (2) (Table 19). If the problems with money are combined with the problems related to lack of money, 114 out of 179 problems fall under the category economic limitations. The only other problem found in the category economic is seed availability (2).

The second most mentioned are problems with the environment (40 out of 179 problems) mostly rain is a constraining factor: rain damage and rain irregularity during summer (18 and 4) while yearly shortages (3) and dry year shortages (14) occur during winter. Last mentioned is a monkey problem by 1 farmer. Plagues or diseases don't give problems in the catchment, during winter pesticides against low temperatures and spiders are sufficient solutions. Irrigation during dry spells in summer and improvement of inlets and canals could improve the problems of irregular rain. Overall the environment is mostly favourable for irrigated agriculture also indicated by the fact that four farmers stated that they do not have any environmental problems.

The biggest social problem mentioned is the cow problem.13 farmers state that cows often eat and damage their crops but 10 farmers neglect the problem and state that compensation arrangements fix the problem. The community is led by several chiefs and under-chiefs that manage problems with cows, land ownership and other community related problems and make rules for the community which are accepted and controlled by the community itself. Most other problems are also fixed by the community itself like envy to other farmers (4), water distribution during droughts (3), acceptance of widows (2) and land ownership (1).

By evaluating the results of the interviews the problems related to credit in the category economic limitations grew from 93 to 114 problems. Environmental (40) and (23) social problems are relatively small. Based on the interviews the biggest problem farmers currently have fall in the category economic limitations, especially problems with credit and financing irrigated agriculture. Based on the interviews, current water demand for irrigation is mostly limited by economic limitations considering credit. Improvement in this limitation will lead to a higher water demand for irrigation.

5. Discussion

5.1 Introduction

The discussion is split up in three parts for the 3 main parts of the study. First the land use classification is discussed in (5.2.1 to 5.2.3). In 5.2.4 and 5.2.5 the estimation of water demand for irrigated farmland is discussed. In the last paragraph (5.3.1) the outcome of the results of the limitations experienced by irrigation agriculture is discussed.

5.2 Water demand for irrigation

5.2.1 Selection of satellite imagery

The land use classification is based on Landsat 8 satellite imagery because these images were available without charge and in a frequent time series since the launch in February 2013. Other satellite images acquired from Landsat 5 and Landsat 7 were old (newest image November 2011) and very inconsistent (only 3 imagers per year). An advantage of the Landsat 8 images was that the images were rapidly available after collection, that the satellite included more spectral bands compared to its predecessors and that the image of April had overlap with conducted fieldwork. The recent launch also had some disadvantages for the preparation and execution of fieldwork because Landsat 8 acquired its first images in April. Therefore during the preparation and fieldwork phase the training sites could only be analyzed on an older satellite image of Landsat 5. A second problem was that there were not yet satellite images available for the months August, October and September of the irrigation season. Monthly Landsat 8 data for the winter 2012 summer 2012-2013 would have made it possible to do a monthly land use classification and to include the newest satellite imagery in the preparation and fieldwork phases of the study.

5.2.2 Fieldwork

The choice of Landsat 8 satellite imagery led to some problems during fieldwork. The Landsat 8 satellite images have a pixel size of 30 meter (0.9 hectare) during fieldwork it was often hard to locate land use training sites for irrigated farmland, bare soil and grassland with a sufficient size to compensate for the mediocre resolution of the satellite images. A second problem was that the ground truthing training sites were based on a satellite image of November when there is not a lot of irrigated farmland used.

During visits of ground truthing sites the points made during preparation were hard to find or could not be reached, most mapped land use was therefore based on experience of the interpreter. Additionally, during fieldwork from March until May the growth of irrigated crops was not yet fully started. This gave problems for mapping fields because during the interviews it became apparent that not the whole irrigated fields are planted with crops making the useful training sites of irrigated farmland smaller.

5.2.3 Land use classification

During the classification of the satellite images the georeferenced photos and mapped fields were used to create training sites. As already mentioned, the resolution of the Landsat 8 image and the small relative small fields gave difficulties to train the pixels of the Landsat 8 image to the right land use class. Especially for the less abundant and often also smaller sized classes in the catchment, water, bare soil, irrigated farmland,

bedrock and grassland mapped ground truth points were small. This gave problems to find sufficient pixels that were not mixed with other land use classes (e.g. mapped ground truth splits a pixel in half bush and half bedrock). The separability tools of Erdass Imagine confirm this problems by indicating low separability and small differences in mean average band reflection in these classes.
The results showed differences in both hectares of classified land use per class and the location of where these classes were found. Due to practical constraints the classified images could not be checked for accuracy by visiting sample points but had to be checked behind the computer using an aerial photograph and the acquired fieldwork data. This resulted in a worse accuracy test, especially differences between irrigated farmland and farmland and bare soil and bedrock gave difficulties to check behind the computer.
The image classification of July is chosen as best classification because the locations of the class irrigated agriculture are spatially represented best. Furthermore, overall accuracy and the accuracy of irrigated agriculture are not different from the other classified images and separability of the class irrigated also scores sufficient. Possibly the lack of precipitation made it easier to distinguish irrigated farmland from other land use classes. But the hectares of irrigated farmland are higher than the projections of Oord (2012) and own estimations based on interviews about land use. Better planned fieldwork during the winter months, high resolution satellite images with a larger time series would yield improved results for the land use classification.

5.2.4 Water demand for crops (Reference evapotranspiration, crop factor and effective precipitation)

The method of Brouwer and Heibloem (1986) was used in combination with relatively old climatic data from 1961 to 1990 and some parts of the methodology are roughly estimated e.g. reference evapotranspiration, effective precipitation and the two chosen planting schemes. For relative humidity there was no data available from FAOclim-net resulting in the use of a weather website. More accurate calculation of these factors and adding more recent climatic data would enhance the reliability of reference evapotranspiration and effective precipitation. The interviews about land use about local planted crops, the plant and harvest time of these crops and the time per growth stage gave a lot of information, during the calculation of the crop factor this information is highly aggregated taking only the 4 most planted crops in to account in combination with the two planting schemes.

Lastly the choice to assign crop water demand as the amount of water needed to meet water loss through evapotranspiration for a crop per month does not take into account the actual amount of water distributed to irrigated farmland. Examples are leakages of irrigation water during transport, the effect of different irrigation techniques (e.g. sprinklers or furrow irrigation) and the actual amount farmers distribute to crops is not considered. But for the goal of this study, estimate current water demand in relation with water availability from (Weemstra, forthcoming) the found water demand gives an indication of the order of magnitude of crop water demand in the Messica catchment. In order to check crop water demand estimates match the reality in the Messica catchment an actual test of local water usage for irrigation would be a good addition.

5.2.5 Water demand for irrigation

The calculation of water demand for irrigation is based on both the classification of irrigated farmland and crop water demand. While the method of Brouwer and Heibloem (1986) is implemented with good results, the methodology to classify land use using remote sensing techniques gave more diverse results. The land use classification can be improved by using other satellite images with a higher resolution because the low resolution of the Landsat 8 images in relation with the size of irrigated farmland and other land use classes gave troubles to select sufficient training sites. Also the accuracy assessment that could not take place during fieldwork gave less certain results to the outcome of the total size of irrigated farmland. Therefore, a better estimation of the total size of irrigated farmland would increase the estimation of water demand for irrigation.

5.3 Limitations that affect current water demand

5.3.1 Limitations that affect current water demand for irrigated agriculture

The current limitations that affect current water demand for irrigated agriculture are based on interviews. During all interviews an interpreter was needed to communicate between researcher and the farmer. Farmers were very hospitable and friendly but due to indirect contact (interpreter), cultural differences and the power relation answers on interviews can be biased. During the interviews became clear that nearly all farmers stated that they lack money to buy inputs was their main limitation but during field visits irrigated farmland was fully used. Another example is that during interviews farmers answer quite shortly while during the visit of their field or during lunch they came up with more details concerning their problems. A possible explanation can be that farmers feel pressure during the interview or expect direct financial assistance from the interviewer.

The results of the interviews about current limitations helped to understand the current problems farmers experience with smallholder irrigation. The results show that problems related to financing irrigated agriculture are limiting their business most affecting current water demand for irrigation.

6. Conclusion

6.1 Research question 1: Water demand for irrigation

The land use classification of the satellite images of 7 April, 8 June and 26 July 2013 gave different results for the total area of irrigated farmland. The area increased from April to June from 1087 to 1389 hectares and in July to 1609 hectare. The numbers found in April and June comes close to the projection of Oord (2012) of 1000 hectares. But the spatial locations of irrigated farmland in April and June do not match observations from fieldwork, Oord (2012) and Reumkens and De Boer (2011). Secondly, compared to the amount of visited irrigated farmland during fieldwork the values are also high namely from the 882 hectare visited 388 is planned to be used. Nevertheless, chosen is to use the value of July for the estimation of water demand for irrigation because the accuracy is same as the other images and the spatial distribution of farmland fits better with Reumkens and De Boer (2011), Oord (2012) and field observations.
The big differences in estimated total area of found irrigated farmland indicate that the land use classification based on Landsat 8 satellite needs improvement. The usage of higher resolution satellite images and better planned fieldwork especially for the accuracy assessment would improve the land use classification.

The calculation of water demand is based on the two most found planting schemes in the catchment that consist of maize, tomatoes, covo, and beans. Crop water demand exceeds the amount of water supplied by precipitation from April to August (Figure 20). The amount of water needed to supplement the deficit of precipitation differs per month and by the amount of irrigated farmland. But the classification of irrigated farmland gave big fluctuations in the results therefore total water demand becomes a rough estimation. Based on 1608 hectares of irrigated farmland, water demand is highest in June with 44 liters per second. In combination with the water availability study of Weemstra (forthcoming) the result indicate the sustainability of current water use for irrigation in the Messica catchment**.**

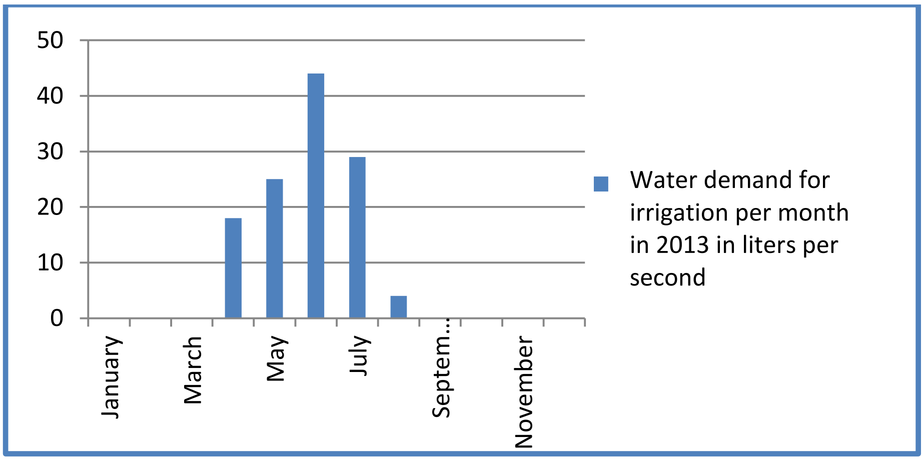

Figure 20: Water demand for irrigation per month in liter per second. In combination with Weemstra (forthcoming) the result indicates in the sustainability of current water use for irrigation in the Messica catchment

6.2 Research question 2: Limitations that effect current water demand

In 47 interviews with farmers 179 problems were mentioned that are divided over the 3 categories of limitations by Tafesse (2003), Kortenhorst (1980) and Mujere (2005).

Most mentioned were the problems related with economic limitations (93 times), in which money to buy inputs is mentioned most (36 times). Several other problems have the same origin or are related to the economic limitation lack of money to buy inputs. In total 114 problems are related to money and credit to buy or finance inputs or other essentials for irrigated agriculture. Examples are the position of vendors, low market prices, possibilities to get credit from a bank and problems with loans.
The second most mentioned problem is environmental damage due to abundance or scarcity of water causing damage to crops and irrigation systems mentioned by 39 farmers. In the category social limitations, problems with cows were mentioned most by 13 farmers in total.
The effects of these found problems in the different categories of limitations on current water demand for irrigation are not quantified but based on the interviews lack of financial means currently limits the amount of irrigated crops planted on irrigated farmland. An illustration of the consequences of the economic limitation is that for each visited irrigated farmland the owner indicated the size that will be used for irrigated agriculture in 2013. In total the visited farmers use 388 hectares from the total amount of 882 hectares irrigated farmland they own. Improvement of the financial position of farmers with irrigated farmland will increase the amount of planted crops and subsequently water demand for irrigation.

6. References

Alfani, F., Azzarri, C., d'Errico, M. and Molini, V. (2012). Poverty in Mozambique, New Evidence from Recent Household Surveys. Policy Research Working Paper 6217 The World Bank, October 2012

AsterGDEM (2013). Product information of AsterGDEM satellite imagery. Accessed (16-08-2012): http://asterweb.jpl.nasa.gov/gdem.asp

Brouwer, C., and Heibloem M. (1986). Irrigation Water Management: Irrigation Water Needs, Training manual no. 3. FAO, Viale delle Terme di Caracalla, 00100. Rome, Italy

Burrough, P. A., and McDonell, R. A. (1998). Principles of Geographical Information Systems, Oxford University Press, New York, New York, USA

IFAD (2012). Enabling poor rural people to overcome poverty in Mozambique, Rome February 2012

Chirwa, PW., Syampungani, S., and Geldenhuys, C. J. (2008). The ecology and management of the Miombo woodlands for sustainable livelihoods in southern Africa: the case for non-timber forest products. Southern Forests, 70(3) pp 237-245

De Jong, S. M., Addink, E., Zeijlmans, M., Nijland, W. (2009). Remote sensing – a Tool for Environmental Observations. Lecture notes Remote Sensing Course GEO 2-4208. University Utrecht Faculty of Geosciences, The Netherlands

DigitalGlobe (2010). Aerial photograph of Mozambique, accessed through ArcMap basemap application.

Pouncey, R., Swanson, K. and Hart, Katy (1999). ERDASS Field Guide. Atlanta, Georgia, USA

FAOclim-net (2013). Climate data from the Manica weather station Accessed (16-08-2012): http://geonetwork3.fao.org/climpag/agroclimdb_en.php

FAO (2000). Land Cover Classification System (LCCS): Classification Concepts and User Manual. Information Division, FAO, Viale delle Terme di Caracalla, 00100. Rome, Italy

Goodbody, S., Philpott, J. and Pound, J. (2010). FAO/WFP crop and food security assessment mission to Mozambique. FAO, Viale delle Terme di Caracalla, 00100, Rome, Italy

Green, J. and Thorogood, N. (2009). Qualitative Methods for Health Research. Sage Publications Ltd, London, UK.

Guerschman, J., P., Paruelo, J. M., Bella, C. D. I., Giallorenzi, M., C., and Pacin, F. (2013). Land cover classification in the Argentine Pampas using multi-temporal Landsat TM data. International Journal of Remote Sensing 24(17), 3381-3402

Koistinen, T., Lehtonen, M. I., Fernando, S. and Matola, R. (2008). Contribution to the Structure at the Eastern Margin of the Achaean Zimbabwe Craton, Mozambique. Geological Survey of Finland, Special Paper 48, pp 121–144

Kortenhorst, L. F. (1980). Factors affecting the viability of smallholders' irrigation. International Institute for Land Reclamation and Improvement 27 pp 125-138

Lankford, B.A. (2005). Rural infrastructure to contribute to African agricultural development: the case of irrigation. Report for the Commission for Africa, School of Development Studies, University of East Anglia, Norwich

Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. PNAS 104(50) pp 19680-19685

Mujere, N. and Mazvimavi, D. (5005). Challenges Affecting Irrigation Water Supply at Nyanadzi Smallholder Irrigation Scheme in Zimbabwe

MyWeather, (2013). Weather data from Weather station Chimoio, Average relative humidity per month from (1992 – 2013) accessed (16-08-2012): http://www.myweather2.com/City-Town/Mozambique/Chimoio/climate-profile.aspx

Nhantumbo, I., Dent, J. B., and Kowero, G. (2001). Goal programming: Application in the management of the miombo woodland in Mozambique. European Journal of Opreational Research 133 pp 310-322

Oord, A. L. (2012). Hydro(geo)logical Study Messica Catchment, Manica Province, Mozambique

Van den Pol, B. (2012). 'hot tomatoes' Smallholder business strategies, market opportunities and irrigation system dynamics in Messica, Central Mozambique and MSc thesis report, Irrigation and Water engineering Group, Wageningen University, the Netherlands

Reumkens, D. A. and De Boer, J. P. (2011). Irrigation Development along Africa's Rift Valley - A performance assessment of smallholder irrigation systems in the Manica district of Mozambique a literature review of systems along the Rift Valley. Internship and BSc thesis Report, Irrigation and Water Engineering Group, Wageningen University, the Netherlands

Strahler, A. H. and Archibold, O., W. (2004). Physical Geography: science and systems of the human environment. 3rd edition

Tafesse, M. (2003). Small-scale irrigation for food security in sub-Saharan Africa. The ACP-EU Technical Centre for Agricultural and Rural Cooperation (CTA), Ethiopia

Tschirley, D. L. and Benfica, R. (2001). Smallholder agriculture, wage labor and rural poverty alleviation in land-abundant areas of Africa: evidence from Mozambique. The Journal of Modern African Studies, 39, pp 333-358

Turker, M., Arikan M. (2005). Sequential masking classification of multi-temporal Landsat7 ETM+ images for field-based crop mapping in Karacabey, Turkey. International Journal of Remote Sensing 26(17) pp 3813-3830

USGS, (2013) Landsat 8 Data Product Information. Accessed (16-08-2012): http://landsat.usgs.gov/LDCM_DataProduct.php

Appendix 1: Questionnaire

Part 1: Land use

Land use

1. Which crops do you plant every year?
2. When do you plant and harvest these crops (which month and begin and of middle)?
3. Can we measure your biggest fields and what did you plant on them in 2002, 2003, 2007, 2008, 2012 and 2013?
4. How much of your irrigated farmland do you plan to use in 2013?

Part 2: Limitations

Overall limitations

1. Do you want to expand your irrigated fields or the crops you plant on these fields?
2. What kind of problems do you have by the expansion of your fields?
3. Did you have the same problems in the past?
4. How did you try to solve these problems?

Economic limitations

1. Is it always possible to sell your crops?
2. What options do you have to get credit?
3. Can you manage to do all the labour on your fields?

Environmental limitations

1. Do you have environmental problems like plant diseases or droughts?
2. Can sum up some exceptional dry years that affected your agriculture?

Social limitations

1. Do you have social problems like conflicts with neighbours?
2. Do you have enough knowledge to develop your agriculture?

Appendix 2: Visited irrigated farmland

Field code	Size	Usage	Size used	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1_1_1	17,5	0,5	8,8	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Beans	Beans	Beans	Maize	Maize
1_2_1	6,9	0,5	3,5	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Maize	Maize
1_2_2	7,5	0,5	3,8	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Maize	Maize
1_2_3	1,0	0,5	0,5	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Maize	Maize
1_2_4	7,8	0,5	3,9	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Maize	Maize
1_2_5	1,7	0,5	0,8	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Maize	Maize
1_3_1	3,0	0,5	1,5	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Maize	Maize
1_3_2	5,9	0,4	2,2	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Maize	Maize
1_3_3	8,9	0,0	0,0	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing
1_4_1	4,3	1,0	4,3	Maize	Maize	Maize	Maize	Covo	Covo	Covo	Tomato	Tomato	Tomato	Tomato	Maize
1_4_2	8,4	1,0	8,4	Maize	Maize	Maize	Maize	Covo/B eans	Covo/B eans	Covo/B eans	Tomato	Tomato	Tomato	Tomato	Maize
1_4_3	1,5	1,0	1,5	Nothing	Beans	Beans	Beans	Nothing	Nothing	Nothing	Beans	Beans	Beans	Maize	Maize
1_5_1	15,4	0,5	7,7	Maize	Maize	Maize	Maize	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Maize	Maize
1_5_2	1,5	1,0	1,5	Maize	Tomato	Tomato	Tomato	Tomato	Nothing	Nothing	Nothing	Nothing	Nothing	Maize	Maize
1_5_4	9,9	0,0	0,0	Maize	Maize	Maize	Maize	Maize	Nothing	Nothing	Nothing	Nothing	Nothing	Maize	Maize
11_1_2	25,3	0,6	15,2	Maize	Maize	Maize	Tomato /Beans/ Covo	Tomato /Beans/ Covo	Tomato /Beans/ Covo	Tomato /Beans/ Covo	Tomato /Beans/ Covo	Tomato /Beans/ Covo	Tomato /Beans/ Covo	Maize	Maize
11_3_1	12,8	0,5	6,4	Maize	Maize	Maize	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Maize	Maize
11_4_1	10,5	0,0	0,0	Maize	Maize	Maize	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Maize	Maize

11_5_1	8,3	0,5	4,2	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Tomato	Maize	Maize	Maize
11_5_2	6,8	0,0	0,0	Maize	Maize	Maize	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Maize	Maize
12_2_1	9,7	1,0	9,7	Maize	Maize	Maize	Nothing	Nothing	Nothing	Tomato /Maize	Tomato /Maize	Tomato /Maize	Tomato /Maize	Tomato /Maize	Tomato /Maize
12_2_2	11,6	1,0	11,6	Maize	Maize	Maize	Beans	Beans	Beans	Tomato /cabbage	Tomato /cabbage	Tomato /cabbage	Tomato /cabbage	Maize	Maize
13_1_2	10,3	0,1	1,0	Maize	Maize	Maize	Maize	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Maize	Maize
13_2_1	12,4	0,1	1,2	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Maize	Maize
14_1_2	1,4	1,0	1,4	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Covo	Covo	Covo	Maize	Maize
14_2_1	24,4	0,3	6,1	Maize	Maize	Maize	Maize	Tomato /Covo	Tomato /Covo	Tomato /Covo	Nothing	Nothing	Nothing	Maize	Maize
15_1_1	13,3	0,5	6,6	Maize	Maize	Maize	Beans	Beans	Beans	Tomato	Tomato	Tomato	Tomato	Maize	Maize
15_2_2	10,5	1,0	10,5	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Maize	Maize
16_2_1	10,0	0,3	2,5	Maize	Maize	Maize	Maize	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Maize	Maize
16_3_1	8,4	0,5	4,2	Maize	Maize	Maize	Maize	Covo	Covo	Covo	Covo	Covo	Covo	Maize	Maize
17_1_1	43,8	0,2	8,8	Maize	Maize	Maize	Maize	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Maize	Maize
19_1_1	29,7	1	29,7	Maize	Maize	Maize	Beans	Beans	Beans	Tomato	Tomato	Tomato	Tomato	Maize	Maize
2_1_1	8,3	0,8	6,2	Maize	Maize	Maize	Covo/Beans	Covo/Beans	Covo/Beans	Peas	Peas	Peas	Peas	Maize	Maize
2_2_2	13,1	0,5	6,5	Maize	Maize	Maize	Maize	Beans	Beans	Beans	Tomato /Covo	Tomato /Covo	Tomato /Covo	Maize	Maize
20_1_1	12,6	1,0	12,6	Maize	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Beans	Beans	Beans	Maize
3_1_1	14,0	0,5	7,0	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato /Covo	Covo	Covo	Maize	Maize
3_2_2	28,4	0,2	5,7	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato /Covo	Covo	Covo	Maize	Maize

3_3_1	31,3	0,4	12,5	Maize	Maize	Maize	Maize	Tomato /cabbage	Tomato /cabbage	Tomato /cabbage	Tomato /cabbage	Tomato /cabbage	Tomato /cabbage	Maize	Maize
4_3_1	19,8	0,5	9,9	Maize	Maize	Maize	Maize	Tomato /cabbage	Tomato /cabbage	Tomato /cabbage	Tomato /cabbage	potato	potato	potato	Maize
5_4_2	13,2	1,0	13,2	Maize	Maize	Maize	Covo	Covo	Covo	Covo	Covo	Covo	Covo	Maize	Maize
5_5_1	229,6	0,3	68,9	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato /Covo	Covo	Covo	Maize	Maize
6_1_1	24,6	0,4	9,8	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Maize	Maize
7_1_1	12,2	0,5	6,1	Maize	Maize	Maize	Maize	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Tomato /Covo	Maize	Maize
7_2_1	10,7	0,2	2,1	Maize	Maize	Maize	Maize	Beans/union	Beans/union	Beans/union	Beans/union	Beans/union	Beans/union	Maize	Maize
7_2_2	21,1	0,5	10,6	Maize	Maize	Maize	Maize	Maize	Nothing	Nothing	Tomato	Tomato	Tomato	Tomato	Maize
8_2_1	5,1	1,0	5,1	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Beans	Beans	Beans	Maize	Maize
8_2_2	15,3	1,0	15,3	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Beans	Beans	Beans	Maize	Maize
9_1_1	6,8	1,0	6,8	Covo	Tomato	Tomato	Tomato	Tomato	Maize	Maize	Maize	Maize	Maize	Covo	Covo
9_2_1	38,3	0,5	19,2	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Maize	Maize
9_3_1	9,8	0,3	2,9	Maize	Maize	Maize	Maize	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Maize	Maize