Sustainable agricultural development in Mozambique

A case study on the opportunities for sustainable agricultural development in the Mugrima community, Zambezia province, Mozambique

M.Sc. Thesis by Alex Roest

May 2008
Irrigation and Water Engineering Group
Associação de Promoção de Agricultura Comercial (APAC)

WAGENINGEN UNIVERSITY
WAGENINGEN UR

Sustainable agricultural development in Mozambique

A case study on the opportunities for sustainable agricultural development in the Mugrima community, Zambezia province, Mozambique

Master thesis Irrigation and Water Engineering submitted in partial fulfillment of the degree of Master of Science in International Land and Water Management at Wageningen University, the Netherlands

Alex Roest

May 2008

Supervisor(s):

Ir. Gerrit van Vuren
Irrigation and Water Engineering Group
Centre for Water and Climate
Wageningen University
Wageningen, the Netherlands
www.iwe.wur.nl

Ir. Jan de Moor
Associação de Promoção de Agricultura
Comercial (APAC)
Quelimane, Mozambique

Summary

Goal of this thesis research was the inventory of sustainable agricultural development opportunities in the Mugrima community with an emphasis on irrigation. The research was a case study of one out of approximately 100 communities in the Zambezia province. Every community has its own specific development opportunities depending on the resources at hand.

The first step was an overview of the land use rights in the community. Based on data available at the Cadastro (land registry) it seems that a part of the land is registered twice by Mugrima community members and "outsiders". This occurs despite the official recognized land use rights of the Mugrima community. Outsiders are pursuing large areas of land for different commercial purposes. Large parts of the community are currently unused and Mugrima community members don't have a plan to utilize the land use rights they officially own. This situation resulted in the request for a plan to utilize the land within the border of the Mugrima community and the quest for opportunities for development.

Mapping of land use in the community was a next step with which more insight in the Mugrima community was obtained. An overview of the hydrological situation was a final required action which needed to be taken in order to create a complete overview of the community. Mapping of land use and the hydrological situation was carried out with GPS field visits in combination with Google Earth Pro images.

Next to mapping of the different characteristics of the Mugrima community the fresh water availability for irrigation has been determined based on river discharge analyses and salinity intrusion modeling. Because of the short distance from the community towards the Indian Ocean, salinity intrusion occurs. Salinity intrusion into the estuary has been analyzed by a predictive model. This predictive model calculates the salinity intrusion into the estuary based on measurable parameters such as geometry, fresh water flow and tide. Based on these calculations it appears that the fresh water availability in the rivers is limited to the period from January until May. This requires a short cycle rice variety to be able to fit the growing season of the rice crop in the "window of opportunity" of fresh water availability.

Based on climatic data, soil samples, cropping data and fresh water availability the total new area which can be irrigated is 4000 hectares. Fresh water is available for such an irrigation area in the most upstream part of the community, because of decreasing salt water intrusion in the more upstream area. The layout of an irrigation system in the Mugrima community is dependent on the natural drainage pattern of the plains. In the mapping of the hydrological situation of the Mugrima community the natural drainage pathways of the plains in the Mugrima community are included. With the layout of the canals the natural drainage pattern is followed to reduce the required earth work. Canals run in between the natural drainage pathways.
Next to irrigation systems road rehabilitation and construction of new roads is seen as one of the main needs in order to open up the area and assure rural development. Currently

dry land rice cultivation is practiced by hand. This is a very labour intensive practice. By hand, the population of the Mugrima community is not able to cultivate more then the current area under dry land rice cultivation. Therefore, mechanization with tractors and ploughs is needed to be able to cultivate the new area of 4000 hectares.

Costs of the construction of irrigation systems, rehabilitation of the roads and construction of new roads are in total around US$ 20 million. Canal lining is the main expense due to the high costs of concrete. Local materials and labour are much less expensive (e.g.: earth work). The costs of construction, operation and maintenance have been compared to the net profits in rice yield over a period of 20 years. Based on the yearly difference between the costs and profits the internal rate of return of the construction of the irrigation and roads can be determined. The internal rate of return can be compared to the interest which is received for money on a bank account. Over a period of 20 years the internal rate of return of an irrigation system in the Mugrima community is 8.04%. The moment to invest in irrigation systems for rice cultivation is very good. Currently rice prices are rising rapidly due to decreasing food stocks and use of crops in bio fuel production.

The emphasis of the research was on irrigation opportunities. 4000 hectares of new irrigation systems are possible with a high economic rate of return. However, currently there is approximately 11,500 hectares unused. As a result, after the completion of the irrigation systems there will still be around 7,500 hectares of unused terrain left. This terrain is full of grass and ideally suitable for a cattle breeding (which is already done by an outsider in the community). In addition, opportunities are present in dry land rice cultivation as well. Currently large quantities of rainwater are lost due to drainage through the natural drainage network. By means of water harvesting in the field the rainwater can be harvested which can result in sufficient water, for rice cultivation, in one out of two years.

Acknowledgements

In this part of the report I would like to thank each one who helped me during the research.

To begin with I would like to thank Ir. Jan de Moor and Ir. Gerrit van Vuren who both supervised this research. Ir. Jan de Moor was my supervisor in Mozambique and gave valuable advice during my stay in Quelimane. Next to this he arranged several appointments with people in the irrigation business, listened to my train of thoughts, brought me to the hospital when I was sick and showed me a large part of the Zambezia province during my stay.
Ir. Gerrit van Vuren is the supervisor from Wageningen University. He arranged a university laptop which I could bring to Mozambique. Furthermore, after my return in the Netherlands he gave advice on how to finalize this thesis report.

Other people to whom I would like to show my gratitude are the people working at the APAC office; Abel who brought me to the research area several times in the early morning and picked me up just as many times, arranged data and prepared presentations, Martha who cooked meals for us when we got tired of the restaurant food and prepared coffee the whole day and Bia who arranged plane tickets.

Appreciation goes also to Dr. ir. Adrie van den Dries for his advice. He gave direction to the research and suggestions for information sources. In addition, previous research carried out in the research area, done by Dr. ir. Adrie van den Dries, was of high importance to this research as well.

Prof. Dr. Ir. H.H.G. Savenije of the Technical University of Delft helped me with the construction of a model to simulate the salinity intrusion into the Rio Licuari River. Based on the research done by Prof. Savenije and his indications and suggestions via email, it was possible to simulate the salinity intrusion into the estuary and calculate the resulting fresh water availability. For that reason, I would like to thank Prof. Savenije.

All the people who showed patience gave advice or helped in any other way I also would like to thank.

Table of contents

1. Introduction

1.1 Background to the case study

The research is carried out in the Mugrima community in the Zambezia province in the center of Mozambique. This community is part of the Mucelo river plain just outside the provincial capital Quelimane. The approximate location of the community in the Zambezia province is shown in figure 1.1 (within the circle).

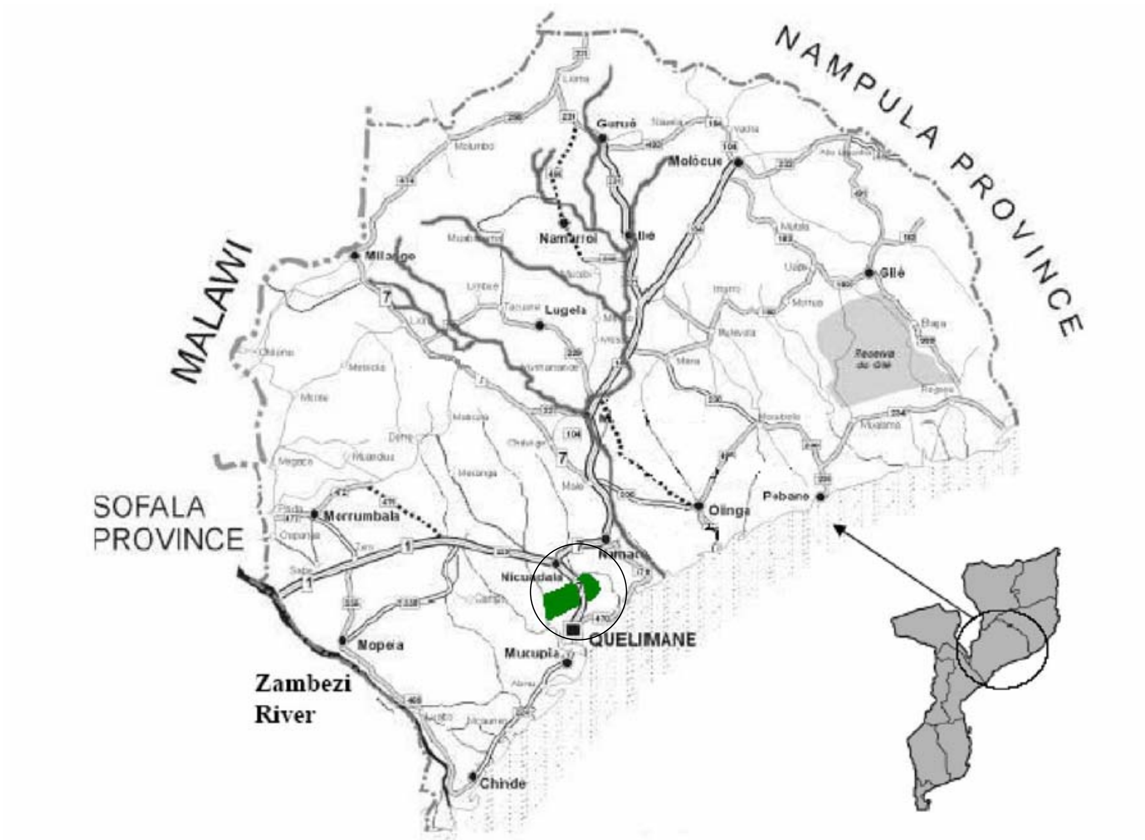


Figure 1.1: Location of the Mugrima community in the Zambezia province in the center of Mozambique (Source: Perry-Castañeda library Map Collection)

In total around 100 communities similar to the Mugrima community are located in the Zambezia province. Of these 100 communities, 31 communities are officially registered at the land registry and have, as a result, officially recognized land use rights. The Mugrima community is also such a community which has officially recognized land use rights.

This thesis research is a case study on the sustainable agricultural development opportunities of the Mugrima community as an example on how to reach development in similar communities in the Zambezia province. A more detailed overview of the community is shown in figure 1.2.

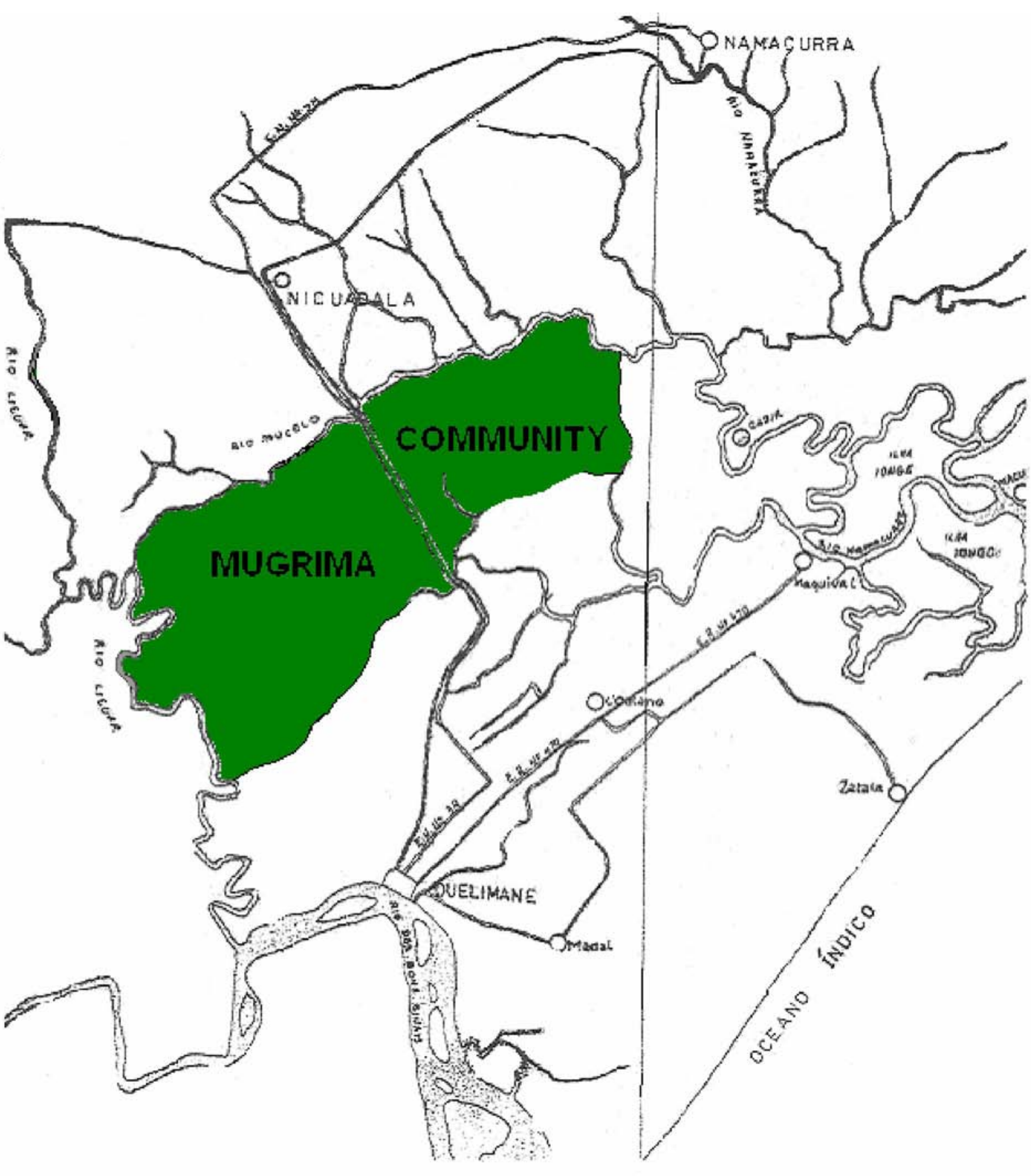


Figure 1.2: location of the research area (source: Dries, A. van den, 1984)

Mozambique is a country situated in Southeast Africa along the Indian Ocean with more than 20 million inhabitants. For almost five centuries it was a Portuguese colony.
Independence came after a guerrilla war that lasted from 1964 until 1974.
FRELIMO (Frente pela Libertacão de Mocambique, Front for the Liberation of Mozambique) declared independence on June 25, 1975. After independence, Mozambique became a one party state following the Marxist-Leninist doctrine. Soon after independence a civil war started between FRELIMO and RENAMO (Resistência National de Mozambique, Mozambique National Resistance). RENAMO was formed in Rhodesia (present-day Zimbabwe) as an opposition to the socialist FRELIMO regime. They were supported by the Rhodesian government of Ian Smith and later by the South African apartheid regime. (Varzi, M.M., 2008).

1.1.1 Mozambique and agricultural development

In October 1992 Peace treaties were signed in Rome after 16 years of civil war in Mozambique. Since the signing of these Peace treaties the agricultural sector has grown rapidly, because farmers were able to return to their lands, and markets began to open up, providing an outlet for surplus production (Bias, C. and Donovan, C., 2003).

The gross domestic product (GDP) in Mozambique shows high growth rates, at 7.5% in the year 1999, and predicted average annual growth in GDP for the years 2000 until 2004 of 7.7%, with agriculture making up 30 to 32% of GDP. However, floods in 1999 and 2000 resulted in lower than expected growth rates in GDP and agriculture for 2000 (World Bank, 2001; World Bank, 2002 in Bias, C. and Donovan, C., 2003). Despite these lower growth rates in 2000 agriculture remains to be of high importance (30 to 32% of GDP) for the national economy of Mozambique.

However, these positive growth rates in agriculture are not sustainable and rural incomes face a substantial risk of stagnation (World Bank, 2006). Agricultural growth over the past decade was almost entirely driven by farming more land with a larger rural labour force, with few technological improvements. Improved agricultural technologies played only a minor role. Access to and use of improved crop technologies remains very limited, and there is evidence that crop yields are stagnant. If appropriate action is not taken, agricultural growth will slow down and rural poverty will remain widespread (World Bank, 2006).

Furthermore even though GDP shows high growth rates, nearly 70% of the population lives below the poverty line and most of them in rural areas, dependent on the agricultural sector for consumption and income (Bias, C. and Donovan, C., 2003).

This demonstrates the very high importance of sustainable agricultural development, by improved agricultural technologies, in Mozambique. These improved agricultural technologies include *introduction of irrigation*, *new seed varieties*, *fertilizer use*, *construction of roads* etc. A sustainable increase in agricultural productivity is expected to have positive consequences on the economy, food security and poverty reduction in the rural areas.

1.1.2 Dry land rice cultivation vs. irrigated rice

Due to the erratic nature of rainfall in Mozambique irrigation is a critical factor in rice farming. The risk of crop losses in rain fed areas in the centre and north of Mozambique is between 5 and 30 percent (Agrifood Consulting International, 2005). Next to this, the range between the actual and potential rice yield is determined by 0.5-1.8 t/ha and 2.5-6.0 t/ha respectively (Howard, J. A., et al., 1998). Climatic conditions, in particular insufficient rainfall, play the most significant role in creating this difference (Bias C. and Donovan C., 2003).

Concluding from this, climate is a major factor which influences the possibilities for sustainable development of the rice sector in the Mugrima community. In rain fed areas the risk of a crop failure is high. Furthermore, when a crop is not lost, the yield is far below the potential yield that could be obtained with irrigation. For a sustainable development of the rice sector in the Mugrima community irrigation is therefore crucial.

An experiment in irrigated rice demonstrates that the consequence of using no fertilizers to yield seems less then the effect of using no irrigation (table 1.1).

Table 1.1: Irrigated rice responses to fertilizer use in Chokwe, Mozambique (Source: FAO, 2002)

	Fertilizer dose (kg/ha)	Control yield (t/ha)	Fertilizer dose at Maximum yield (kg/ha)	Maximum yield (t/ha)
Chokwe, variety C4-63, Irrigated	0	4.13	135	5.29
Chokwe, variety IR52, Irrigated	0	4.8	90	6.8

In table 1.1 can be seen that the irrigated rice without application of fertilizers already yields between 4 and 5 t/ha (in comparison to a yield in rain fed rice of approximately 1 t/ha). The effect of fertilizer application increases the yield with another 1 to 2 t/ha.

1.1.3 Farming techniques

For rice production traditional seeds are being used in most areas of Mozambique. These seeds are often not pure and High Yielding Varieties could increase yield (FAO, 2002). However, these High Yielding Varieties are often not available. This is also the case for the supply of fertilizers, credit, farm equipment, etc (FAO, 2002).

1.2. Conceptual framework

In this conceptual framework several concepts are shown which are relevant for the topic of this thesis. These concepts are based on theory and will be used as a framework in which the thesis should be carried out.

1.2.1 Sustainable agricultural development

Without adoption of improved agricultural technologies (e.g.: smallholder households that use fertilizer, animal traction, or small-scale irrigation) production growth will not be attained and rural poverty will remain widespread. Over the past decade, improved agricultural technologies have played only a minor role in Mozambique. Instead the agriculture sector grew primarily through area expansion and an increase in the labour force, with a large increase in cultivated area in the central region of Mozambique (World Bank, 2006).

According to the World Bank, rebuilding roads and bridges is now a priority and a necessary condition for any growth in the agriculture sector. The vast terrain and scattered and sparse population makes it all the more critical to ensure rural connectivity (World Bank, 2006).

Another constrain to sustainable rice production is the lack of effective farmer organizations and cooperatives (FAO, 2002).

1.2.2 Land rights (according to land law of 1997)

The vast majority of rural households have customarily acquired land rights, which are now legally recognised as equivalent to an official state land use right. When necessary, they can be proven through an analysis of local land management and production systems, which can result in very large areas being registered in the name of 'local communities' (also the case for the Mugrima community). With their rights recognised and recorded, communities are then able to enter into negotiations with investors and the state on a more equal footing and secure agreements that bring real benefits to promote local development and reduce poverty (Concern Worldwide, Oxfam International and Southern African Regional Poverty Network, 2006).

1.2.3 Participatory approach

Participation of the local community in a development project seems a very important issue. Without this participation, a development project can be very difficult to 'sell' to the local community. With a participatory approach, during a development project, the local community will be more likely to support the project. Furthermore, participation of the local community can provide useful information and insights in the situation.

Bart Pijnenburg has done a PhD research on participation in rural Mozambique. Concluding from this research, he states that keeping participation a vague concept can be very useful. Keeping it vague allows more possibilities for framing. To allow this to happen he formulated four strategies:

1 Using non-threatening language
Participatory development is being portrayed as a neutral, a political and inherently good approach. Presenting the approach in a populist way, and stressing the possibility of creating a win-win situation serves to maintain this positive image (Pijnenburg, B., 2004).

2 Suggesting 'ownership'
Create and maintain an image of ownership. In the presentation of a project for different audiences, Pijnenburg observed that staff made many efforts to stress how their projects were aligned with government policies. They stressed for example how government approved, or collaborated with, the project. In the reports to the donors it was often stressed that the projects were done with the support and ownership of the local population (Pijnenburg, B., 2004).

3 Brushing aside conflicts

In addition to presenting the approach as a neutral and non-conflictive one, Pijnenburg observed that there was also the tendency to avoid and brush aside conflicts as soon as they emerged. And if this proved difficult to avoid- for example in the case of obstruction of the work by a district administration – all attempts were made to resolve the conflict as rapidly as possible (Pijnenburg, B., 2004).

4 Allowing ignorance

Project staff has to ignore conflicts and power relations. Images of local participation can only be upheld by keeping a certain distance from what is actually happening in the communities (Pijnenburg, B., 2004).

1.3. Problem definition

Despite the high importance of sustainable agricultural development for Mozambique's economy, food security and poverty reduction, opportunities to increase agricultural productivity and profitability for farmers are not always utilized. Within the Zambezia province of Mozambique, communities have recognized land use rights and have as a result the right to utilize the land within their borders. In these communities, several sustainable development opportunities exist depending on the existing resources and already existing technology. The Mugrima community is one of these communities. Currently it is unclear which sustainable development opportunities exist within this community. Research is needed to determine the opportunities for sustainable development of especially the rice sector which is the main source of income. Next to the rice sector other opportunities can also result in sustainable development.

1.4 Research goal

The main goal of this thesis research is the creation of land use opportunities plan for the Mugrima community. With such a land use opportunity plan the Mugrima community can raise funds and protect the community against outsiders who would like to develop unused land in the community for their own benefits.

1.5 Research methodology

This research is carried out by doing a case study of the Mugrima community in the Zambezia province, Mozambique. Different methods where used to execute this study. Methods that where used are: literature study, interviewing, observations and participatory meetings. These methods are described below.

1.5.1 Literature study

Next to research in the field, literature was used to provide addition information on the local situation. Some examples are water availability (river discharge and salinity intrusion), soil characteristics, climatic data, land use rights databases. Next to specific information about the research area also general information about, for example, agricultural development has been used.

However, due to the location of the research area (rural Africa), the availability of specific literature is limited. This is amplified by the civil war which ended in 1992 and destroyed almost all infrastructure and measurement devices which results in incomplete data.

1.5.2 Interviews and participatory meetings

To gather necessary information, interviews and meetings have been carried out with farmers within the community. Specific characteristics of the research area such as: land use, natural drainage system, soil types and water availability in dry land rice cultivation where discussed with the farmers during meetings and interviews. During the mapping process a meeting was organized to discuss the maps with the community. In addition, local names where used for rivers, drainage pathways and villages to create a better understanding of the situation among the farmers.

1.5.3 Observations

In this research it was very important to do observations in the field with regard to mapping of land use and the hydrological situation. Sustainable development opportunities are dependent on these area characteristics. Mapping is done based on GPS information in combination with Google Earth Pro images. By travelling through the area and saving land use types by their coordinates into the GPS, a detailed land use map of the area could be created. Next to land use, other important characteristics of the research area where filed in the GPS as well (e.g.: drainage pathway). This data has been uploaded into Google Earth Pro which results in a map with land use type by their coordinates (dots). From this map a new map with the contour lines and as well showing the different land uses in the area has been created.

1.6 Report layout

This report is divided into the following parts: Part A consists of the description of some area characteristics which are based on three maps, i.e. land use rights, land use and the hydrological situation (chapter 2, 3 and 4), part B consists of irrigation opportunities in the Mugrima community (chapter 5, 6, 7, 8 and 9), part C consists of alternative development opportunities next to irrigation (chapter 10) and part D consists of conclusions and recommendations (chapter 11 and 12).

Part A - Area characteristics

2. Land use rights

2.1 History of land rights, concessions and occupation in the Zambezia province

In the first part of the 16th century the Portuguese where dominating the trading ports along the coast of the Zambezia province. They had well-established fortresses and trade fairs along the Zambezi, where Africans came to exchange ivory and gold for bears and cloth. After 1541 Portuguese residents at these outposts elected representatives who were delegated certain powers by the local rulers. Individual Portuguese were granted land and judicial rights from local rulers, which enabled them to extract tribute from the local populations. In other words, African land holdings within these areas were governed by traditional rules, but subject to the control of the Portuguese land grantees (Norfolk, S., et al., 2003).

These early grants formed the basis of what became known as the *prazo* system of landholding. Between the 17th and 19th centuries, *prazeiros* became immensely powerful players in local African politics, creating an Afro-Portuguese society in the lower Zambezi valley independent of either African or Portuguese jurisdiction. Tribute, forced labour, and taxes formed the backbone of these institutions, with family production limited to ensure labour availability.

From the late 19th century, the *prazo* system began to come under attack from modernizing elements that were keen to see a more strictly commercial involvement in the colony. In the 1870s there was a noticeable growth in small-scale agricultural activities, mainly as a result of the Labour Code of 1878 (which stated that no African could be obligated to contract his labour) and various colonial government directives that permitted the free trade of locally grown crops. Peasant production therefore flourished in some areas, as the newly 'liberated' were able to barter freely with a large network of merchants keen to purchase agricultural surpluses (Vail and White 1980).

However, not long after, this brief period of free production and trade by the local population was squeezed out by the advent of the 'company system', where commercial entities were encouraged to take up large land grants (the old *prazo* areas, now re-classified) and to stand between the people and the government, providing workers with a company store, housing in enclosed compounds and a daily food ration dependent upon the satisfactory completion of the days work (Vail and White 1980).

The private sector was encouraged to apply for concessions and provided with incentives to exploit 'new' areas. In the 1900s more and more land concessions increased to large companies and the law of 1918 facilitated the issue of land titles to concessionaires. Companies such as the Sociedade Agrícola do Madal (located near Quelimane), extended and consolidated their considerable land holdings during the middle part of the 20th century. At this time, individual African land holdings were protected through legislation. However, some forced removals took place at the request of companies that wanted exclusive control over local resources and needed reserves of cheap labour (Norfolk and Soberano 2000).

A year after independence, in 1976, concessions and all other private land holdings, were nationalized. The resulting large-scale departure of colonial landholders meant that land areas that had been in private hands were available for use by local populations and in many areas they took advantage of the better-located and higher quality land. However, due to the civil war, which started soon after independence, there was a growing insecurity in rural areas in the mid 1980s. Communities displaced by the war moved closer to the district centers and occupied surrounding land.

After the Peace treaties where signed in 1992, the communities where able to return to their lands. The re-establishment according to widely accepted land holding patterns (between groups and individuals that had remained in the countryside, those that had returned, and those arriving to new areas) occurred within the framework of customary rules of the rural populations. The process occurred largely without conflict and required little intervention from formal authorities (Norfolk, S., et al., 2003). This demonstrates the durability of traditional institutions of land allocation and negotiation.

At the same time, a chase for land began between the national urban elite. These elite sought to acquire and register land for speculation rather than investment and development (Negrão, 1998). External factors such as the end of apartheid in South Africa and the economic crisis in Zimbabwe led many foreigners to seek land in the irrigated areas, in urban peripheries and along main roads. This, coupled with population resettlement, led to disputes over land use rights in the Zambezia province.

As a response to this demand for land a new national land policy was drawn up in 1995. Its goal was to '*promote national and foreign investment without harming local people occupying the land with no formal registration'* (Chilundo, A., et. al., 2005). Within the framework of this policy, the Council of Ministers created the Interministerial Land omission and mandated it to coordinate the process of consultations, discussion and national debate leading to the drafting of a new land law. The new land law was realized with the participation of the government (especially the Ministry of Agriculture and Rural Development and the National Directorate of Geography and Land Registry), civil society organizations, nongovernmental organizations and research institutions (Chilundo, A., et. al., 2005). The new land law was passed in October 1997.

The land law of 1997 '*re-affirms state ownership of land, but recognizes and safeguards rights acquired traditionally through occupation and inheritance. At the same time it creates incentives for private investment, by granting land use concessions to private entities for renewable periods of 50 years'*.

Based on this, it became possible, for communities like the Mugrima community, to register traditionally acquired land use rights by occupation and inheritance. Through registration of these land use rights communities can acquire a recognized legal status. This legal status is required for establishing partnerships with 'outsiders'. This indicates that the land law of 1997 recognizes important roles to local communities. This type of officially recognized land use right, provided to a community, gives the right within the borders of the community to decide about the use of the land.

Furthermore the new land law represents a considerable advance in assuring land access for women as well as men. It provides that verbal evidence on '*the right of use and exploitation of the land can be given to women or men of local communities* (Article 15, line b); *that transfer by inheritance occurs without gender discrimination* (Article 16); *and that women have the right to possess individual titles'* (Article 13, paragraph 5) (Kanji, N. et. al., 2002). This is an import aspect to the Mugrima community as well given that a lot of the land is owned by men and most farming is done by women. Based on the new land law, land use rights can be inherited by women just as often as by men. This provides an incentive to change the existing gender discrimination.

After the introduction of the land law of 1997, NGO's started to support communities in the registration process. Currently 31 communities in the Zambezia province are officially recognized.

2.2 Land use rights, concessions and occupation in the Mugrima community

2.2.1 Mugrima community members

The Mugrima community is one out of the 31 communities in the Zambezia province that have registered land use rights to which government certificates have been issued. With this registration the Mugrima community is now being accorded legal recognition for the first time. The right to use a particular area of land is linked to occupation. Therefore, the members within the Mugrima community (farmers) have the officially recognized right to use the land within their area in which they live and cultivate crops. These land use rights have been recognized with government certificates issued in the name of the respective community. The Mugrima community obtained the land use right of 22,414 ha. In annex 1 of this report the border of the Mugrima community land use right is shown and in annex 2 the government certificate of the Mugrima community is added. The existence of these land rights on community level indicates that within the community the land use rights are divided among the members of the community. Different members have the right to use a particular area of land. This can also be observed in the plains of the Mugrima community. In areas suitable to grow rice, the land is completely utilized. These areas are subdivided into plots with an average size of approximately 0.5 ha. Every plot is enclosed by small dikes to retain water.

2.2.2 Outsiders in the Mugrima community

In the Mugrima community there is considerable interest from local companies and individuals in re-establishing old Portuguese family concessions or occupying newly accessible areas of resource-rich land. Regardless of the registered land use rights of the community members, these outsiders have claimed the land use rights of extensive parcels of the same land within the Mugrima community. They base their claim on concessions obtained before the current land law of 1997 became effective.

In the year 2000, the government announced that the land use rights needed to be updated in consultation and with the acceptance of the community in which the land rights were located (which is in accordance with the new land law of 1997). When these updates were not provided within one year by the owner of the land use right, the land use right would be deleted from the land register books in Quelimane (Serviços Provinciais de Geografia e Cadastro Zambézia) (Duvani, L, 2007). Based on the current documented land use rights in the Mugrima community (as they can be consulted in the Cadastro books) it seems that a lot of the land use rights have been updated between the years 2000 and 2001. A part of the land use rights are located on villages and densely utilized areas of land. It is therefore unlikely that these updates were done with the acceptance and consultation of the community. To get a better insight in the legality of the foreign land use rights in the Mugrima community, meetings where organized with the land committee and Mugrima (the community leader). The land committee and Mugrima are in charge of granting land use concessions to outsiders. The land committee, as well as Mugrima, where not aware and fairly shocked of the land use rights of outsiders in the area. Despite the registration of the land use rights in the Cadastro books it was obvious that no grants where provided to the concessionaires by the Mugrima community.

It is not clear how the illegal land use rights where obtained. Bribes of Cadastro personnel, forged grants of the Mugrima community and undeleted land use rights in the Cadastro books are possible explanations of the existing invalid land use rights.

Nevertheless, currently a lot of invalid land use rights are present in the Mugrima community resulting in parts of the community which are registered twice. A map of the registered land use rights is shown in annex 1 (Land use rights map Mugrima community). A list with the owners of these different land use rights and the corresponding hectares is shown in table 2.1.

Table 2.1: Registered land use rights at the Cadastro in Quelimane

Cadastro Nr.	**Owner of land use right**	**Terrain purpose**	**Amount of hectares according to books Cadastro**	**Amount of hectares according to map Cadastro (based on AutoCAD calculations)**
Pr. 3	Electricidade de Moçambique	Industry	3.6	2.6
Pr. 1961	Ângelo Sacur dos Reis	Agriculture	5	7.5
Pr. 2021	Maquina Portugal de Oliveira	Agriculture	7	6.25
Pr. 2082	Cooperativa Agricola Jozina Machel	Agriculture	41	41
Pr. 2091	Angelina César	Agriculture	10	10
Pr. 2092	Organização da Mulher Moçambique	Agriculture	60	58
Pr. 2111	Constructora Integral De Zambezia (CIZAM)	Industry	2,000	1,214
Pr. 2160 / 2960	Favezal	Agriculture / Livestock	3,000	2,815
Pr. 2266	Associação Agricola do OMM	Agriculture	250	160
Pr. 2329	Campos Mulima Vicente	Agriculture / Livestock	10	20

Pr. 2485	Abdul Rashid A. Karim	Agriculture	15	5
Pr. 2534	**Roberto Edgar T.O. da Silva**	**Agriculture / Livestock**		**1,379**
Pr. 2536	Lourenco / ZAP (Zambezia Agro Pecuaria)	Livestock	2,950	2,437
Pr. 2726	Escola da Comunidade M. de inh	Agriculture	250	190
Pr. 2736	Associação Cerâmica	Agriculture	250	180
Pr. 2737	Samuel Fulano Ferreira	Livestock	1,000	73
Pr. 2754	Dulce Major Silveira	Other purpose	0.65	1.5
Pr. 2758	**Associação 4 Outubro Muculo (farmers association)**	**Agriculture / Livestock**	**600**	**470**
Pr. 2763	Dulce Major Silveira	Other purpose	1	1
Pr. 2845	Associação Niwanana	Agriculture	500	514
Pr. 2926	Grupo Ibraimo Hassan Lda	Agriculture	3,025	3,093
Total area with registered land use rights (ha)			**13,978**	**12,678**
Total area with registered land use rights other then Mugrima community members (ha)			**13,378**	**10,829**
Total area Mugrima community (ha)			**22,414**	

In table 2.1 a difference can be observed between the amount of hectares which are registered in the books of the Cadastro and the amount of hectares which are indicated on the map of the Cadastro. The areas of the Cadastro numbers on the map of the Cadastro have been calculated using AutoCAD. The accuracy of these measurements is relatively high. Reasonably small differences are probably caused by inaccuracy of indicating the borders of the plots onto the map (which has been done by hand).

In total, the registered land use rights within the Mugrima community based on the Cadastro map, which are owned by others then the Mugrima community inhabitants, is almost half of the total area of the Mugrima community (10,829 hectares of 22,414 hectares). These 10,829 hectares are not including the Cadastro numbers Pr. 2534 and Pr. 2758. Pr. 2534 is not registered in the Cadastro books despite the existence on the map. Pr. 2758 is a land use right owned by the “Associação 4 Outubro Mucelo”. This is a farmers association founded by farmers which have land in the Mucelo irrigation system and who live within the Mugrima community. These farmers are thus part of the Mugrima community itself.

The other registered Cadastro numbers with a total area of 10,829 hectares are owned by “outsiders”. These “outsiders” who own land use rights in the Mugrima community are both companies and individual people with different interests in the area. For example: “Constructora Integral De Zambezia” (CIZAM) is a brick factory which needed raw material from the area for the brick construction process, Ibraimo Hassane is an individual who wants to grow rice in the area and “Zambezia Agro Pecuari (ZAP)” is a company which grows cattle.

All these land use rights were documented before the new land law was approved in July 1997. After the documentation of these land use rights little has been done in these areas. CIZAM had been shut down, Ibraimo Hassane didn't start cultivating rice and currently ZAP raises cattle on 1250 hectares of land despite the land use right of more then 2400 hectares.

2.3 Making use of the land use rights before someone else does

Concluding from paragraph 2.2 it is obvious that, in the Mugrima community, there has been a real hunt for community land by outsiders. So far, land use rights by outsiders are rarely utilized in the sense of investments or development activities. Apparently land use rights are acquired for speculations rather then investments or development activities. However, outsiders are not in the position to speculate, invest or develop community lands without the permission of the community itself.

On the other hand, the Mozambican government is carrying out an agricultural development programme and a Poverty Reduction Strategy that are based upon '*attracting direct commercial investment*' into rural areas (Norfolk, S., et al., 2003).

When outsiders are planning to undertake investments or development activities in unused or plan less community areas, the government is expected to encourage these intentions. Besides, according to the Cadastro books, outsiders have land use rights in the Mugrima community.

This situation results in a serious threat for the Mugrima community members. In order to secure the existing land use rights of the Mugrima community and resulting possibilities for existing activities and future development activities, the community needs to be in the possession of a land use plan which indicates intensive land use in the future. However, although the community possesses the land use rights on paper, currently farmers do not have a plan to develop their area. With the land use plan the Mugrima community can give a clear statement towards outsiders and the government that the Mugrima community has a plan to utilize their land use rights in the future. This report is such a land use plan which discusses opportunities for sustainable agricultural development, which can be utilized by the Mugrima community in the future.

3. Land use inventory and farming practices in the Mugrima community

An overview of the current land use in the Mugrima community is given in annex 3. In this overview the hectares of the main areas are included. An overview of the land uses in the Mugrima community is shown in the following table.

Table 3.1: Land use in the Mugrima community

<table>
<tr><th>Land use type</th><th>Area (ha)</th><th>Area (%)</th><th>Current rice cultivation (ha)</th><th>Suitable area for rice cultivation (ha)</th></tr>
<tr><td>Dry land rice cultivation (70% rice)</td><td>7,890</td><td>35.36</td><td>5,523</td><td>7,890</td></tr>
<tr><td>Mainly unused land suitable for rice cultivation (5% rice)</td><td>11,375</td><td>50.98</td><td>569</td><td>11,375</td></tr>
<tr><td>Irrigated rice cultivation (100% rice)</td><td>220</td><td>0.99</td><td>220</td><td>220</td></tr>
<tr><td>Cattle breeding (ZAP)</td><td>1,211</td><td>5.43</td><td rowspan="4">0</td><td>1,211</td></tr>
<tr><td>Salt water mangroves</td><td>214</td><td>0.96</td><td rowspan="3">0</td></tr>
<tr><td>Higher dune area</td><td>337</td><td>1.51</td></tr>
<tr><td>Settlements</td><td>1,067</td><td>4.78</td></tr>
<tr><td>Total (road, railway and rivers not included)</td><td>22,315</td><td>100</td><td>6,312</td><td>20,697</td></tr>
</table>

The information from table 3.1 is primarily based on field visits using GPS for positioning. After the field visits, the obtained GPS data on land use at visited spots has been imported into Google Earth Pro. Based on this, a verification of different land use types in Google Earth Pro images could be carried out. Area calculations have been carried out in AutoCAD. An overview of the gathered GPS data on land use in combination with the Google Earth Pro images is enclosed in annex 4.

The Mugrima community is registered at the land register office in Quelimane (Serviços Provinciais de Geografia e Cadastro Zambézia) as a total area of 22,414 ha. This is 99 ha more then the total area calculated in AutoCAD. However, in the AutoCAD calculations the road, railway and rivers on the borders of the Mugrima community are not included in the calculation. This can explain the difference in total area.

From table 3.1 some interesting things can be observed. More then half of the area in the Mugrima community is currently unused (50.98%). This is a very large area of more then 11,000 ha. However despite this large area of unused land there is also a big area of land in which rice is cultivated very dense (35.36%). Other land uses cover much less land. Currently irrigation only covers 1% of the area.

When the current rice cultivation is reviewed there is approximately 6,300 ha under cultivation of which 220 ha irrigated. The total area suitable for rice cultivation is approximately 20,700 ha. The big difference is mainly because of the large area of land which is unused and suitable for rice cultivation. This whole area consists of Vertisols which are very suitable for rice cultivation.

In the following paragraphs the different land uses and farming practices in the Mugrima community are discussed.

3.1 Irrigation

In the Mugrima community currently there are two irrigation systems. One is “Regadio de Elalane”, the other “Regadio de Mucelo”. These irrigation systems where constructed during the Portuguese colonial time. In total they occupy only 550 hectares of land of the total area of 22.414 hectares. “Regadio de Mucelo” is the only still functional irrigation system with an irrigated area of 220 ha. The amount of water which is currently used by irrigation practices is insignificant in relation to the amount of available water in Rio Licuari in the rainy season (Dries, A. van den, 1984).

“Regadio de Mucelo” is located at the Mucelo river (Rio Mucelo) and “Regadio de Elalane” at the Licuari river (Rio Licuari). The exact location can be seen from annex 3 (land use map Mugrima community).

At “Regadio de Mucelo” some design improvements could be made. At “Regadio de Mucelo” an electrical pump is installed which pumps water into the main irrigation canal. The efficiency of such an irrigation pump depends mainly on the appropriate head capacity. The pump head capacity should be near the required head capacity needed to bridge the water height difference between the river and the irrigation canal. However, the chosen pump at this irrigation system has a much bigger head capacity then needed. This situation results in higher electricity needs per m^3 of irrigation water in comparison to a pump which has an appropriate head capacity. Unnecessary electricity costs and lower profits are the result.

Contributing to even higher electricity costs and low irrigation efficiency is the main canal which is not lined, resulting in added conveyance losses which need to be compensated for by more pumping hours (with an inefficient pump).

Another problem is the location of the secondary canals which run perpendicular to the main road through the area (see figure 3.1). A few of these secondary canals are crossed by natural drainage pathways (meandering line through the irrigation area). These natural drainage pathways are considerably lower then the surrounding terrain. During the construction of the canals (in the Portuguese colonial time) this natural drainage pattern was not taken into account. Secondary canals are now crossing these natural drainage pathways. To prevent water from flowing directly from the secondary canals into the drainage pathways dikes have been constructed along the secondary canals at the locations of the natural drainage pathways. However, when constructing an irrigation system, crossing a drainage pathway should be prevented to reduce construction problems, height differences, etc. When it is possible, with the design of an irrigation system, the natural streams and drainage pattern should be used.

Finally there is a problem with height differences in the irrigation system. The irrigation water can’t reach the end of the irrigation system because of an increase in height of the farm plots in downstream direction.

In figure 3.1 the location of the irrigation canals, drainage canals and natural drainage pathways in the Mucelo irrigation system are depicted.

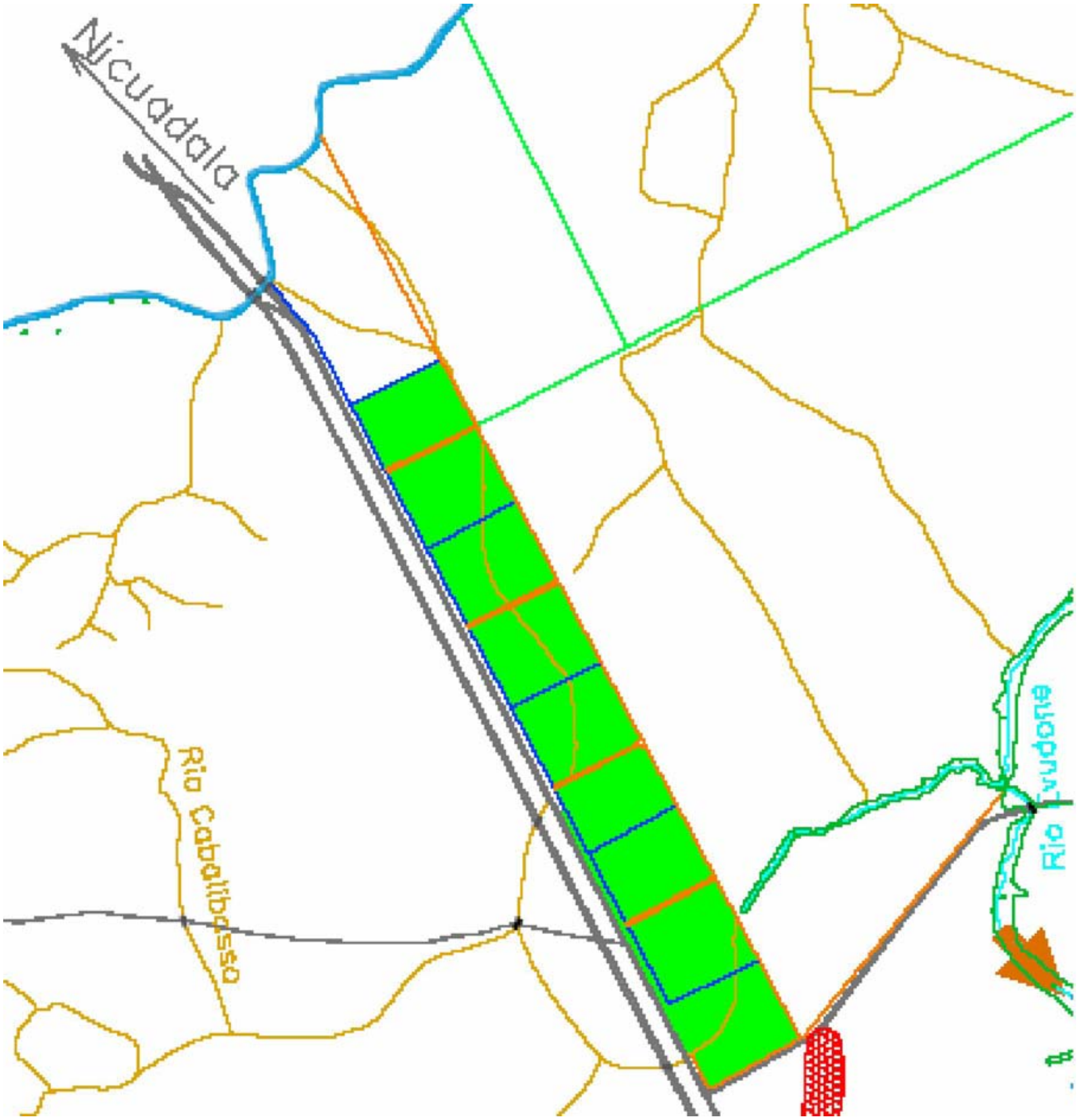


Figure 3.1: Mucelo irrigation system

Currently a redesign of “Regadio de Mucelo” is carried out to deal with the above mentioned problems.

“Regadio de Elalane” is the second irrigation system in the Mugrima community. This irrigation system is not functional at the moment. It has also been constructed during the colonial time. This irrigation system is located in the southwest of the Mugrima community (see annex 3). The water intake exists of several canals perpendicular to Rio Licuari. At these canals pump stations were installed to pump water into the canals. From these canals secondary canals take water to the farm plots. This irrigation system is not functional anymore and farmers are only practicing dry land rice cultivation at the moment.

The location of “Regadio de Elalane” is more downstream then “Regadio de Mucelo”. So it is more influenced by salt water intrusion. Therefore, compared to “Regadio de Mucelo”, it is in a disadvantaged situation.

3.2 Traditional farming practices

The traditional agriculture practiced at the moment in the Mugrima community exists already for a long time. It is mostly women who are practicing agriculture in these areas and they have adapted their agricultural practices to the local conditions. Adaptation has been a necessity to reduce the prospect of hunger.

The first objective of agricultural practices is the survival of the family. This implies that farmers are trying to reach a higher production. Next to this, in agriculture there is a strong tendency to minimize the production risks. To reach these objectives, the farmers have developed some ways to reach food security. This includes the following practices.

1. Crop diversification

Farmers do not only cultivate rice but always vary in crops, each one with its specific requirements. If the conditions are not favorable for the development of a specific crop, the same conditions can be favorable for the development of other crops. In the Mugrima community there appear to be a few crop types. In the areas close to houses sweet potatoes and sugarcane are grown. To prevent water excess in the soil where the sweet potato is growing, sweet potatoes are planted on small ridges constructed by the farmers.
Sugarcane is grown in small plots of maximally 0.25 ha. The fertility of the clayey soils is very high and sugarcane plants of three meters in length are no exception.

2. Optimal location for crop growth

Based on experience farmers know in which areas crops grow well and in which areas problems will occur when a crop is grown. In the Mugrima community, in general, there are two types of soils, Vertisol (A. Mate and J.M.M. Scholten, 1987) in the plains and sandy soils in the dunes. Other names for Vertisols are ‘black clay’ or ‘delta clay’. Some major soil properties of Vertisols are: a high clay content, low permeability, medium to low organic matter content (0.5 – 3%) and shrinking and swelling resulting in wide cracks during drought (Grunwald, S., 2007). When Vertisols are saturated they swell and become almost impermeable which makes it very suitable for rice cultivation.
Crops are grown in the heavy clayey soils of the plains. The fertility of these soils is much better then in the sandy dune soils. Furthermore, the water availability in the plains is better then in the dunes. However, within the plains also differences exist in water availability. Some areas are more elevated then others. Rice is grown in the lower areas (especially in the natural drainage pathways which have the best prospect of sufficient water availability during the growing season). Because of the high clay content of the soils, infiltration rates are very low and water remains in the lower areas for long periods of time. The plains surrounding these lower drainage pathways are relatively flat. Parts of these flat plains are cultivated but also large parts are not cultivated at all. These areas are left fallow while grass is growing wildly. The chance of a rice crop failure increases with the altitude of the terrain. This can directly be observed in the field as well. The higher the land, the less rice cultivated.

Next to the influence of water availability on the amount of rice cultivated, the access possibilities to an area seems also a very important aspect in the decision of the farmers to grow rice. Close to the main road (see annex 3) the drainage pathways and higher terrain is completely put into use by rice cultivation. However, the further the terrain is located from this main road the less rice is being cultivated. After a certain point the terrain is almost completely unutilized. This situation also occurs in parts of the terrain which are not accessible due to deep drainage pathways which are full of water whole year round. Some small bridges have been installed to cross these deep drainage pathways but they are only just large and strong enough to support one person.

In annex 3 an overview of the current dry land rice cultivation is shown. When looking at the map the above mentioned situation should be kept in mind (there is a gradually decrease in dry land rice cultivation with decreasing moisture availability and access possibilities).

3.2.1 Dry land rice cultivation practiced

For rice cultivation there are two ways of sowing: transplantation and directly sowing the rice seeds on the farm plot.

Transplantation occurs when it doesn't rain much in the first period of the season (November/December). With transplantation rice is sown on the farm plot in one area (very densely). This area is the lowest and functions as a nursery for the rice plants. Before sowing takes place the farm plots are cleaned of weeds. These weeds are burned or used to heighten small dikes around the farm plot to retain water. Later when torrential rains occur and the soils are saturated and plots become flooded, the transplanting takes place. During this practice the densely sown rice plants are equally divided on the farm plot. Because of the more regulated conditions inside the nursery, transplanting is a more secure method of rice cultivation. On the other hand, it is also a more labour intensive method of rice cultivation.

When it rains enough during the first period of the season (November/December) rice is sown directly on the entire farm plot (normal density). Directly sowing the rice plants on the farm plant is in the principle little work because transplantation is not needed. Downside of this method is the risk involved. When heavy rains occur during the germination, seeds can rinse out of the soil which will result in loss of rice plants.

The period of sowing and transplantation has the tendency of being long. This is mainly because of the preparation of the land which is done by hand (and therefore takes a long time).

After the sowing/transplantation of the rice plants the plot needs to be kept in good condition by removing any weeds which start growing in between the rice plants. Furthermore, birds will have to be kept away from the plot to get an optimal yield.

The harvest consists of two parts: mowing the plants and harvesting the rice.

Al these activities are currently carried out by hand in the Mugrima community. In the following table an overview is given of the activities which a farmer has to fulfill in order to grow rice. This list is based on the production standards used by Monteiro e Giro. Monteiro e Giro was a company at the Ceramica factory during the colonial time which had areas in the Mugrima community under rice cultivation. In order to receive payments (money and food) workers for Monteiro e Giro had to fulfill the productivity standards as shown in table 3.2.

Table 3.2: Production standards used by Monteiro e Giro for rice cultivation by hand (source: Dries, A van den, 1984)

Activity	Used productivity standard 1 person	
1st round land preparation	20	days/ha
2nd round land preparation	10	days/ha
3rd round land preparation	8	days/ha
Total land preparation	**38**	**days/ha**
Hand sowing	**0.5**	**days/ha**
Transplantation – transport of plants	10	days/ha
Transplantation - transplantation	20	days/ha
Total transplantation of rice plants	**30**	**days/ha**
Land work after transplantation	**10**	**days/ha**
Guard land for birds (scarecrow)	**1**	**days/ha**
Harvest – Mow rice plants	20	days/ha
Harvest – Carry rice plants to mechanical harvester (max. distance 150 meters)	10	days/ha
Total harvest	**30**	**days/ha**
Total	**169.5**	**days/ha/p**
	5.67	**months/ha/p**
	0.47	**year/ha/p**

From this list can be seen there are three main activities: land preparation (38 days), transplantation (30 days) and harvest (30 days). In the land preparation process the amount of work decreases with every round. In the first round land is full of weed and the cleaning process takes a lot of time. The second and third rounds of land preparation are to maintain the land ready for sowing.

As discussed in paragraph 1.1.2, the yield of dry land rice cultivation are around 1 ton/ha. Farmers practicing dry land rice cultivation in the Mugrima community confirm this situation. The yield of irrigated rice can be around 4 ton/ha without fertilizer use (Agrifood Consulting International, 2005 and FAO, 2002).

3.3 Livestock

In the Mugrima community livestock is not a widespread land use type. The local community sometimes has a few chickens and a goat for home consumption.

However, in one area this situation is different because of land in use by Zambezia Agro Pecuaria (ZAP). ZAP, with a registered land use right in the Mugrima community of more then 2400 ha of land (pr. 2536), currently raises cattle on 1250 hectares. This area is fenced off from the other land on which dry land rice is cultivated (see annex 3).

3.4 Settlements

In the Mugrima community the highest parts are occupied by small villages (less prone to floods). These higher areas are a type of dunes in the landscape. They consist of sandy soil on which trees grow. These villages are fixed and exist already for a long period of time. Buildings are relative sizable and small schools exist. In annex 3 an overview of these settlements is shown.

Furthermore, villages in the lower areas exist. These villages are smaller and have fewer facilities. To reduce problems with flooding, houses are constructed with a second floor.

Finally, small settlements directly next to farm plots can also be seen. These settlements are mostly not bigger then 15 houses or sometimes just one single house. The houses are very small and constructed of not more then a few branches covered with palm leaves or other material which is easily available. Because these houses are not on higher ground and only very simple constructed, they are only used to be closer to the farm plot. In the land use map this category of settlements are not included.

3.5 Mangroves

The Mugrima community is surrounded by rivers which border the community as well (see annex 5 - Hydrological map Mugrima community). Because of the short distance of the community to the sea, tidal influence and salt water are present in these rivers. This resulted in the development of mangroves.
Depending on the altitude of the surrounding terrain and the salt water intrusion into the different rivers these mangroves have developed. In annex 3 an overview of these mangroves can be seen.

3.6 Road / Railway

Through the Mugrima community there is one main road (Estrada Nacional nº 7) which is the main entrance road to the provincial capital Quelimane. This road also has a direct connection to the main road to the north (Estrada Nacional nº 104), south (Estrada Nacional nº 213) and west (Estrada Nacional nº 7) of Mozambique.

Parallel to the road there is a railway which is not used anymore. During the war landmines where placed at the railway, bridges where destroyed and local people took away parts of the rail.

4. Hydrological situation

The boundaries of the Mugrima community, which are discussed in chapter 2 (land use rights), are rivers. These rivers are the main rivers in the Mugrima community. Next to these rivers a lot of deep and shallow drainage pathways through the area exist. In annex 5, the hydrological map of the Mugrima community is shown.

The main rivers which influence the hydrological situation of the Mugrima community are “Rio Mucelo”, “Rio Licuari”, “Rio Namacurra”, “Rio Nedone”, “Rio Domela” and “Rio Dabada”. A schematized overview of the hydrological situation is shown in the following figure.

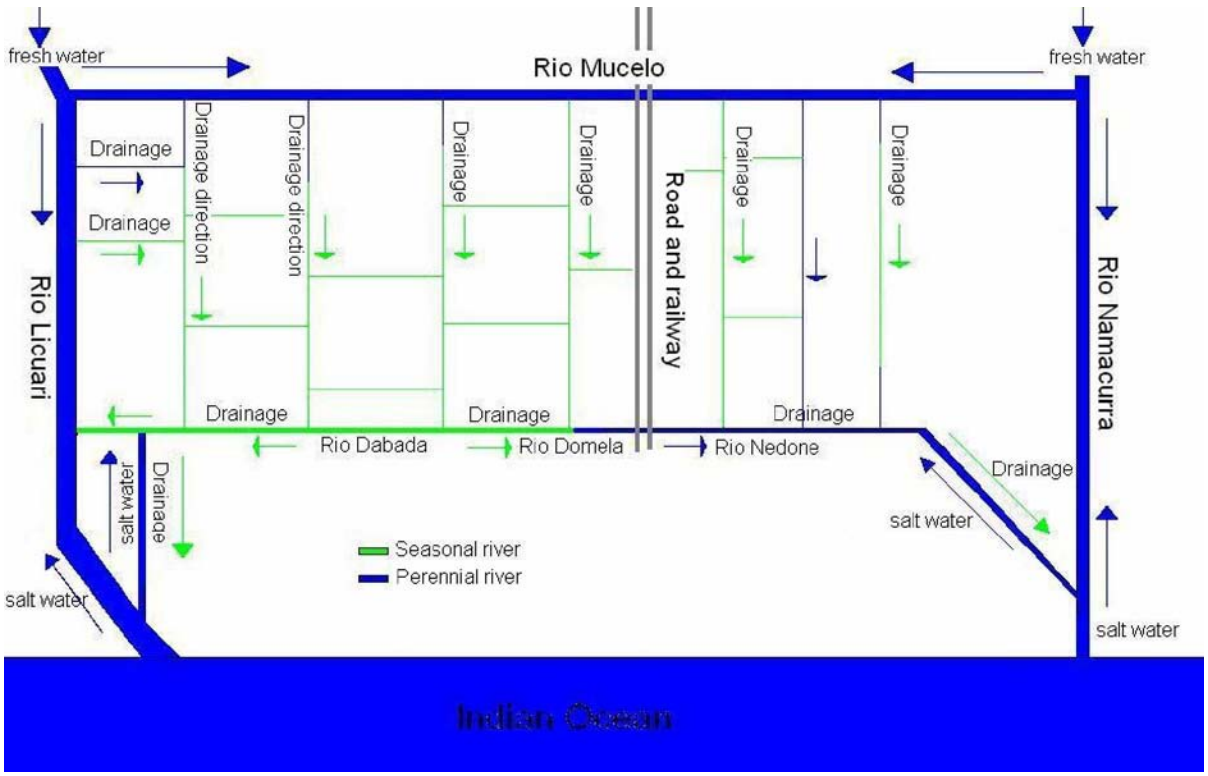


Figure 4.1: simplified overview of the hydrological situation in the Mugrima community

4.1 Rio Licuari and Rio Namacurra

Fresh water is collected in the river basins of Rio Licuari and Rio Namacurra. These river basins are located upstream of the Mugrima community. Rio Licuari has a river basin area of 3775 km^2. The discharge of these two rivers is very erratic. During the rainy season the discharge of Rio Licuari can be more then 120 m^3/s. During the dry season it can be as low as 0.02 m^3/s. Depending on the discharge of these rivers the salinity intrusion will differ. During the rainy season, salt water is pushed back downstream by fresh water. During the dry season, salt water is able to intrude far upstream.

4.2 Rio Mucelo

Rio Mucelo is a connection between Rio Namacurra and Rio Licuari. Water in Rio Mucelo comes from these two rivers. The salinity content of this water depends on the discharge from Rio Licuari and Rio Namacurra. During a salinity measurement on the 27th of November 2007 the salinity content of the water in Rio Mucelo at the pump station of the Mucelo irrigation system was 0.992 g/l. This is nearly fresh water and suitable for rice irrigation. The maximum allowable salinity content for rice irrigation on clayey soils is 1.024 g/l (www.lenntech.com/irrigatie/irrigatiewater-zoutgehalte.htm, 1-12-2007).

However, the salinity content in Rio Mucelo depends on a lot of variables: the tide, the discharge from Rio Licuari and the discharge from Rio Namacurra. Every day the salinity content will therefore vary, depending on the situation of the three variables. However, in general in the rainy season there is a period in which salt water is pushed back downstream and water in "Rio Mucelo" and a large part of "Rio Licuari" and "Rio Namacurra" is fresh. Farmers in the Mugrima community indicate that water is always fresh in "Rio Mucelo" from February until as far as August. In chapter 5, salinity intrusion is discussed in more detail.

4.3 Rio Nedone

Rio Namacurra is not visible on the hydrological map of the Mugrima community. However, a branch of Rio Namacurra does enter into the Mugrima community. By the local population this branch is called "Rio Nedone". Rio Nedone splits from Rio Namacurra near the river mouth of Rio Namacurra into the Indian Ocean. Resulting from this situation, Rio Nedone is almost for 100% fed by seawater which enters into Rio Nedone at the split off from Rio Namacurra. Salinity measurements confirm this situation. The salinity content of the water in a deep drainage pathway, connected to Rio Nedone, at the location of the main drainage from the Mucelo irrigation system, (see annex 5) is 22.297 g/l. Water with such salinity content can be entitled as brackish. All the deep drainage pathways connected to Rio Nedone contain salt water.

Furthermore, next to a high salinity content of Rio Nedone and all connected deep drainage pathways, the tidal influence is also high resulting in the development of mangroves along the banks of the river and deep drainage pathways.

Another river which has the same type of characteristics is located just southwest of the Mugrima community. This river is a branch from "Rio dos Bons Sinais". This river is very close to the Indian Ocean and is always salt. Just like "Rio Nedone" this branch is almost for 100% fed by seawater which enters into the branch at the split off from Rio dos Bons Sinais.

A very important characteristic of these two river branches is that the water level is not influenced by the river discharge from Rio Licuari and Rio Namacurra in contrast to Rio Mucelo. This results in a water level independent from the rainy season. This is further discussed in the paragraph 4.5 (flood and drainage system).

4.4 Rio Domela and Rio Dabada

These two rivers are the border of the Mugrima community in the south. Rio Domela is connected to Rio Nedone. Rio Dabada is connected to the river branch of Rio dos Bons Sinais. Both rivers are seasonal. In the rainy season they contain water and in the dry season they remain dry. In a part of Rio Domela salt water intrusion occurs where it is a deep drainage pathway. However, at a certain point, the soil level becomes too high and tidal water can't enter Rio Domela any further.

Rio Domela and Rio Dabada in combination with Rio Nedone and the river branch of Rio dos Bons Sinais play an important role in the drainage of the Mugrima community. This is further discussed in paragraph 4.5 (flood and drainage system).

4.5 Flood and drainage system

In the plains a whole network of shallow and deep drainage pathways exist (see annex 5). All the deep drainage pathways are connected to a main river and are the whole year filled with water from these rivers. The local population entitles these deep drainage pathways also as rivers and provided them with names. These deep drainage pathways continue through the area as shallow drainage pathways which are seasonal and contain only water in the rainy season. Next to shallow drainage pathways which are seasonal there is also a seasonal river in the Mugrima community which is wider then the shallow drainage pathways.

The water in these waterways is often just from rainfall which falls in the Mugrima community itself. In the beginning of the rainy season the soils in the Mugrima community are dry and in the Vertisols of the plains wide cracks can be observed of five centimeters wide. When the rainy season starts the first large rains drain directly into the dry soils and cause them to swell. This closes of the cracks in the soil. After this process the permeability of the soil becomes very low. New rains do not infiltrate very fast and the shallow drainage pathways and seasonal river start to fill up with water. The water flow direction in these shallow drainage pathways and the seasonal river is south; towards Rio Domela and Rio Dabada (based on observations and interviewed farmers working in the field).

In some years overland flow occurs where water enters the shallow drainage pathways and seasonal river through the deep drainage pathways. This occurs when water levels in the main rivers are very high (due to high discharges from the river basins). Most of the deep drainage pathways enter the area from Rio Mucelo. Therefore, during overland flow, most of the water also enters the area via Rio Mucelo (see annex 5, flood entrance).

In both situations Rio Domela and Rio Dabada play an important role in the drainage of the Mugrima community. The water in the plains of the Mugrima community runs south through all the different waterways towards these two rivers. Because Rio Domela and Rio Dabada are in direct connection with Rio Nedone and the river branch of Rio dos Bons Sinais they have always the possibility to drain the water which is coming from the Mugrima community. This is caused by the fact that the water level from Rio Nedone and the river branch of Rio dos Bons Sinais are not influenced by the river discharge from

Rio Licuari and Rio Namacurra in contrast to Rio Mucelo. This results in a water level independent from the rainy season creating a constant possibility for drainage.

Part B – Irrigation opportunities

5. Water availability

5.1 Discharge analyses

The research area is liable to tropical weather conditions with a distinct rainy season and dry season. Precipitation and the resulting river discharge are therefore unequally spread over the year. The rainy season starts around December and ends in April. River discharges will increase a bit later in comparison to the rainfall. The first rains in December are still absorbed by the soil and only a small part enters the river. However in January until June the river discharge is high. Even after the rainy season has ended (May and June) water drains from the soils which results in a relative high river discharge in comparison to the rest of the dry season (July until December).

Based on 11 years of discharge measurements in Rio Licuari (see annex 6), upstream of the Mugrima community, the dependable discharge has been determined. For the dependable discharge a probability of 80% (P80%) has been chosen in which:

Actual discharge ≥ dependable discharge

For the determination of F (probability of occurrence) the following formula is used:

F = Year / (N + 1)

In table 5.1 the calculated values for P75%, P80% and P90% in Rio Licuari are shown.

Table 5.1: Probability of occurrence of different discharges in Rio Licuari (P75%, P80%, P90%)

	Discharge – Probability of occurrence (F)		
	P75%	**P80%**	**P90%**
Nov	0.02	0.02	0.02
Dec	0.16	0.15	0.12
Jan	13.93	**6.17**	0.44
Feb	10.26	**6.88**	3.60
Mar	10.08	**8.31**	5.13
Apr	9.49	**9.44**	9.23
May	2.14	1.80	1.34
Jun	0.86	0.77	0.26
Jul	0.49	0.47	0.19
Aug	0.15	0.15	0.07

From this table it is noticeable that the dependable discharges (P80%) in the months January until May (highlighted values in the table) are relatively high. This is therefore also the most suitable period for irrigation. From table 5.1 it becomes also visible that the variation in the river discharge decreases later in the rainy season (in April there is less variation then in January). The reliability of the river discharge is therefore also higher in the end of the rainy season then in the beginning.

However, next to the dependable discharge, salinity intrusion plays also an important role in the water availability for irrigation at the Mugrima community. This is therefore discussed in paragraph 5.2.

5.2 Salt intrusion model

5.2.1 Situation

The Mugrima community is located relatively close to the Indian Ocean. This results in sea water intrusion into the rivers surrounding the community. The degree of salinity intrusion depends, for a large part, on the fresh water discharge from the river. In the rainy season salt water is pushed back downstream by the high (fresh water) river discharge. During a certain period the salinity content of the rivers surrounding the Mugrima community is then fresh and suitable for irrigation purposes. However, the exact period in which this occurs is not known. Also the gradient of decrease of salinity content along the course of the river is not known.

Some indications provided by farmers and inhabitants of the city of Quelimane on the situation are as follows:

1. Farmers at the pump station of the Mucelo irrigation system indicate that the salinity content is low enough from January until sometimes as far as August. Local farmers along large parts of Rio Mucelo confirm this situation. The discharge from January until August of the Rio Licuari River is in most years therefore apparently large enough to push back salt water downstream resulting in fresh water in Rio Mucelo. From table 5.1 this situation can be observed as well. With a probability of occurrence of 75% and 80% the river discharge in the months January until May is high (> 6 m^3/s). In May, June and July the discharge is still relative high (≥ 0.5 m^3/s). From August until January the river discharge drops (≤ 0.15 m^3/s). Such a river discharge is apparently not enough to prevent salinity intrusion into Rio Mucelo.
2. At the Elalane irrigation system this situation is different. The salinity content stays unfavorable for irrigation for a longer period. This is also quite logical considering the distance form the estuary mouth (the Elalane irrigation system is located more then 20 kilometers closer to the sea). This irrigation system is not in use at the moment. Only during a high river discharge the water becomes fresh enough for irrigation. A farmer near this irrigation system explained: “the system was abandoned because of salt in the river. Only for a short period we where able to get fresh water from the Licuari river.” However, when irrigating, there needs to be fresh water at least 4 months, when using a short cycle rice variety. Furthermore, the growing season of the traditional rice variety is at least 6 months.
3. According to the inhabitants of Quelimane, the river, near Quelimane, stays salt the whole year round. Even during a very high river discharge the salinity content remains relatively high (which is the result of the fact that Quelimane is located another 30 kilometers further downstream then the Elalane irrigation system).

This information gives only a very rough indication of the actual salt intrusion into the river and the effect of the fresh water discharge on the salinity content at different locations along the course of the river. For the management of estuarine water resources, a water manager needs to know the salt intrusion length and the salinity content along the course of the estuary during different periods of the year.

5.2.2 Predictive model

An opportunity, to achieve a more detailed overview of the salt intrusion length and the salinity content along the course of the estuary, is the creation of a predictive salinity intrusion model.

The results, presented in this paragraph, are based on research done by Prof. Dr. Ir. H.H.G. Savenije from the Technical University of Delft.
Prof. Savenije found a relationship between directly measurable parameters such as geometry, fresh water flow and tide and the salt intrusion length and the longitudinal distribution of the salinity throughout the estuary. A predictive salinity intrusion model for Rio Licuari is constructed using the model of Prof. Savenije. A justification, basic theory and used data, on the Rio Licuari salt intrusion model is presented in annex 7 (background information Rio Licuari salt intrusion model).

The result, generated by the Rio Licuari salt intrusion model, is the salinity intrusion into the estuary from the estuary mouth until 90 kilometers upstream. This data is based on the specific estuary characteristics (estuary shape, cross sectional area of the estuary at the mouth, average estuary depth, local tide) and the fresh water discharge from the river. Depending on the fresh water discharge the salinity intrusion will differ.

To be able to compare the results of the Rio Licuari salt intrusion model with reality. The rough indications on salt intrusion, provided by local people, as described in paragraph 5.2.1 for Quelimane, Elalane irrigation system and Rio Mucelo, can be compared with calculated salinity concentrations at these locations. These calculated salinity concentrations during different months (with the dependable discharge as the fresh water discharge) are shown in the following figure.

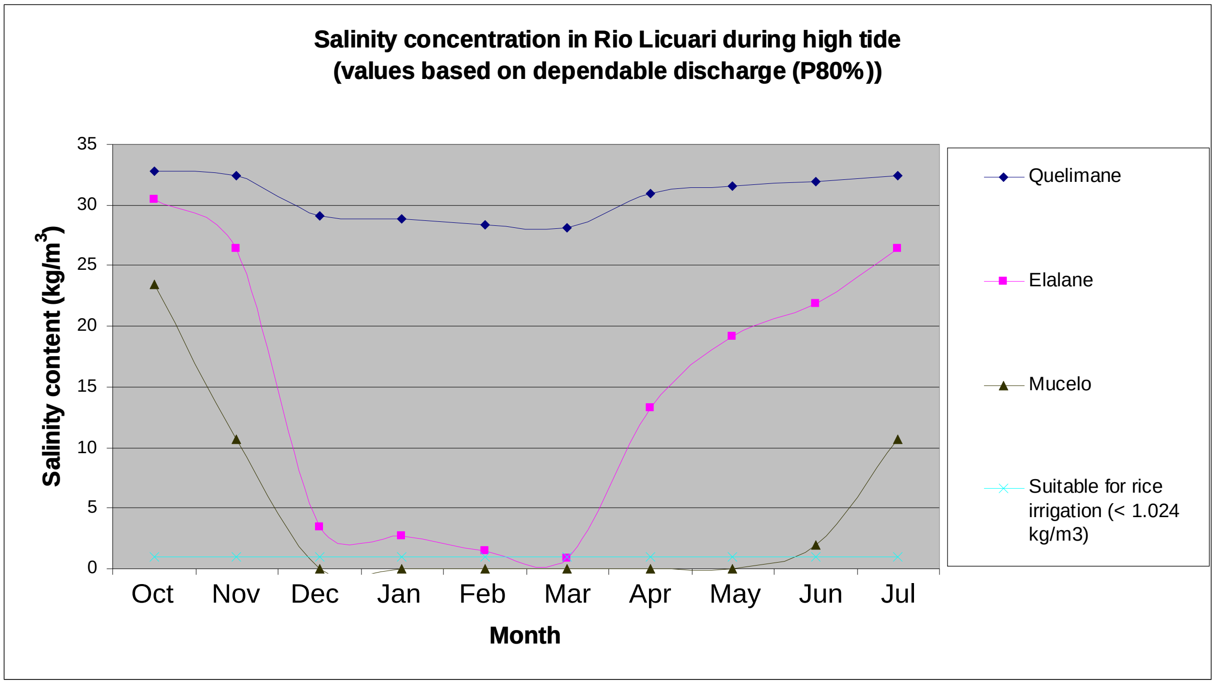


Figure 5.2: Calculated salinity concentration Rio Licuari

When the indications on salinity intrusion provided by local people (§ 5.2.1) are compared with the calculated values from figure 5.2 the flowing observations can be made.

1. According to local people Rio Mucelo contains fresh water from January until August. When we look at the calculated salinity concentrations of Rio Licuari at the crossing with Rio Mucelo this situation is the same. The salinity concentration drops rapidly in November and December and is below the limit of maximum allowable salinity for irrigation in January. In July the discharge decreases again and the salinity concentration rises above the maximum allowable salinity concentration for rice irrigation. This period of fresh water availability is exactly the same as described by the local people.
2. The second indication was the poor fresh water availability at the Elalane irrigation system (only with a high river discharge). Values calculated by the model show the same situation. Only in April the dependable discharge is large enough to reduce the salinity intrusion, during high tide, to an acceptable level for rice irrigation. In the months January, February and March the salinity content during high tide is just above the maximum allowable salinity concentration for rice irrigation.

   However, these values are the calculated values during high tide. This situation is different at average and low tide. Calculated values at average and low tide indicate that the salinity content becomes suitable for rice irrigation in all three months. As example, the situation in January during high, average and low tide is shown in the following figure.

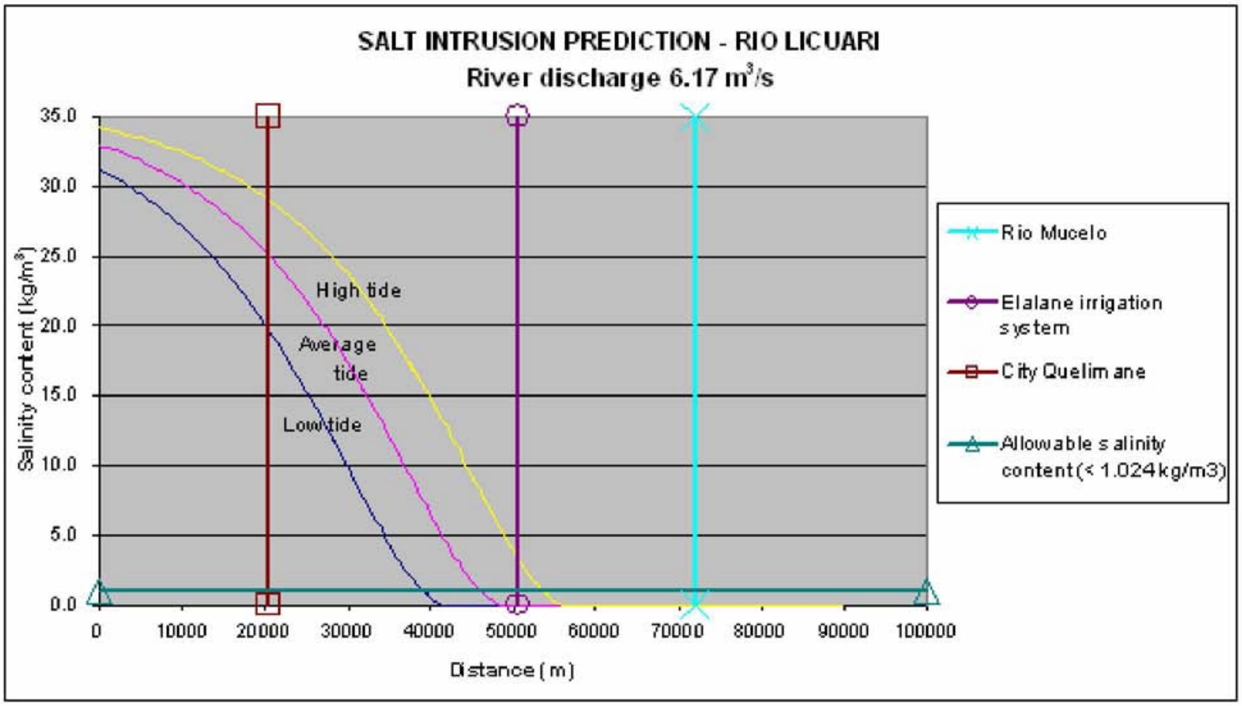


Figure 5.3: Calculated salinity intrusion in Rio Licuari during a river discharge of 6.17 m^3/s (dependable discharge in January)

In this example it is obvious that the salinity concentration at the Elalane irrigation system during average and low tide is 0 kg/m^3 and therefore Rio Licuari contains fresh water. Even when the salinity intrusion in May is calculated (dependable discharge = 1.8 m^3/s), during low tide the salinity content is only 0.1 kg/m^3 which is well below the maximum allowable salinity concentration for rice irrigation (1.024 kg/m^3). However, during high tide, with a river discharge of 1.8 m^3/s, the salinity concentration in Rio Licuari at the Elalane irrigation system becomes 13.3 kg/m^3, which is brackish.

This indicates that (according to the model) at Elalane there are much more difficulties with salinity intrusion (especially during high tide) compared to the situation at Rio Mucelo. This is again in agreement with the indications provided.

3. A final indication was the river near Quelimane which never becomes fresh. In the calculated values can be seen that indeed the salinity content stays very high in this part of the river throughout the year almost independently of the river discharge.

Based on this data it seems that the calculated values by the model give a reasonably good representation of the actual situation in the area.

A more detailed list of the calculated salinity intrusion during high tide with the dependable river discharges of different months is shown on the next page.

Table 5.2: Calculation results, Rio Licuari salinity intrusion model, during high tide, with dependable discharge of different months

	Salinity content during high tide throughout the estuary with dependable river discharge (kg/m³)									
Distance from estuary mouth (m)	November Q = 0.02 m³/s	December Q = 0.15 m³/s	January Q = 6.17 m³/s	February Q = 6.88 m³/s	March Q = 8.31 m³/s	April Q = 9.44 m³/s	May Q = 1.80 m³/s	June Q = 0.77 m³/s	July Q = 0.47 m³/s	August Q = 0.15 m³/s
10000	33.0	32.9	32.5	32.4	32.4	32.3	32.7	32.8	32.9	32.9
15000	32.9	32.7	31.1	31.0	30.8	30.6	32.0	32.3	32.5	32.7
20000	32.8	32.4	29.3	29.1	28.7	28.4	31.0	31.7	32.0	32.4
Quelimane	**32.8**	**32.4**	**29.1**	**28.8**	**28.4**	**28.1**	**30.9**	**31.6**	**31.9**	**32.4**
25000	32.6	32.0	26.9	26.5	25.9	25.5	29.6	30.8	31.3	32.0
30000	32.4	31.5	23.7	23.2	22.3	21.7	27.8	29.6	30.3	31.5
35000	32.2	30.7	19.7	19.1	17.9	17.0	25.5	28.0	29.0	30.7
40000	31.8	29.7	14.9	14.1	12.6	11.6	22.4	25.8	27.3	29.7
45000	31.3	28.4	9.4	8.5	6.9	5.9	18.5	23.1	25.1	28.4
50000	30.6	26.6	3.9	3.1	1.9	1.2	13.8	19.5	22.2	26.6
Elalane	**30.5**	**26.4**	**3.4**	**2.7**	**1.5**	**0.9**	**13.3**	**19.1**	**21.8**	**26.4**
55000	29.7	24.3	0.3	0.1	0.0	0.0	8.5	15.1	18.4	24.3
60000	28.4	21.2	0.0	0.0	0.0	0.0	3.3	10.0	13.9	21.2
65000	26.7	17.4	0.0	0.0	0.0	0.0	0.1	4.8	8.8	17.4
70000	24.5	12.8	0.0	0.0	0.0	0.0	0.0	0.7	3.7	12.8
Mucelo	**23.4**	**10.7**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**2.0**	**10.7**
75000	21.6	7.6	0.0	0.0	0.0	0.0	0.0	0.0	0.3	7.6
80000	17.9	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7
85000	13.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90000	8.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Salinity content to high for rice irrigation (> 1.024 kg/m³) = [yellow]
Good salinity content for rice irrigation (≤ 1.024 kg/m³) = [green]

The information from table 5.2 can be used to determine the available fresh water for irrigation purposes and the most suitable location for irrigation pumps at the Mugrima community.

Rio Mucelo is the most upstream location in the Mugrima community and therefore most suitable for irrigation purposes. In Rio Mucelo salinity problems remain limited to the period in which the river discharge is below 0.6 m^3/s. This situation is shown in the following figure.

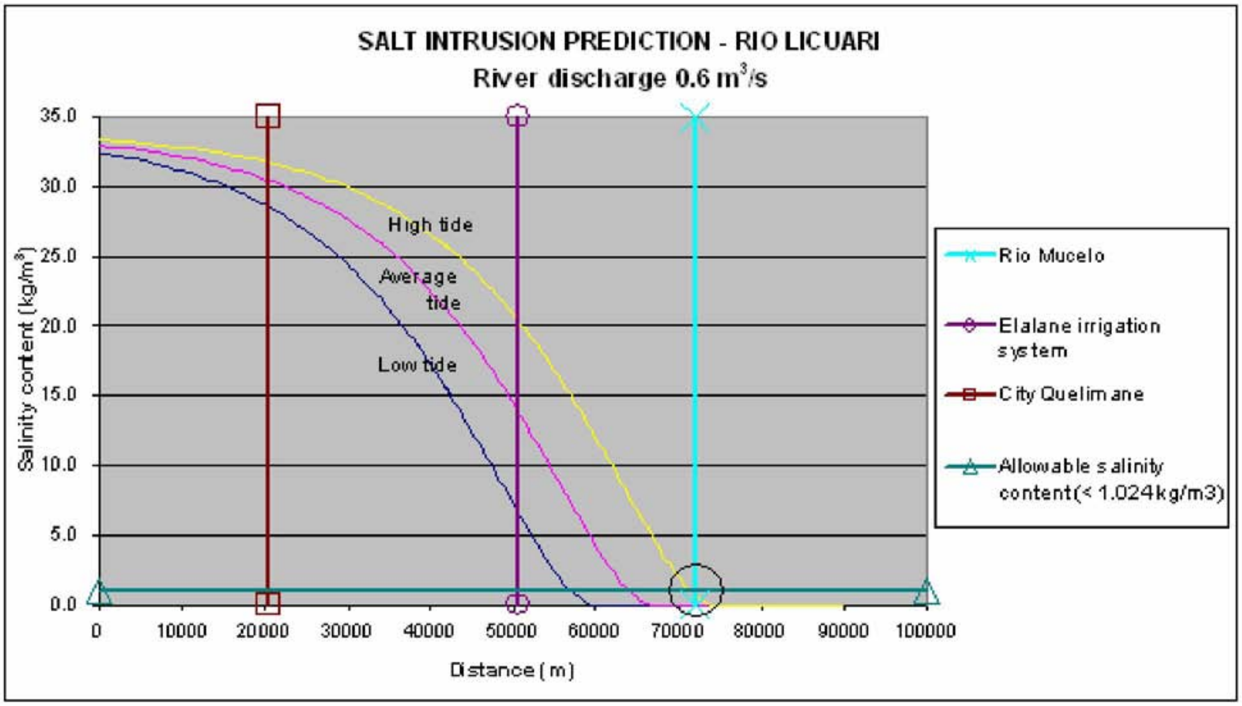


Figure 5.3: Salt intrusion prediction for Rio Licuari with a river discharge of 0.6 m^3/s

The yellow line is the salinity intrusion during high tide which is the most important (salinity intrusion is the most). In the figure can be seen that the salinity content, at Rio Mucelo, during high tide, with a river discharge of 0.6 m^3/s, is just below the maximum allowable salinity content for rice irrigation (within the circle). When practicing irrigation in Rio Mucelo this means that the minimum amount of fresh water which needs to remain flowing downstream, to prevent salinity intrusion into Rio Mucelo, is **0.6 m^3/s**. As an addition, to prevent damage to the rice crop, it is recommended to install measurement equipment at the intakes of irrigation systems to measure the salinity content of the irrigation water.

The salinity intrusion downstream of Rio Mucelo will increase because of the irrigation water extraction. This increase in salinity intrusion can result in negative effects on the environment. However, the area where the salinity intrusion will change due to irrigation water extraction is already an area with very erratic salinity content. The salinity content fluctuates with high and low tide and with the fresh water discharge. Irrigation water extraction will increase the salinity intrusion mainly in the period of peak water requirement in the beginning of the growing season. In the rest of the growing season irrigation water extraction is less and therefore salinity intrusion will not be effected.

5.3 Upstream water use

The final aspect which may influence the water availability for irrigation is upstream water use. Upstream water use, below the hydrological station where the discharge measurements have been carried out, will result in a decrease of the dependable river discharge as shown in paragraph 5.1.

Between the hydrological station and the Mugrima community no decrease in discharge is expected due to drinking water. People living near the river might take a few buckets of water to use as drinking water but no large quantities are extracted.

However, approximately 17 kilometers upstream of the crossing of Rio Licuari with Rio Mucelo the M'ziva irrigation system is located. This irrigation system, with a size of 500 hectares, is not functional at the moment. Nevertheless it is another 17 kilometers further upstream then Rio Mucelo and therefore in a more favorable location situation with regard to salinity intrusion. In the future this irrigation system might be rehabilitated. As a result this is a water extraction which needs to be taken into account in the water availability for irrigation at the Mugrima community. The maximum amount of extracted water per hectare at this irrigation system will be comparable to the calculated peak irrigation requirement for the Mugrima community (table 7.9). In these calculations the peak irrigation requirement is 1.16 l/s/ha. This results in a total extraction at this irrigation system of:

1.16 l/s/ha * 500 ha = 582 l/s = **0.582 m^3/s**

5.4 Available irrigation water at crossing Rio Licuari – Rio Mucelo

From paragraph 5.2.2 it is evident that when irrigation is practiced in Rio Mucelo, the discharge from Rio Licuari which remains flowing downstream needs to be at least 0.6 m^3/s to prevent salinity intrusion until the crossing of Rio Licuari and Rio Mucelo.

This situation reduces the available irrigation water from the dependable river discharge which has been calculated in paragraph 5.1.

The available irrigation water will be reduced by another 0.582 m^3/s caused by the extraction at the M'ziva irrigation system.

When the requirements for salinity intrusion prevention and irrigation at M'ziva are deducted from the dependable river discharge the total available fresh water for irrigation at the Mugrima community is calculated. This situation is shown in the following table.

Table 5.3: Available irrigation water

	Dependable discharge - P80% (m^3/s)	Salinity intrusion prevention (m^3/s)	Extraction at M'ziva irrigation system (m^3/s)	Available irrigation water (m^3/s)
Nov	0.02	- 0.6	- 0.582	0.00
Dec	0.15	- 0.6	- 0.582	0.00
Jan	6.17	- 0.6	- 0.582	**4.99**
Feb	6.88	- 0.6	- 0.582	**5.70**
Mar	8.31	- 0.6	- 0.582	**7.13**
Apr	9.44	- 0.6	- 0.582	**8.26**
May	1.8	- 0.6	- 0.582	0.62
Jun	0.77	- 0.6	- 0.582	0.00
Jul	0.47	- 0.6	- 0.582	0.00
Aug	0.15	- 0.6	- 0.582	0.00

Based on the used data, conducted calculations and acquired results in this chapter some concluding remarks have to be made.

In annex 6 the available discharge data of the Licuari river is shown. Available data on river discharge is limited to a period of 11 years which is relatively short. Such a short period of discharge data results in a less accurate approximation of the probability of occurrence of a certain discharge. Unfortunately, more extensive datasets on river discharge were not available.

Based on the conducted calculations it is clear that the dependable discharge, of the Rio Licuari river, is not the discharge which can be used for irrigation. Salinity intrusion and upstream water use decrease the available fresh water for irrigation with approximately 1.2 m^3/s.

Finally the results from table 5.3 show a short period of fresh water availability of only 4 months. This has important consequences for irrigation possibilities like a double cropping season or irrigation of the traditional rice variety with a long growing cycle. This is discussed in more detail in chapter 6. In addition, the amount of available irrigation water is not enough to irrigate the entire area suitable for rice irrigation in the Mugrima community (20,700 ha). Calculations on the possible irrigated area are done in chapter 7 (irrigation requirement).

6. Growing season possibilities of traditional and modern rice varieties

Because of the short period of water availability in Rio Licuari (January until May) it is necessary to search for rice varieties which are able to grow in this short period of water availability. Factors which influence the possibility to fit the growing season to the water availability period are: daylight length, average minimum temperature and growing season length.

6.1 Daylight length

The traditional varieties are sensitive to the duration of the day. For traditional varieties with a long growing cycle the critical value of light period is around 12 hours and 15 minutes during the panicle initiation (entrance of reproductive phase). This duration of the day occurs in the Zambézia province around mid-March (10-20) (Dries, A. van den, 1984).

The modern varieties are not sensitive to the daylight period. The duration of the cycle of growth of these varieties is constant and does not depend on the duration of the day.

This phenomenon has important consequences in practice. The traditional varieties need to be sown in November in order to arrive at the panicle initiation before mid-March.
The moment of harvest of the modern varieties depends on the moment of sowing, as it does not have other limiting factors.

6.2 Average minimum temperature

Modern varieties are very sensitive to low temperatures in the flowering stage: flowering must coincide with a minimum average temperature of at least 18ºC in order to get an optimal yield. The traditional varieties are more tolerant to the low temperatures in the flowering stage.

In the following figure a projection of the possible cycles of the different varieties is presented, taking into account the daylight length, average minimum temperature and growing season length. These projections are based on the average minimum temperature before 1998 at Quelimane airport.

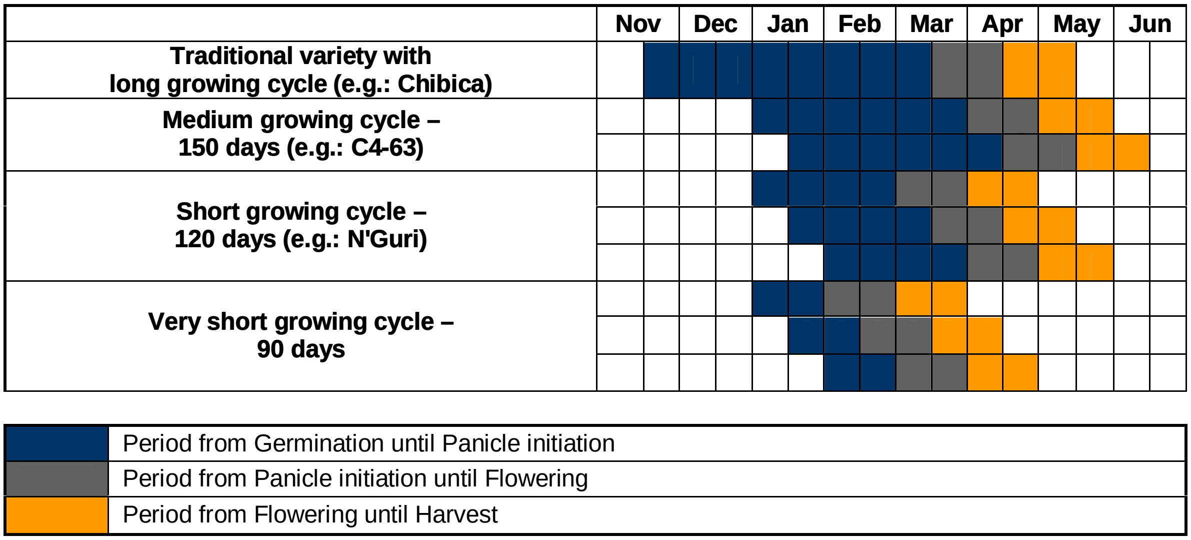


Figure 6.1: growing season possibilities different rice varieties (source: Dries, A. van den, 1984)

6.3 Window of opportunity for rice irrigation in the Mugrima community

In comparison to other areas in Mozambique, the Mugrima community is in a disadvantaged situation when looking at irrigation possibilities. In the lower Licungo and Zambezi River (located in the Zambezia province as well) there is water availability during the entire year. The irrigated rice season can start from August/September (thus, 4 to 5 months earlier than in the Mugrima community) which even makes a double cropping season possible.

However, this does not mean that irrigation in the Mugrima community is impossible. There is a *window of opportunity* in which the fresh water availability from Rio Licuari and the growing season possibilities of some rice varieties match. This window of opportunity is shown in the following figure in between the arrows.

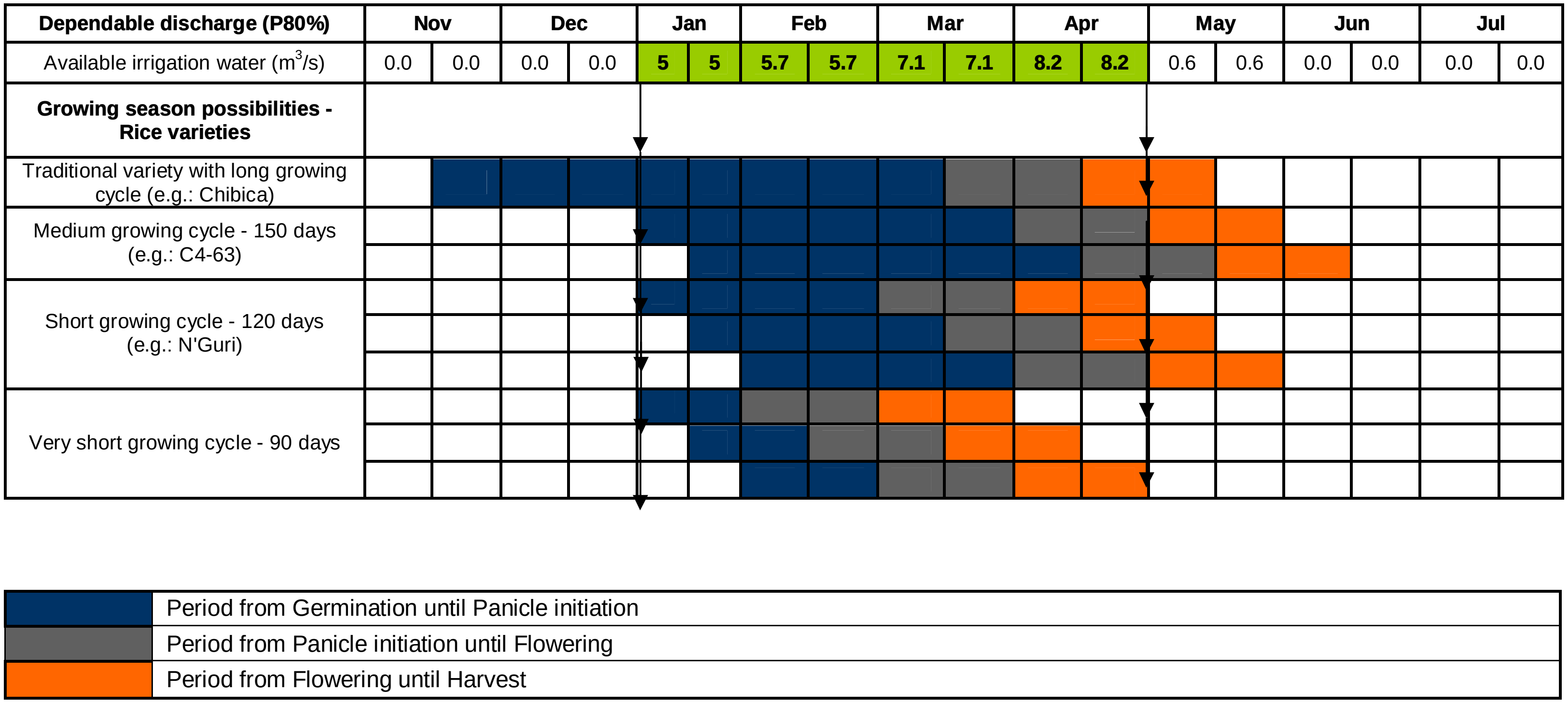


Figure 6.2: Window of opportunity for an irrigated rice crop in the Mugrima community

From the figure above constrains and possibilities for irrigated rice cultivation of different rice varieties can be seen. For the traditional variety the biggest constrain is that it's sensitive to the length of daylight. Therefore it must be sown before the end of November to reach the stage of panicle initiation before mid-March (see paragraph 6.1). In irrigated rice, this is a big disadvantage for the traditional rice variety because fresh water availability from Rio Licuari is only secure from the beginning of January. Furthermore, the growing season is very long (180 days) resulting in the end of the growing season outside of the fresh water availability period (harvest in second part of May).

Other rice varieties are more flexible in relation to the daylight length. Furthermore, the length of the growing season is shorter of the modern varieties resulting in possibilities to fit together a high river discharge and the rice growing season (window of opportunity for rice irrigation). In figure 6.2 some *windows of opportunity* are bordered by a thick line.

These opportunities emerge with the short and very short growing cycle varieties. A disadvantage of these modern varieties is their high sensitivity to water shortage. When water shortage occurs, the effect on the rice yield of modern varieties will be very high in comparison to the effect on traditional varieties. Traditional varieties are more resistant to drought and will still produce some yield when a drought occurs. Therefore, in dry land rice cultivation the traditional rice variety is much more suitable.

However, the rice yield with sufficient water availability, which can be achieved in irrigated rice cultivation, will be much higher of modern varieties in comparison to traditional varieties. Current rice yields in the Mucelo irrigation system are around 1 ton/ha according to farmers cultivating rice in this irrigation system. With a modern variety the rice yield in irrigated rice cultivation can be as high as 4 ton/ha (Agrifood Consulting International, 2005).

7. Irrigation requirement

The first step to determine the irrigation water requirements for rice cultivation is to determine the net irrigation requirement of the rice crop cultivated. The net requirement is obtained by subtracting the expected gains of water from the water needs for an optimal crop growth.

7.1 Irrigation water needs

In rice cultivation with an inundated soil, there are four expected water needs during a growing season:

1. Saturation of the soil (at the beginning of the growing season)
2. Water for establishing a water layer in the field
3. Water for evapotranspiration
4. Water for percolation

Ad 1. – Saturation of the soil (at the beginning of the growing season)

The amount of water needed for saturation of the soil prior to sowing/transplanting depends on the soil type and the initial soil moisture content.

In the Mugrima community the soils in the plains are Vertisols (J.H.M. Scholten, 1987 and A. Mate and J.H.M. Scholten, 1987). Other names for such a soil are 'black clay' or 'delta clay'. Some major soil properties of Vertisols are: a high clay content, low permeability, medium to low organic matter content (0.5 – 3%) and shrinking and swelling resulting in wide cracks during drought (Grunwald, S., 2007). When Vertisols are saturated they swell and become almost impermeable which makes it very suitable for rice irrigation.

In the Mugrima community these characteristics can be observed as well. Just before the rainy season wide cracks of up to 5 cm are visible. The first rains run in these cracks and water is directly lost due to deep percolation. After these first rains the soil swells and the wide cracks close. New rains hardly infiltrate and water remains on the fields for long periods of time.

The irrigation water requirement to saturate this type of soil can vary greatly over the years. In some years the soil might already be saturated by rainfall before the growing season starts. In other years no rainfall might fall and the soil has to be saturated completely by irrigation water. Because of the soil type and the occurrence of wide cracks in dry situation, the amount of irrigation water needed, to saturate the soil prior to the growing season, can be as high as 200 mm. However, because the irrigation season starts no earlier then the 15th of January (because of water availability from Rio Licuari) the irrigation water requirement for the saturation of the soil will be much less because the rainy season starts already from the beginning of December. Rain in December and the first part of January will already cause the soil to swell and cracks will be closed.

Thus, when water is needed, prior to the growing season, it will only be to supplement the water already present. **50 mm** would therefore most likely be sufficient.

Ad. 2 – Water for establishing a water layer in the field

Adequate water during the total growing period is needed for an optimal growth. A water layer also decreases weed growth and acts as a temperature regulator. Often a water depth of 100 to 200 mm is maintained throughout the growing period (Dries, A. van den and Gerbrandy G., 2006). In the irrigation requirement calculations this is an additional water requirement of at least **100 mm**.

Ad. 3 – Water for evapotranspiration

A first step to determine the evapotranspiration of a rice crop in the Mugrima community is to establish a list of the reference evapotranspiration (ET_o). ET_o values estimates can be obtained by using the Penman-Monteith method. This method requires climatic and geographic data. Values are needed for air temperature, humidity, solar radiation (which can be derived from hours of sunshine), wind speed and latitude.

The nearest location where climatic data is available is the meteorological station at Quelimane airport. Across flat or undulating country, evapotranspiration rates do not vary greatly unless there are major changes in local climate linked to local geography (e.g. the coastline of the sea or a large lake) (W.P. Field, F.W. Collier and H.R., 1998). The location of this meteorological station is approximately five kilometers south of the southwest border of the Mugrima community. Its distance from the northeast border is approximately 25 kilometers. ET_o calculations for the Mugrima community have been carried out using data from the meteorological station of Quelimane airport from before 1998.

An overview of the climatic data including calculated ET_o values (using the Penman-Monteith method), per month, is shown in the following table.

Table 7.1: Climatic data and calculated ET_o values (using Penman-Monteith method in CROPWAT 8.0), location meteorological station Quelimane airport (altitude (meters): 16; Latitude (degrees): -17.53; Longitude (degrees): 36.53) (Source climatic data: Clarke, Smith et al., 1998 in Agrifood Consulting International, 2005)

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sunshine (hours)	Radiation (MJ/m²/day)	ET_o (mm/day)
January	23.3	32.5	79	164	6.9	21.4	**5.01**
February	23.6	32.2	80	147	6.9	21	**4.8**
March	23.2	31.5	80	156	6.6	19.3	**4.4**
April	21.7	30.7	80	138	7.3	18.2	**3.92**
May	19	29	81	138	7	15.6	**3.2**
June	16.6	26.7	84	138	6.6	14	**2.63**
July	15.8	26.5	84	138	6.3	14	**2.67**
August	16.5	27.7	82	156	7.9	17.9	**3.48**
September	18.5	29.8	77	190	8.5	21.2	**4.58**
October	21	32	72	225	9.2	24	**5.73**
November	22.5	32.7	72	199	8.2	23.2	**5.68**
December	23.1	33	76	164	7.4	22.2	**5.29**
Average	20.4	30.4	79	163	7.4	19.3	**4.28**

Based on the ET_o values from table 7.1 the values of rice evapotranspiration in the Mugrima community can be obtained by multiplying the ET_o values with the crop coefficient (K_c). Typical K_c values of a rice crop during the growing season are shown in table 7.2.

Table 7.2: K_c values of a rice crop (Source: Allen, R. G., L. S. Pereira, et al., 1998)

	K_c initial	K_c mid season	K_c late season
Rice	1.05	1.20	0.60 – 0.90

To be able to multiply ET_o values with K_c values the K_c values need to be specified for each month for a chosen rice variety. Because of the period of water availability in Rio Licuari (see chapter 5) a short cycle rice variety needs to be cultivated to be able to fit the cropping season in the period in which water in the rivers is available (see chapter 6). The beginning of the growing season will be the first of February just after the land preparation. The calculated ET_o values in time during the growing season are shown in table 7.3.

Table 7.3: ET_{CROP} values of a short cycle rice variety in the Mugrima community

Month	Feb	Feb	Mar	Mar	Apr	Apr
Crop stage	init	dev	mid	mid	late	late
Days	15	15	15	15	15	15
Kc	1.05	1.1	1.2	1.1	0.9	0.75
ET_0 (mm/day)	4.80	4.80	4.40	4.40	3.92	3.92
ET_C (mm/day)	**5.04**	**5.28**	**5.28**	**4.84**	**3.53**	**2.94**

Ad. 4 – Water for percolation

As discussed in the part about saturation of the soil. The permeability of a Vertisol decreases greatly after the soil has been saturated. Infiltration measurements carried out in the irrigation system 'Regadio de Mucelo' indicate that the infiltration after saturation of the soil is as low as (**0.3 – 0.5 mm/day**).

7.2 Water gains

On the other side, in rice cultivation with an inundated soil, there is one water gain: rainfall.

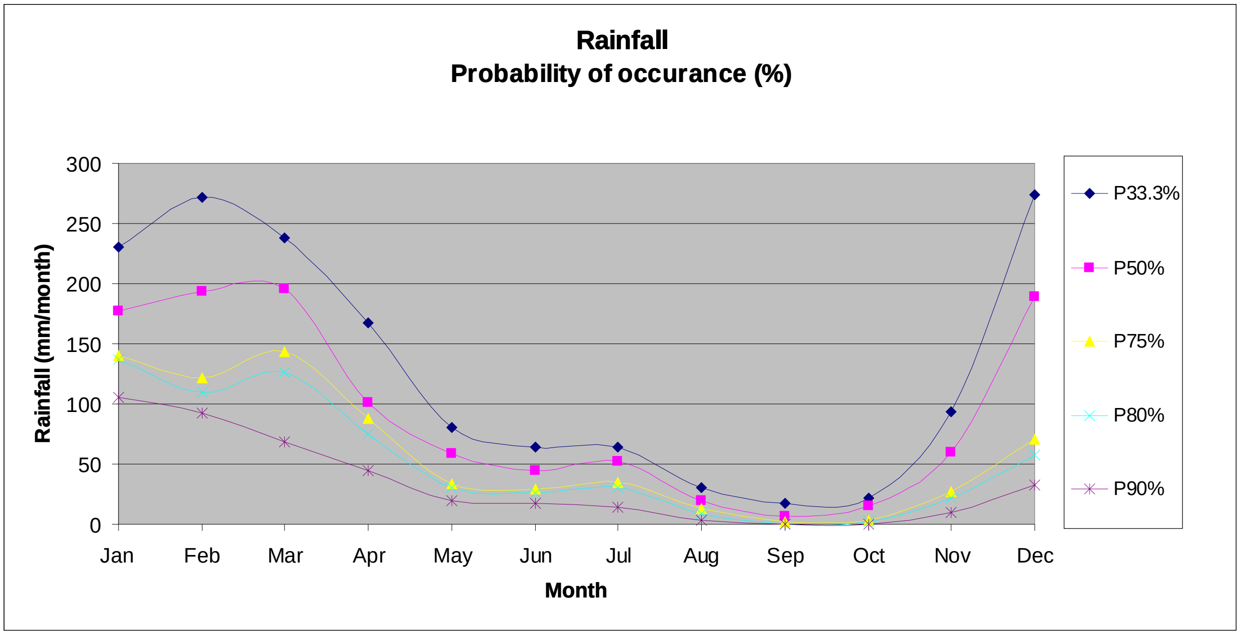
To be able to analyze rainfall in the Mugrima community, data is used from the meteorological station at Quelimane airport. This data consists of rainfall data over a period of 30 years between 1967 and 2004 (see annex 8). With this data the dependable rainfall has been determined.

The probability of occurrence of the rainfall needs to be chosen. When a high percentage is chosen it is more likely that the dependable rainfall will occur in a certain month. In the design of an irrigation system a high probability will make the water availability more secure. A common value for the dependable rainfall is 80 percent. In this case in 8 out of 10 years the rainfall will be equal or higher then the dependable rainfall value. With such a dependable rainfall value the security of having sufficient water availability is relatively high. Such a high level of water security is needed because of the modern rice variety which will be used (as discussed in paragraph 6.3). Modern rice varieties are very sensitive to water shortage which requires a high water security level. The dependable rainfall with an 80 percent probability (P80%) of occurrence is shown in table 7.5 and figure 7.1.

Table 7.5: Rainfall probabilities (P33.3%, P50%, P75%, P80% and P90%) meteorological station Quelimane airport during a year.

Rainfall probability (mm)													
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
P33.3%	**mm/month**	230	272	238.3	167.3	80	64.33	64	30	17	22	93.33	274
	mm/day	7.42	9.71	7.69	5.58	2.58	2.14	2.06	0.97	0.57	0.71	3.11	8.84
P50%	**mm/month**	177	193.5	196	101	59	45	52	20	7	15.5	60	189
	mm/day	5.71	6.91	6.32	3.37	1.90	1.50	1.68	0.65	0.23	0.50	2.00	6.10
P75%	**mm/month**	140.5	121.75	144	88	33.75	29.25	34.25	13.5	2	3	27.25	71
	mm/day	4.53	4.35	4.65	2.93	1.09	0.98	1.10	0.44	0.07	0.10	0.91	2.29
P80%	**mm/month**	136.8	109.6	126.2	74.6	30	25.8	30	9	0	1.8	22	58
	mm/day	**4.41**	**3.91**	**4.07**	**2.49**	**0.97**	**0.86**	**0.97**	**0.29**	**0.00**	**0.06**	**0.73**	**1.87**
P90%	**mm/month**	105.6	92.5	68	44.4	19.3	17.2	13.7	3	0	0	10	32.4
	mm/day	3.41	3.30	2.19	1.48	0.62	0.57	0.44	0.10	0.00	0.00	0.33	1.05

Figure 7.1: Rainfall probabilities (P33.3%, P50%, P75%, P80%, P90%) meteorological station Quelimane airport during a year.



From table 7.5 and figure 7.1 can be concluded that the rainfall is very irregular during the year. The dependable rainfall (P80%) varies from 137 to 0 mm/month which is 4.4 to 0 mm/day. However during the months of irrigation (January until May) the amount of rainfall is relatively high, which reduces the amount of irrigation water needed and the size of conveyance structures in an irrigation system.

In table 7.5 and figure 7.1 other rainfall probabilities of occurrence are included as well. The lowest probability of occurrence is 33.3%. An indication provided by farmers in the Mugrima community, who practice dry land rice cultivation, is that one out of three years there is sufficient water available. With a probability of occurrence of 33.3% this situation is simulated. It is clearly visible that indeed, with a probability of occurrence of 33.3%, rainfall is high in the months November until May with values of up to 250 mm/month in December, January, February and March.

Other probabilities of occurrence which are included are P50%, P75% and P90%.
P75% is very close to P80% the whole year round with differences no more then 20 mm/month. Rainfall with a probability of occurrence of 90% is also relatively close to the dependable rainfall (P80%) the whole year round except for March where the difference is almost 60 mm/month.

For a probability of occurrence of 50% the situation is different. In the rainy season the amount of rainfall with a probability of occurrence of 50% is much higher then the dependable rainfall. Especially in the months December through March this difference is relative big with a difference of 130 mm/month in March. This demonstrates the erratic nature of rainfall in the rainy season.

With large quantities of rain at once, a part of the rainfall can be lost when the amount of rain exceeds the in-field storage capacity. Aspects which influence the in-field storage capacity are the height of the bunds, the depth of the water layer maintained in the field and rain intensity. Especially with a probability of occurrence of 50% or less, rainfall can be lost when it exceeds the in-field storage capacity. A minimum height difference of 15 cm between the maintained water layer in the field and the top of the bunds is therefore recommended to make optimal use of the rainwater. This method will also result in the possibility to store the dependable rainfall completely in the field. Based on this, all dependable rainfall can be considered effective.

7.3 Net irrigation requirement

7.3.1 Irrigation requirement during the growing season

Based on the information from paragraph 7.1 and 7.2 the net irrigation requirement during the growing season can be determined. An overview is given in table 7.7.

Table 7.7: net irrigation requirement during the growing season

	Feb	Feb	Mar	Mar	Apr	Apr
Crop stage	init	dev	mid	mid	late	late
Days	15	15	15	15	15	15
Kc	1.05	1.1	1.2	1.1	0.9	0.75
ET_0 (mm/day)	4.8	4.8	4.4	4.4	3.92	3.92
ET_C (mm/day)	**- 5.04**	**- 5.28**	**- 5.28**	**- 4.84**	**- 3.53**	**- 2.94**
Deep percolation (mm/day)	**- 0.40**	**- 0.40**	**- 0.40**	**- 0.40**	**- 0.40**	**- 0.40**
Rainfall (mm/day)	**+ 3.91**	**+ 3.91**	**+ 4.07**	**+ 4.07**	**+ 2.49**	**+ 2.49**
Net irrigation (mm/day)	**1.53**	**1.77**	**1.61**	**1.17**	**1.44**	**0.85**

7.3.2 Peak irrigation requirement

The peak irrigation water requirement, however, will be at the start of the irrigation period because of the water requirement for soil saturation and establishing a water layer in the field (paragraph 7.1). To determine the peak irrigation water requirement the following formula can be used:

$$q = \frac{M\, e^{\frac{Mt}{s}}}{e^{\frac{Mt}{s}} - 1}$$

(van den Goor and Zijlstra, 1968)

In which:

q = supply required during land preparation (mm/day)
M = supply required for maintaining the water layer after saturation (mm/day)
= rainfall – (ET_o * K_c of open water < 2 meter depth; = 1.05) – deep percolation
= 4.41 mm/day – 5.26 mm/day – 0.40 mm/day
= 1.25 mm/day (In January)
t = duration of land preparation (days)
S = water required for saturation and establishing a water layer (mm)
= 150 mm (see paragraph 7.1)

Figure 7.2 shows the relation between the irrigation water requirement for land preparation and the length of the land preparation.

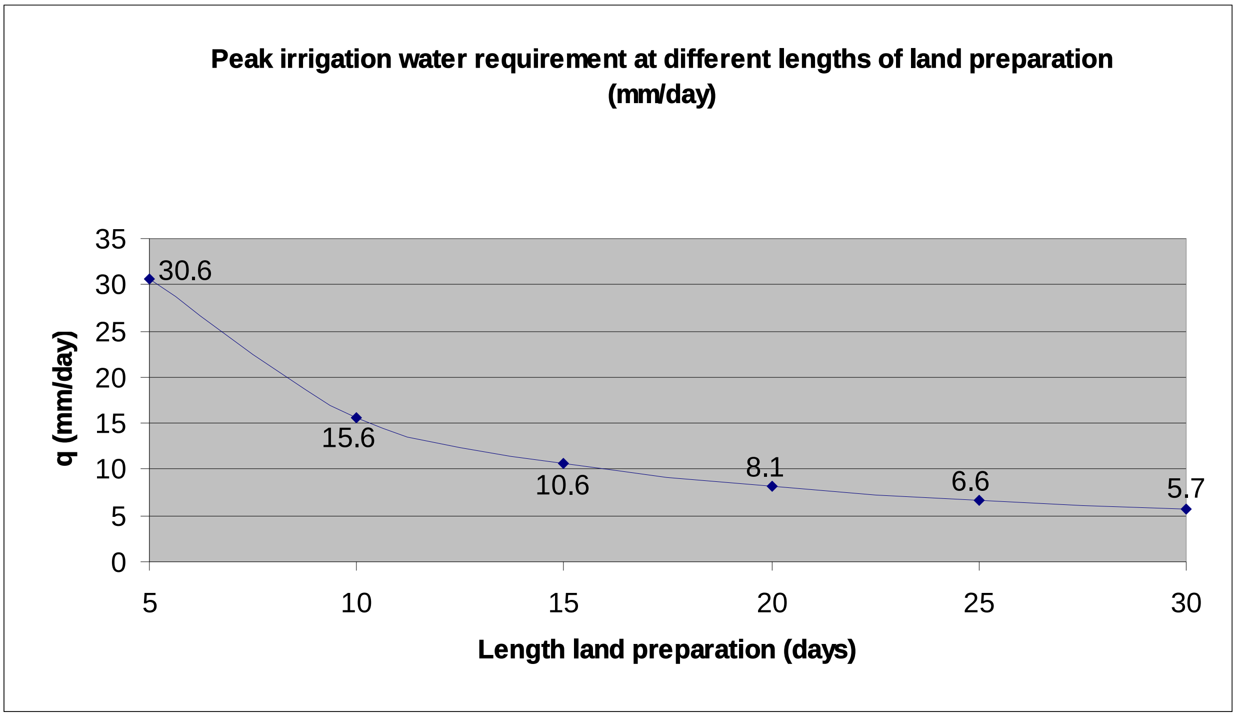


Figure 7.2: peak irrigation water requirement for different lengths of land preparation

As can be seen from figure 7.2, very short land preparation periods are not attractive because of the enormous water requirement. A more practical length for land preparation in this situation is around 20 days (8.14 mm/day).

7.4 Gross irrigation requirement

The calculated irrigation requirement during the growing season and the peak irrigation water requirement during land preparation are net irrigation water requirements. The gross irrigation water requirement can be determined by including the efficiency of the entire irrigation scheme. This efficiency is determined by three separate components:

- E_a: field application efficiency = 1.0 (losses are already considered as percolation losses)
- E_b: field canal efficiency (unlined, well compacted, heavy clay) = 0.9
- E_c: conveyance efficiency (main canal lined) = 0.9

By multiplying these separate components the irrigation scheme efficiency is calculated:

- E_p: scheme efficiency = 0.9 * 0.9 = 0.81

Resulting from this the gross irrigation requirement during the growing season can be determined:

Table 7.8: Gross irrigation requirement during the growing season

	Feb	Feb	Mar	Mar	Apr	Apr
Crop stage	init	dev	mid	mid	late	late
Days	15	15	15	15	15	15
Irrigation gross - 81% eff. (mm/day)	1.89	2.19	1.99	1.44	1.78	1.05
Irrigation gross (l/s/ha)	**0.22**	**0.25**	**0.23**	**0.17**	**0.21**	**0.12**
Available irrigation water (l/s)	5,671	5,671	7,101	7,101	8,231	8,231
Possible irrigation area (ha)	25,940	22,423	30,867	42,475	40,058	67,769

In table 7.8 the potential irrigation area during the growing season is also shown. It is clear that during the growing season a large area could be irrigated with the available irrigation water. However, the eventual possible irrigation area depends on the gross peak requirement (20 days of land preparation) which is needed prior to the growing season.

The gross peak requirement can be determined by:

Net peak requirement / scheme efficiency = 8.14 / 0.81 = **10.05 mm/day**

The available irrigation water, divided by the gross peak requirement, determines the maximum possible irrigation area. In the Mugrima community the maximum possible irrigation area is for that reason:

Table 7.9: Possible irrigation area in the Mugrima community

	January 12th through 31st
Irrigation gross – during land preparation - 81% eff. (mm/day)	10.05
Irrigation gross – during land preparation – 81% eff. (l/s/ha)	1.16
Available irrigation water (l/s)	4,988
Possible irrigation area (ha)	**4,287**

From table 7.8 and 7.9 a big difference can be observed between the irrigation requirement during land preparation (1.16 l/s/ha) and during the growing season (max. 0.25 l/s/ha). Such a big difference will result in difficulties in the water distribution. The irrigation system should be able to function at 0.25 l/s/ha. However, the design needs to be able to handle 1.16 l/s/ha as well during the land preparation.

Because of the short period of water availability, it is not possible to lengthen the land preparation period. Another possibility to reduce the differences in irrigation requirement is shortening the length of irrigation time during the growing season. In stead of irrigating 24 hours a day it is also a possibility to irrigate only 8 hours a day which results in an irrigation water requirement which is three times as high during these hours. Such a measure results in a smaller difference in irrigation water requirement and less difficulties in water distribution. With an irrigation time of 8 hours/day the irrigation requirement during the growing season is as follows:

Table 7.10: Gross irrigation requirement during the growing season (8 irrigation hours per day)

	Feb	**Feb**	**Mar**	**Mar**	**Apr**	**Apr**
Crop stage	init	dev	mid	mid	late	late
Days	15	15	15	15	15	15
Irrigation gross - 81% eff. (mm/day)	1.89	2.19	1.99	1.44	1.78	1.05
Irrigation gross (l/s/ha)	**0.66**	**0.75**	**0.69**	**0.51**	**0.63**	**0.36**
Available irrigation water (l/s)	5,671	5,671	7,101	7,101	8,231	8,231
Possible irrigation area (ha)	8,592	7,561	10,291	13,924	13,065	22,864

8. Irrigation system development opportunities

8.1 Irrigation system area and location

Based on the calculations in chapter 7 the total area which can be irrigated in the Mugrima community has been determined. This total area is approximately 4300 hectares (see table 7.9). Currently, from the 550 hectares of irrigation systems, 250 hectares are already irrigated. This irrigated area is in the Mucelo irrigation system. The other 300 hectares is located in the Elalane irrigation system. As discussed in paragraph 5.2 this irrigation system is in a disadvantaged situation when looking at the salinity intrusion in comparison to the further upstream Rio Mucelo. Based on calculations on salinity intrusion it is clear that, irrigation at the Elalane irrigation system, is not possible due to a period of fresh water availability which is too short (fresh water availability only in April). Therefore, it is unwise to rehabilitate the Elalane irrigation system, because in most years irrigation cannot fulfill the water needs of the rice crop.

This situation results in the need for approximately 4000 hectares (4300 hectares possible irrigation – 250 hectares existing irrigation) of new irrigation systems as far as possible upstream (Rio Mucelo). Another advantage of the construction of irrigation systems as far as possible upstream is the reduction of conflicts. Conflicts might rise when, in the future, new irrigation systems would be constructed upstream and take away the irrigation water which was used by the downstream existing ones. In this chapter the construction of 3800 hectares of new irrigation systems is discussed.

8.2 Main irrigation canals and intakes

In annex 9 of this report an overview of the suggested new irrigation systems with a total area of 3800 hectares is shown. The location of the main canals is based on the existing drainage pattern through the Mugrima community (see Annex 9 – Suggested irrigation systems and roads Mugrima community). Main canals are placed in between these drainage pathways in order to reduce the amount of work needed to construct the irrigation systems. It is mainly a reduction in earth work for construction of drainage system and leveling of the field (no need for filling up of the natural drainage pathways).
On the banks of these main irrigation canals access and maintenance roads will be constructed.

However, the choice if this type of irrigation system arrangement, results in several smaller irrigation systems with separate intakes, instead of one bigger irrigation system with one main intake. In the Mugrima community one big irrigation system with one main intake would not be appropriate because of the complex network of drainage pathways (see annex 5 – hydrological map Mugrima community). The construction of one big irrigation system would results in crossing of the canals with drainage pathways which is not recommendable. Furthermore, the amount of earth work and construction complexity would be increased.

In annex 9 a difference can be observed between the size of the different irrigation systems in the western part of the Mugrima community (5 different intakes for 1550 hectares) and the eastern part of the Mugrima community (only two different intakes for 2255 hectares). This is a big difference in size of the irrigation systems of 310 hectares per intake and 1130 hectares per intake. This difference is caused by the difference in natural drainage pattern. In the eastern part of the Mugrima community the drainage pattern is more favorable then in the western part which makes it possible to irrigate larger areas with one intake without having to cross the natural drainage pathways.

8.3 Irrigation pumps or canal construction

In contrast to the Zambezi and Lower Licungo River in Mozambique, the Licuari River does not have an annual period of flooding during which water levels are high enough to allow full gravity irrigation. Water levels in the Licuari River are high in the months January through April. However, in many years the water does not reach such a high level with which full gravity irrigation can be practiced. In the Mugrima community, in most years, irrigation water needs to be pumped into the main canal, from where it can travel further by gravity to the farm plots. This situation can also be observed in the existing Mucelo irrigation system. In this irrigation system water is pumped by an electrical pump into the main canal from where irrigation water travels by gravity to the farm plots.

An opportunity, to avoid the use of pumps, is the construction of an irrigation canal which transports irrigation water from further upstream towards the Mugrima community. With such an irrigation canal, head loss, which occurs in the river, can be reduced which will result in higher water levels in the canal at the Mugrima community and ultimately in full gravity irrigation without pumps.

The most logical location for such a canal would be from Rio Licuari at the M’ziva irrigation system (which is outside of the tidal influence) towards the Mugrima community (see figure 8.2). The M’ziva irrigation system is located, through Rio Licuari, 13.6 kilometers further upstream then the crossing of Rio Licuari with Rio Mucelo. When a canal would be constructed, in a straight line, from the M’ziva irrigation system towards the crossing of Rio Licuari and Rio Mucelo the length would be approximately 7.2 kilometers. This is 6.4 kilometers less and thus also 6.4 kilometers less head loss. To maintain the increase of head in the supply canal in comparison to Rio Licuari and Rio Mucelo, a supply canal towards the irrigation system is also needed alongside Rio Mucelo (see figure 8.2).

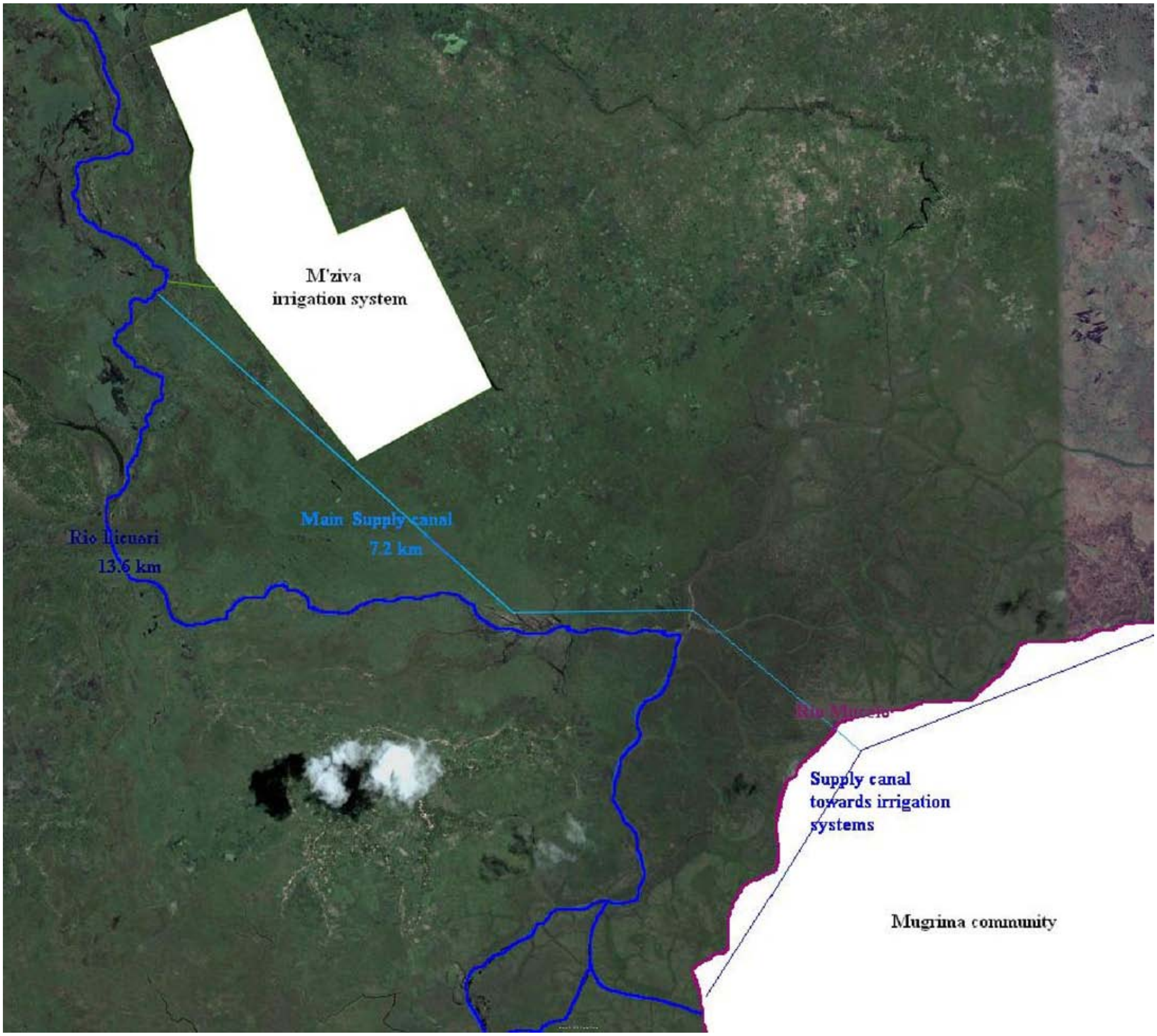


Figure 8.2: irrigation water supply by means of canal construction

A common amount of head loss due to slope which is needed in a canal is 0.0002 m/m. The head loss in a river depends on the distance from the origin and decreases further downstream. Especially in a deltaic area the head loss is less then close to the origin which is often in a mountainous area. The Mugrima community is located in the deltaic area of Rio Licuari and Rio Namacurra near the mouth of Rio Licuari in the Indian Ocean. Head losses in rivers vary from around 0.0001 m/m to 0.0015 m/m depending on local conditions (Schulze K. et. al., 2005). Because of the location of the research area along the course of the river (in a delta plain near the river mouth) the head loss will be relative low. This can be observed in the field as well through some typical characteristics of a small river slope: sedimentation of small particles (muddy sediments) and a meandering river course.

The Netherlands are also characterised by deltaic plains. The average head loss of the rivers in the Netherlands is 10 centimeters per kilometer (http://www.natuurinformatie.nl/ndb.mcp/natuurdatabase.nl/i000338.html) which is equal to 0.0001 m/m. In Mozambique, another river, which flows through the same deltaic plains as the Licuari River, is the Zambezi River. The slope of the Zambezi River in these deltaic plains is 0.0002 m/m (Zoltan Kovács Consulting Engineers and Sinotech CC, 2006).

Based on this, it can be presumed that the slope of the Licuari River near the Mugrima community will be low as well and will be within the range of 0.0001 m/m to 0.0004 m/m. When considering a maximum head loss of 0.0004 m/m in the Licuari River and a head loss of 0.0002 m/m in the supply canal the head losses will be:

Rio Licuari head loss = 0.0004 * 13,600 = 5.44 meter

Supply canal head loss = 0.0002 * 7,200 = 1.44 meter

The resulting maximum head loss gain with the construction of the supply canal will be:

5.44 – 1.44 = 4.00 meter

The water level in the Mucelo River is around three meters below the soil level in the Mugrima community. With an increase of 4.00 meter of head in the main supply canal the water level would be high enough to allow gravity irrigation at the end of the supply canal. However, from the end of the main supply canal, irrigation water needs to be transported further through the Mugrima community towards the different irrigation systems (see figure 8.2: supply canal towards irrigation systems). To reach the eastern part of the Mugrima community this would mean an additional canal length of 14 kilometers and also an additional head loss of 2.80 meter (0.0002 * 14,000). The resulting head gain is therefore also decreased with 2.80 meter to 1.20 meter. Even with irrigation systems at a distance of 5 kilometers from the end of the main supply canal the head gain would not be enough to allow full gravity irrigation. Based on the natural drainage pattern of the plains in the Mugrima community it is not possible to design all irrigation systems close to the end of the main supply canal. An overview of proposed irrigation systems based on the natural drainage pattern is shown in annex 9 (suggested irrigation systems and roads Mugrima community). Only the irrigation systems in the north-west corner of the Mugrima community with an area of 535 and 185 hectares are close enough to allow gravity irrigation through the supply canal.

Next to this, the main supply canal would cross through terrain of which the land use rights are from another community. This community might not accept the construction of the irrigation canal or start using water from it as well. As a final point, the irrigation canal which should be constructed from the western part of the community to the eastern part is expensive because several drainage pathways must be crossed. To cross these lower drainage pathways aqueducts are needed.

Based on the explanations above the construction of a main supply canal to allow full gravity irrigation is not appropriate in this situation.

Therefore irrigation pumps are the only alternative. Using irrigation pumps, Rio Mucelo can function as the main supply of fresh water for the irrigation systems. As discussed in paragraph 8.2, it is needed to construct 7 irrigation pumps in order to make optimal use of the natural drainage pattern.

Electrical pumps will be used for irrigation. An additional advantage of the use of electrical pumps is the construction of electricity lines. Electricity lines can simultaneously be used by inhabitants. In addition, electrical pumps need less maintenance and there is no need for fuel supply. The location of the electricity lines will be alongside the roads which are located on small dikes which results in fewer problems with water and better maintenance access. A disadvantage is the dependence on the electricity supply which breaks down once in a while in this region. However, because of an irrigation time of only 8 hours/day, a breakdown in the electricity supply can be compensated for by extra irrigation time.

8.4 Road rehabilitation and construction

In annex 9 the existing roads which run into the area are shown in grey. A first step to development, more access and opening up the Mugrima community is the rehabilitation of these roads. Currently these roads are in a very bad condition. During the rainy season access possibilities in some areas are limited to tractors only.

After rehabilitation of the existing roads, new roads should be constructed in order to reach the more remote regions. In annex 9 the suggested new roads are depicted in brown and are mainly extensions of the existing roads. In total four new roads are suggested.

The first is a road starting at settlement Muirrua over the dunes towards settlement Elalane. A big advantage of this road is the higher elevation of the dunes in comparison to the surrounding terrain which results in less earth work. With this road the existing villages on the dunes get better access opportunities. During meetings with Mugrima community members this road was seen as the most important with respect to unlocking the area.

The second is a road from the settlement of Elalane towards the M’ziva irrigation system. This road goes through lower terrain which will result in more earth work. The goal of this road is to increase the access of the north-western part of the community. This access is mainly needed to be able to construct the irrigation systems in the north-western area. Furthermore, with this road a new connection between Quelimane and Nicuadala will be created.

The third new road in the western part of the Mugrima community is an extension of the existing road which ends at the Muanamuambene settlement. This new road runs south of the Mucelo River towards the north-west corner of the community. This road runs in between the new irrigation systems and therefore results in more access.

The last new road is located in the eastern part of the community. It runs through the existing Mucelo irrigation system and the new irrigation systems to the east of the Mucelo irrigation system and ends at Settlement Ecundane. This road creates access to the irrigation systems and opens up the settlements to the east of the community.

8.5 Mechanization

A final action which is needed to be able to cultivate an additional 4000 hectares of land in addition to the existing cultivated areas is mechanization. Currently farmers are cultivating rice by hand. An inventory on rice cultivation in the Mugrima community has been carried out by APAC in 2004. This was an inventory on 1,640 families in the Mugrima community. Of these 1,640 families, 3,925 family members where cultivating rice in the Mugrima community. These family members where cultivating rice on 1,637 hectares (APAC, 2004). This is an average cultivated area of 0.41 hectare per family member and 1.00 hectare per family.

Based on table 3.1 of this report, the total area in the Mugrima community, on which currently dry land rice cultivation is practiced, is 6,312 hectares which would mean that 15,395 family members are cultivating rice (6,312 hectares / 0.41 hectare per person). It is unlikely that these family members are able to cultivate larger areas of rice by hand. This is partly caused by the larger distances which need to be crossed in order to cultivate more rice. Furthermore, a part of the family members who cultivate rice at the moment are still children.

Mechanization is a necessity in order to be able to cultivate the areas which become available in the new irrigation systems. Tractors and ploughs are needed to be able to cultivate larger areas of land with an equal amount of people.

In the next chapter the costs of the construction of the complete irrigation systems including roads and mechanization are calculated. Furthermore, the profits, which result from these investments, are calculated. Based on these calculations the economical return of investments in the irrigation systems is determined.

9. Economical return of an irrigation system in the Mugrima community

The possibility to attract investments depends, for a great deal, on the economic return of a project. The internal rate of return (IRR) is a value used by governments and funding agents to decide whether they will investment in a project. It is an indicator of the return on invested money.

The IRR is the annualized effective compound rate of return which can be earned on the invested capital (the yield on the investment). A project is a good investment proposition if its IRR is greater than the rate of return that could be earned from alternative investments. The IRR can function as an indicator for the government and funding agents for the effect of their investments. With a high IRR the government and funding agents will be more willing to invest in development projects. Governmental investments in projects with a high IRR will result in economical growth.

For the attraction of investments into the development of the Mugrima community this would mean that the IRR of investments in construction of roads, irrigation systems and mechanization needs to be as high as possible.

In the following paragraphs the costs and benefits of the project are shown in chronological order. In addition, in the last paragraph, the internal rate of return of the project, based on the costs and benefits over a period of 20 years, is determined.

In annex 10 a detailed overview of the calculated costs and benefits is shown.

9.1 Costs

The costs of earth work per m^3, gravel application per m^3, concrete per m^3, irrigation pumps etc are based on the knowledge of the organizations ORAM and APAC. These organizations have been working in the Zambezia province on the construction of roads, bridges and dikes and therefore have the necessary knowledge to give indications on local construction costs. A list of construction and material costs is shown in table 9.1.

Table 9.1: construction and material costs

	$/m³ earth work	$/m³ gravel	$/m³ concrete	$ Large bridge	$ Medium bridge	$ Small bridge	$ per 100 liter pump capacity	$ per meter electricity line	$ per pump house	$/kWh electricity	$ per tractor + plough	$ employee /day	$/y/ha irrigation system maintenance	$/y/ tractor+ plough maintenance	$/y/km road maintenance
Road rehabilitation	2	35													
Road construction	2	35		300,000	150,000	20,000									
Irrigation system construction	2		300				5,000	10	15,000						
Operation										0.2	50,000	4			
Maintenance													100	3,000	400

A first step to development in the area is the rehabilitation of the existing roads. Through the area there are three roads which need to be rehabilitated. The roads are already elevated and therefore doesn't need any extra earth work. Necessarily siphons and bridges are also already present. The main need at these roads is the reconstruction of the roads profile. In costs calculations road rehabilitation will be carried out during the first year of the project.

In year 2 until 5 of the project the new roads will be constructed. A detailed overview of the costs is shown in annex 10. In total the costs of the new roads come down to US$ 3,877,629. Lengths of the roads are measured in AutoCAD drawings. The amount of earth work and gravel application is based on the cross-sectional profile as shown in the following figure.

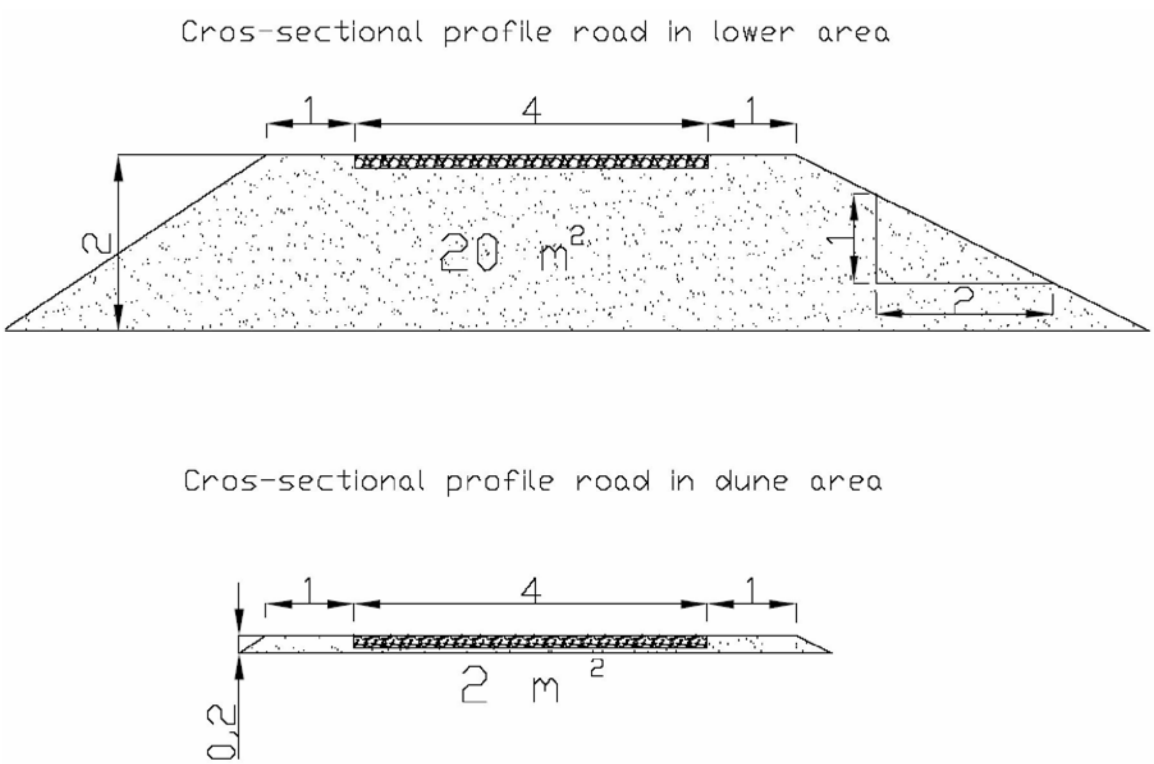


Figure 9.1: cross-sectional profile area roads

After the first roads are finished the construction of the irrigation systems can start. For the main canals the earth work has been estimated to be 20 m^3/m, for secondary canals 8 m^3/m and tertiary canals 4 m^3/m. The amount of earth work has been estimated relatively high to compensate for transport of soil. Soil transport is needed to maintain an even field and prevent unequal excavation of the soil in the rice fields. To construct drainage canals less earth work is needed, mainly because of the use of the natural drainage pattern. Other costs are electricity lines, irrigation pumps, concrete for main canal lining and maintenance and access roads. To be able to determine the internal rate of return the amount of time needed to construct the irrigation should be assumed. A reasonable period for construction is 6 years.

Because mechanization is needed in the irrigation system (in order to be able to cultivate the entire irrigated area) the costs of the purchase of tractors and ploughs are also included in the internal rate of return calculations. One tractor should be able to prepare 200 hectares of land, thus, in total, 16 tractors with ploughs are needed. The costs of a tractor with a plough are approximately US$ 50,000.

A final item which is included in the costs estimate is the operation and maintenance costs for roads, irrigation systems and mechanization. These costs include electricity costs, irrigation system and road maintenance, maintenance of tractors and ploughs and labour.

An overview of the construction costs of roads and irrigation systems is shown in table 9.2. From this table can be observed that the biggest expense is due to the application of construction materials. This is mainly concrete for the main canal lining. The application of 1 m^3 of concrete already costs US$ 300 in comparison to only US$ 2 per m^3 earth work or US$ 35 per m^3 gravel application. This difference is mainly caused by the materials needed. Earth work is only labour costs which are very low in Mozambique. Concrete application requires material supply to a remote area, transport and labour. Especially supply of materials in this area is relative expensive because of the long distances.

Table 9.2: overview of construction costs

Application of construction materials	11,234,880
Earth work	5,035,476
Gravel application	1,638,105
Bridges	1,030,000
Power line	445,000
Electrical pumps	232,105
Pump houses	105,000
Total construction costs	**19,720,556**

9.2 Profits

Profits have been determined based on international rice market prices minus the costs of rice cultivation. Prices on the international rice market are high. In comparison to 2005 and 2006 the rice prices have increased. Furthermore, the prospects for the future are also positive. World food reserves of wheat and rice are decreasing which has a positive effect on the rice prices and good expectations for the future. The introduction of bio fuels from crops adds to this tendency. In figure 9.2 recent rice prices are shown.

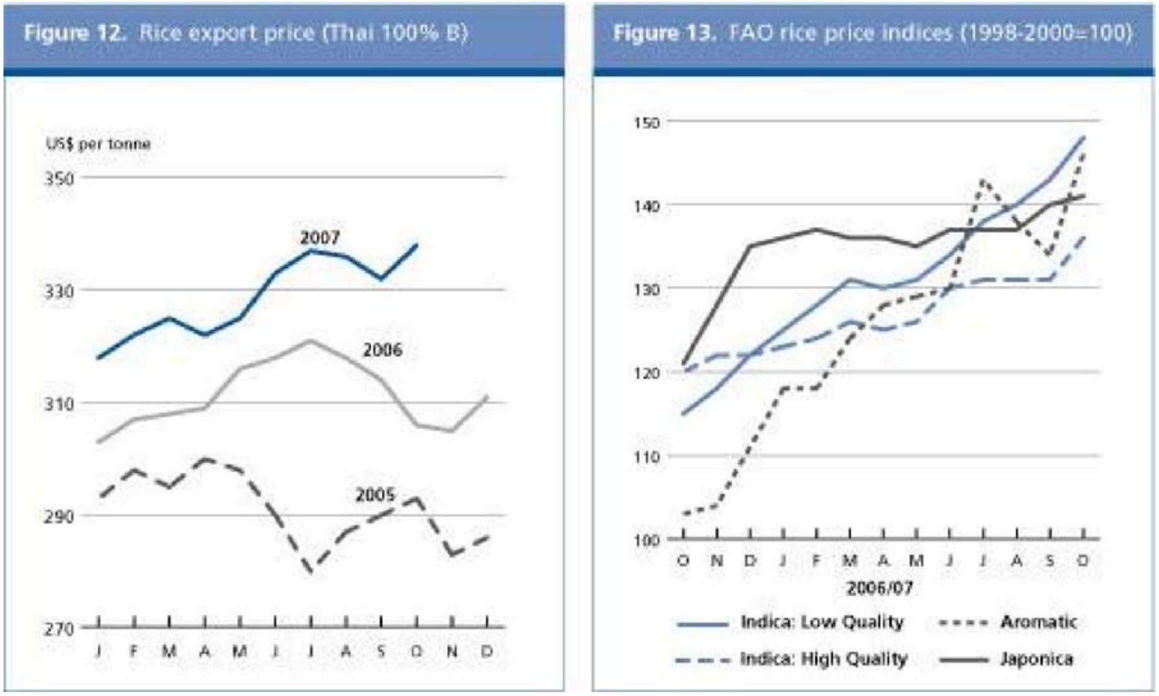


Figure 9.2: international rice market prices

Based on recent developments it is clear that rice prices are raising. Therefore, the moment, to invest in the development of the rice sector, is very appropriate. The average rice price of the last three years is around US$ 310 per ton (figure 9.2). A safe value for rice prices is therefore also US$ 310 per ton which is still below current rice prices.

Costs of rice cultivation in the Zambezia province of Mozambique are 2,392 Meticais per ton with a yield of 4 tons per hectare (Agrifood Consulting International, 2005). This is equal to approximately US$ 100 per ton.

Based on this data the profit of rice cultivation in the new irrigation systems have been determined. Profits start running 5 years after the start of the project with 400 hectares (when roads have been constructed and parts of the irrigation systems are ready). After 10 years the entire irrigation system will be functioning. The profit will be US$ 210 per ton (310 – 100).

The costs and benefits of the project over a period of 20 years are shown in the following figure (costs are including road construction, mechanization, operation and maintenance).

A detailed overview of the costs and benefits is shown in annex 10.

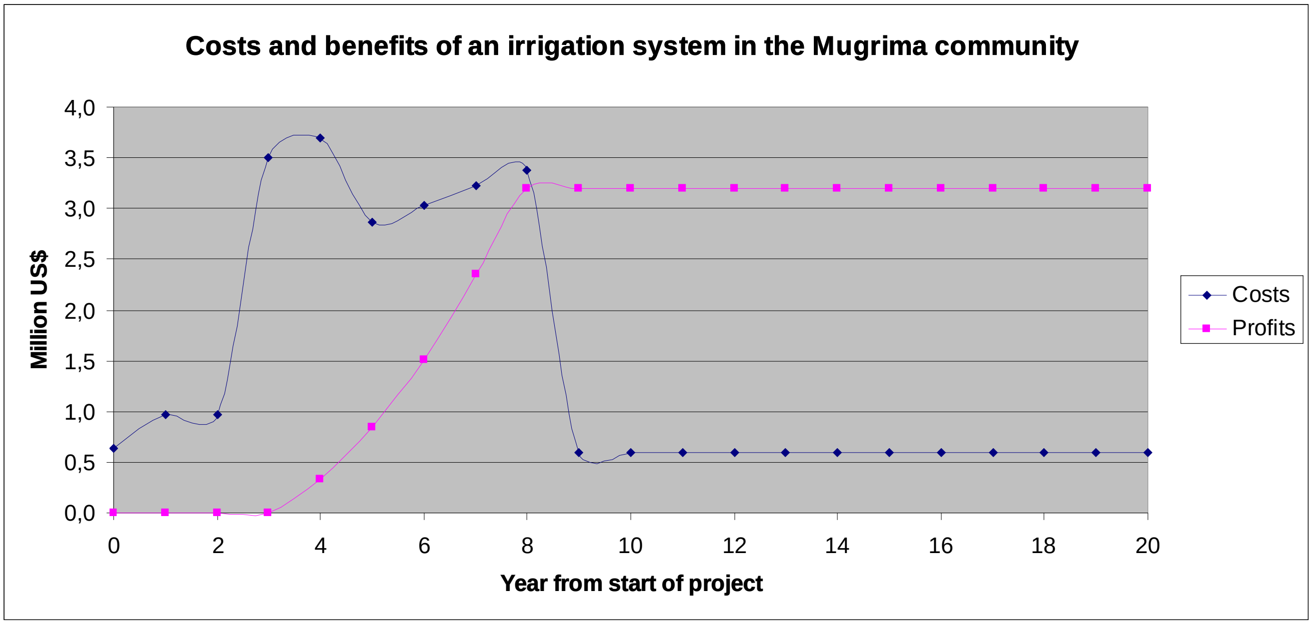


Figure 9.3: costs and benefits of an irrigation system in the Mugrima community

9.3 Internal rate of return (IRR)

Generally speaking, the higher a project's internal rate of return, the more desirable it is to undertake the project. As such, IRR can be used to rank several prospective projects the government or funding agents are considering. Assuming all other factors are equal among the various projects, the project with the highest IRR would probably be considered the best and undertaken first.

IRR is sometimes referred to as "economic rate of return (ERR)".

The IRR is the interest which is expected on an investment, expressed in percentage. To find the IRR, the value for *r* needs to be found that satisfies the following equation:

$$\sum_{t=0}^{N} \frac{C_t}{(1+r)^t} = 0$$

As an example, the internal rate of return, of the costs and benefits during a 5 year period, which is shown in table 9.3, has been determined.

Table 9.3: cash flow example during a period of 5 years.

Year	Cash Flow
0	-100
1	+30
2	+35
3	+40
4	+45

Using the equation, which was shown earlier, the IRR can be determined:

$$-100 + \frac{30}{(1+r)^1} + \frac{35}{(1+r)^2} + \frac{40}{(1+r)^3} + \frac{45}{(1+r)^4} = 0 \Rightarrow r \approx 17.09$$

In this example the IRR of the cash flows shown in table 9.3 is 17.09 %. The IRR has been computed by Excel.

Based on the costs and benefits per year, of the development activities in the Mugrima community, which have been determined over a period of 20 years (see figure 9.3), the IRR over the same period has been determined. In the case of the Mugrima community, the development activities over a period of 20 years have an IRR of:

IRR = 8.04 %

This value indicates the feasibility of the development activities in the Mugrima community. Such a high IRR is an additional incentive to the government or funding agents to invest in sustainable development activities (because of the positive effect on rural poverty reduction and economic growth).

Very recent developments in the rice sector indicate that prices of a rice crop are getting higher due to a decrease in worldwide food reserves. This could result in higher profits as indicated in paragraph 9.2. When the profit of a rice yield increases with 0.03 US$/kg (which is very plausible) the internal rate of return over a period of 20 years will increase from 8.04 to 10.51%.

Based on this it is clear that the moment to invest in an irrigation system in the Mugrima community is very good. The rice prices are high and the calculated internal rate of return of an irrigation system is at least 8% over a period of 20 years.

Part C – Alternative development opportunities

10. Alternative development opportunities

So far, the main opportunity for sustainable agricultural development in the Mugrima community, as discussed in this report, is the development of an irrigation system for rice cultivation in combination with road construction and mechanization. However, next to this primary development opportunity some other possibilities for sustainable agricultural development are available within the Mugrima community. In this chapter two alternative development opportunities are discussed.

10.1 Cattle breeding

Water availability only allows for a new irrigation area of approximately 3800 hectares. However, based on the land use inventory (in chapter 3 of this report), the total area currently unused in the Mugrima community is 11,375 hectares. With a new irrigation area of 3800 hectares the total area unused in the Mugrima community will still be around 7575 hectares. The area which will still be unused after the construction of irrigation systems can be seen in annex 9 (suggested irrigation systems and roads Mugrima community).

Another opportunity for sustainable agricultural development in these areas is the establishment of cattle breeding farms. Currently, in the Mugrima community, there is already a cattle breeding farm with a fenced off area of approximately 1200 hectares which is owned by Zambezia Agro Pecuaria (outsider, see chapter 2 and 3). A large number of cattle are raised in this area of which Zambezia Agro Pecuaria receives al the profits. In the following picture the fence around the cattle breeding farm is shown.

Figure 10.1: Cattle breeding in the Mugrima community by Zambezia Agro Pecuaria

This cattle breeding farm in the Mugrima community demonstrates the potential of cattle breeding in the Mugrima community. The current unused areas in the Mugrima community are mainly elevated areas which are less suitable for dry land rice cultivation. In these areas, run-off of rainwater occurs, resulting in a dryer/disadvantaged situation for dry land rice cultivation. In these areas grass is growing in abundance.

Before the civil war in Mozambique, which lasted for 17 years and ended in 1992, farmers in the Mugrima community already owned cattle. During the civil war farmers fled to the city of Quelimane, cattle was stolen or killed for food. Currently farmers in the community indicate that they would like to restart raising cattle in the community.

Cattle can increase food security and reduce poverty in the community. Furthermore, currently dry land rice cultivation is practiced by hand. Cattle can reduce problems of shortage in man power in dry land rice cultivation. During the colonial era, Portuguese used large numbers of cattle to plough the soil in order to be able to cultivate large areas of land more easy.

10.2 In-field storage capacity in dry land rice cultivation

Currently dry land rice cultivation is practiced on approximately 6000 hectares of land (see annex 3 – land use map Mugrima community). An indication provided by farmers is that in dry land rice cultivation approximately one out of three years sufficient water is available for a good crop growth, one out of three years the crop yield is reduced due to lower rainfall and one out of three years a rice yield is completely lost due to drought.

In the currently practiced dry land rice cultivation, in some areas rainwater is retained in the field by small dikes surrounding the farm plots. However, during intensive rainfall these structures have too many shortcomings to prevent rainwater loss through drainage. After heavy rains only a small part of the rainwater can be harvested in the field and a lot of the rainwater is therefore lost by the natural drainage system (see annex 5 – hydrological map Mugrima community). In the following picture a large drainage pathway which drains the rainwater from the Mugrima community is shown.


Figure 10.2: Large drainage pathway in Mugrima community

In the picture shown above one of the main drainage pathways flowing out of the Mugrima community is shown. During the rainy season this drainage pathway constantly drains fresh water out of the Mugrima community. In the rainy season, after a short period of drought, water in the fields is lost and rice yields are affected. Farmers in the Mugrima community realize this situation but do not have the means to harvest more rainwater.

The negative water balance is mainly caused by the water losses due to a low in-field storage capacity. Especially during higher rainfall intensities large quantities of rainwater are lost by drainage. When the in-field storage capacity in dry land rice cultivation is increased by means of higher bunds around the farm plots, most of the rainwater can be retained in the rice plots. In a water balance in which actual rainfall values are used this situation is visible (see figure 10.4).

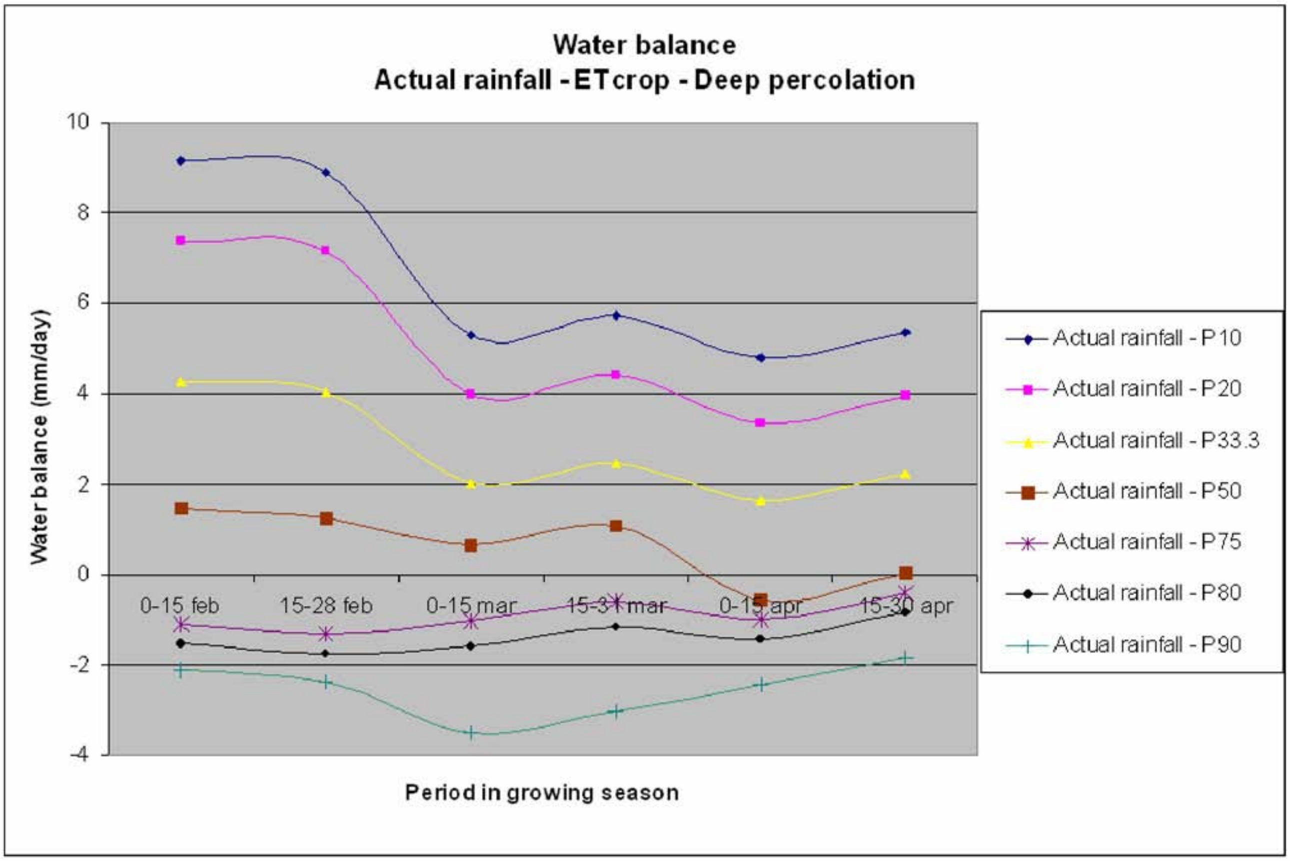


Figure 10.4: Water balance in dry land rice cultivation for different actual rainfall probabilities

In the figure above can be seen that when rainwater is harvested in dry land rice cultivation this would result in positive water balances in almost one out of two years. This means that water harvesting in the existing dry land rice cultivation in the Mugrima community could result in much better and reliable yields. A possibility to increase the in-field storage capacity is an increase in the height of the bunds around farm plots.

Part D – Conclusion and Recommendations

11. Conclusions

In this report opportunities for sustainable agricultural development in the Mugrima community area are discussed. Attention is paid to the technical and financial feasibility of irrigation, road construction and mechanization as well as increasing the in-field storage capacity in dry land rice cultivation and cattle breeding.

The fact that the community has an officially recognized land use right creates an opportunity for community based development activities. The Mugrima community has a land committee which decides about what to do with the land within the border of the community.

Based on the calculations on water availability and water requirements it is possible to irrigate 4000 hectares of new irrigation area with a short cycle rice variety. These irrigation systems, including all necessary roads and mechanization (tractors and ploughs) can attain an internal rate of return of 8.04 % over a period of 20 years. Based on calculations made, it is clear that the construction of irrigation systems in the Mugrima community is financially feasible. In addition, the terrain is flat and the soils are of heavy clay which is ideal for rice irrigation. Investments in rice irrigation in recent years are more likely to get a high internal rate of return. It is the perfect moment to invest in rice cultivation (irrigated and dry land rice cultivation). Rice prices are high and demand is increasing. Investments in rice cultivation by the government or funding agents can boost the economy and reduce rural poverty and famine.

During meetings with the community it became clear that the community is positive about these developments in the area. Especially road rehabilitation and road construction are valued as the most important even prior to the construction of irrigation systems. Community members indicate that within the community there are enough farmers to occupy the new irrigation areas with the use of mechanization.

Currently approximately 11,500 hectares of land within the Mugrima community is unused. Irrigation systems will occupy around 4,000 hectares of these unused lands. As a consequence 7,500 hectares of land are still unused. A proven opportunity for development is cattle breeding, which is currently done by an outsider in the community on 1250 hectares. Cattle can reduce problems with labour force in dry land rice cultivation as well by means of animal traction.

In dry land rice cultivation there is an opportunity for better yields through increasing the in-field storage capacity. Currently, according to farmers one out of three yields is relatively good, one out of three yields is moderate and one out of three yields fails due to drought. In dry land rice cultivation a lot of water is lost through the natural drainage system. Farmers are aware of this situation but indicate that they are not able to harvest more with the resources at hand. Harvesting of rainwater in the fields can result in an increase of yield and sufficient water availability in dry land rice cultivation in one out of two years.

12. Recommendations

This report is a case study on agricultural development opportunities of communities in the Zambezia province in Mozambique. Next to the Mugrima community there are approximately 100 other communities in the Zambezia province which are in a similar situation of development. The Mugrima community is located in the delta area and has its specific development opportunities depending on the situation at hand. In other communities other opportunities are present which can differ from sustainable wood logging to cashew nut harvesting. In the Zambezia province there is a need for an inventory of the sustainable development opportunities in the different communities in order to reduce famine and rural poverty. Communities have well defined land use rights and are therefore clear-cut landholdings. Borders are easily recognizable and are mostly rivers. The community is a unity with often a land use committee who decides about developments within the community. This structure makes it easier to do research, communicate with the population and find development opportunities in a participatory way. A development opportunity inventory on community level is therefore the best possibility to get an overview of options for sustainable development in the entire Zambezia province. Nevertheless, because of the location of the communities, accessibility is low and data collection is difficult. Consequently, to do research on development opportunities in these communities asks for more time then needed in more developed regions.

The research done on the agricultural development opportunities in the Mugrima community area, as shown in this report, is limited to the technical and financial feasibility of development opportunities. Management of the irrigation systems, market access in the area and social consequences of introducing the different development opportunities require additional research in the future. Furthermore, in this thesis report the emphasis is on irrigation. Therefore, other agricultural development opportunities are discussed in less detail. The potential of increasing the in-field storage capacity in dry land rice cultivation and raising cattle on unused areas require addition research to get an insight in the agricultural development opportunities with the highest potential.

The research carried out in the Mugrima community is based on all currently available data and is primarily focused on irrigation possibilities. Based on existing data it was possible to determine the potential irrigation area in the Mugrima community. However, some of the data on which the calculations are based are relatively old, especially the data on river discharge. It is not clear if more recent datasets from after the civil war are available. Datasets run to 1984. A search for more recent datasets at the government of Mozambique ended up with no results. A new measurement post for river discharge and water levels is desirable. With new measurements, changes in the recent past can be observed in river discharge which might lead to a small adjustment of the possible irrigation area as calculated in this report.

Salinity measurements should be carried out in order to validate the salinity intrusion model. These measurements must be carried out during high tide at the moment when the tide is turning in a location where the water was running fast before the tide started to turn (Savenije, 2008). The best way to carry out such a measurement is by boat. In the same day the discharge of the river has to be measured in order to be able to compare the measured salinity content with the calculated salinity content by the salinity intrusion model with the same river discharge. However, these measurements require a lot of organization which is difficult to realize in rural Mozambique.

Necessary measurements, needed to make a more detailed design of an irrigation system are water level measurements in Rio Mucelo and a topographic survey of the Mugrima community land. Water level measurements are needed in order to determine the required pump head capacity. Also fluctuations in water levels due to tides are important to record to take into account the range in water levels with which the irrigation pumps need to function. A topographical survey is required to reveal the small differences in land levels which are present in the Mugrima community. However, it may be assumed, based on existing measurements and observations, that there are no major level differences in the area (apart from the dunes).

With regard to the salinity intrusion into the estuary it is recommendable to do research on the effect of a salinity threshold in Rio Licuari. A salinity threshold is a small threshold on the bottom of the river which prevents salt water intrusion. Salt water often enters the river on the bottom of the river underneath the lighter fresh water. With a salt water threshold this intrusion could be reduced. Construction costs are probably acceptable. However, such a structure might result in negative effects on the environment and local economy (salt winning, fishing, etc.).

Next to the fresh water discharge from Rio Licuari, fresh water from Rio Namacurra also enters the Mugrima community via Rio Mucelo. Discharges from Rio Namacurra are not measured. Salt water intrusion via Rio Namacurra can, as a result, also not be determined because the models' predictions on the salt water intrusion are based on the fresh water discharge from the river. Consequently, discharge measurements in Rio Namacurra will serve a double purpose and are needed to get a more detailed insight of salt water intrusion and fresh water availability in the Mugrima community.

In this report the emphasis was on agricultural development through irrigation. Alternative development opportunities mentioned in chapter 10 might also be very cost effective measures to increase rural development. Especially increasing the in-field storage capacity in dry land rice cultivation can result in rural poverty reduction and less scarcity of food. Growing cattle is another opportunity to get more profit from the unused grass lands and could be examined in more detail.

Based on this study there is evidence that there are opportunities for sustainable agricultural development in the Mugrima community. However, additional research on surrounding factors is needed. National and international market access possibilities need to be examined. The presence of input provisions near the Mugrima community is another factor which can influence the feasibility of a development project and needs to be examined as well. Finally research on the need for farmers' education to be able to research higher yields with other rice varieties and growing cycles is required.

Bibliography

- Agrifood Consulting International (2005) 'Development Strategy for the Rice Sector in Mozambique' Report on Irrigated Rice Production. Prepared for the Cooperazione Italiana by Agrifood Consulting International. Bethesda, Maryland
- Allen, R. G., L. S. Pereira, et al. (1998) 'Crop evapotranspiration: guidelines for computing crop water requirements' Rome, FAO.
- APAC (2004) 'Listagem dos Agricultores de arroz no distrito de Nicoadala' Quelimane, Mozambique
- Bias, C. and Donovan, C. (2003) 'Gaps and opportunities for agricultural sector development in Mozambique' Maputo, Mozambique
- Schulze K. et. al. (2005) 'Simulating river flow velocity on global scale' Center for Environmental Systems Research, University of Kassel, Germany / Institute of Physical Geography, Johann Wolfgang Goethe University, Frankfurt, Germany
- Chilundo, A., et. al. (2005) 'Research Report 6 Land Registration in Nampula and Zambezia Provinces, Mozambique' Land Studies Unit, University Eduardo Mondlane, Maputo
- Coelho, J.B. and Littlejohn, G.M. (2000) 'The Case of the 1997-98 El Niño - Mozambique Case Study - Reducing the Impact of Environmental Emergencies Through Early Warning and Preparedness'.
- Concern Worldwide (CW), Oxfam International (OI) and Southern African Regional Poverty Network (SARPN). (2006) 'Strengthening responses to the Triple Threat in the Southern Africa region – learning from field programmes in Malawi, Mozambique and Zambia'
- Dartmouth Flood Observatory (DFO) (2007) 'Mozambique: Zambezia Province - Rapid Response Inundation Map 2' Hanover, U.S.A.
- Dries, A. van den (1984) 'Disponibilidade de agua para rega na regiao de Quelimane' Quelimane, Mozambique
- Dries, A. van den and Gerbrandy G. (2006) 'Irrigation and Water Management - Part 2: Plant – Water – Soil – Atmosphere Relationships' Wageningen University, Wageningen, The Netherlands
- Dries, A. van den and de Moor, J. (2007) 'Terms of reference for a study to make a land use plan with emphasis on irrigation for the Mugrima community in Mozambique.' Quelimane
- Duvani, L. (2007) President of ORAM, Zambezia province, Mozambique
- FAO (2002) 'FAO Rice information'
- GCOS (Global Climate Observing System) (2008) 'Monthly rainfall data meteorological station Quelimane 1967-2004'
- Goor, van den and Zijlstra (1968) in ILRI publication 14, 'Irrigation requirements for double cropping of lowland rice in Malaya'
- Howard, J. A., et al. (1998). Is Agricultural Intensification Profitable for Mozambiquan Smallholders? An Appraisal of the Inputs Subsector and the 1996/97 DNER/SG2000 Program. Policy Synthesis No. 38. USAID - Office of Sustainable Development

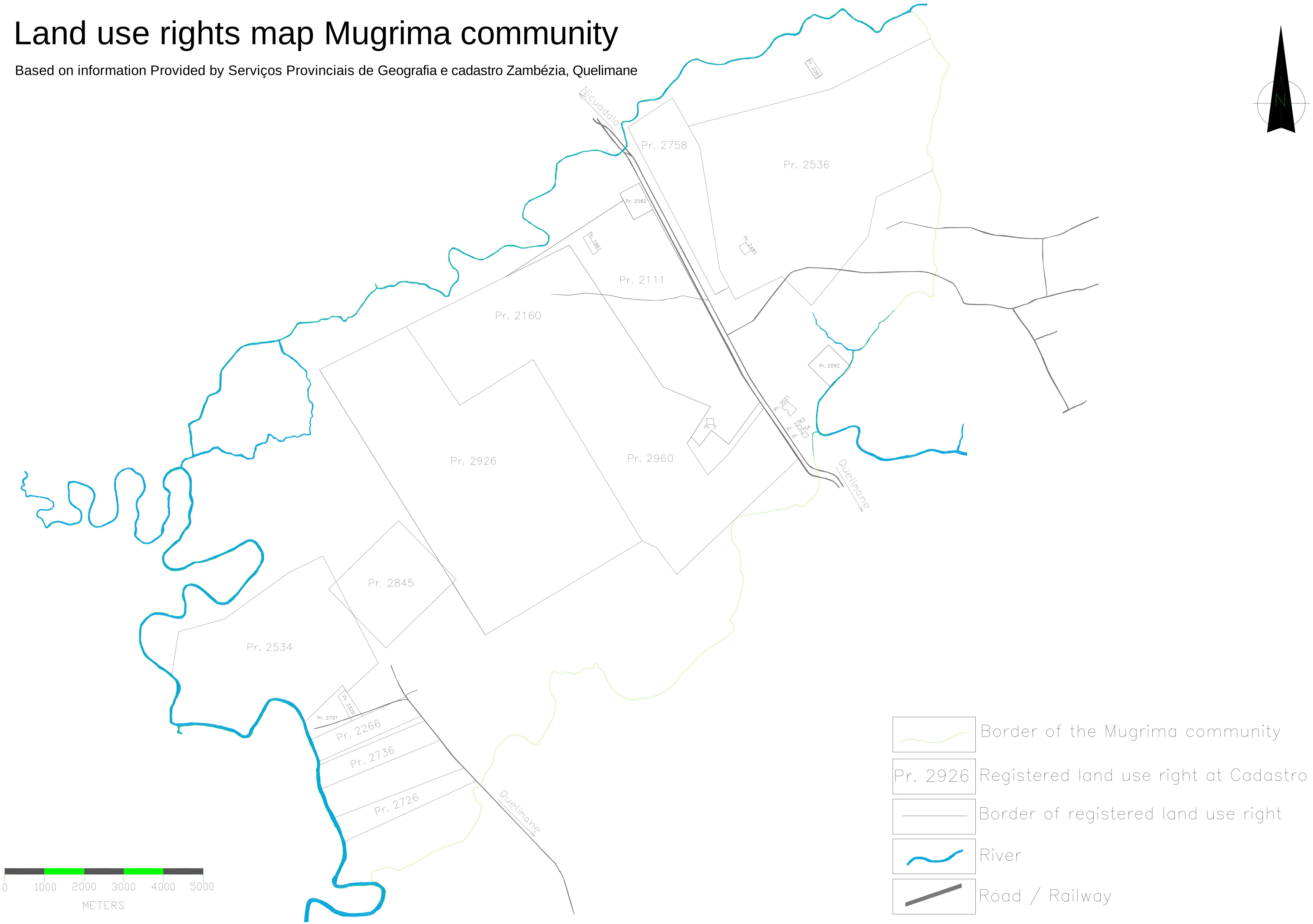
- INAHINA (Instituto nacional de hidrografia e navegação) (2007), 'Tabela de Marés – 2008 Ano XXIII Moçambique' Maputo, Moçambique
- J.H.M. Scholten (1987) 'Estudo de Solos ao Nível de Reconhecimento da Faixa Costeira de Quelimane' Maputo, Mozambique
- Kanji, N., et. al. (2002) 'The development of the 1997 land law in Mozambique' Promoting land rights in Mozambique and Kenya: How do NGOs make a difference, Mozambique
- Low, J. and Tschirley, D. (2003) 'Towards sustainable nutrition improvement in rural Mozambique: addressing macro and micro nutrient malnutrition through new cultivars and new behaviours' Technical report: first year of project activities Washington D.C.
- Mate A. and Scholten J.M.M. (1987) 'Carta de solos ao nivel de reconhecimento da faixa costeira de Quelimane' Maputo, Mozambique
- Negrão, José (1998). 'Land and rural development in Mozambique' The Land Campaign, Mozambique.
- Norfolk, S., et al. (2003) 'The 'New' Communities: Land Tenure Reform and the Advent of New Institutions in Zambézia Province, Mozambique' Sustainable Livelihoods in Southern Africa Research Paper 12, Institute of development studies, Brighton
- Norfolk, S. and Soberano, D. (2000) 'from conflict to partnership: a report on relationships between local communities and investors and land conflicts in Zambézia province' Agricultural Development Project, Quelimane.
- ORAM, et al. (2005) Development of cooperatives for agricultural and agro-industrial commercialization in the centre region of Mozambique, presentation of business plans and implementation strategy
- Perry-Castañeda Library Map Collection, http://www.lib.utexas.edu/maps/, University of Texas Libraries, 01-04-2008.
- Pijnenburg, B. (2004) 'Keeping it Vague - Discourses and Practices of Participation in Rural Mozambique' Wageningen, The Netherlands
- Savenije, H.H.G. (1986) 'A one-dimensional model for salinity intrusion in alluvial estuaries' Journal of Hydrology, Elsevier Science Publishers B.V. Amsterdam, The Netherlands
- Savenije, H.H.G. (1989) 'Salt intrusion model for high-water slack, low-water slack, and mean tide on spread sheet' Journal of Hydrology, Elsevier Science Publishers B.V. Amsterdam, The Netherlands
- Savenije, H.H.G. (1993) 'Predictive model for salt intrusion in estuaries' Journal of Hydrology, Elsevier Science Publishers B.V. Delft, The Netherlands
- Savenije, H.H.G. (2008) Direct email correspondence, 05 February 2008
- TNO Bouw en Ondergrond Geological survey of The Netherlands, http://www.natuurinformatie.nl/ndb.mcp/natuurdatabase.nl/i000338.html, 24-04-2008
- Vail, L. and White, L. (1980) 'Capitalism and Colonialism in Mozambique: A Study of Quelimane District'. Heinemann, London

- W.P. Field, F.W. Collier and H.R. (1998) 'Checklist to Assist Preparation of Small-scale Irrigation Projects in Sub-Saharan Africa' Wallingford International Commission on Irrigation and Drainage
- World Bank (2006) 'Mozambique Agricultural Development Strategy Stimulating Smallholder Agricultural Growth' Washington D.C.
- Zoltan Kovács Consulting Engineers and Sinotech CC (2006) 'Analysing the mighty Zambezi River' Civil Engineering

Annex 1 – Land use rights map Mugrima community

Land use rights map Mugrima community

Based on information Provided by Serviços Provinciais de Geografia e cadastro Zambézia, Quelimane



Annex 2 – Land use right certificate Mugrima community

REPÚBLICA DE MOÇAMBIQUE

GOVERNO DA PROVÍNCIA DA ZAMBÉZIA

DIRECÇÃO PROVINCIAL DE AGRICULTURA E DESENVOLVIMENTO RURAL

SERVIÇOS PROVINCIAIS DE GEOGRAFIA E CADASTRO DA ZAMBÉZIA

Telefs.213242 ; 213330 ; e 213443 ; Fax.214473 ; E-MAIL spgczam@teledata.

CERTIDÃO N°08/2001

----------**LÁZARO TITOS MATLAVA**, Técnico Profissional de Planificação e Chefe dos Serviços Provincias de Geografia e Cadastro da Zambézia - Quelimane.---

----------Certifico que nos termos do Artigo 13 do Anexo Técnico ao Regulamento da Lei de Terra publicado pelo Diploma Ministerial N°29 – A/2000 de 17 de Março, foi lançado no Cadastro Nacional de Terras a informação relativa as terras da comunidade de **MUGRIMA** e feito o respectivo registo **Folhas n°s 1736D2 e D4 – Escala 1: 50000,** com a àrea de **22500 ha**, situado em **Mugrima**, Localidade de **Nicoadala**, Distrito de **Nicoadala**, Província da Zambézia, destinado para fins comunitários.---

----------A referida comunidade tem as seguintes confrontações de Sul seguindo por Oeste com a **Comunidade de Nicoadala-Sede, Comunidade de Mucelo-Novo, Comunidade de Wachita, Comunidade de Mariebe, Comunidade de Mirremene, e a Comunidade de Marrongane**.--

----------E por ser verdade, mandei passar a presente Certidão que por mim vai assinada e autenticada com carimbo a tinta de óleo em uso neste serviços.

Serviços Provinciais de Geografia e Cadastro da Zambézia em Quelimane, aos 12 de Novembro de 2001.

Conta

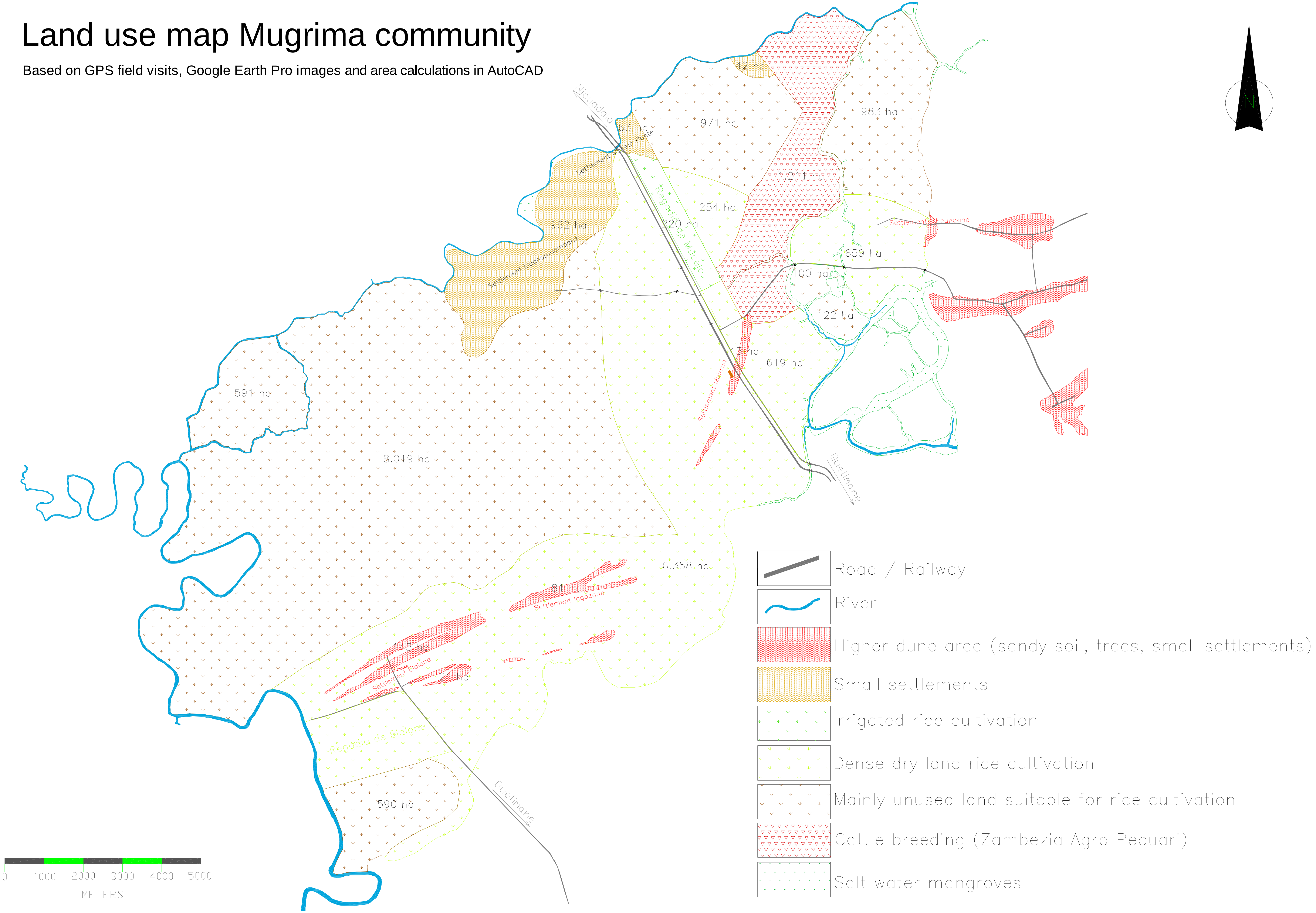
Emol----------120.000,00MT
Selos---------------400,00MT

Soma----------120.400,00MT

Annex 3 – Land use map Mugrima community

Land use map Mugrima community

Based on GPS field visits, Google Earth Pro images and area calculations in AutoCAD



Annex 4 – GPS data in combination with Google Earth Pro image

Waypoint number	Information
1	Start sand road at the main road
2	On sand road, both sides completely rice
3	On sand road, both sides completely rice
4	Siphon underneath sand road because of drainage way, +/- 20 meters wide. Goes until Rio Mucelo
5	On sand road, no rice: no use of the land
6	On sand road, drainage way connected to drainage way 4
7	50% Rice, 50% unused
8	70% Rice, 30% unused
9	Border of a village with a school
10	Dorpje
11	Dorpje
12	Drainageway, +/- 10 meters wide. Siphon installed to cross this drainageway because there is still water in (+/- 1 meter deep minimally)
13	Border of a village with a school
14	No rice, only grass
15	Rice fields on the west
16	Rice on the north, grass on the south
17	Rice on the north, grass on the south
18	Lower area on the east, Higher area on the west
19	Village on the west
20	Village
21	East village, west grass
22	Grass both sides
23	Village on the west
24	Village with sugarcane fields
25	Village with sugarcane fields
26	Drainageway, very deep!! (+/- 3 meter). Water in direct contact with Rio Mucelo the whole year round
27	A few houses, No rice, sugarcane and very small plots of sweet potatoes for home consumption
28	A few houses, No rice, sugarcane and very small plots of sweet potatoes for home consumption
29	A few houses, No rice, sugarcane and very small plots of sweet potatoes for home consumption
30	A few houses, No rice, sugarcane and very small plots of sweet potatoes for home consumption
31	Grass both sides
32	Rio Mambio, Deep drainage in direct contact with Rio Ebongoni which is in direct contact with Rio Mucelo. On other side of Rio Mambio nothing (no access)
33	Village of a few houses with small sugarcane fields
34	Village of a few houses with small sugarcane fields
35	Village of a few houses with small sugarcane fields
36	Grass both sides
37	Grass both sides
38	Small sugarcane plot
39	South-west sugarcane, north-east rice fields
40	South-west rice fields, north-east grass

Waypoint number	Information
41	Grass both sides
42	Grass west, Rice east
43	Rice west, grass east
44	Wild plants
45	Rio Mucelo
46	Grass both sides
47	Grass both sides
48	Small village
49	Rice
50	Rice
51	Small village
52	Grass
53	Drainageway, +/- 15 to 20 meters wide. For a part rice cultivation
54	Drainageway, +/- 15 to 20 meters wide. For a part rice cultivation
55	Drainageway, +/- 15 to 20 meters wide. For a part rice cultivation
56	Drainageway, +/- 15 to 20 meters wide. For a part rice cultivation
57	40% Rice, 60% Grass
58	10% Rice, 90% Grass
59	Drainageway, +/- 30 meters wide
60	Drainageway, +/- 30 meters wide
61	Grass
62	Drainageway
63	Drainageway
64	Drainageway
65	Drainageway
66	Village
67	Drainageway, +/- 20 meters wide
68	Lower area
69	Lower area
70	Crossroad main road and road to Mucelo rice warehouse
71	Natural drainageway in Mucelo irrigation system

Waypoint number	Information
73	Completely cultivated with rice
74	Grass and a few plots of rice
75	Grass and a few plots of rice
76	Small footpath. Grass lands both sides. Small canal already present. Area is called Zona Cekera
77	Small footpath. Grass lands both sides. Small canal already present. Area is called Zona Cekera. Rice in drainage pathway
78	Drainage pathway. Rice cultivation.
79	Footpath. Shallow canal already present. Grass.
80	Footpath. Shallow canal already present. Grass.
81	Footpath. Shallow canal already present. Grass.
82	Footpath. Shallow canal already present. Grass.
83	Footpath. Very small settlements (15). Cultivating a few small plots of rice. Shallow canal still along the foot path.
84	Footpath. Shallow canal already present. Mostly grass with some small rice plots.
85	Footpath. Shallow canal already present. Mostly grass with some small rice plots.
86	Footpath. Shallow canal already present. Mostly grass with some small rice plots.
87	Fence cattle breeding. Footpath and shallow canal present.
88	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
89	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
90	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
91	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
92	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
93	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
94	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
95	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
96	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
97	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
98	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
99	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
100	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
101	Fence cattle breeding until Rio Mucelo. Cattle breeding field until mangroves (see map).
102	Small village
103	Deep drainage (still water inside)
104	Deep drainage (still water inside)
105	Shallow drainage
106	Shallow drainage
107	Shallow drainage
108	Shallow drainage
109	Shallow drainage
110	Shallow drainage
111	Shallow drainage
112	Shallow drainage crossing existing canal

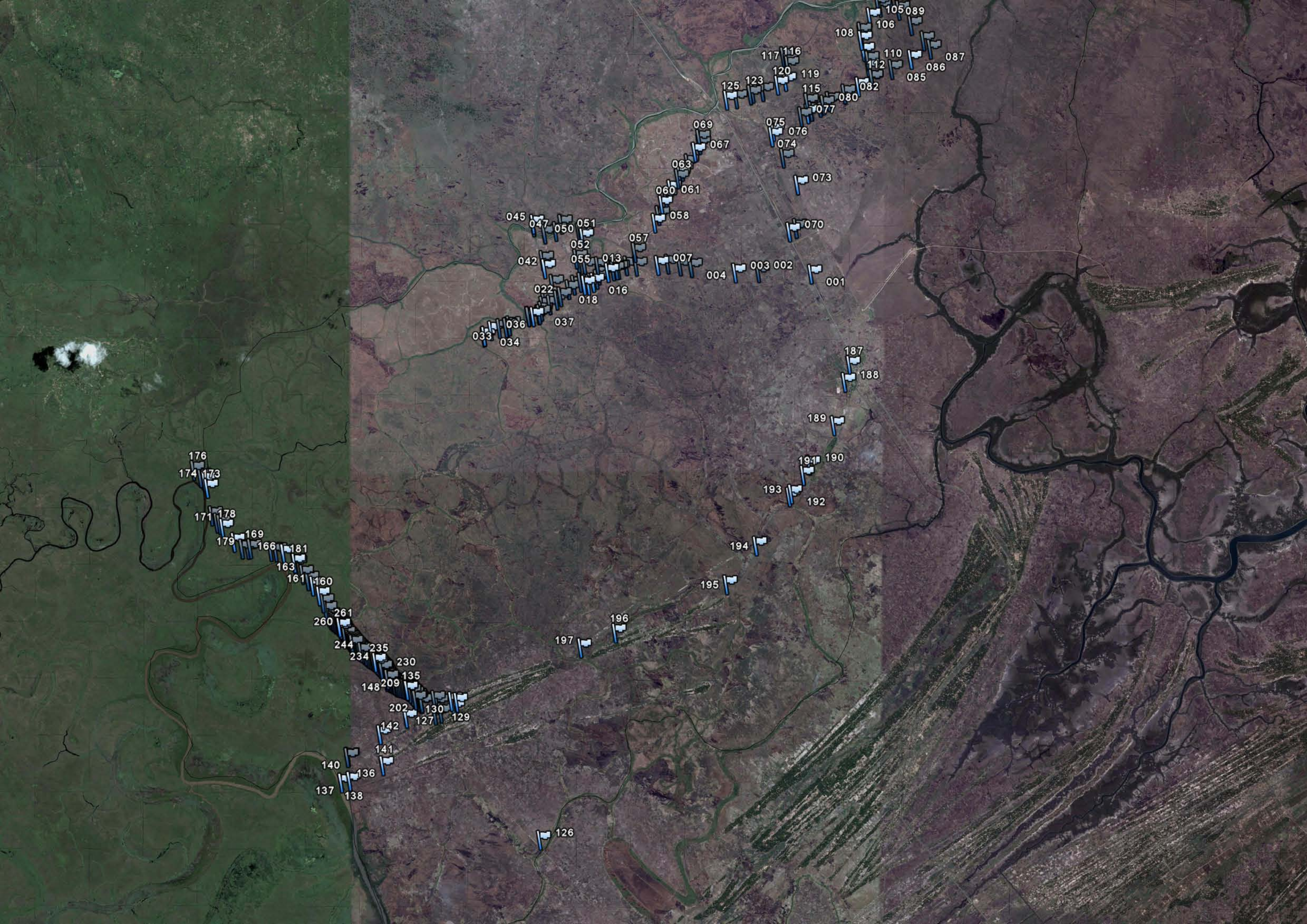
Waypoint number	Information
113	Shallow drainage crossing existing canal
114	Branch canal from other canal in direction of Rio Mucelo
115	Branch canal from other canal in direction of Rio Mucelo
116	Branch canal from other canal in direction of Rio Mucelo
117	Branch canal from other canal in direction of Rio Mucelo
118	Branch canal from other canal in direction of Rio Mucelo
119	Foot path through fields. Mainly grass and scattered a few small rice plots
120	Foot path through fields. Mainly grass and scattered a few small rice plots
121	Foot path through fields. Mainly grass and scattered a few small rice plots
122	Shallow drainage
123	Main drainage Mucelo Irrigation system
124	Small Village
125	Shallow drainage

Waypoint number	Information
126	Border community, Rio Dabada, On road towards "Regadio de Elalane"
127	Hospital in village on dune along the main road
128	Path through village on dune
129	Path through village on dune - House guide
130	Border between village and lower area
131	Lower area between two dunes
132	School in village on higher dune
133	Rice fields just outside the village on lower soil
134	Rice fields, north only plains as far as the eye can see
135	Rice fields, north only plains as far as the eye can see
136	Road to Elalane warehouse and Rio Licuari
137	Broken pump, Rio Licuari, Intake into "Regadio de Elalane"
138	Division structure in main canal
139	Higher spot in the landscape, Further north only plains as far as the eye can see, some small plots of rice
140	Higher spot in the landscape, Further north only plains as far as the eye can see, some small plots of rice
141	Graveyard in village on dune
142	Border village and lower area
143	Dune, village

Waypoint number	Information
144	Rice plots completely
145	Rice plots completely
146	Rice plots completely
147	Border rice, grass
148	Grass
149	Rice in lower area
150	Grass completely
151	Lower area also grass (no rice)
152	Completely grass
153	Completely grass
154	Completely grass
155	Completely grass
156	Lower area also grass (no rice)
157	Rio Mululu (deep drainage, however only a few spots of water at the moment)
158	Lower plain with reed growing
159	Border lower plain and higher plain with grass
160	Grass completely
161	Grass completely
162	Grass completely
163	Grass completely, near Rio Licuari
164	Grass completely
165	Grass completely
166	Grass completely
167	Grass completely, left river (Rio Licuari)
168	Grass completely, left river (Rio Licuari)
169	Grass completely, left river (Rio Licuari)
170	Grass completely, left river (Rio Licuari)
171	Grass completely
172	Grass completely, some trees scattered around the area
173	Grass completely, some trees scattered around the area
174	Grass completely, some trees scattered around the area
175	Grass completely, some trees scattered around the area, near to Rio Licuari
176	Rio Mucelo and Rio Licuari come together
177	Border from area with scattered around the area some trees, in front only grass
178	Grass completely
179	Grass completely
180	Grass completely
181	Shallow drainage pathway
182	Border from grass into rice in lower area
183	Border from rice in lower area into grass
184	Border from grass into rice
185	Rice completely until dune
186	Border rice into dune

Waypoint number	Information
187	Ceramica
188	Houses near Ceramica
189	Dune
190	Shallow drainage filled with water in between dunes. Had to walk through the water with bike on back (+/- 20 cm deep).
191	Flat area rice
192	Deep drainage filled with water. Water running south towards Rio Domelia. According to guide water always runs south here. Had to walk through the water with bike on back (knee deep)
193	Deep drainage filled with water. Water running south towards Rio Domelia. According to guide water always runs south here. Had to walk through the water with bike on back (knee deep)
194	Almost completely grass on flat area in a few areas rice.
195	Deep drainage filled with water. Water running south. Had to walk through the water with bike on back (knee deep)
196	Dune called Ingozane
197	Large baixa called Battie filled with water. Water running north. Water could be crossed by a siphon and a small dike. According to farmers, working in the baixa, the water starts to run south when it rains more. This baixa is the old river. However it is very wide and can't be recognized as a river in the field.
198	Side river from Rio Dos Bons Sinais going north. Large river. Is in contact with Rio Dabada (main drainage of the Mugrima community). Functions as drainage for the Mugrima community area.

On the next page the Google Earth Pro image is depicted with the location of all GPS points.

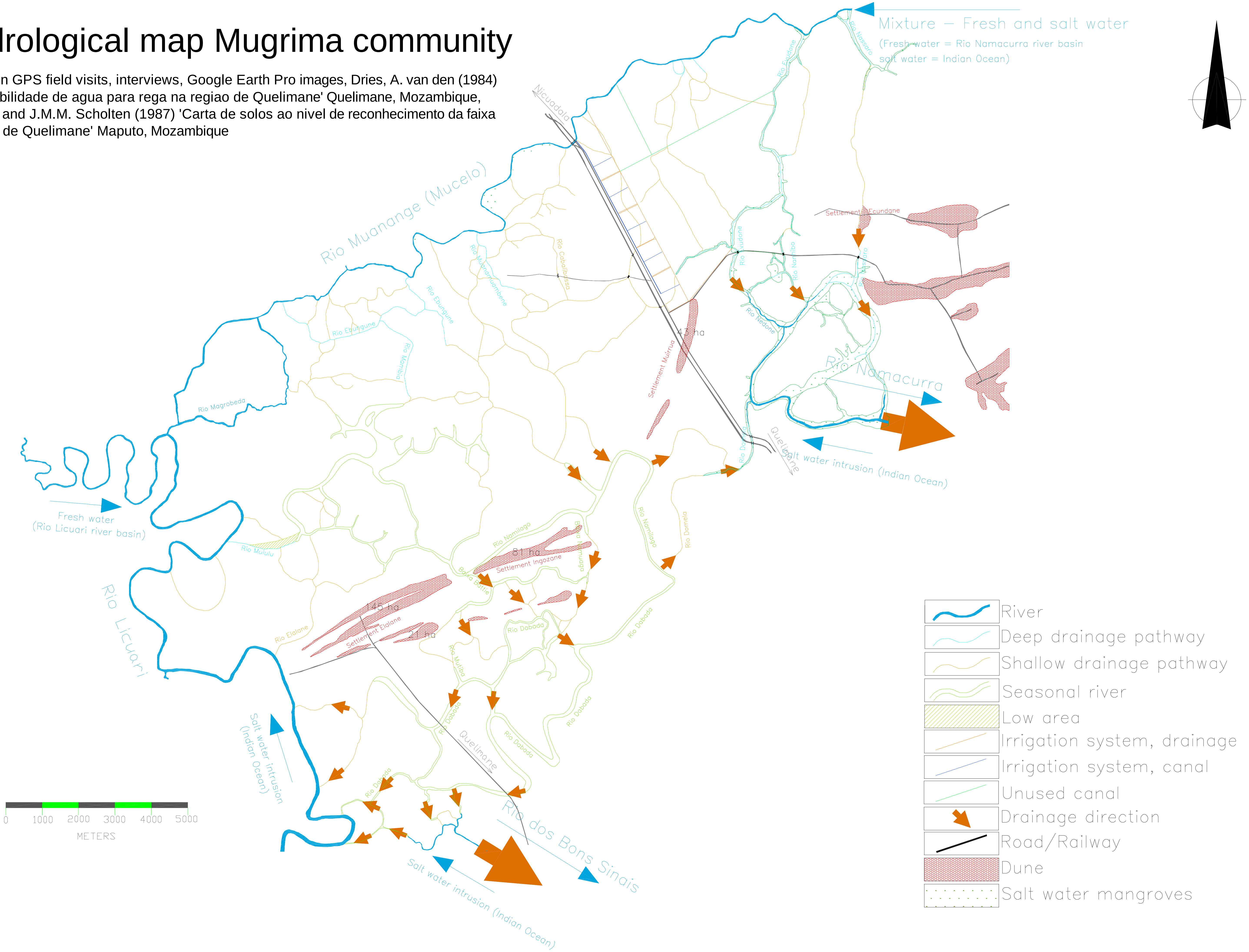


105
089
106
108
087
110
086
085
112
117
116
120
119
125
123
082
115
080
077
075
076
069
067
074
063
073
060
061
058
070
045
047
050
051
052
057
042
055
013
007
003
002
004
001
022
016
018
037
036
033
034
187
188
189
176
174
173
191
190
171
178
193
192
169
179
166
181
194
163
161
160
195
261
260
196
197
244
235
234
230
148
209
135
202
130
129
127
142
141
140
136
137
138
126

Annex 5 – Hydrological map Mugrima community

Hydrological map Mugrima community

Based on GPS field visits, interviews, Google Earth Pro images, Dries, A. van den (1984) 'Disponibilidade de agua para rega na regiao de Quelimane' Quelimane, Mozambique, A. Mate and J.M.M. Scholten (1987) 'Carta de solos ao nivel de reconhecimento da faixa costeira de Quelimane' Maputo, Mozambique



Annex 6 – Discharge data Rio Licuari

Monthly discharges Rio Licuari (m^3/s)											
Hydrological year	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
1967-1968	0.27	0.13	0.14	0.30	4.63	7.13	9.41	3.04	1.04	0.49	0.15
1968-1969	0.05	0.84	1.08	15.98	13.05	10.08	11.34	4.14	1.20	0.50	0.27
1969-1970	0.02	0.03	20.20	27.67	33.88	4.63	9.49	2.57	0.86	0.49	0.19
1970-1971	0.03	0.54	66.46	92.97	73.44	14.15	9.18	7.77	7.48	4.59	0.25
1971-1972	0.15	0.09	8.55	45.55	31.49	20.31	13.12	1.28	0.14	0.12	0.06
1972-1973	0.02	0.02	0.12	19.71	13.81	21.62	83.33	22.77	3.21	1.79	0.83
1973-1974	0.09	0.02	7.54	45.92	94.59	104.91	119.60	44.43	17.32	21.95	7.28
1974-1975	x	5.36	9.63	13.93	25.18	21.17	10.65	1.57	0.70	0.46	0.15
1975-1976	0.06	0.02	0.16	1.00	10.26	31.29	84.10	30.20	11.54	4.97	0.38
1976-1977	x	x	x	x	x	x	x	x	x	x	x
1977-1978	x	x	x	x	x	x	x	x	x	x	x
1978-1979	x	x	x	x	x	x	x	x	x	x	x
1979-1980	0.31	0.30	23.48	15.23	3.34	41.82	10.92	2.14	1.00	0.68	0.52
1980-1981	0.12	0.04	0.16	41.07	183.59	76.61	20.64	13.93	4.86	3.27	1.71
1981-1982	x	x	x	x	x	x	x	x	x	x	x
1982-1983	x	x	x	x	x	x	x	x	x	x	x
1983-1984	x	x	x	x	x	x	x	x	x	x	x

Monthly discharges Rio Licuari (m^3/s) descending order											
Sequence number	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
1	0.31	5.36	66.46	92.97	**183.59**	104.91	119.60	44.43	17.32	21.95	7.28
2	0.27	0.84	23.48	45.92	94.59	76.61	84.10	30.20	11.54	4.97	1.71
3	0.15	0.54	20.20	45.55	73.44	41.82	83.33	22.77	7.48	4.59	0.83
4	0.12	0.30	9.63	41.07	33.88	31.29	20.64	13.93	4.86	3.27	0.52
5	0.09	0.13	8.55	27.67	31.49	21.62	13.12	7.77	3.21	1.79	0.38
6	0.06	0.09	7.54	19.71	25.18	21.17	11.34	4.14	1.20	0.68	0.27
7	0.05	0.04	1.08	15.98	13.81	20.31	10.92	3.04	1.04	0.50	0.25
8	0.03	0.03	0.16	15.23	13.05	14.15	10.65	2.57	1.00	0.49	0.19
9	0.02	0.02	0.16	13.93	10.26	10.08	9.49	2.14	0.86	0.49	0.15
10	**0.02**	0.02	0.14	1.00	4.63	7.13	9.41	1.57	0.70	0.46	0.15
11		0.02	0.12	0.30	3.34	4.63	9.18	1.28	0.14	0.12	0.06

Probability of occurrence (F = Sequence number / (N + 1))												
Sequence number	**Oct**		**Nov**		**Dec**		**Jan**		**Feb**		**Mar**	
	Q (m^3/s)	**F**	**Q (m^3/s)**	**F**	**Q (m^3/s)**	**F**	**Q (m^3/s)**	**F**	**Q (m^3/s)**	**F**	**Q (m^3/s)**	**F**
1	0.31	0.09	5.36	0.08	66.46	0.08	92.97	0.08	183.59	0.08	104.91	0.08
2	0.27	0.18	0.84	0.17	23.48	0.17	45.92	0.17	94.59	0.17	76.61	0.17
3	0.15	0.27	0.54	0.25	20.20	0.25	45.55	0.25	73.44	0.25	41.82	0.25
4	0.12	0.36	0.30	0.33	9.63	0.33	41.07	0.33	33.88	0.33	31.29	0.33
5	0.09	0.45	0.13	0.42	8.55	0.42	27.67	0.42	31.49	0.42	21.62	0.42
6	0.06	0.55	0.09	0.50	7.54	0.50	19.71	0.50	25.18	0.50	21.17	0.50
7	0.05	0.64	0.04	0.58	1.08	0.58	15.98	0.58	13.81	0.58	20.31	0.58
8	0.03	0.73	0.03	0.67	0.16	0.67	15.23	0.67	13.05	0.67	14.15	0.67
9	0.02	0.82	0.02	0.75	0.16	0.75	13.93	0.75	10.26	0.75	10.08	0.75
10	0.02	0.91	0.02	0.83	0.14	0.83	1.00	0.83	4.63	0.83	7.13	0.83
11			0.02	0.92	0.12	0.92	0.30	0.92	3.34	0.92	4.63	0.92
	Oct		**Nov**		**Dec**		**Jan**		**Feb**		**Mar**	
	0.03	**0.75**	**0.02**	**0.75**	**0.16**	**0.75**	**13.93**	**0.75**	**10.26**	**0.75**	**10.08**	**0.75**
	0.02	**0.80**	**0.02**	**0.80**	**0.15**	**0.80**	**6.17**	**0.80**	**6.88**	**0.80**	**8.31**	**0.80**
	0.02	**0.90**	**0.02**	**0.90**	**0.12**	**0.90**	**0.44**	**0.90**	**3.60**	**0.90**	**5.13**	**0.90**

Probability of occurrence (F = Sequence number / (N + 1))										
Sequence number	**Apr**		**May**		**Jun**		**Jul**		**Aug**	
	Q (m^3/s)	**F**	**Q (m^3/s)**	**F**	**Q (m^3/s)**	**F**	**Q (m^3/s)**	**F**	**Q (m^3/s)**	**F**
1	119.60	0.08	44.43	0.08	17.32	0.08	21.95	0.08	7.28	0.08
2	84.10	0.17	30.20	0.17	11.54	0.17	4.97	0.17	1.71	0.17
3	83.33	0.25	22.77	0.25	7.48	0.25	4.59	0.25	0.83	0.25
4	20.64	0.33	13.93	0.33	4.86	0.33	3.27	0.33	0.52	0.33
5	13.12	0.42	7.77	0.42	3.21	0.42	1.79	0.42	0.38	0.42
6	11.34	0.50	4.14	0.50	1.20	0.50	0.68	0.50	0.27	0.50
7	10.92	0.58	3.04	0.58	1.04	0.58	0.50	0.58	0.25	0.58
8	10.65	0.67	2.57	0.67	1.00	0.67	0.49	0.67	0.19	0.67
9	9.49	0.75	2.14	0.75	0.86	0.75	0.49	0.75	0.15	0.75
10	9.41	0.83	1.57	0.83	0.70	0.83	0.46	0.83	0.15	0.83
11	9.18	0.92	1.28	0.92	0.14	0.92	0.12	0.92	0.06	0.92
	Apr		**May**		**Jun**		**Jul**		**Aug**	
	9.49	**0.75**	**2.14**	**0.75**	**0.86**	**0.75**	**0.49**	**0.75**	**0.15**	**0.75**
	9.44	**0.80**	**1.80**	**0.80**	**0.77**	**0.80**	**0.47**	**0.80**	**0.15**	**0.80**
	9.23	**0.90**	**1.34**	**0.90**	**0.26**	**0.90**	**0.19**	**0.90**	**0.07**	**0.90**

Annex 7 – Background information on the Rio Licuari salt intrusion model

In this annex the basic theory on which the Rio Licuari salt intrusion model is based is presented. In addition the data, needed to construct the model, is included.

For the management of estuarine water resources, a water manager needs to have an instrument to determine the salt intrusion length and the longitudinal distribution of the salinity as a function of directly measurable parameters such as geometry, fresh water flow and tide. This instrument is called a predictive model; which can be used to simulate a "what-if" situation in case one or more of these parameters are changed (Savenije, H.H.G., 1993). The method is particularly useful during the reconnaissance stage of an estuarine management study (Savenije, H.H.G., 1993). This indicates the suitability of the predictive model for this research which has an investigative nature.

Justification

The predictive model developed by Savenije does not require prior calibration (although calibration can be used to refine the estimates made) as long as the estuary is alluvial and the longitudinal variation of the estuary width can be described by an exponential function (Savenije, H.H.G., 1993).

Based on observations it can be concluded that the estuary is alluvial. During low tide, mudflats can be seen throughout the estuary, which demonstrates its alluvial character.

According to the second condition, it must be possible to describe the longitudinal variation of the estuary width by an exponential function.

This second condition has been tested with measurement of the estuary width at different distances from the estuary mouth using Google Earth Pro. The result is presented in the following table.

Table 1: relation between estuary width at average high tide and distance from the estuary mouth.

Estuary width at average high tide (m)	Distance from the estuary mouth (m)
2550	0
2050	2365
1775	12545
818	18070
796	20870
833	27220
480	29340
201	29575
119	32217
107	37592
104	40910
88	45849
80	50805
63	54494
56	64517
50	72099

When this relationship is visualized in a graph (figure 1), the exponential variation of the estuary width along the longitudinal axis becomes visible. The exponential function which describes the relationship between the estuary width and distance from estuary mouth in Rio Licuari is as follows:

$$\text{Estuary width} = 2269.80e^{-0.00006325974\,\text{distance from estuary mouth}}$$

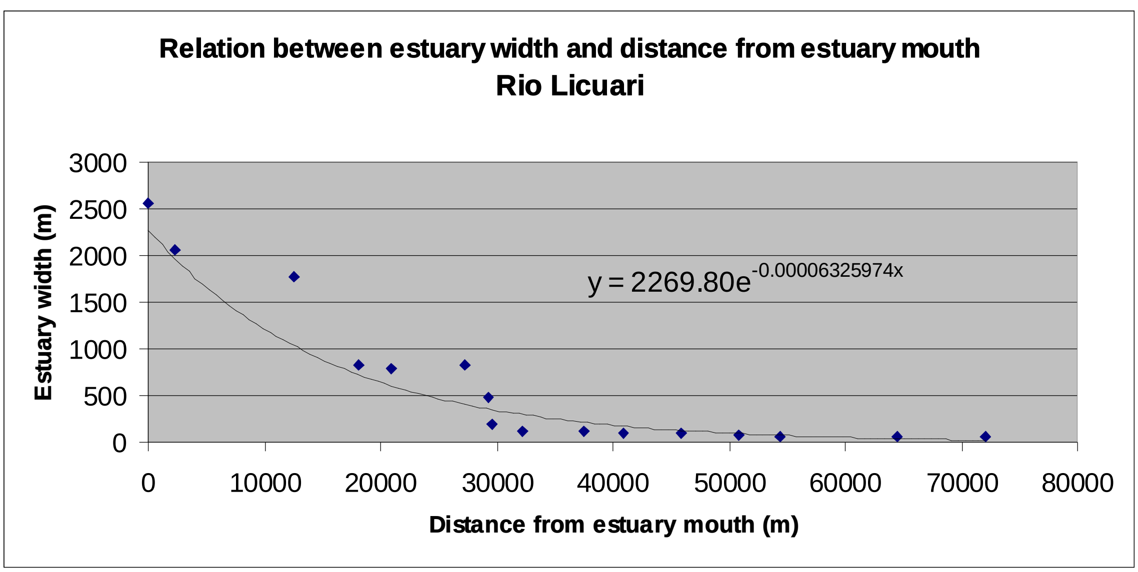


Figure 1: relation between estuary width and distance from estuary mouth in Rio Licuari

Based on this, it can be concluded that it is possible to use the predictive model developed by Savenije to create a predictive salinity intrusion model for the Rio Licuari estuary.

Basic theory
The model is based on one constant and one variable which both differ in every estuary. To create a model which is valid for the Rio Licuari estuary, these two numbers have been determined based on measurable and observable parameters.

Van der Burgh coefficient
The constant is the Van der Burgh coefficient (K). This coefficient is an indicator of the mixture of salt and fresh water in an estuary. Each different estuary appears to have its own characteristic value of K (Savenije, 1986, 1989). A formula to determine K of a specific estuary is as follows:

$$K = 0.3 * 10^{-3}\left(\frac{E}{H}\right)^{0.65}\left(\frac{E}{C^{2}}\right)^{0.39}(1-\delta b)^{-2.0}\left(\frac{b}{a}\right)^{0.58}\left(\frac{Ea}{A_{0}}\right)^{0.14}$$

(Savenije, 2008)

In which:

E = tidal excursion (m)
H = tidal range (m)
C = Chezy coefficient
δ = Tidal damping degree along the estuary
b = convergence length (m)
a = convergence length (m)
A_0 = Cross-sectional area at the estuary mouth (m^2)

<u>The tidal excursion (E)</u> can be determined by the following formula:

$\upsilon_o * T/\pi$

In which υ_o is the amplitude of the rate of flow of the tide. This is all around the world 1 m/s during springtide. T is the length of the tidal period which is 44400 seconds.

<u>The tidal range (H)</u> differs depending on the local situation. At the estuary mouth of Rio Licuari the maximum tidal range in the year 2008 is 4.34 meters (INAHINA, 2007).

<u>The chezy coefficient (C)</u> can be determined by the following formula:

$45 * h^{0.167}$

In which h is the estuary mean depth. According to local people the depth of the river near Quelimane is approximately 8.5 meters during high tide.

The tidal damping degree along the estuary (δ) can be determined by:

$1/H * \Delta H/\Delta x$

In which H is the tidal range (4.34) and x the distance from the estuary mouth. The best way to determine the tidal damping is to take measurements along the length of the estuary to determine the tidal range at different locations. However, because of a lack of equipment and manpower this is not possible. Therefore, the tidal damping degree is estimated based on observations in the field and knowledge of local people. The most appropriate value for the tidal damping in the Rio Licuari estuary is around 10% per 10 kilometers. This indicates a decrease in tidal range of 10% of the total 4.34 meters every 10 kilometers further upstream. During a field visit at the crossing of Rio Licuari with Rio Mucelo (72 kilometers from the estuary mouth), the sediments on the riverbanks where more then one meter above the water during low tide. When considering a decrease of 10% per 10 kilometers, after 72 kilometers 28% of the total 4.34 would be left of the tidal range:

0.28 * 4.34 = 1.22 meters (which is very close to the observed tidal range)

Furthermore, the M'ziva irrigation system is located outside of the tidal influence. The distance between the M'ziva irrigation system and the estuary mouth is approximately 90 kilometers. When considering a decrease of 10% per 10 kilometers this would result in:

0.10 * 4.34 = 0.43 meters (which is during spring tide only a very small tidal range)

The convergence length (a, b) is based on the estuary shape coefficient:

b = -1 / shape coefficient

The estuary shape coefficient can be determined by the exponential relationship between the estuary width and distance from estuary mouth (figure 1). The exponential function which describes the relationship between the estuary width and distance from estuary mouth in Rio Licuari is as follows:

$\text{Estuary width} = 2269.80e^{-0.00006325974 \text{distance from estuary mouth}}$

In this exponential function the value -0.00006325974 is the estuary shape coefficient

The cross-sectional area at the estuary mouth (A_0) can be determined by:

$A_0 = h * \text{width estuary mouth}$

The Van der Burgh coefficient (K) specific for the Rio Licuari estuary has been determined based on the information shown above. The Van de Burgh coefficient for the Rio Licuari estuary is:

K = 0.49

Dispersion at estuary mouth (m^{-1})

The variable which is used in the model is a parameter which describes the amount of dispersion at the estuary mouth (α_0).

$\alpha_0 = D_0^{HWS} / Q_f$

In which:

D_0^{HWS} = dispersion at the estuary mouth (m^2/s)
Q_f = Fresh water discharge from the river (m^3/s)

The fresh water discharge from the river (Q_f) is not fixed and can be changed in the model in order to predict the salinity intrusion during different fresh water discharges from the river.

The dispersion at the estuary mouth (D_0^{HWS}) can be determined by the following formula:

$$\frac{D_0^{HWS}}{\upsilon_0 E_0} = 1500 \frac{h_0}{a} N_R^{0.5}$$

(Savenije, 2008)

In which N_R can be determined by:

$$N_R = \frac{E_m}{E_t} = \frac{\Delta\rho}{\rho} \frac{ghQ_f T}{A_0 E_0 \upsilon_0^2} = \frac{\Delta\rho}{\rho} \frac{ghQ_f T}{P_t \upsilon_0^2}$$

(Savenije, 2008)

In which:

E_0 = Tidal excursion at estuary mouth (m)
h_0 = Estuary depth at estuary mouth (m)
ρ = Density of water (kg/dm^3)
g = Acceleration of gravity (m/s^2)
Q_f = Fresh water discharge from the river (m^3/s)

In these formulas a part of the parameters are already explained in a previous part of this annex. These will not be discussed anymore. New parameters are discussed in the following part.

The tidal excursion at estuary mouth (E_0) is the same as the tidal excursion (E) because the tidal excursion is invariable with x (distance from estuary mouth):

$E_0 = E$

The estuary depth at estuary mouth (h_0) is the same as the mean estuary depth (h) because the estuary depth is invariable with x (distance from estuary mouth):

$h_0 = h$

The density of water (ρ) is included in the formula as:

$\Delta\rho / \rho$

In this formula Δρ is the density difference over the intrusion length. The density of seawater is approximately 1.025 kg/dm^3 compared to 1.000 kg/dm^3 of fresh water. In an estuary with a relative small discharge (Rio Licuari) the salinity at the estuary mouth will be more or less equal to the sea salinity. The difference in salinity content over the intrusion length (Δρ) is therefore:

$1.025 - 1.000 = 0.025$ kg/dm^3.

ρ can be taken as 1 (density of water). Resulting in:

$\Delta\rho / \rho = 0.025 / 1.000 = 0.025$

The acceleration of gravity (g) is equal to:

$g = 9.81$ m/s^2

The fresh water discharge from the river (Q_f) is not fixed and can be changed in the model in order to predict the salinity intrusion during different fresh water discharges from the river.

The dispersion at the estuary mouth (α_0) specific for the Rio Licuari estuary has been determined based on the information shown above. α_0 for the Rio Licuari estuary however differs per given fresh water discharge (Q_f). Some α_0 values for the Rio Licuari estuary are shown in the following table.

Table 2: Dispersion at estuary mouth with different fresh water discharges

Fresh water discharge - Q_f (m^3/s)	Dispersion at the estuary mouth - α_0 (m^{-1})
0.2	73.91
0.5	46.74
1	33.05
2	23.37
5	14.78
10	10.45
15	8.53
25	6.61

Functioning of the model

The predictive salinity intrusion model has been constructed by Prof. Savenije. The values determined in this annex where used to adjust the model to the specific characteristics of the Licuari River. In the following figure, the excel spreadsheet with the used formulas on which the model is based, is shown.

	B	C	D	E	F	G	H	I	J	K	L	M	N
4	sea salinity		C0		29	kg/m3	Area at mouth			A	4250	m2	
5	Van Den Burgh		K		0.75		Shape coeff.			b	-9.2	10^-6 1/m	
6	Dispersion coeff.		Alfa0		11.1	1/m	step length			dx	3000	m	
7	step alpha		Dalpfa		0.1	1/m	selected alph0			alf.s	11.4	1/m	
8	Tidal Excursion		E0		22000	m							

I

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
9																				
10							LWS				HWS									
11			calibration				observ.		model		observ.			calibration					model	
12			salinities				on		salinities		on			alphas's					alpha's	
13							4/6/62	LWS	MEAN	HWS	5/6/62							LWS	MEAN	HWS
14	alpha	11.1	11.2	11.3	11.4	11.5		5.8	8.5	11.4			11.1	11.2	11.3	11.4	11.5	5.80	8.46	11.40
15	x:							II	III			x:						IV	V	
16	0	29.0	29.0	29.0	29.0	29.0	15.1	15.4	22.3	29.0	28.5	0	11.10	11.20	11.30	11.40	11.50	5.80	8.46	11.40
17	3000	27.1	27.2	27.2	27.2	27.2	13.2	13.5	20.4	27.2	26.7	3000	10.56	10.66	10.76	10.86	10.96	5.26	7.92	10.86
18	6000	25.3	25.3	25.3	25.4	25.4	12.2	11.7	18.5	25.4	26.3	6000	10.01	10.11	10.21	10.31	10.41	4.71	7.37	10.31
19	9000	23.4	23.4	23.5	23.5	23.6	9.7	9.8	16.7	23.5	25.8	9000	9.44	9.54	9.64	9.74	9.84	4.14	6.80	9.74
20	12000	21.5	21.5	21.6	21.7	21.7	8.1	8.0	14.8	21.7	24.3	12000	8.86	8.96	9.06	9.16	9.26	3.56	6.22	9.16
21	15000	19.6	19.6	19.7	19.8	19.9	5.8	6.3	12.9	19.8	20.9	15000	8.26	8.36	8.46	8.56	8.66	2.96	5.62	8.56
22	18000	17.6	17.7	17.8	17.9	18.0	4.6	4.6	11.1	17.9	18.1	18000	7.65	7.75	7.85	7.95	8.05	2.34	5.00	7.95
23	21000	15.7	15.8	15.9	16.0	16.1	3.4	3.0	9.2	16.0	16.6	21000	7.01	7.11	7.21	7.31	7.41	1.71	4.37	7.31
24	24000	13.8	13.9	14.0	14.2	14.3	2.6	1.6	7.4	14.2	14.9	24000	6.36	6.46	6.56	6.66	6.76	1.06	3.72	6.66
25	27000	11.9	12.0	12.2	12.3	12.4	1.3	0.4	5.7	12.3	12.9	27000	5.69	5.79	5.89	5.99	6.09	0.39	3.05	5.99
26	30000	10.0	10.2	10.3	10.5	10.6	0.3	0.0	4.1	10.5	9.9	30000	5.00	5.10	5.20	5.30	5.40	-0.30	2.36	5.30
27	33000	8.2	8.3	8.5	8.6	8.8	0.0	0.0	2.5	8.6	9.5	33000	4.30	4.40	4.50	4.60	4.70	-1.01	1.65	4.60
28	36000	6.4	6.5	6.7	6.9	7.0		0.0	1.2	6.9	7.5	36000	3.57	3.67	3.77	3.87	3.97	-1.73	0.93	3.87
29	39000	4.7	4.8	5.0	5.2	5.3		0.0	0.1	5.2	4.9	39000	2.82	2.92	3.02	3.12	3.22	-2.48	0.18	3.12
30	42000	3.1	3.2	3.4	3.5	3.7		0.0	0.0	3.5	3.3	42000	2.05	2.15	2.25	2.35	2.45	-3.25	-0.59	2.35
31	45000	1.6	1.7	1.9	2.0	2.2		0.0	0.0	2.0	1.7	45000	1.26	1.36	1.46	1.56	1.66	-4.04	-1.38	1.56
32	48000	0.4	0.5	0.6	0.8	0.9		0.0	0.0	0.8	0.8	48000	0.45	0.55	0.65	0.75	0.85	-4.85	-2.19	0.75
33	51000	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	51000	-0.38	-0.28	-0.18	-0.08	0.02	-5.69	-3.03	-0.08
34	54000	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		54000	-1.24	-1.14	-1.04	-0.94	-0.84	-6.55	-3.89	-0.94
35	57000	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		57000	-2.12	-2.02	-1.92	-1.82	-1.72	-7.43	-4.77	-1.82
36	60000	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		60000	-3.03	-2.93	-2.83	-2.73	-2.63	-8.34	-5.67	-2.73

VI VI VII

block I : input
block II : LWS salinity at the mouth
block III: mean salinity at the mouth
block IV : LWS alpha at the mouth
block V : mean alpha at the mouth
block VI : salinity distributions
block VII: alpha distributions

FORMULAE:

```
I16=+$F$4*(I14/$L$7/@EXP($L$5/1E6*$F$8))^(1/$F$5)
J16=+$F$4*(J14/$L$7/@EXP($L$5/1E6*$F$8/2))^(1/$F$5)
S16=@EXP($L$5/1E6*$F$8)*$L$7*(1+$F$5/$L$4/$L$5*1E6/$L$7*(@EXP(-$L$5/1E6*$F$8)-1))
T16=@EXP($L$5/1E6*$F$8/2)*$L$7*(1+$F$5/$L$4/$L$5*1E6/$L$7*(@EXP(-$L$5/1E6*$F$8/2)-1)
C17=+C$16*((+N17/C$14)*@IF(N17>0,1,0))^(1/$F$5)
N17=+N$16+$F$5/$L$4/$L$5*1E6*(@EXP(-$L$5/1E6*$M17)-1)
```

Figure 2: Spreadsheet model salinity intrusion (Savenije, 1989).

Annex 8 – Rainfall data

Rainfall data, meteorological station Quelimane airport (GCOS, 16-01-2008).

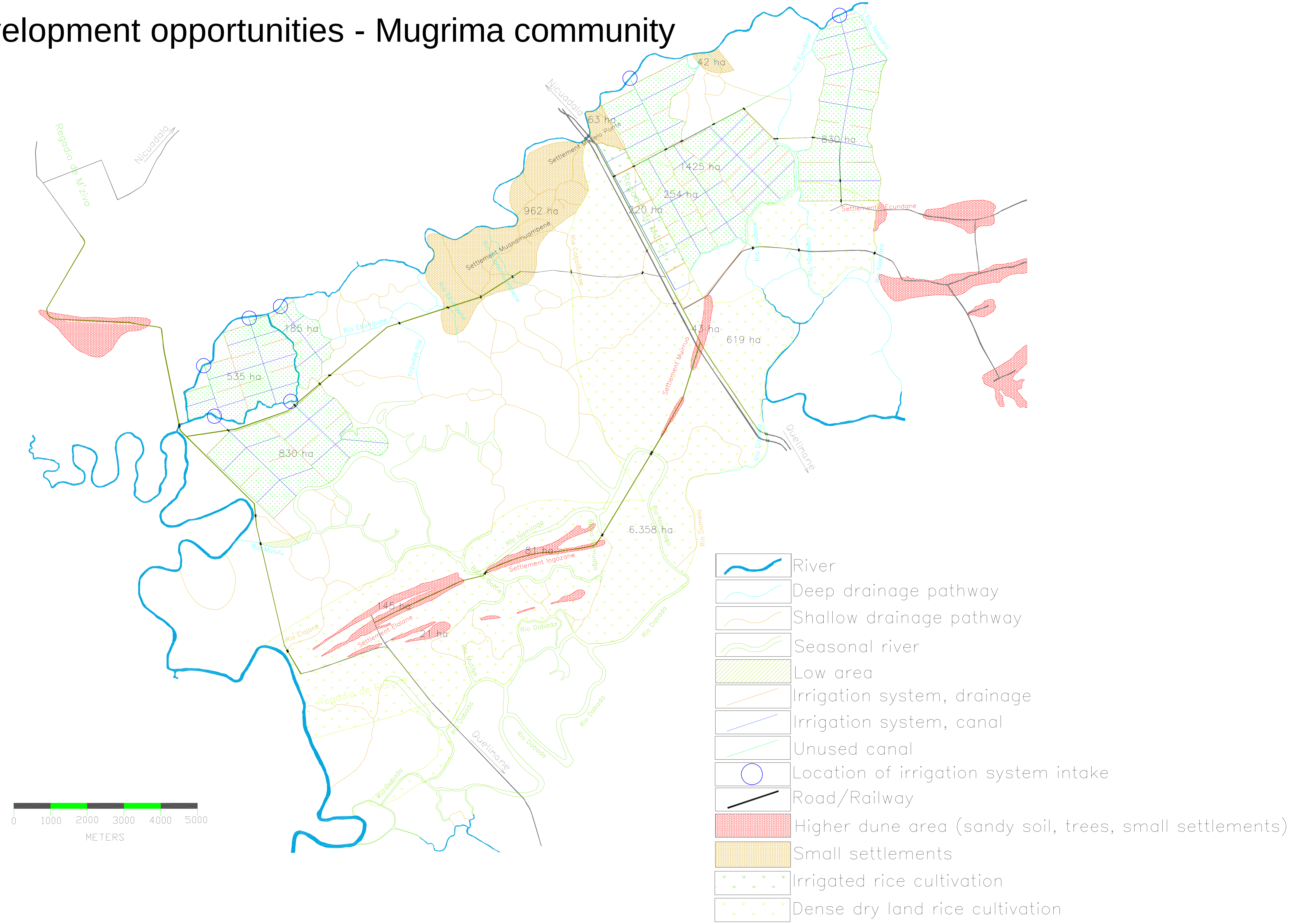
	Rainfall (mm)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
1967	172	106	194	152	30	30	54	54	2	15	120	102	1031
1968	128	148	182	88	11	9	7	15	4	13	98	287	990
1969	141	249	201	281	70	45	52	18	3	16	31	608	1715
1970	93	272	87	220	30	74	26	5	0	13	202	60	1082
1971	394	371	292	42	109	24	196	8	9	31	79	210	1765
1972	140	82	153	101	58	38	35	12	24		50	24	
1973	320	160	256	232	238	45	41	16	10	12	191	274	1795
1974	136	140	352	259	86	47	52	20	21	0	22	173	1308
1975	177	115	158	183	80	93	66	50	0		47		
1976	218	164	188	434	121	113	53	25	7	24	70	229	1646
1977	166	137	311	45	22	16	152	60	17	3			
1978	145	97	52	160	13	68	94	0	4	19	34	334	1020
1979	253	407	234	87	60	77	180	18	57	0	231	496	2100
1980	209	79	196	97	47	65	90	83	25	9	3	354	1257
1981	114	412	289	148	74	34	105	76	38	21	43	615	1969
1982		245	235	171	51	27	63	23	87	163	50	113	
1983	87	195	141	33	61	20	96	47		30	8		
1984	403	342	365	88	133	74	41	30	0	73	237	71	1857
1985	252	203	104	218	55	42	14	30	2	74	140	206	1340
1986	386	289	337	270	48	44	60	1	5		106	189	
1987	280	97	162	93	35	53	11	9	7	20	12	45	824
1988	218	293	240	92	130			25	0	32	84	276	
1989	154	461	415		55	72	31	3	19	36	178	281	
1990	271	124	43	56	165		22	17		3		79	
1991	149	376	329	144			52	19	60	0	83	73	
1992	238	192			25		50	25				50	
1993			72										
1994													
1995													
1996	226	427	231	88	165	64	45	48	0	0	26	16	1336
1997				96				17			21		
1998				54			72						
1999													
2000													
2001													
2002													
2003							509	146					
2004			144	210	145		34	145					

Rainfall data placed in ascending order for each month, location: meteorological station Quelimane airport (GCOS, 16-01-2008).

Rainfall (mm)													
	Sequence number	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Data from low to high values	**1**	87	79	43	33	11	9	7	0	0	0	3	16
	2	93	82	52	42	13	16	11	1	0	0	8	24
	3	114	97	72	45	22	20	14	3	0	0	12	45
	4	128	97	87	54	25	24	22	5	0	0	21	50
	5	136	106	104	56	30	27	26	8	0	3	22	60
	6	140	115	141	87	30	30	31	9	2	3	26	71
	7	141	124	144	88	35	34	34	12	2	9	31	73
	8	145	137	153	88	47	38	35	15	3	12	34	79
	9	149	140	158	88	48	42	41	16	4	13	43	102
	10	154	148	162	92	51	44	41	17	4	13	47	113
	11	166	160	182	93	55	45	45	17	5	15	50	173
	12	172	164	188	96	55	45	50	18	7	16	50	189
	13	177	192	194	97	58	47	52	18	7	19	70	206
	14	209	195	196	101	60	53	52	19	9	20	79	210
	15	218	203	201	144	61	64	52	20	10	21	83	229
	16	218	245	231	148	70	65	53	23	17	24	84	274
	17	226	249	234	152	74	68	54	25	19	30	98	276
	18	238	272	235	160	80	72	60	25	21	31	106	281
	19	252	289	240	171	86	74	63	25	24	32	120	287
	20	253	293	256	183	109	74	66	30	25	36	140	334
	21	271	342	289	210	121	77	72	30	38	73	178	354
	22	280	371	292	218	130	93	90	47	57	74	191	496
	23	320	376	311	220	133	113	94	48	60	163	202	608
	24	386	407	329	232	145		96	50	87		231	615
	25	394	412	337	259	165		105	54			237	
	26	403	427	352	270	165		152	60				
	27		461	365	281	238		180	76				
	28			415	434			196	83				
	29							509	145				
	30								146				

Annex 9 – Suggested irrigation systems and roads Mugrima community

Development opportunities - Mugrima community



Annex 10 – Overview costs and benefits of irrigation systems

Costs rehabilitation existing roads in US$							
	Length (m)	Average earth work (m^3/m)	Earth work (m^3)	Price per m^3	Gravel application m^3/m	Price per m^3	Total price US$
Road south of mucelo irrigation system	5,896	1	5,896	2	0.6	35	135,608
Road Quelimane - Elalane	16,000	1	16,000	2	0.6	35	368,000
Road until Muanamuambene	3,964	6	23,784	2	0.6	35	130,812
Total	25,860		45,680				634,420

Costs construction of new roads in US$							
	Length (m)	Amount	Average profile area (m^2)	Gravel application m^3/m	Total (m^3)	Price per unit US$	Total price US$
Road Ceramica - Elalane							
Length	12,384						
Bridge small		6				20,000	120,000
Earth work			10.21		126,480	2	252,960
Gravel application	12,384			0.6	7,430	35	260,064
Road Elalane - M'ziva							
Length	20,727						
Bridge small		3				20,000	60,000
Bridge large		1				300,000	300,000
Earth work			17.81		369,132	2	738,264
Gravel application	20,727			0.6	12,436	35	435,267
Road Muanamuambene - Licuari							
Length	10,305						
Bridge small		11				20,000	220,000
Earth work			20.00		206,100	2	412,200
Gravel application	10,305			0.6	6,183	35	216,405
Road Mucelo - Ecundane							
Length	8,729						
Bridge small		9				20,000	180,000
Bridge medium large		1				150,000	150,000
Earth work			20.00		174,580	2	349,160
Gravel application	8,729			0.6	5,237	35	183,309
Total length	43,416						
Total bridge small		29					580,000
Total bridge medium large		1					150,000
Total bridge large		1					300,000
Total earth work					876,292		1,752,584
Total gravel application					31,287		1,095,045
TOTAL							**3,877,629**

Costs construction of irrigation systems in US$								
Irrigation system Magrobeda north - Island - 535 ha								
		Length (m)	**Earth work m^3/m**	**Earth work m^3**	**Concrete m^3/m**	**Concrete m^3**	**Price per unit US$**	**Total price US$**
Main	Canal constructio n+road	3,953	20	79,060			2	158,120
	Canal lining	3,953			1.2	4,744	300	1,423,080
	2 electrical pumps						5,000	32,635
	Electricity supply	8,667					10	86,667
	1 drainage	2,227	6	13,362			2	26,724
	Pump house						15,000	30,000
Secondary	canals	7,006	8	56,048			2	112,096
	drainage	5,777	3	17,331			2	34,662
Tertiary	canals	14,012	4	56,048			2	112,096
	drainage	14,012	1.5	21,018			2	42,036
Irrigation system Magrobeda north east - east of island - 185 ha								
Main	Canal construction +road	1,899	20	37,980			2	75,960
	Canal lining	1,899			1.2	2,279	300	683,640
	1 electrical pump						5,000	11,285
	Electricity supply	6,667					10	66,667
	Pump house						15,000	15,000
Secondary	canals	1,924	8	15,392			2	30,784
	drainage	1,451	3	4,353			2	8,706
Tertiary	canals	3,848	4	15,392			2	30,784
	drainage	3,848	1.5	5,772			2	11,544
Irrigation system Magrobeda south - 830 ha								
Main	Canal construction +road	5,295	20	105,900			2	211,800
	Canal lining	5,295			1.2	6,354	300	1,906,200
	2 electrical pump						5,000	50,630
	Electricity supply	5,167					10	51,667
	Drainage	5,300	6	31,800			2	63,600
	Pump house						15,000	30,000
Secondary	canals	8,460	8	67,680			2	135,360
	drainage	6,980	3	20,940			2	41,880
Tertiary	canals	16,920	4	67,680			2	135,360
	drainage	16,920	1.5	25,380			2	50,760

Irrigation system Mucelo east - East of regadio de mucelo - 1425 ha								
Main	Improvement existing unused canals	4,040	15	60,600			2	121,200
	Canal lining	4,040			1.2	4,848	300	1,454,400
	1 electrical pump						5,000	86,925
	Electricity supply	4,000					10	40,000
	3 canals + road	8,861	20	177,220			2	354,440
	Canal lining	8,861			1.2	10,633	300	3,189,960
	Improvement existing unused drainage	3,758	4	15,032			2	30,064
	Increase existing drainage mucelo irrigation system	5,904	2	11,808			2	23,616
	New drainage	1,295	6	7,770			2	15,540
	Pump house						15,000	15,000
Secondary	canals	16,000	8	128,000			2	256,000
	drainage	16,000	3	48,000			2	96,000
Tertiary	canals	32,000	4	128,000			2	256,000
	drainage	32,000	1.5	48,000			2	96,000
Irrigation system Nassaro - west of Rio Nassaro - 830 ha								
Main	Canal construction +road	7,160	20	143,200			2	286,400
	Canal lining	7,160			1.2	8,592	300	2,577,600
	1 pump						5,000	50,630
	Electricity supply	20,000					10	200,000
	Pump house						15,000	15,000
Secondary	canals	8,500	8	68,000			2	136,000
	drainage	8,500	3	25,500			2	51,000
Tertiary	canals	17,000	4	68,000			2	136,000
	drainage	17,000	1.5	25,500			2	51,000
TOTAL								**15,208,517**

Costs operation irrigation systems in US$						
	year 4	year 5	year 6	year 7	year 8	year 9-20
Hectares irrigated	400	1,000	1,800	2,800	3,800	3,800
Tractor amount	2	5	9	14	19	19
Plough amount	2	5	9	14	19	19
Work force	4	10	18	28	38	38
Costs tractor + plough	100,000	150,000	200,000	250,000	250,000	0
Costs kWh for electrical pumps	8,000	20,000	36,000	56,000	76,000	76,000
Costs Work force	5,840	14,600	26,280	40,880	55,480	55,480
TOTAL	113,840	184,600	262,280	346,880	381,480	131,480

Costs maintenance in US$						
	year 4	year 5	year 6	year 7	year 8	year 9-20
Irrigation system	40,000	100,000	180,000	280,000	380,000	380,000
Roads	27,710	27,710	27,710	27,710	27,710	27,710
Tractor + plough	6,000	15,000	27,000	42,000	57,000	57,000
TOTAL	73,710	142,710	234,710	349,710	464,710	464,710

Profits of rice yield in US$						
	year 4	year 5	year 6	year 7	year 8	year 9-20
Hectares irrigated	400	1,000	1,800	2,800	3,800	3,800
Tons/ha	4	4	4	4	4	4
Tons	1,600	4,000	7,200	11,200	15,200	15,200
US$/ton	310	310	310	310	310	310
TOTAL yield profits	496,000	1,240,000	2,232,000	3,472,000	4,712,000	4,712,000
TOTAL Production costs	159,467	398,667	717,600	1,116,267	1,514,933	1,514,933
NETTO profits rice yield	336,533	841,333	1,514,400	2,355,733	3,197,067	3,197,067

Costs and benefits difference in millions US$																						
YEAR		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Costs	MUS$	0.6	1.0	1.0	3.5	3.7	2.9	3.0	3.2	3.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Profits	MUS$	0	0	0	0	0.3	0.8	1.5	2.4	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Difference		**-0.6**	**-1.0**	**-1.0**	**-3.5**	**-3.4**	**-2.0**	**-1.5**	**-0.9**	**-0.2**	**2.6**	**2.6**	**2.6**	**2.6**	**2.6**	**2.6**	**2.6**	**2.6**	**2.6**	**2.6**	**2.6**	**2.6**