Irrigation practices and water management in Rugeramigozi Marshland

A case study of surface irrigation in Rugeramigozi Marshland, Rwanda

MSc. Thesis by Theodore Dusabimana

August 2012

Irrigation and Water Engineering Group

WAGENINGEN UNIVERSITY

WAGENINGEN UR

Irrigation practices and water management in Rugeramigozi Marshland

A case study of surface irrigation in Rugeramigozi Marshland, Rwanda

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

Theodore Dusabimana

August 2012

Supervisors:

Dr.ir. Henk Ritzema
Irrigation and Water Engineering Group
Centre for Water and Climate
Wageningen University
The Netherlands
www.iwe.wur.nl/uk

Dr.ir. Leon Nabahungu

Rwanda Agriculture Board (RAB)
Kigali, Rwanda

Acknowledgment

This thesis research could not have been written without Henk Ritzema and Leon Nabahungu who helped me as Supervisors, in writing of my research proposal and continuous assistance through their comments, in shaping and making the report comprehensive till the end.
I would like to acknowledge and extend my gratitude to RSSP and KIABR staff and farmers who shared their experience with me and provided information on Rugeramigozi marshland. Moreover I thank so much the Country Director of Welthungerhilfe in Rwanda who provided technical reports and maps of marshlands.
May 05 2008 07:10:58I would also like to thank my family members and friends for their support.

Especially I express my thanks to Almighty God, who made all things possible. His name is Holy.

Abstract

With a rapid growing population of Rwanda which has left no land unoccupied for food production except marshlands, irrigation practice is one the key tools to reach harvest security and contribute to integrated water resources management. Around 90% of Rwanda's population is engaged in agriculture which is the biggest water user in Rwanda accounting more than 70% of the water demand but unfortunately is used inefficiently.

This study aims to analyze the current irrigation practices and water management of irrigation dam of 270,000m^3 in Rugeramigozi marshland. This is to find how available water can be distributed to the existing water users, evaluate if the available water can satisfy the demands and look for how improved irrigation practices can contribute to management of this finite resource under competition. By using FAO CROPWAT model and literature the crop water crop requirement and water demand for agriculture were determined. The hydrological analysis with the use of SCS Curve Number method helped to determine the inflow to the dam. Taking into account 45litter/sec for domestic water supply by EWSA, the available water is compared to the demands in Rugeramigozi wetland. The analysis points out that there is enough water for all demands in season B but water scarcity in season A doesn't allow irrigation of rice; even drinking water supply is not met. The solutions could be the re-use of irrigation water from the field, expansion of the reservoir capacity and release of additional water from Misizi dam located in upstream.

Irrigation practices are analyzed by using Institutional Analysis and Development (IAD) framework in which the complex interaction between physical setting of the scheme, rules and irrigation staff are discussed. By using interviews, group discussions and observations the rules behind irrigation practices are discovered and categorised within the framework. These practices were compared with the governing rules in papers. Generally the practices follow the management rules, but weakness is identified in lack of awareness of farmers in respecting irrigation turns, too much water is wasted in irrigation; maintenance works doesn't fully meet the needs, low enforcement of irrigation rules and poor involvement of farmers in setting management rules.

Furthermore the stakeholder analysis was used for water allocation to the three water users (KIABR, EWSA and VTC Mpanda) and their participation in water resource management. Drinking water supply is prioritized, maintenance of the system seems to be left in the hands of farmers of KIABR only and sustainable use of water requires an integrated water resource management approach. From these discussions, conclusions and the recommendations are drawn thereafter.

Keywords: Irrigation practices; water management; domestic water supply; Institutional Analysis and Development; irrigation rules.

List of acronyms

AGCD-Belgique	Administration Générale de la Coopération au Développement- Belgique
IWRM	Integrated Water Resources Management
KIABR	***K**operative **I**mparaniramusaruro y' **A**bahinzi **B**orozi ba **R**ugeramigozi.*
KOKAR	***KO**perative yo **K**wihaza umusaruro y'**A**bahinzi ba **R**ugeramigozi*
MINAGRI	Ministry of Agriculture and Animal Resources
MINECOFIN	Ministry of Finance and Economic Planning
MININFRA	Ministry of Infrastructure
MINIRENA	Ministry of Natural Resources
RAB	Rwanda Agriculture Board
RSSP	Rural Support Sector Project
VTC Mpanda	Vocational Training Centre, Mpanda
WUA	Water Users Association.

Table of contents

List of Tables

List of figures

1. Introduction

1.1. General Introduction

Rwanda is a landlocked country of 26,338km^{2}surface area. The latest demographic surveys show that the population is 11,370,425. Given that the growth rate is 2.8%, the population is expected to be 12millinos by 2015 (IndexMundi, 2011). This country is among the poorest in Africa, the GDP per capita was US$1100 in 2010. Some of the causes of this poverty are the constraints which undermine the agricultural development whereas agriculture is the backbone of the national economy and it contributes more than 40% of the GDP. Those constraints are like high population density living on increasingly scarce land and high growth rate while economic growth is lagging behind, erosion and climatic hazards and lack of modern technology in agricultur (IFAD, 2009).

The agriculture sector employs 90% of the population. Rain fed agriculture which is largely practiced on small farms of relatively 0.5 hectare produces a relatively low production for subsistence. The low crop yields situation worsened in the 1980's when the agricultural policy makers failed to transform from low-value agriculture to high value farming. There were not enough policies to encourage agricultural transformation. Other factors are continuous environmental degradation, soil fertility decline, poor water management, and deforestation (Ministry of Finance and Economic Planning, 2002).“Because Rwanda's economy is heavily dependent on agriculture, the key to poverty reduction lies in stimulating rapid and sustainable growth in the agricultural sector.”(Diao et al, 2009, p.1) (Bingxin Yu, 2009)

Therefore wetland transformation to agricultural land will increase the people's livelihoods. Besides the government the government supports wetland development with the aim to boost agriculture, revitalize the rural economy and reduce poverty (REMA, 2009). The majority of farmers engage in traditional ways of farming, they grow food crops for subsistence such sweet potatoes, cassavas, dry beans in highland and wetlands with little irrigation. Currently irrigation sector is being developed due to unpredictable rainfall patterns and also because the Government is investing in rice cultivation in order to increase food production and poverty reduction. The rice is cultivated in the marshlands with sufficient water to irrigate this high water consuming crop.(IFAD, 2009)

The current surveys point out that land under irrigation is 17,500 hectares and the government plans to achieve 100,000ha by 2017and the total irrigable land is 600,000 ha according to Rwanda irrigation master plan (The Rwanda focus, 2011).

Several assessments already done showed that in Rwanda, irrigation sector is associated with problems like water distribution between farmers in equitable ways, water shortage especially dry season, deterioration of irrigation infrastructures sometimes resulting in high sediment deposit in the canals, low maintenance of the irrigation scheme, lack of proper management skills of water users and technical staff. (IFAD, 2009)

As it was proved the farmer's managed irrigation scheme are more functional than those managed by the Government or Irrigation agencies. Therefore it is necessary to promote and strengthen farmers' organizations and to encourage the involvement of the private sector in the development of marshlands for their sustainable exploitation (FAO SAFR, 1998). In this respect more than 80 farmers' cooperatives have been formed, and are expected to manage their irrigation schemes. MINAGRI through RSSP supports marshland development by creating new irrigation marshlands, rehabilitation and extension of the existing ones. It also provides training to cooperatives members where they gain technical and managerial skills to use in their respective schemes (RSSP, 2011). Rugeramigozi is among those wetlands and has been undergoing the development several years and the irrigation practices and water management in this scheme will be the focus of this research.

1.2. Background

Rugeramigozi marshland is located in Muhanga district approximately in the centre of the country, in the Southern Province of Rwanda. The annual range of rainfall is 1200–1400mm in Rugeramigozi and the temperature varies between 11°C and 28°C in Southern Province. The so called Rugeramigozi marshland consists of three schemes in row: Rugeramigozi II(121ha in upstream) irrigated by Misizi dam, Rugeramigozi I (66ha in the middle) in the down-stream there is Biringanya marshland of 63 ha (Welhungerhilfe,2011). This research focus on the latter two schemes which are irrigated by the so called Rugeramigozi dam of 270,000m^3.

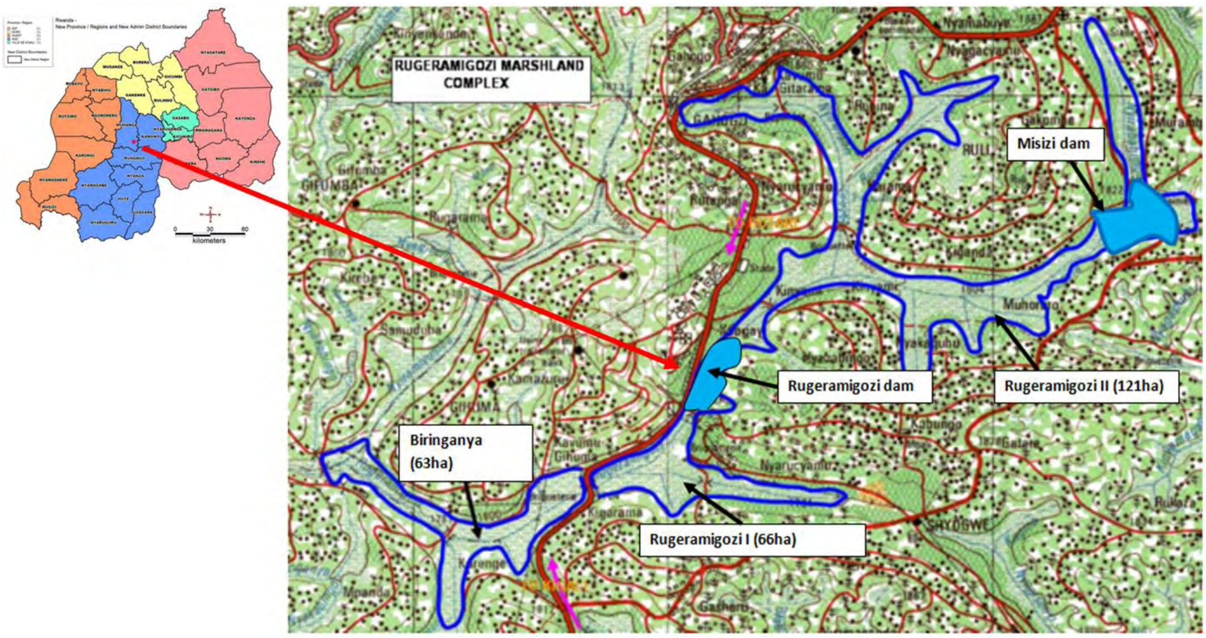


Figure 1: Map of Rwanda, and Muhanga District, Rugeramigozi marshland
Source: (USAID/Rwanda, 2010 and Murekashungwe et al, 2007)

Rugeramigozi area like other regions of Rwanda consists of 2 wet seasons, one from mid-September to mid-December and the second from mid-February to the beginning of June, and the two dry seasons: one form June to September and the other from December to February (Ker and Downey, 2008) (see figure 5)

Initially this marshland was cultivated by farmers to grow food crops like soya beans, maize, sweet potatoes and vegetables. In 2001, Welthungerhilfe (former Germany Agro Action) started to support the agriculture in this wetland and the landowners founded the farmers' cooperative KIABR ***(K****operative* ***I****mparaniramusaruro y' **A**bahinzi **B**orozi ba **R**ugeramigozi).* Rehabilitation and extension works were done and rice crop was introduced in some fields, but due to insufficient irrigation water, the only one season harvest was poor. This irrigation scheme was supplied by water from Rugeramigozi stream. The earlier research shows that its average discharge was 40.15l per second whereas the rice cultivation was designed for 114l/ per second. The same stream used to provide the drinking water about 23.5l per second for Muhanga town (Murekashungwe et al, 2007). Due to water shortage in this marshland especially in dry season one of the recommendations given was the construction of an irrigation dam to store water to enable farmers to use their land more profitably and have two harvests in year (Murekashungwe et al, 2007). In this respect in 2010 through the MINAGRI through RSSP finished the construction of an irrigation dam with a storage capacity of 270,000 m^3 to allow an irrigation of 120 ha. (MINAGRI, 2009). At present the rice is grown at 80ha and 40ha with other food crops like beans, maize and some vegetables. (The cropping patterns: see figure 3)

Rugeramigozi irrigation scheme is managed by farmers in the cooperative called KIABR. They are in charge of full operation and maintenance of the scheme but RSSP intervenes in case of extension, rehabilitation, training activities and farming cropping. This scheme has been undergoing different problems that resulted in poor crop production. The major constraints identified by farmers are water shortage, soil fertility decline, lack of availability of improved seeds and fertilisers. The acute problems includes lack of trust of the association/cooperative committee (poor institutional management) and the unreliable water flows which leads to non-equitable distribution of available water where some fields experience water shortage whereas others receive an excess of water. (Nabahungu et al, 2011). In addition to this, the competition between the water users of Rugeramigozi dam, especially RSSP standing for the farmers' cooperative and EWSA as a water company supplying water in Muhanga town contributes to the reduction of water quantity in the Rugeramigozi wetland.

1.3. Problem Statement

As mentioned above Rugeramigozi irrigation scheme has been undergoing a poor crop production several years. Some of the reasons are the insufficient water for irrigation to satisfy the crop water requirement especially in dry season, inequitable water distribution between the water users and inadequate delivery of water to crops.

The earliest surveys pointed out that the maintenance and application efficiencies in Rugeramigozi are poor and the system was unable to supply the intended water needs in the marshland and they recommended a construction of reservoir to store the runoff for use during the water storage period **(**Murekashungwe et at, 2007**)**. The target of the new dam constructed in 2012 is to increase the irrigated area in order to fully exploit the wetland and ensure food security in this region.

However, the challenge in water sector is not only about the quantity and quality but also comprises the poor integrated water resources management(IWRM). In this regard Klooster et al (2011) argue that the importance of IWRM for Rwanda has been under-valued. Water development has been approached from a service-oriented more than from a sustainable development and utilization of a finite resource perspective. Main water users such as agriculture, hydro-power and water supply work nearly independently in their own domains without significant coordination with other sectors in using the same source. Each of these big water users has not taken the concerns of the other users seriously into account. Due to this poor collaboration among water users, the water supply company EWSA which has been taking water from this marshland for a long time and supplying it to Muhanga city has not been taken into account in the design of the dam. Consequently, the competition of domestic water supply and agriculture reduces the quantity allocated to irrigation and will not allow the scheme to have 2 harvests (season A and B) per year.

Thus there is a lack of concrete knowledge on how the water resource is managed and distributed between the water Users and whether the available water allocated to agriculture can sustain the irrigation needs according to the cropping pattern in Rugeramigozi marshland.

Furthermore one of the reasons behind a weak agricultural production is an inadequate institutional framework for water and wetland management. The interventions proposed for the development of water resources management related to quantity and quality issues have been taken with minimal effort which affected its implementation (REMA, 2009).

Therefore there is a lack of information on how the management rules are conceived within the farmers' cooperative, how they are implemented and how they influence irrigation practices in Rugeramigozi scheme.

The lack of a clear figure about interrelation and connection between management rules and irrigation practices makes difficult to propose the strategies to guide decision making about water distribution, operation, maintenance and the sustainable development of the scheme well as.

1.4. Objectives

The main objective of this study is to assess the irrigation and water management practices; and the crop water requirement in comparison to the available water in Rugeramigozi irrigation scheme.

1.4.1. Specific objective

- Understand the water allocation between the Water users.
- To determine whether the available water is enough according to existing cropping pattern.
- To determine the optimum irrigated area after construction of a new irrigation dam
- To determine management rules and their implication to irrigation practices within the scheme.
- To prove if there are discrepancies between the management rules and irrigation practices and
- Suggest the measures to correct them.

1.5. Research questions

1. How much water is available for agriculture and what is the optimum cropping pattern that can be irrigated in Rugeramigozi marshland?
2. What are management rules and their implication to irrigation practices within Rugeramigozi marshland?

1.5.1. Sub questions

1.1. What is the overall cropping pattern of the irrigation scheme of Rugeramigozi marshland?
1.2. Who are the water users of Rugeramigozi irrigation dam?
1.3. How is the water resource managed and distributed between the Users?

2.1. How are the irrigation rules conceived and implemented within the farmers' cooperative?
2.2. Are the management rules match to the practices?
2.3. If there is any mismatch, what are the strategies to overcome the discrepancy?

1.6. Theories and Concepts

1.6.1. Definitions

In order to connect the research questions to methodology into a coherent structure, the appropriate definitions and concepts are defined in irrigation context.

Crop water requirement

The term crop water requirement is defined as the "amount of water required to compensate the evapotranspiration loss from the cropped field" (Allen et al. 1998)

Irrigation water requirement

It is the amount of water that has to be applied in addition to rainfall to serve crop water requirements. For irrigation planning it is determined as the difference between CWR (i.e. potential crop evapotranspiration) and the actual crop evapotranspiration under rain-fed conditions with periods of water stress (FAO, 1986).

Evapotranspiration concepts, ETo and ETc

Distinction should made between ETo and ETc;

According to FAO, "reference crop evapotranspiration(ET_o) is a climatic parameter expressing the evaporation power of the atmosphere "whereas "Crop evapotranspiration under standard conditions (ET_c) refers to the evaporating demand from crops that are grown in large fields under optimum soil water, excellent management and environmental conditions, and achieve full production under the given climatic conditions"

$ET_c = K_c\ ET_o$ (FAO, 1998). **Equation 1**

(Kc=Crop coefficient)

Crop coefficient (K_c) is a defined as dimensionless coefficient used to calculate evapotranspiration requirement for a particular crop from the potential evapotranspiration for a reference crop (ETo). Crop coefficients are determined experimentally and take into account leaf area development of the crop and the crop canopy physiology (The Australian National Committee on Irrigation and Drainage, 2001).

When studying the design of an irrigation system, it is also important to talk about **the cropping pattern and Irrigation schedule.**

Cropping pattern or cropping schedule of an irrigation area gives information on three important elements of a least one season:

- which crops are grown
- when they are cultivated
- how many hectares of each crop are grown (FAO,1992)

The irrigation schedule indicates how much irrigation water has to be given to the crop, and how often or when this water is given(FAO, 1989).

Institutional analysis

This research was undertaken by adopting a socio-technical approach. "This approach focuses on the interrelations between water, water technologies and water users and the resulting agro–ecologies and water networks" (Wester, 2008, p.19). As irrigation system is a socio-technical phenomenon, this served to understand the close relationship among people (water user, management staff, farmer Cooperatives, resource), and infrastructure (main, secondary and tertiary level) of the irrigation system.

1.6.2. Framework of Institutional Analysis and Development (IAD)

In order to gain an insight on the irrigation practices and water management in Rugeramigozi, Ostrom's Framework for Institutional Analysis and Development was be used. Ostrom states that 'frameworks identify the elements and general relationships among these elements that one needs to consider for institutional analysis and they organize diagnostic and prescriptive inquiry' (2011, p.8). By using this framework as a guide, the researcher records the elements which are relevant to a particular question and make general working assumptions about the shape and strength of these elements.

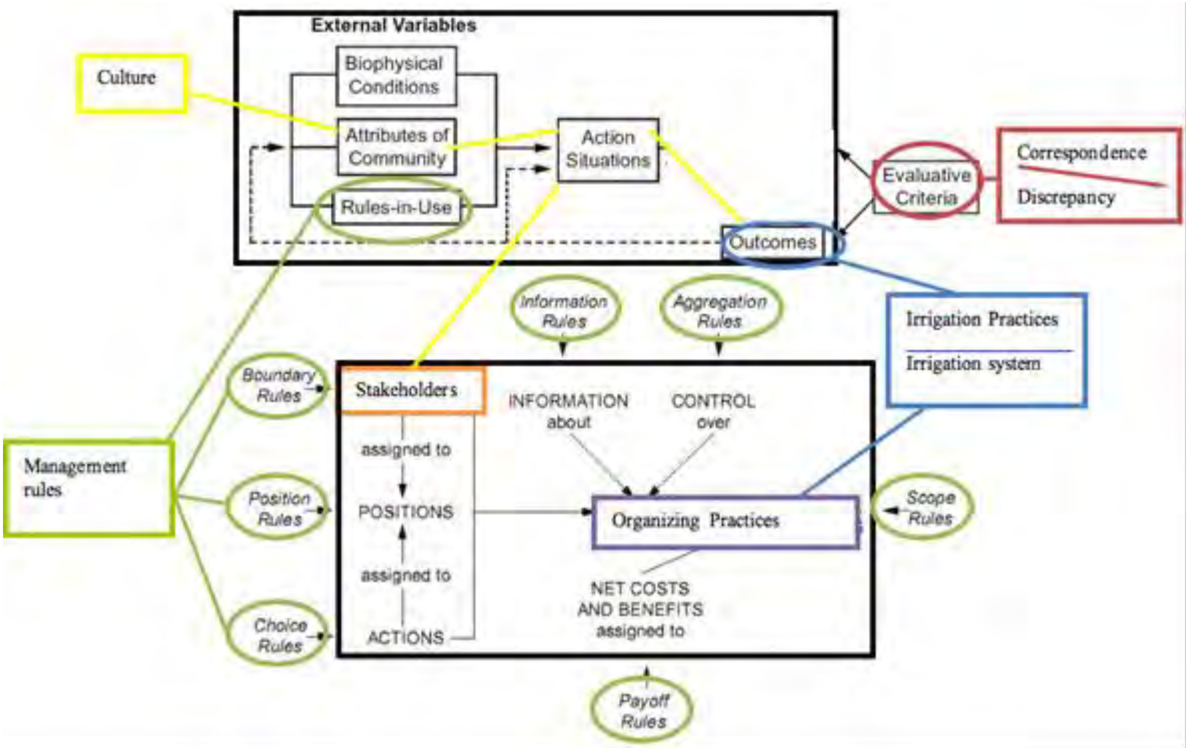


Figure 2: **A Framework for Institutional Analysis (**Source: Ostrom, 2011, p.10, Adapted from E. Ostrom, 2005, p.15**)**

The following concepts are used in this framework and explained according to Ostrom (2011)

Culture
A set of norms, values, believes, and habits that influence the attributes of the community and interaction between stakeholders, influencing its outcomes, i.e. irrigation practices

Rules
According to Ostrom (2011, p.17), "Rules are defined as shared understandings among those

involved that refer to enforced prescriptions about what actions (or states of the world) are required, prohibited, or permitted' and can be implicit or explicit.
Management rules are formally eestablished rules concerning irrigation practices whereas **Rules in use** are those "...to which participants make reference if asked to explain their actions to fellow participants".

Action Situations

Since 'a key part of the framework is the identification of an action situation and the resulting patterns of interactions and outcomes, and evaluating these outcomes' (Ostrom, 2011, p.10), Ostrom elaborated the element Action Situations (figure 2). As can be seen the Rules-in-Use lead to Action Situations together with the Biophysical Conditions and the attributes of the Community.

Interaction, correspondence and discrepancy

Interaction can be defined as mutual action or influence occurring between rules and practice. If the rules are 'accord' to practices, it will be called correspond; if the rules are 'non accord' to practices, it 'deviate' to practices, it will be called discrepancy.

Management staff

The management staff are defined as People (employed by KIABAR and RSSP*)* to operate the physical structure in the fields. This research mainly focuses on the lower staff because they are the ones who put the rules into practices.

Organizing practices

Within the irrigation system there are activities related with: resource (water), people or forms of organizations, irrigation technology, economical and political resource. The organizing practices are defined as "the sets of socio–technical practices that organize the access to and control over resource such as water, maintenance machinery, administrative means and other political and economic resources involved in irrigation management" (Rap, 2004:10).

Water users and water user association (WUA)

Wikipedia defines a WUA as a group of water users who pool their financial, technical, material and human resources for the operation and maintenance of a water resource. The water users are defined as the users of the water resources (Wikipedia, 2011). In this case there are three water users: the farmers' cooperative(KIABR), the water supply company (EWSA) and the Vocational training Centre(VTC) of Mpanda growing the vegetables in the tail end of the scheme. These water users form a WUA of Rugeramigozi.

2. Methodology

In this chapter the means and materials to obtain the required data to meet the objective of this research and to answer the research questions are presented. Data were collected by means of semi and unstructured interviews and literature review, participant observation, institutional analysis and the models were used in this research.

2.1. Interviews

2.1.1. Semi (un)structured interviews and focus group discussions

Semi (un)structured interviews were used to get full information. this kind of data collection was selected to allow the interviewees to have freedom to give information in their own words. Eighty interviews with different respondents and seven group discussions with farmers (3-5 people) were done. In addition to this it is important to say that interviews with the leaders of cooperative, Irrigation staff and Reprentatives of WUA were done more than four times depending on the situation and state of irrigation system. The field work used to be done three days and two days for arranging and writing of data for one week.

Leaders of KIABR and the Engineers in charge of the Rugeramigozi from RSSP
From these interviews the collected information was served to gain information on:

- The historical background and development process of the Rugeramigozi and the cooperative.
- The crops grown in the area and the irrigated area
- How the rules are conceived (irrigation rules in papers) and applied within the cooperative
- Management rules related to irrigation and water management
- Organizational structure of the cooperative
- Background on water management of Rugeramigozi irrigation and WUA.
- Irrigation practices from the leaders perspective
- Cooperation of KIABR and other the partners

From the RSSP staff and the irrigation Engineer in charge of Rugeramigozi who also participated in the construction of the dam and the design of Rugeramigozi irrigation system, the data gathered consist of:

- Background of the construction of Rugeramigozi irrigation dam, its design capacity and introduction of rice in the whole wetland as a cash crop.
- The other sources of water available in Rugeramigozi that are considered in irrigation.
- The volume of Misizi dam constructed by Germany Agro Action in upstream of Rugeramigozi
- Irrigation practices from RSSP perspective.
- The challenges faced in Rugeramigozi related to:
    - Water distribution between RSSP and EWSA from RSSP perspective

- The problems related to water delivery in the wetland whereby some fields do not receive water because of the mistakes done in leveling of the fields and the measures to be taken accordingly
- The real problem of poor yield of rice in Rugeramigozi which is still unknown and its effects on irrigation practices.
- The RSSP plan to increase the irrigated area in Rugeramigozi marshland.

Interviews and focus group discussion with Farmers

The farmers (as members of KIABR) scattered throughout the marshland were interviewed. In order to have a common understanding from farmers, the focus group discussion with farmers after the community work was done.

The collected data gave insight from the farmer's perspective on:

- Irrigation practices and interaction between farmers and Irrigators in Rugeramigozi marshland.
- How the rules are conceived and applied within the cooperative and how they participate in the decision making of the cooperative
- Different problems occurring in the system related to irrigation and the channels to find solutions.
- Their participation in the maintenance activities and how they perceive the water fees.

Irrigators

With this group of temporary workers hired during irrigation period, I got information on how they distribute water and the frequent challenges faced and the way to find solutions and how they collaborate with farmers.

The representatives of WUA

After construction of irrigation dam of Rugeramigozi by RSSP, its management was transferred to the farmers' cooperative even though RSSP still supports the cooperative. However it was noticed that KIABR its self is unable to manage the dam, given that there are other users taking water from the dam. Therefore the Association of all water users was formed in October 2010 to manage and distribute water between the users in equitable way and participate in the conflict resolution.

As said before the WUA is composed by KIABR as cooperative of farmers of Rugeramigozi marshland, EWSA as a water supply company in Muhanga district and the Vocational Training Centre (VTC of Mpanda. During the interview with the Representatives of the WUA, the information obtained refers to:

- The background on the water users association of Rugeramigozi
- The role of water user association in the management of the irrigation dam and conflict resolution.
- The amount of water allocated to each user and the problems occurring in this distribution.
- How the management rules are conceived and applied in the association
- The power relation and cooperation between WUA and External partners.

The Country-Director of German Agro Action (Welthungerhilfe Rwanda)
As the initiator of the development of Rugeramiozi marshland in 2001, this German NGO provided useful information regarding the scheme. By four emails the Country Director provided all maps of Rugeramigozi marshland, the latest report on technical notes of the scheme containing information of all aspects of the marshland. Moreover he provided information of Misizi dam they constructed in upstream of Rugeramigozi in 2006.

2.2. Participant observation

Given that this research seeks to identify irrigation practices and the extent to which the irrigation rules are applied the observation behavior is crucial. All these observations are important and serve to examine the biased answers from interviews and help to fill the Institutional Analysis and Development (IAD) framework. Therefore this kind of data gathering helped to gain a clear image of the daily irrigation practices in the scheme, the operation and the state of irrigation infrastructures, the fields and the effects of the topography of the area on the irrigation practices. The conveyance of irrigation water from the dam till the field level and the extent to which farmers respect the irrigation schedules and participate in the maintenance activities were also observed. The participation in community works with farmers, opening of the gate of the dam by irrigators, measurement of water level in the dam and observing how farmers open and close their fields for irrigation helped me to come closer to the respondents and gain deep insight and answers of what they do. Furthermore during the field work, in the whole month of January Rugeramigozi scheme didn't receive even any single drop of rainfall; therefore I got an opportunity to observe a significant effect of dry period on the irrigation dam(water level dropped down for 1.8m).

2.3. Literature

The literature was used to get relevant information from different publications, NGO archives, internet and reports. Some important data obtained in literature are mentioned in the following categories:

- General overview of irrigation practices and water conservation in some wetlands in Rwanda (Nahayo et al, undated)
- Background information and maps of Rugeramigozi marshland (Welthungerhilfe Rwanda, 2011).
- Evaluation on the distribution performance of the scheme (Murekashungwe et al, 2007).
- Nation policy for Water Resources Management, (MINIRENA,2011)
- Problems and opportunities of wetland management in Rwanda, (Nabahungu et al, 2012).

2.4. Models

2.4.1 CROPWAT model

To calculate the crop water requirement, the FAO CROPWAT model was used. The main inputs for this model are the following:

- **Climatic parameters of BYIMANA station for Rugeramigozi marshland.** These records (like rainfall, max and min temperature, relative moisture) were obtained from the Headquarter of METEO- Rwanda for a period of 30 years from 1960-1990. Because of the war happened in Rwanda in the 90's the meteorological devices were destroyed which resulted in missing some data. This data helped to get the ETo and with the Kc values for specific crops from the literature (FAO, 1986), then ETC values were determined.
- **Crop data.** The existing crops grown (rice, maize, beans and vegetables) in the wetland were recorded though observation and interview with the cooperative leaders. The other specific data like planting dates, growing cycle of the crops and the activities associated with it in Rugeramigozi were obtained from the farming guiding brochure provided by the Agronomist of RSSP in charge of crops in Rugeramigozi marshland. The technical data (like K_c values, length of growth stages) were obtained from the literature.
- **Soil data.** This data was obtained from the literature of the thesis research done on the analysis on soil characteristics of Rugeramigozi wetland (Murenzi et al, 2010).

2.5. Hydrological data

The water supply and the agricultural use depend on the availability of water in the catchment. Therefore the rainfall data was used to estimate the amount of runoff from the catchment that can feed Rugeramigozi irrigation dam. The catchment area was determined by using Google earth and GIS packages. Taking into account the vegetation cover, variety of catchment surfaces and large area of sub catchments, the SCS[1] Curve Number method was found useful for discharge estimation.(see table 1a-3a in appendices). The determination of irrigation supply requirements and the water supply by EWSA in comparison with the available water in the reservoir helped to suggest the strategies on water uses, distribution and management.

[1] SCS: Soil Conservation Service

2.6. Stakeholder analysis

As mentioned above, water distribution and management between the users is still a challenge. Therefore the stakeholder analysis was used to identify the individuals who are involved in this project, their influence, support and how their interests are prioritised. Thereafter water allocation, participation of the water users towards sustainable management of water resources are discussed.

2.7. Institutional Analysis

As mentioned before irrigation practices and water management by the cooperative of farmers were analysed by using the Institutional Analysis and Development (IAD) framework developed by Elinor Ostrom. In the preceding chapter, the concepts that are used in this framework, and how they are related to each other and how it may be used to analyze interactions, are explained in details. In this respect the previous methods used to gather data were aiming to get enough information to fill the components of this framework. To elaborate this point, the conceptualization of rules presented by Ostrom is examined. In asking people why they perform a certain practice, I could record aspects of the response in terms of the different rule types. Then after, the interview responses were compared to the official rules in the papers which were referred to Ostrom's rule types. In so doing, a comparison is made to find where there is an agreement and disagreement. The strength of this framework is that it offers a convenient method for decoding and categorizing the data collected. From this method the discrepancies between irrigation practices and rules are determined and in the last sections of this research the tools and measures to overcome them are suggested.

2.8. Data analysis

The discussion section of this research is based on the outputs from the model, hydrological analysis, stakeholder analysis and the IAD framework. The results are interpreted and discussed in terms of the existing setting of Rugeramigozi irrigation scheme. The suggestions for the improvement of irrigation practices and integrated water management in Rugeramigozi scheme are given in the details. From this point conclusion and recommendations are withdrawn.

3. **Findings**

3. 1. Biophysical settings

Location and Climate

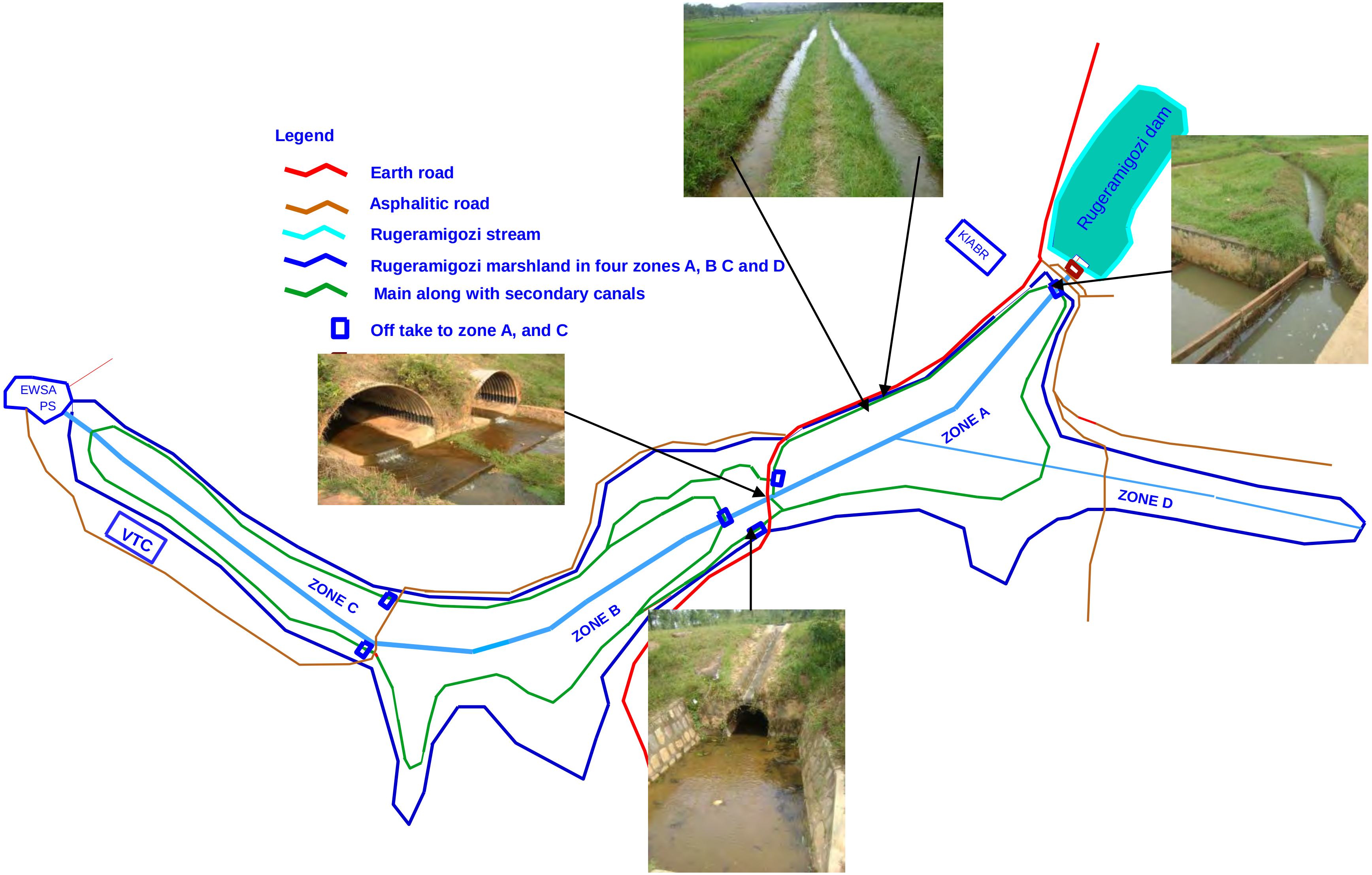
Rugeramigozi marshland is located in the Muhanga district (02^0 07′ 40″ S, 29^0 45′ 20″ E), on the plateau agro-ecological zone of Rwanda at altitude around 1650m and covers an area of 245 ha. The annual range of rainfall is 1200–1400mm in Rugeramigozi and the temperature varies between 11°C and 28°C in southern Province. In Rwanda the climate is temperate; the rainfall pattern is bimodal with the short, most important and reliable rains season from September to January (named Season A). The long rains season runs from mid-February to May (Season B) and has high intensity rainfall (Nabahungu et al, 2011).

Irrigation system, dams and Water distribution

As said above the study area consists of the two former sub marshlands: Biringanya marshland of 63 ha and Rugeramigozi I of 66ha (see figure 1) which are irrigated by the so called Rugeramigozi dam of 270,000m^3. The dam is still new, in good condition and surrounded by the grass to avoid erosion of soil mass to fill the dam. This earth dam has no permanent river as source of water except seasonal springs, runoff from the catchment and the and the outflow of the up-stream dam in Rugeramigozi II. Along the wetland there are few small sources of water (streams occurring in rain season) which disappear in dry period. Some fields rely on these sources because the water from the main canal doesn't reach them. When there is much rain, these fields are full of water and it is difficult to drain it from the fields due to the poor condition of the drains. Even though the water resources seemed to be dedicated to agriculture the water supply in Muhanga town is taken from this wetland. This shows how a close collaboration with the agriculture sector and the water supply should be strengthened.

For the matter of design and sharing one source of irrigation water, Rugeramigozi I and Biringanya are managed as one marshland of 120 ha by the farmers' cooperative (KIABR) and is divided into 4 zones (A, B, C and D). The rice crop is grown in all zones except D because water from the dam can't reach it due to topography of the area. The other crops grown are maize, beans and some vegetables that can be found in zone D and non-irrigable terraces outside the marshland. The construction of the new dam was to permit the two harvests per year but the higher completion of water the low capacity dam probably shall not allow it (see the discussion section).

Figure 3 : Schematic map of irrigation system



Irrigation canals and Drainage system

These scheme is characterised by compacted peripheral earth canals of 2%o slope (Welhungerhilfe, 2011) and the drainage system in the middle. Most of secondary canals go along with primary canals and their sizes vary from 50cm -100cm as width and 60-110cm as depth. In the beginning of this research there were no tertiary canals. The farmers who is close to the secondary canal used to get water directly from it and when the field was full it continued to the next field. After realising the mistake made in the preparation of the marshland and the consequences due to the lack of tertiary canal(20x30-25x35cm), farmers were obliged to create those canals themselves.

Photo 1: Farmer creating a tertiary

The irrigation infrastructures are maintained by the farmers in the community work that takes place every week. Due to topography of the area and the mistakes done in levelling, there are some field s in zone A and B which do not receive irrigation water. To solve this problem in zone B they installed the conveyance pipes that take water directly from a higher level of the main canal and deliver it into the special secondary canals created for this purpose.

In zone A the water level is raised by putting a plywood structure or a grass mass in the canal in order to convey water in the fields that which are higher than the canal. The farmers pointed out that the lack of tertiary canals created a problem of:

- Over irrigation in the fields
- The spreading of fertilisers from one field to another and
- Irrigation problems between farmers because water should pass in the field belonging to someone(who sometime doesn't need water) in order to reach the other one.

Moreover the field irrigation engineer pointed out that the small slope of the canals and the variation in fall and rise occurring in them make difficult to deliver water in some fields (zone C and some fields of zone B). A high pressure from the dam is always needed but this is not possible in the dry period when the water level goes down.

Photo 2, 3,4: Pipes installed to provide water to fields which are higher than the normal canals

In zone C, some fields have a problem of high infiltration in such a way during irrigation, water infiltrates and after a certain time it appears in the next downstream fields. Furthermore the drainage system is not maintained. This creates a problem of water logging when the time comes to drain out it from the fields.

Field system, cropping pattern, farming practices and soil

Before the construction of irrigation dam and the support from RSSP, the farmers' cooperative used to grow what they wanted. But with the new government policy regarding Land consolidation and crop intensification RSSP enforced the growing of one crop in Rugeramigozi. And the rice as a cash crop was selected for the cost recovery of the construction of the dam. The types of rice grown are short grains varieties (Zhong Geng, Yun Keng and Yun Yin) (Nabahungu et al, 2011).

The fields are in mostly in rectangular shape but there are others in triangular form. The normal size of the fields differs from 20x20m to 25x30m but the big parcels of 1/10ha can be found. Initially the marshland was not designed for rice plantation; therefore the available maps of the scheme don't match with current layout of irrigation system of rice and water resources.

The fields were redistributed in 2001 after reclamation of the wetland by Welhungerhilfe and farmers took the fields according to their capability. In these respect some people own more than three fields. In addition to this, farmer owns one or more rain fed terraces (average size 10x20m) which are in good condition outside the marshland for maize or beans cultivation. There are also big land owners: VTC (vocational training centre of Mpanda with around 1ha), Kavumu College of Education (1ha) and the Sisters cathedral (1.2ha). These special landowners also grow rice except the VTC that is still growing the vegetables.

The growing of one crop replaced the tradition farming practices of mixed cropping and comply with the new policy for land use consolidation and crop intensification which aims at bringing fragmented plots of land together and growing of a crop suited to a particular area (consolidated land) as one way of maintaining food security. The crop choice is motivated by agro- bio climate conditions and economic potential (MINAGRI, 2012). However there are farmers who are still in favour of mixed farming. During the field survey 35% farmers said that they would prefer to spend more time in the dry lands where they have many crops rather than in the wetland whose only one crop which is not even giving a good yield and there is not a possibility to bring back the old system when they used to grow according to their choice. This mentality was supported by the bad yield of rice in the preceding season where the average yield was 0.22ha.

Till the season B, 2012 the irrigated area of rice was 80 ha whereas other 40 ha was occupied by other crops. From the RSSP side the target is to increase the irrigated area for rice. In the rain season the crops are normally in good condition but in dry period some of them suffer from the lack of irrigation water. At the harvest farmers are not allowed to take home the yield, there is a new rice-drying-platform including the store constructed by RSSP where the rice is weighted and sold by the private business companies.

According to the cropping brochure provided by RSSP Agronomist in charge of crops, the growing cycle of rice is 150 days for KIABR and 120 days for cabbage for VTC Mpanda. Transplanting of rice starts with December, but land preparation and nursery are done before in November. This is the season B. In the same way, the season A starts with in June but some preceding activities are done in May.

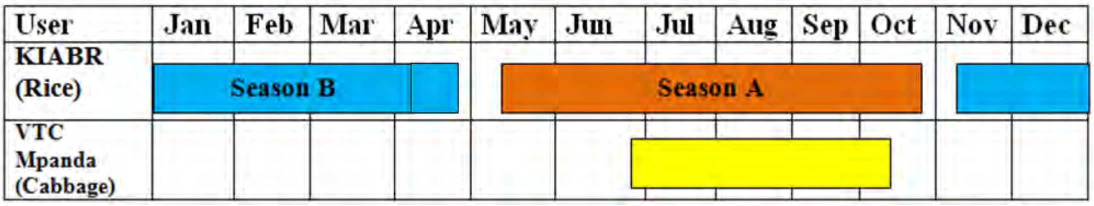


Figure 4: Cropping-schedule

The soil survey done before indicates that the arable soil of marshland is made of three main layers(see table 10a in appendices). From the top of the soil to 2ocm deep: Loamy sand; from 20-40cm: Sandy clay loam and from 40-60cm: Sandy clay loam. The Sandy loam soil can be also found in some parts of the wetland (Murenzi et al, 2010 unpublished).

3.2. Determination of the runoff volume

As mentioned before, the source of water for the retention dam of Rugeramigozi is the runoff from the catchment. Hence there are different ways to determine the catchment runoff. The simplest method is the use of the rational equation.

Rational method

The rational equation for estimating the runoff potential is expressed as:

$Q = CiA$ **Equation 2**

Where;

Q = the maximum rate of runoff cubic feet per second (cfs)
C = runoff coefficient representing the fraction of rainfall that becomes runoff
i = rainfall intensity for a duration equal to the time of concentration (in/hr)
A = drainage area (acres)

(City of Springfield, 2007)

However to this method is associated with some limitations:

- Rational equation is suitable for small watershed (<200 acres)
- When using it the drainage basin characteristics are assumed to be fairly homogeneous
- It becomes more accurate when the drainage basin is made of impervious surface

If the watershed consists of a variety of surfaces then another method should be selected. (Mountain Empire Community College, 2012). In this way the SCS curve number method is used to estimate the runoff for the irrigation dam of Rugeramigozi.

3.2.1. SCS curve number method

The CN (curve number) was initially developed by the USDA[2] **Soil Conservation Service(SCS)** as a design tool to estimate runoff from rainfall events on agricultural fields. It is a coefficient that reduces the total precipitation to runoff potential, after "losses": Evaporation, Absorption, Transpiration and Surface Storage. The higher the CN value the runoff potential will be (Paul Schiariti et al, 2008).

The final equation of SCS Runoff is expressed as:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$ **Equation 3**

Where
Q = runoff (in or mm)
P = precipitation (maximum potential runoff) (in or mm)
S = potential maximum watershed retention (in or mm)
S is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by:

Equation4

$$S = \frac{1000}{CN} - 10 \quad \textit{for} \quad Q, P, S \textit{ in inches} \quad \text{OR} \quad S = \frac{25400}{CN} - 254 \textit{ for } Q, P, S \textit{ in mm.}$$

For a given CN and precipitation depth, the volume of runoff can be calculated using Equations 3 and 4. The determination of the CN value for a watershed is a function of soil characteristics, hydrological conditions and cover or land use (Idem).
(see table 1a-3a in appendices).

By using GIS and Google earth models, the catchment area of the irrigation dam of Rugeramigozi was determined. The watershed was divided into small areas for the modelling purpose and better determination of the CN.

---

[2] USDA: US Department of Agriculture.

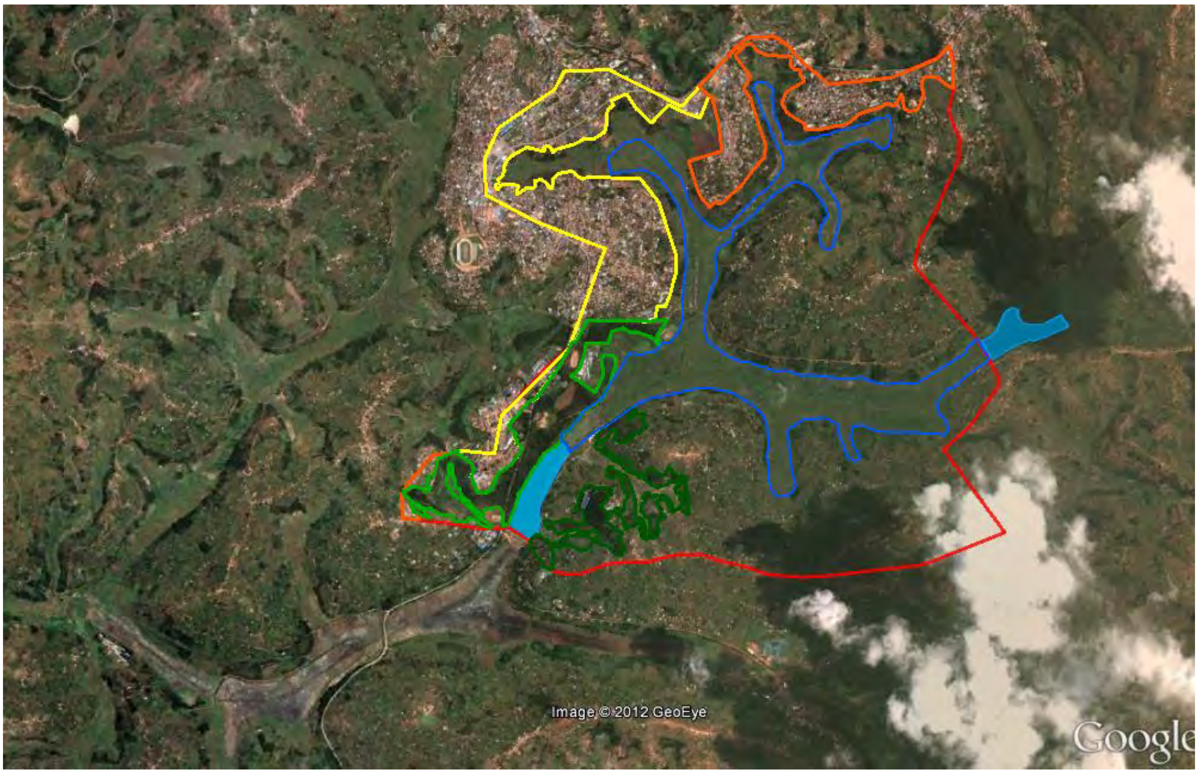


Figure 4: Study area of Rugeramigozi catchment

Legend:

: Study area of catchment ;

: Residential area of Muhanga city

: Business area of Muhanga city

: Marshlands

: Surface water(Rugeramigozi and Misizi dam)

: Forest and vegetation cover

Other : Cultivated with conservation tillage

3.2.2. Calculation of the runoff

As mentioned above the soil data of Rugeramigozi marshland is sand clay loam. But according to MINAGRI and AGCD-Belgique (2001) the uplands part is made of a wide range of soil such as sandy loam, loamy sand, clay, sand clay loam. For the design purpose the Hydraulic soil group (HSG) whose a small CN was chosen for the uplands: , **sandy loam and loamy sand** whose HSG=A and HSG=C for the wetlands (see able 3a for soil characteristics in appendices)

Table 1: Determination of CN

	ZONES	HSG	Surface(ha)	% area	CN
1	Business area	A	132	12.99	77
2	Residential area	A	69.5	6.841	77
3	Cultivated with conservation tillage	A	554.9	54.62	72
4	Forest and vegetation cover	A	87.1	8.573	45
5	Marshlands	C	161	15.85	85
6	Surface water	D	11.5	1.132	98
	Total catchment area(A)		**1016**	100	
	Average (CN_{avg})*				**73**

*The CN average is calculated based on the weights of the % of zone in comparison to total catchment area.

By replacing the value of CN in the **equation 4**, **S= 93.94** Again, by replacing the above data and the rainfall data (see table 11a in appendices) in **equation 3**, the annual runoff flowing to the dam is obtained in the table below.

Table 2: Runoff calculation

Month	Rainfall (mm)	Runoff Q(mm)	Inflow to dam* V(m^3/month)	Total available water for use (m^3)**
Jan	104	41	413,035	371,732
Feb	120	52	533,059	479,753
Mar	132	62	625,117	562,605
Apr	206	125	1,269,775	1,142,797
May	147	74	749,826	674,844
Jun	36	3	25,880	23,292
Jul	22	0	943	848
Aug	42	5	47,752	42,977
Sept	89	30	302,879	272,591
Oct	101	39	392,521	353,269
Nov	142	70	712,473	641,226
Dec	110	45	456,292	410,662
Year	1251	545	5,529,551	4,976,597

*Inflow to dam (V)= Q*A (where A is catchment area=1016ha)

** Total available water for use=V-Environmental flow (assumed value of ≈10% outflow for replenishment of the marshland and recharge of groundwater).

From the table 2, a considerable amount of water flows to the dam except in the dry season starting in June to August. Given that the dam capacity is 270,000m^3, this indicates that a considerable amount of water overflows the dam. This was also confirmed by the irrigation Engineer who said that in wet season, the dam becomes completely full in such away they release enormous quantity of water.

The three months of dry season are characterised by a severe water scarcity.
Normally in the rain season VTC practices the rain fed agriculture, but in this period they grow the vegetables which requires irrigation water from the dam. This increases water demands in the wetland.

3.3. Water needs in Rugeramigozi marshland

As mentioned before, the water uses in Rugeramigozi is divided in three categories:

- Water supply by EWSA for Muhanga town(45litter/sec)
- Irrigation of rice plantation for the farmers 'cooperative(80ha)
- Irrigation of the vegetables (cabbage)for VTC Mpanda (1 ha)

The following sections aim to determine the water requirement and distribution for these three users. To estimate the crop water requirement (CRW) and irrigation water requirement of rice and cabbage the CROPWAT 8.0 was used. This program uses the (FAO 1992) Penman-Montheith equation for calculating the reference crop evapotranspiration with the climatic data of the area. The determination of Irrigation water requirement was determined after calculating the effective precipitation by using FAO equation.

$Pe = 0.8\ P\ 25$ if $P > 75$ mm/month **Equation 5**
$Pe = 0.6\ P\ 10$ if $P < 75$ mm/month **Equation 6**

With P = Precipitation (mm/month)
Pe = Effective precipitation (mm/month) (FAO, 1986)

Some of its inputs data were obtained from the field other in the literature (see the detailed explanation on the appendices). The climatic data obtained from Rwanda Meteorological Agency, the Kc values of rice and Vegetables from FAO publications helped to determine the crop water requirements (CWR) of rice and Cabbage.

Irrigation water requirement (IWR). =ETcrop-Eff.Precipitation (Idem) **Equation 7**

From the model the rainfall availability in Rugeramigozi is displayed in the figure 4 below

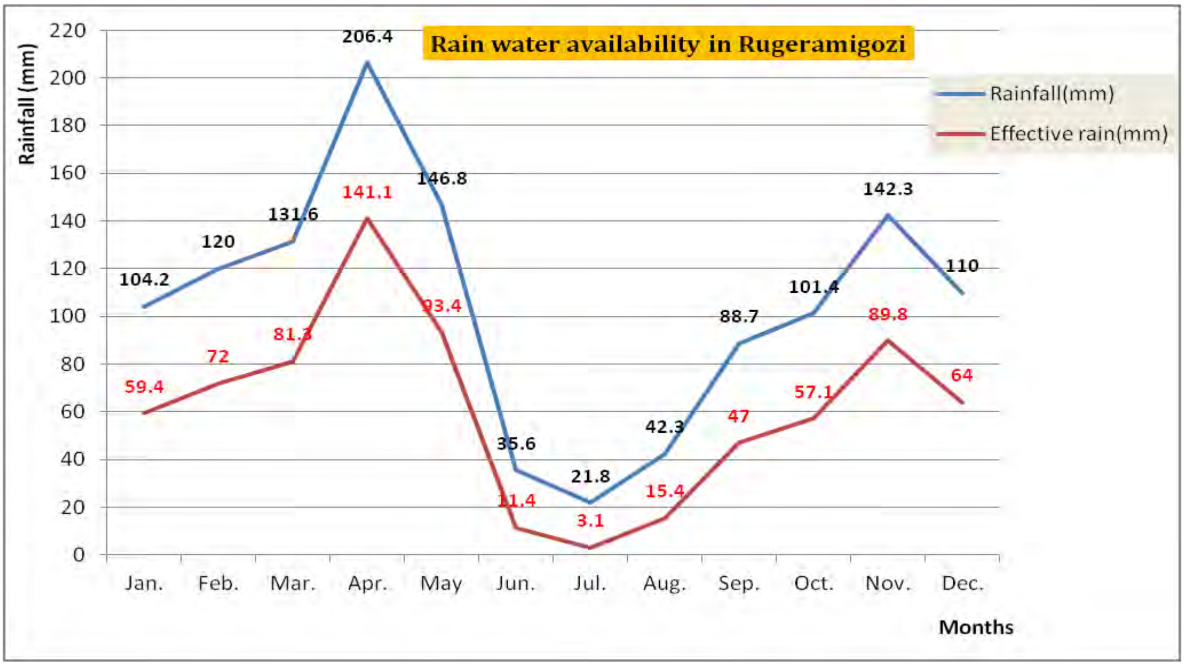


Figure 5: Precipitation in Rugeramigozi wetland

The characteristics of rice, and the climatic data of the area were put in the model for both season A and B (see Table 4a-6a in appendices). The idea is to determine the CWR and irrigation needs of rice throughout the year. After processing the data the outputs are visualized in the figure 5 below for a better analysis (refer to Table 7a-9a in appendices).

From figure 5, it is important to note that the irrigation requirements for rice are higher in June and November(the periods of land preparation and nursery for season A and B respectively). This is due to the considerable amount of irrigation water which is normally applied for land preparation and inundation prior to transplantation. A first application to bring the soil to saturation after which puddling and land cultivation are carried out. Then prior to transplanting, a second irrigation for inundation water of 100 mm should be affected. The total irrigation requirements for land preparation amount to 200-300 mm is applied (FAO, 1992).

In season A the irrigation requirements for land preparation and nursery is 290 mm in June whereas it is 300 mm in November for season B. In addition to this there is another irrigation requirement for cabbage for VTC Mpanda as it is shown in the table 9a in appendices. By combining the Table 2 (runoff to dam) and all water demands in Rugeramigozi the Table 3 is generated

Figure 6: CWR, Eff. precipitation and Irrigation requirement for season A & B for rice

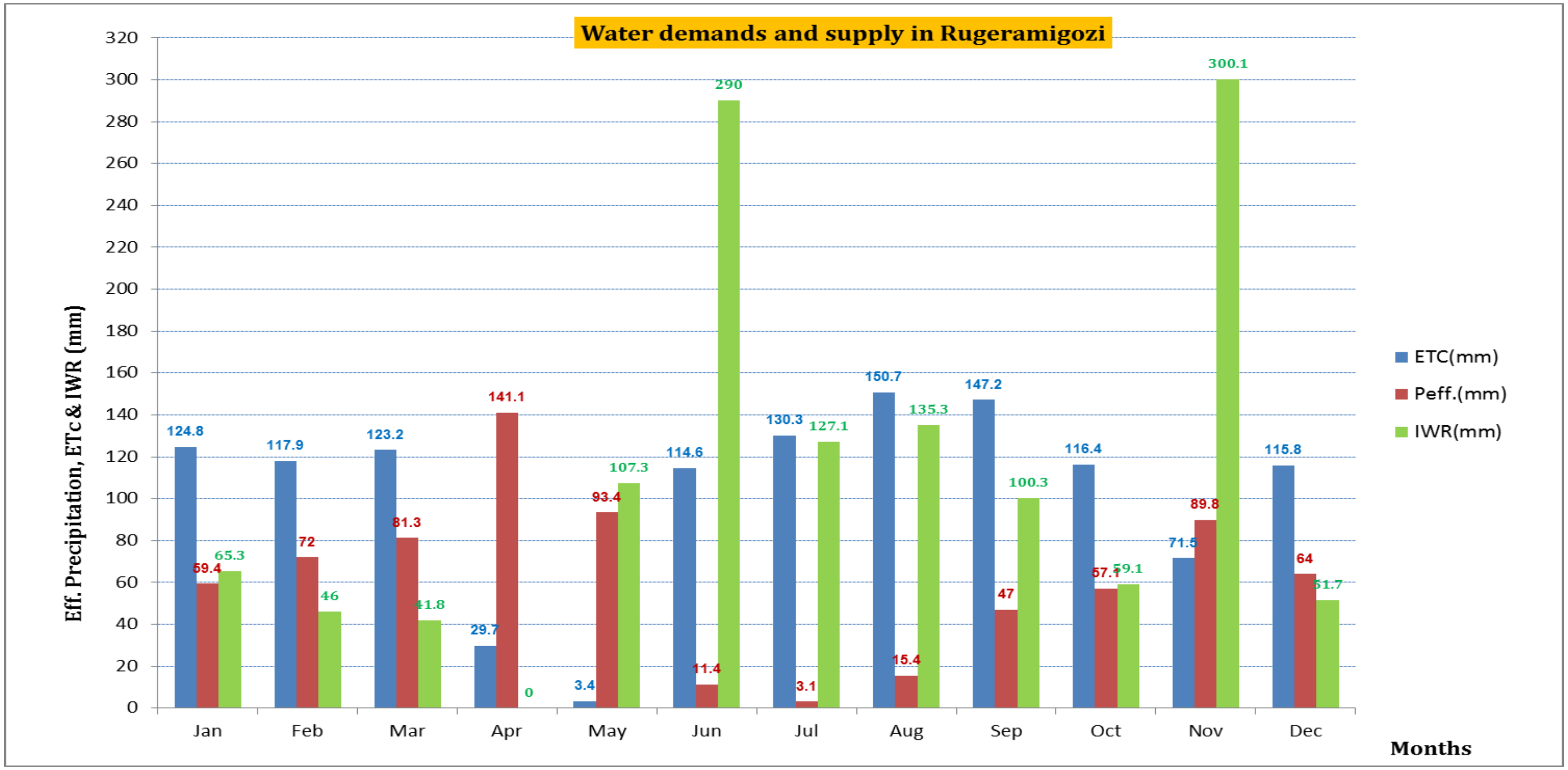


Table 3: Water supply and demands in Rugeramigozi marshland.

Month	Volume in reservoir	Total inflow (m3)	Total available volume (m3)	Drinking water needs - EWSA (m3)	Irrigation needs - KIABR (m3)	Irrigation needs VTC (m3)	Total needs (m3)	Surplus/ Deficit (m3)	Balance in the lake (m3)	Remarks

Jan	270,000	371,732	641,732	116,640	52,240	0	168,880	472,852	270,000	Enough water for irrigation
Feb	270,000	479,753	749,753	116,640	36,800	0	153,440	596,313	270,000	Enough water for irrigation
Mar	270,000	562,605	832,605	116,640	33,440	0	150,080	682,525	270,000	Enough water for irrigation
Apr	270,000	1,142,797	1,412,797	116,640	0	0	116,640	1,296,157	270,000	No irrigation needed
May	270,000	674,844	944,844	116,640	85,840	0	202,480	742,364	270,000	Enough water for irrigation
Jun	270,000	23,292	293,292	116,640	232,000	1,750	350,390	-57,098	**0**	**lack of irrigation water**
Jul	0	848	848	116,640	101,680	7,310	225,630	-224,782	**0**	**lack of irrigation water**
Aug	0	42,977	42,977	116,640	108,240	11,800	236,680	-193,703	**0**	**lack of irrigation water**
Sept	0	272,591	272,591	116,640	80,240	8,210	205,090	67,501	67,501	Enough water for irrigation
Oct	67,501	353,269	420,770	116,640	47,280	3,560	167,480	253,290	253,290	Enough water for irrigation
Nov	253,290	641,226	894,516	116,640	240,640	0	357,280	537,236	270,000	Enough water for irrigation
Dec	270,000	410,662	680,662	116,640	41,360	0	158,000	522,662	270,000	Enough water for irrigation
Year	2,210,791	4,976,597	7,187,388	1,399,680	1,059,760	32,630		4,695,318		

Notes:
- Drinking water needs: water supplied by EWSA to Muhanga town (=45l/sec)
- Irrigation needs KIABR: Rice plantation on current irrigated area of 80 ha.
- Irrigation needs VTC: Cabbage plantation on current irrigated area of 1 ha
- Total needs: EWSA + KIABR + VTC
- Surplus/Deficit: Total available volume - Total needs
- Balance in the lake: Volume in reservoir + Inflow - Total consumption (with a maximum of 270,000 m3 and a minimum of 0 m3)

Table 3 clearly shows the expected inflows and outflows for the irrigation dam of Rugeramigozi. The agriculture water use is subjected to change because the irrigated area can be increased or reduced whereas the water supply is fixed because of the priority given to drinking water. The calculations indicate that in the rain season (B) there is enough water satisfying all water needs. In addition to this there is a considerable runoff that overspills from the Misizi dam during the rainy season. But the season B starting in June is practically unfeasible because of lack of drought even domestic water supply water requirement will not be met. This confirms what was observed on the field where the dry period of one month of January, 2012 caused the water level in the dam to go down 2m deep. As solution the Misizi dam was opened to release water to Rugeramigozi dam.

From theses outcomes the idea of RSSP to increase the irrigated area can be supported only if the cooperative could grow the rice in one season B. In season A the farmers' cooperative could grow other dry crops like maize(but after a feasibility study of irrigation water requirement for maize) if EWSA could get other source of drinking water like Misizi dam as it was before construction of Rugeramigozi dam. For the current setting, irrigation is done to a certain extend because EWSA is getting water in the downstream of the marshland. In this way the water used by EWSA consists of the excess water from the fields, canals and water allocated to environmental flow. But if EWSA starts getting water directly from the dam, it will have impact on water uses and lead to a serious water crisis in dry season.

3.4. Institutional Analysis and Development (IAD) framework

From this point ahead the focus is to describe how irrigation practices lead to water management. Hence the components of IAD framework: the physical settings of the irrigation system, culture of farmers (attributes of the community) and irrigation rules in theory are analysed in order to see how they shape interactions between actors (management staff of the system) and outputs which are finally assessed by evaluative criteria: correspondence or discrepancy (see figure 2). As the biophysical aspects of the scheme is described in the preceding part (see the section 3.1), the following paragraph describes the farmers 'culture of Rugeramigozi.

3.4.1. Attributes of the community

In this part the main idea is to attempt to capture the complexities of widely accepted norms of how business is done. Therefore I argue that we must consider how the cultural context influences the stakeholders and shapes the irrigation and maintenance practices in Rugeramigozi marshland. This cultural perspective is even stated in the national constitution "that it is necessary to draw from our centuries-old history the positive values which characterized our ancestors that must be the basis for the existence and flourishing of our Nation." **(**The constitution of the Republic of Rwanda, 2003). Some of the Rwandan values refer to better ethical practices and behavior appreciated by others: **Mutual help**, **forgiveness**, living in peace with others, Maintaining and management of the public property in Community work "**Umuganda**". (National unity and reconciliation commission, 2009). While describing the attribute of the community, each norm and its influence on irrigation practices is discussed separately.

Mutual help

This refers to the norm of the community-based or a consumer-driven social organisation whose primary focus is on collective action to improve the lives of members and others with specific disabilities and needs (Resource Library, 2011).

This behaviour was observed and also pointed out by the farmers interviewed by only saying that a farmer can ask his/her neighbour to irrigate his/her field and the following irrigation day they do the same but in other way around. This can save time of the two farmers but it results in mismanagement of water when the farmer open the field and go home and thereafter ask his neighbour to close his/field when he goes to the marshland. The other example of the mutual help that characterises this community is the gathering of efforts of the farmers in community work and choose one member who is left behind on the farming calendar because

there is a sound reason and they decide to work in his/her field. In this way they can also irrigate for him/her for a long time.

Maintaining and management of the public property in Community work "Umuganda"

The Community work is the gathering of efforts of many people in order for them to carry out a general public interest activity. Community works shall also aim at promoting development activities in the frame work of supporting national budget and to provide an opportunity for conviviality among people. (MINIJUST, ***2007).***

This cultural practice has been legalized in such a way every Rwandan aged from 18-65 years must perform community works. In this way in Rugeramigozi marshland the farmers maintain the irrigation infrastructures through the community work. This collective action consists of cleaning the canals and drainage system or creating the new ones for a better conveyance of water to/from the fields. This reduces the expenses that could be spent in the maintenance of the scheme and makes the farmers feel responsible of the management of the system. As said earlier those who miss the community work are supposed to pay a fine of 0.83USD. The tables shows the activities related to the culture but leading to water management

Photo 5: Farmers in the community work weeding of rice for the patient member of the cooperative.

Method	Activity	*Efficiency
Mutual help	Irrigation for each other	It is an arrangement between farmers
	Weeding for a member	only happens when there is a sound reason like sickness
	Sharing of crop from nursery	mostly done at block level
	Apply the fertilizer for each other	It is an arrangement between farmers
Community work "Umuganda"	Maintenance of the system (Cleaning, rehabilitation, of canals)	It is done every week at zone level and efficient when attention is paid.
	Weeding for a member	It is done if there is sound reason like sickness, it is efficient because the task of the day must finish.

Table 4: Roles of "Mutual help" and "Umuganda" in water management

* Is difficult to assess efficiency of "Mutual help" because it is not done regularly and there is no is no rule followed, except trust between farmers.

Forgiveness

Forgiveness is the renunciation or cessation of resentment, indignation as a result of a perceived offense, disagreement, or mistake, or ceasing to demand punishment or restitution. The Oxford English Dictionary defines forgiveness as 'to grant free pardon and to give up all claim on account of an offense or debt'. Forgiveness may be considered in terms of the relationship between the forgiver and the person forgiven. (Wikipedia, 2012). This behavior is manifested when a farmer is caught violating the irrigation schedule by stealing water, he/she can apologize and let her/him go free. As far as this happens several times the farmers can think that it is normal to break the regulation and always get forgiveness easily. Forgiveness its self is good but when the offender thinks that the pardon is always guaranteed, it leads to the lack of awareness of keeping the regulations of the cooperative. This becomes worse when in that society there is a culture of impunity.

The culture of impunity

The term "culture of impunity" refers to a situation in which people in a society have come to believe that they can do whatever they want with impunity (without having to face any sanction) (eNotes, 2012). As mentioned in the preceding paragraph the too much forgiveness and the culture of impunity has a sound influence on irrigation practices and maintenance of the system. Given that the community work has been legalized, the answers from farmers concerning their participation were biased being afraid to be punished or considered as criminal. Even though there are regulations governing irrigation practices and maintenance of the system and the corresponding fines charged those who violate the laws but 100% of the respondents interviewed pointed out that no one has yet fined because of stealing water, irregularity in the maintenance activities and disrespect of cropping activities (for instance not weeding on time). In summary there is a need to improve the law enforcement and sensitization of farmers in performing appropriate irrigation practices that will lead to improved harvest.

3.4.2. Irrigation and water management rules

The main focus of this analysis is to classify the information collected into different groups of rules according to Ostrom‟s IAD framework (see figure 5). However for the practical reasons all the rules are not covered and mentioned in this report, only the ones which are have effects on irrigation and water management are mentioned and discussed otherwise the results would be too long and become rules oriented research. Hence on the annexe the rules were identified throughout this research and the summary is provided.

3.4.3. Action situation and interaction

Ostrom (2011) defines action situations as the social spaces where individuals interact, exchange goods and services, solve problems, dominate one another or fight. In this way though the interactions seemed to be consequences of action situation they are both described within the following section. According to Ostrom (idem) the internal structure of an action situation depends on several variables:

- The set of actors: Who and how many individuals withdraw water resource units (irrigation water, EWSA, VTC).
- The positions: What positions exist (e.g. KIABR, Engineer, Irrigators)
- The set of allowable actions: Which types of irrigation methods are used?
- The potential outcomes: Who/what is affected by the actions (e.g. water supply affect water deficit for irrigation of rice)
- The level of control over choice: Do stakeholders take actions on their own initiative, or confer with others?
- The information available: How much information do stakeholders have about the irrigation water, about other stakeholders' cost and benefit functions, and about how their actions lead to outcomes?
- The costs and benefits of actions and outcomes: How costly are various actions to each type of appropriator, and what kinds of benefits can be achieved as a result of various group outcomes.

Landowners: Farmers

As said before in Rugeramigozi marshland there are 870 registered landowners whose plots of variable sizes and big landowners of 0.8 to 1.2ha. All the landowners must be members of the farmers' cooperative KIABR. To become a member of the cooperative the new farmer should have at least one plot in the marshland and pay non-refundable membership fee of 5000RWF (≈8.3 USD). As explained in the Rules, the administrative committee is elected by the general assembly of the farmers and everyone who has formal education can be elected and there is no limit of re-elections. The rules are suggested by the leading committee and the general assembly votes or reject them. However some rules are based on government policy like land consolidation and crop intensification. Moreover due to the lack of technical and managerial skills of the cooperative, KIABR implements the irrigation activities planned by RSSP, but the irrigation problems are solved within the cooperative basing on bylaw.

The landowners have also other plots in the uplands where they are engaged in rain fed agriculture. Moreover, some landowners have other daily job like commerce, education, workers in the public institution. As mentioned above farmers do not have the right to grow what they want. Therefore at the beginning of the planting period the farmers are given the instructions on cropping activities(type of crop and cropping calendar). In order to receive irrigation water the landowner must pay 500RWF (0.83USD) per field per season regardless of the size. Each field of rice is supposed to get water twice per week according to the irrigation schedule provided by the Irrigation Engineer. However this irrigation turns are provided based on experience rather than calculations. The farmers irrigate themselves by opening the fields, and water from the canal flows directly to the fields. During irrigation farmer must wait for water to cover the whole plot at a given level of water (say 2cm) according to the instructions given by the field irrigation Engineer. After irrigating the field should be closed. According to the office irrigation Engineer and the president of Zone B there are some fields in Zone B which must receive water every day because they don't receive enough water due to the topography and mistake already done before in the levelling of the lands. Apparently in rain season farmers feel that the water is sufficient but subject to technical difficulties related to poor wetland renovation, eventually resulting in unreliable water flows(Nabahungu et al, 2011).

During the interview, the farmers appointed that they can request special water for weeding. Farmers also said that some landowners when they miss the irrigation day, come any other day and take water, in case they are caught they must be punished with a fine of 500RWF(0.83USD).

Irrigation staff
The irrigation staffs are in two categories; the first one consists of the Staff employed by RSSP: Office irrigation Engineer and Field irrigation engineer. This staffs are paid monthly and are not members of the cooperative.
Other category is made of the irrigators employed by the cooperative. RRSP and the District of Muhanga are the major authorities who take all the decisions in regard to the use of the marshland (see table 7: stakeholder analysis).

Office irrigation engineer
He is employed by RSSP to be in charge of the irrigation works in southern province.
He is always in contact with the field Staff who reports to him the irrigation situation of the scheme, the suggested maintenance and extension activities. Moreover he collaborates closely with the leaders of KIABR and the Water User Association and they have a monthly meeting about the distribution and management of water resources. The conflict that occurs in this Association is solved by the conflict resolution council of the WUA. When it is beyond the association, all the stakeholders in the management of water resources can participate.

The Office irrigation engineer prepares and provides the irrigation schedules and the field engineer supervises their implementation till the field level. In addition to this he designs the extension of the irrigation schemes. In doing this, he prepares the specifications of equipment required and supervise the subcontract for construction of these extensions. For instance the installation of the pipelines which takes water from a high point of the main to the special secondary canals.

Zones	Irrigation schedule		Maintenance
	1st day	2nd day	Day of community work
A	Monday	Thursday	Tuesday
B	Tuesday	Friday	Wednesday
C	Wednesday	Saturday	Thursday
D	Rain fed agriculture		

Table 5: Irrigation schedules

The office irrigation engineer participates in the preparation of the training of farmers in irrigation and other cropping.. He prepares and updates the irrigation plans for the scheme in collaboration with the Coordinator of RSSP in south province and reports to the National Project Coordinator office.

Field Irrigation Engineer

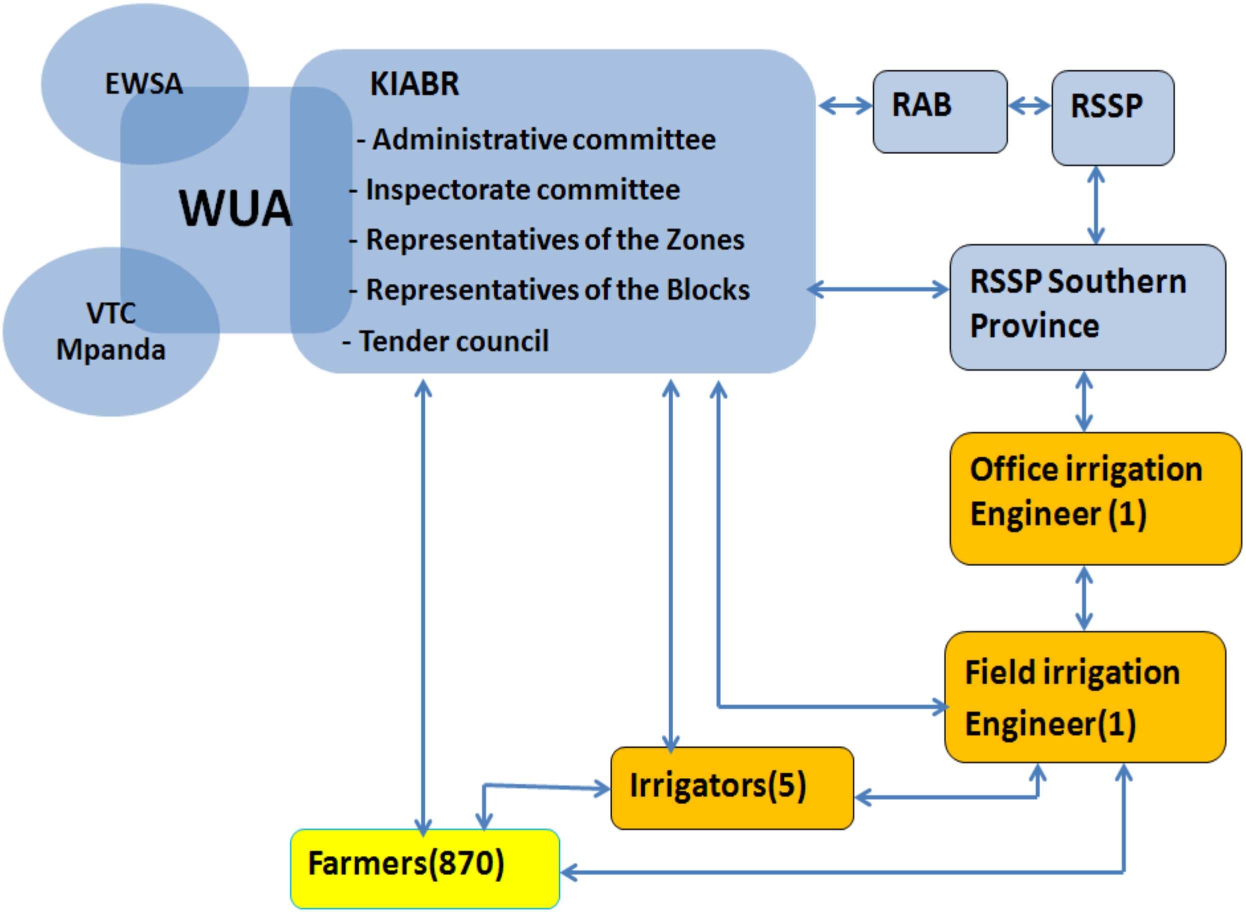
As said above he is in charge of all field work of irrigation in the whole marshland. He has five Irrigators under his duty. He controls and regulates the water flow from the dam to the fields. However the quantity of water to release is not known; basing on what he learnt from school and experience he knows the crop water requirement of a given crop then he estimates the flow of water needed. In addition to this quantity, he should also add more water for EWSA (100m^3/hour) to supply in Muhanga town. In the dry period VTC also needs water for their vegetables grown in the downstream of the wetland. Given that there is not a meter device on the dam all the water flow is released by estimation.

Irrigators

As said these staffs are hired temporary to work for the cooperative only in the irrigation period. They are commanded by the field irrigation engineer to open the dam, check if water reaches the zone which is on the irrigation schedule the field level where their responsibility is limited. From this level farmers are responsible to convey water into their fields themselves. When there is an obstacle to the flow of water, the irrigators remove it, or report it to the field Engineer and find solutions. However there is no report done regarding the fields irrigated per day.

When talking the responsibilities and interactions of the actors involved in irrigation, it is very important to mention that the irrigation Staff collaborate closely with the leaders of cooperative from the President till the Representative of the Block(one block = 7-9 plots). These leaders are also in charge of assessing if the cropping practices flow the rules in general and try to find a solution with the irrigation Staffs if there is a problem.

Figure 6: Actors and interactions in irrigation system of Rugeramigozi



Basing on the answers of the respondents and field observation, the table **5** identifies the Outcomes in terms of irrigation practices and water management in Rugeramigozi wetland.

Irrigation practices and water management	Identification of causes	Outcomes Consequences and extend level	
Farmers irrigate according to the schedule(twice/week)	The understanding and awareness of the importance of irrigation	1. Lead to water management efficiency 2. Better crop production	1. Scheme level 2. Scheme level
Some farmers irrigate once a week	• Sometimes one irrigation time/week is enough • The farmer asks the neighbour to irrigate for him and sometimes he leaves the field open. • They put too much water enough for the whole week	1. The crops suffers from the lack of water 2. Stealing water from other's turn	1. Field level 2. Field level
Few farmers can miss one week without irrigating	Social problems like sickness, a lot of work at home, other business generating income,	1. Results in low productivity or Water theft 2. Demotivation of growing rice because it requires frequent irrigation without a good return.	1. Field level 2. Individual level
Some fields which get less water	• The fields are higher than the canals • Lack of levelling of the fields • Lack of enough pressure in the canal to reach the fields	1. It becomes difficult for farmers to come every day to convey water in the field 2. Results in low productivity	1. Individual level 2. farmer and cooperative level
Too much irrigation water in the field	• Seepage problem in some fields of zone C and unmaintained drains • Lack of drainage for removing dirty water in C • Some farmers open the fields, go home and come after some hours to close	1. Water stays longer in the fields and become dirty and become difficult to replace with fresh water 2. Effect of too much water in the fields	1. Field and zone level(in C) 2. field level
Some fields are abandoned	• Because of poor harvest of rice in the previous seasons, • Some farmers whose many plots are unable to take care of them.	1. These fields are given to other farmers(bylaw) 2. No harvest from these fields	1. Cooperative level 2. Cooperative level
Release of unknown volume of water	• No flow measurement device on the dam • Unknown quantity allocated to each user (except EWSA)	1. Under irrigation or over irrigation in some fields 2. The lack of information on water needed leads to the increase of irrigated area.	1. Scheme level 2. Scheme level
Release of less water from the dam in dry periods	• There is not enough water, less water should be released for saving the crop while waiting for the rainfall	1. Lack of water to meet the crop water requirements leads to a poor production.	1. Scheme level
Low Participation in maintenance of the system	• Some farmers have the fields in different zones and it is difficult to attend all community works in those zones • No fine is charged to the absents, • Low awareness of the importance of community work	1. Missing the irrigation instructions given in the meeting after the community works and other cropping information as well.	1. Farmer level

Low involvement of farmers in the decision making	• It is assumed that the farmers are represented in the decision meeting • Low knowledge of farmers is neglected in cropping practice	1. Some decisions are taken with top down approach are not promising to be sustainable 2. The farmers are not full willing to execute those decisions (payment of 500 RWF/field= too much) 3. The decision on the price of the harvest is not taken in the participatory way. 4. Lack of trust for the farmers in the leaders of the cooperative. 5. Low freedom for the farmers to express their thoughts about the leaders.	1. Cooperative and scheme level 2. Individual level 3. Cooperative level 4. Individual level 5. Cooperative level

Table 6: Irrigation practices and water management in Rugeramigozi

Photo 6: Lack of irrigation water in some fields (the field is higher than the canals)

Photo 7: Unmaintained drains and water logging

Photo 8: Lack of water in the field (disrespect of irrigation schedule)

3.4.4. Evaluative criteria

Correspondence and Discrepancy

From this point onward, the focus is to refer to the figure of Rules in use (see annex) and the box of action situation and interaction, in order to identify correspondence and discrepancies in irrigation and management rules versus the practices. Finally The IAD framework is summarised (see figure 7)

Generally speaking, farmers irrigated according to the rules. All respondents know their irrigation turns and the day of community work for maintenance of the scheme. The field irrigation Eng. provides instructions on irrigation and water uses. 100% of respondents said that a water fee is paid early or later. In case of problems the chain of command is followed in order to get solutions. The leaders of the cooperative are elected by the general assembly and they can end their term they don't comply with the laws. The administrative committee proposes the rules and the general assembly vote or reject them even though there are several exceptional cases.

The discrepancies in the management rules and practices can be categorised in the following aspects:

Lack of enforcement of management rules within the cooperative:

In this category there are landowners who grow other crop rather than rice according to the policy like VTC Mpanda. By observing the whole wetland you can notice different field which do not respect the cropping calendar according to instructions and deadlines given by field staff of RSSP. Weeding is one of the most frequent activity in which farmers delay to finish.

Low participation in maintenance works and management of water resources:

There is not a clear image on the participation of all users in the management of water resource and maintenance of its infrastructures. Even though the Water Users Association is still new, but the water management seemed to be left in the hands of the farmers' cooperative(KIABR).

Within the cooperative, 90% of the respondents said that even though the rules says that those who miss the maintenance work without a reason should be punished, this rules rule has not yet implemented. They said that charging a fine because of some faults like stealing water, absence in the meeting, not always attending the community works, is not yet done.

Lack of awareness of efficiency in irrigation practices:

This irrigation behaviour don't only affect the yield but also the leads to water scarcity because enormous water is wasted during irrigation. this is noticed when farmers apply too much water by leaving their field open and come at any time to close them. Sometimes the crops suffers when farmers miss their turns and come to irrigate on the other day and take water without approval.

Biophysical setting

- Temperate climate
- Water scarcity June till end August
- Variable size of plots
- Irrigation water from the dam
- Topography influence irrigation
- Retention dam is a shared resource
- Tertiary canals under construction
- 80 ha for rice and 40ha for other crops

Attributes of Community

Mutual help

- Doing irrigation for each other
- Helping those who are left behind in cropping

Community work "*Umuganda*"

- Maintenance is done by farmers every week
- Participation in *Umuganda* has been legalised

Forgiveness

- Forgiveness as value of the society
- The rule breaker is forgiven

The culture of impunity

- Too much forgiveness leads to the impunity
- Poor rule enforcement

Rules in use

- Define irrigated area and one crop(rice)
- Water payment
- Water distribution and control by Irrigation Eng. and Irrigators
- Election of leaders by GA
- Defined and provision of irrigation schedules
- Farmers understand irrigation turns
- Farmers irrigate themselves
- Hierarch in communication and reporting.
- Maintenance through community work
- The rules are approved by the GA
- Failure to keep the rules results in fine

Action situation and Interactions

Actors:
KIABR, RSSP, (Office, Field) irrigation engineer, Irrigators, Landowners, RAB, Landowners, WUA

Description and responsibilities:
Position, allowable actions, power and allowable actions, information and skills

Interactions

- Office Irr. Eng. makes irrigation schedule and gives it to Field Irr. Eng. for execution
- Field Irr. Eng. instructs farmers how to irrigate
- Field irr. Eng. estimate and order the irrigators to release irrigation water.
- Field Irr. Eng. helps farmers to level their fields
- Field Irr.Eng. help the leader of zone to coordinate maintenance in community works
- After opening gates, Irrigators convey water till tertiary canals
- Farmers takes water and irrigate themselves
- Farmers pays water fee to WUA
- RAB buys the yields of KIABR and provide money and improved seeds
- WUA makes water distribution to users
- Administrative committee provides rules and GA votes/ reject
- Irrigators checks water theft among farmers

Outputs

- Irrigators convey water till tertiary canal
- Farmers irrigate themselves
- Landowners pay for water
- Infrastructure is maintained except in zone C
- Farmers are instructed in irrigation
- Growing of the agreed crop except VTC
- Low involvement of farmer in decision making
- Poor drainage in zone C
- Lack of trust in selling the yield by the tender committee

Evaluative criteria

Correspondence

- The irrigation staff functions
- Close collaboration of irrigation staff and the leaders
- Almost the chain of command is respected
- Irrigation instructions are Cleary provided by Irrig. Eng.
- All landowners pay for water (on time or late)
- Water fee is used to pay for the temporary staff and maintenance works
- Almost the same crops are grown
- Farmers irrigate themselves
- The maintenance is done in community works by farmers.
- Improves seeds, fertilizers, technical support are provided to farmers
- GA can elect a new leading committee if the existing one doesn't comply with the rules.

Discrepancies

- Some member grows other crop(VTC)
- No fine given to rule breakers(missing maintenance works, disrespect of cropping calendar, stealing water...)
- Amount of Water fee is not agreed on and low accountability in its use to farmers)
- Drains not maintained in zone C so water stays longer in the field
- Some farmers don't know their irrigation turns
- Some Special irrigation are done without approval
- Some farmers miss their irrigation turns and irrigate on the other day.
- During irrigation some farmers don't apply water as instructed, more or less water is applied.
- No clear agreement on fee deducted from harvest for cooperative
- Not all rules are voted or reject the law GA
- No clear picture participation of other water users(EWSA, and VTC) in maintenance of water infrastructures.
- Low of accountability in weighting and selling the yield by

Figure 7: IAD framework for Rugeramigozi wetland

Poor Participatory in the decision making:

During the focus group discussions, farmers said that they are not full involved in the decision making of the cooperative, some fixed rules are presented to them and they have to follow them. For instance the rule of water fee was adopted without comments from farmers. The 80% of respondents understand the necessity of water fee but given that there are big and small fields, the equal amount of water fee for all field makes this rule unfair. Furthermore basing on the life style of indigenous farmers in Rugeramigozi, 60% of respondents said that the amount of water fee is more or less high. Another aspect raised was the poor accountability and transparency in the use of this water fee, cooperative fund and selling of farmers' harvest.

3.5. Stakeholder analysis for allocation and management of water resources

When talking about the water management in Rugeramigozi, it is important to identify and consider the individuals or institutions that can be affected by the management of this water resource and whose participation and support are crucial to the success to of the marshland and sustainable management of water resources as well. This will lead to the stakeholder analysis in order to develop the interventions needed and the relationship between the stakeholders in the future.
In the context of Rugeramigozi we will adopt the definition of stakeholder as "*Any individual, group, or institution who has a vested interest in the natural resources of the project area and/or who potentially will be affected by project activities and have something to gain or lose if conditions change or stay the same.* (Bronwen et al, 2005).

3.5.1. Stakeholder identification

The stakeholder identification is a process whereby the involved people have information that cannot be gained or if their participation is necessary to assure successful implementation of the project (Thomas 1993, 1995). In the case of management of Rugeramigozi water resources, the stakeholders involved are grouped as follows (see also figure)

- Users of water resources: members of Water User Association (green boxes):
    - The farmers 'cooperative (KIABR)
    - The Water supply company in Muhanga town EWSA(is also a government agency)
    - Vocational Training Centre
- Government agencies (purple boxes):
    - Rural Sector Support Project(RSSP) under the Ministry of Agriculture and Animal Resources
    - Rwanda Agriculture Board (RAB) under the Ministry of Agriculture and Animal Resources
- NGO: Welthungerhilfe, Rwanda (Former Germany Agro Action)
- National public organ: District of Muhanga (Ministry of Local Government)

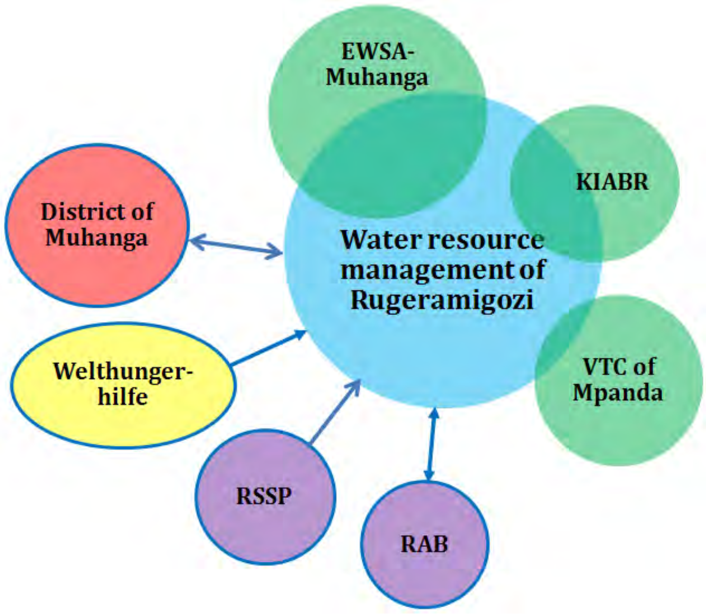


Figure 8: Stakeholder identification in water resources management of Rugeramigozi

The relations between the possible stakeholders involved are visualised in the figure **6**. The two or one way arrow between the stakeholder and the project indicates if the stakeholder has or no return from the project respectively. In the next section the stakeholders are described in details to define their relevance to this project.
The information obtained through interview and observation from the stakeholders were used for the stakeholder analysis. In this process the table 4 is set up to visualise the interventions of different stakeholders involved. The main goal of this analysis is to find out :

- The stake of the stakeholder in the stakeholder process
- The individual interest, power, support and importance of stakeholders in the use of water resources of Rugeramigozi
- The best way to approach the problem and find a sustainable and equitable solution (Idem).

3.5.2. Description of stakeholders

KIABR
As explained before, this is a legally recognised cooperative of farmers of Rugeramigozi marshland. It is made of 870 registered farmers and the main crops grown are the rice and the dry crops like maize and beans in the terraces surrounding the wetlands. KIABR is supported by RSSP as a Project under the MINAGRI, which has a mission of rural and wetland development. KIABR has been using this marshland several years under the support of Germany Agro Action before construction of the irrigation dam. One of the main problems undermining the crop production was the water shortage mainly in the dry season.

RSSP
Founded in 2001, RSSP (Rural Sector Support Project) is a government program working under MINAGRI. Their mission is to support the rural area by increasing the agriculture

production and marketing in marshland and hillside in an environmentally sustainable manner (MINAGRI, 2011). By promoting the marshland development RSSP constructed the retention dam of Rugeramigozi under the support of World bank for the irrigation of rice. After this the management of the dam was given to the farmers' cooperative KIABR which has been using this marshland several years. Given the limited capacity of lower-level structures, Government continues to intervene directly in water resources development until the strong institutional structures are established at local levels(MINIRENA,2011) In this regard, RSSP still provides a technical, financial and managerial support to the use of the marshland. Two permanent field Agronomists are employed to help the farmers to fully exploit the productivity, ensure effectiveness and sustainability of farming practices in this wetland. Given that the dam was constructed for the irrigation purpose only of 120ha, the other water users were not considered in the capacity of the dam even though after construction it was realised that the other users must be included in using the water from that dam. Therefore by sharing this water there is a probability that RSSP will not be able to irrigate the anticipated area and get 2 harvests per year. These other water users are EWSA and VTC Mpanda.

EWSA

EWSA (Energy, Water and Sanitation Authority) was founded in 1939 and works as a government agency that distributes power and water in Rwanda (EWSA, 2010). It has many branches in the whole country and one of them is Muhanga branch where this research was conducted. EWSA supplies water to the consumers after a long process of treatment of raw water. In this regard one of the sources of raw water used by EWSA is from the Rugeramigozi stream and the EWSA station (where the water pumps are installed) is located in the downstream of the marchland (see the map of Biringanya on the appendix). Those water pumps supply water the treatment plant of EWSA located on the crest of Kavumu hill and after treatment water is supplied to the population of Muhanga town. Even before construction of the dam, EWSA used to get water from the Misizi dam in upstream of the wetland at 5km away from Rugeramigozi dam.

VTC Mpanda

VTC is a Vocational Training Centre where people come and get short courses and trainings on entrepreneurship. This centre is located alongside the marshland of Rugeramigozi which makes them easy to grow some vegetables on 1ha for the students. This is a rain fed agriculture of small area of 1ha but in dry period vegetables are irrigated by the dam. However the amount of water needed by this centre is unknown.

RAB

RAB(Rwanda Agricultural Board) is a government agency working under MINAGRI and has *"a mission of developing agriculture and animal husbandry through their reform and using modern methods in crop and animal production, research, agricultural extension, education and training of farmers in new technologies"(MINAGRI,2011).* This means that RAB aims to conduct a research and develop the new technologies and methodologies and after transfer them to the end users (Farmers). Being a research institution RAB intervenes in solving many of the agronomic problems holding back farmer progress. Given that Rugeramigozi has been undergoing a poor production due to water scarcity, lack of improved seeds and soil fertility decline, at present RAB conducts research in this area not only in water resources management but also on different seed varieties in order to identify the best crop types which can adopt the area. In addition to this at the harvest farmers sell their harvest (maize and beans only but rice is sold to other private companies) to RAB in return they get money and improved seeds at beginning of plantation period.

Welthungerhilfe (Former Germany Agro Action)

This is a large Germany private aid agency formed in 1962, created under the umbrella of FAO to promote food security for all people, rural development and the preservation of the natural resources. Welthungerhilfe helps people in developing countries to provide for themselves now and in the future by fighting to change the conditions that lead to hunger and poverty. They support partner organisations in the project countries thereby ensuring that structures are reinforced from the bottom up and that successful project work can be secured for the long term (Welthungerhilfe, 2010).

In 2001 this NGO started an irrigation project in this wetland with the aim of improving food security and poverty reduction in the area of Muhanga district. In 2006 Welthungerhilfe financed the construction of an irrigation dam of 320,000m^3 in Misizi to irrigate rice plantation in Rugeramigozi II and to supply water to Muhanga town by EWSA unfortunately the rice did not adopt this area. At present farmers in the cooperative KOKAR grow maize, beans, vegetables and rice in some plots. Moreover Misizi dam is used into fish farming and the production is around 16kg/day but it is at risk of water- Hyacinth problem.

District of Muhanga

This is one of the 30 districts of Rwanda and located in the southern province. As administrative organ belonging to the ministry of local governance it is highly concerned with the water resources of the district as the owner. Moreover it has the political power and stands for the execution of the natural resources laws. These points make this stakeholder to be the highest decision maker in this case of water resources management. However all decisions and policies should be participatory taken and supported legally. One of the missions of the districts is to mobilise and empower the community by ensuring the effective and sustainable its participation in own development in order to achieve poverty reduction and self-reliance based on the sustainable exploitation of the available resources (MINALOC, 2008). The districts also stand for the implementation of policies and laws for the Ministry of Natural Resources(MINIRENA, 2011). From this point the exploitation and management of water resources of Rugeramigozi toward the development of the livelihood of the community is the concern of the district of Muhanga.

To be useful, the stakeholders are put together in table 4and analysed in terms of their interests, power, influence, support, importance (Eden and Ackernlann, 1998) and involvement of each group in the project of water resources management of Rugeramigozi.

The knowledge gained from this analysis can be used to approach the sustainable use and management of this limited resources of Rugeramigozi.

Stakeholders	Key interests	Support	Influence power	Priority/importance
Primary direct				
Farmers s cooperative (KIABR)	• Get enough water for 120ha of rice for farmers and 2 harvests/year	**Support: Low** KIABR only provides maintenance labour and they are flexible in water allocation	**Influence and power: Low** KIABR is only made of indigenous farmers and their power only relies on the right to water and wetland.	**Medium:** Irrigation for KIABR comes after domestic water supply
VTC Mpanda	• Get enough water for irrigation of 1ha for vegetables • To get 2 harvests/year	Willing to participate in water resources management	**Low:** Their power only relies on the right to water t and wetland.	**Medium:** Irrigation comes after domestic water supply
EWSA /Muhanga	• To supply water to Muhanga town about $150m^3$/hour. • To reduce the chemicals spent in treating raw water from the fields by connecting the pipelines from the dam to treatment plan	**Low:** Willing to participate in water resources management	**Medium:** Is a government agency and supported by the national water law.	**High:** Domestic water supply has priority over other uses.
Primary indirect				
District Muhanga	• To establish a partnership between KIABR and the stakeholders involved in the water uses. • To ensure an equitable water distribution between the users. • Development of the wetland toward, improving food security and poverty reduction in the area	**High:** - Provide administrative support - Facilitator in the discourses between the stakeholders - Owner of the dam & wetland	**Influence: High, Power: High** - Has influence in all aspects of policy and execution - Has an administrative power and legal responsibility - Has a decision making power	
RSSP /MINAGRI	• To provide irrigation water for rice for 120ha for KIABR • Cost recovery of construction of the dam from rice. • To promote the rural area and development of the wetland toward a better livelihood	**High:** - Construction of the dam - Provision of capacity building, technical and financial support.	**Influence: High, Power: Medium** Has influence only in agriculture policies and execution	

Secondary				
RAB /MINAGRI	• Develop and transfer technologies to farmers as a research Agency • Buy the yield from the farmers 'cooperative (KIABR)	**Medium:** - Provision of improved seeds & capacity building to KIABR - Provisional of professional consultancy	**Influence: Low, Power: Low** Has influence and power in agriculture policies and execution	
Welthungerhilfe	• To promote the rural area and development of the wetland toward a better livelihood	- Implementer of the wetland policy - Provision of capacity building, technical and financial support	**Influence: Low, Power: Low** Has influence in execution of rural development policies	

Table 7: Stakeholder analysis in the management of Rugeramigozi water resources

Table 7 shows the implication level of stakeholders in the project where the District of Muhanga manifests high Power and influence simply because of ownership and decision making. They possess also the responsibility to implement the policies and laws of the ministry of natural resources (MINIRENA). RSSP possess a high influence and support because of their financial and technical assistance to the project, but they lack an important aspect: The power. The chapter four discusses the priority to water uses, allocation and integrated water management among the stakeholders of this natural resource

4. Discussion

4.1. Water availability and uses, efficiency, maintenance and irrigation practices

From the calculation (Table 3 and Figure 5), it is clear that the water crisis will be high from June till the end of August (season A) while in season B there is no problem of water at all regardless of the type and the irrigated area because water retained in the dam and the rainfall are enough to satisfy the water needs in the wetland. Therefore the analysis of this section will be mainly based on the season A and two options of managing water shortage in this wetland depending on where EWSA takes water from:

1. If EWSA starts taking water directly from the dam, there will be:
    - No irrigation of any crop in season A
    - Even EWSA will not have enough water supply in dry period
    - Opening of Misizi dam should be done according to the agreement

2. On the other side, in order to permit the harvest of season A and improve water saving in the wetland, there might be a possibility to re-use the huge amount of water from the fields especially in land preparation for rice crop. This calls upon EWSA to keep the pumping station in the downstream of the wetland and use this polluted water by fertilisers even though it is expensive.
    Secondly the Ministry agencies involved in the use of this reservoir (EWSA and RSSP) could find the way to expand its volume in order to retain at least some amount of water wasted in season B and use it in season A.
    Misizi dam would also continue to release water for EWSA in drought period.

But furthermore Table 3 shows that even the irrigation needs of rice are higher than the water in the dam, which means that rice grown on 80 ha in season A could suffer from water shortage. I would suggest the cooperative to prefer to adopt crop rotation by grow other crop consuming less water in this period (after doing a feasibility study especially on crop water requirement). Moreover irrigation practices leading to improved water management should be taken and implemented seriously. In case these is still a problem of water crisis, more water should be released from the MISIZI dam since it doesn't help anything expect the fishing activities by the farmers' cooperative. But this option might be not sustainable because KOKAR (***KO****perative yo* ***K****wihaza umusaruro y'****A****bahinzi ba* ***R****ugeramigozi*) doesn't use the dam in agriculture, they can learn from KIABR and start growing rice and stop providing water to KIABR.

4.2. Maintenance, efficiency in water use and irrigation practices

Similarly to the worldwide consumption, agriculture is the biggest water user in Rwanda accounting for up to 70% of the water demand (UNEP, 2009) and is expected to account for 80% of total water demand in 2020. This is worsened by the fact that most irrigation systems are inefficient (MINERENA, 2011).

The previous surveys mentioned that the efficiency in water use and performance of system has been affected by the problems related to maintenance of irrigation channels (sediment deposits, vegetation, lack of tertiary canals, or inadequate capacity of some structures), poor farmer's irrigation practices (Murekashungwe et al, 2007), poor maintenance of drainage as well as inappropriate cropping systems in wetland(Nabahungu et al, 2011). In rain season, the poor state of drainage system in zone C results in the water logging in the fields.

The problem of improper maintenance of irrigation infrastructures could also noticed in the other wetlands of Rwanda. According to Nahayo et al (undated) Nyamugali and Ndobogo wetlands have the watercourses poorly maintained. The channels are filled with sand and bushes and the watercourses are broken at several places and cleaning is not done any more. This reduces the water supply to framers at the tail end of the canals. The field channels are earthen, not designed and not constructed properly and are poorly maintained. Due to cheap water availability and lack of knowledge of farmers, uncontrolled flood irrigation is commonly used. As a result, considerable amount of water is wasted in the field channels.

The similar solutions for Rugeramigozi case should be taken, There is need to level these fields, so that finite source of water could be used efficiently. In this way, rehabilitation and cleaning of the existing conveyance systems, field adjustments (Nahayo et al, undated) and creation of tertiary canals in the whole scheme should be done. Also awareness in water management through improved irrigation practices should be created. This can be done by "mutual help" in adopting the rotation of irrigation tasks among farmers at block level (7-9 plots). For one irrigation turn, two farmers can irrigate the whole block according to irrigation instruction, and for the following turn others do the same.

4.3. Involvement of farmers in decision making

Apparently there are some rules applied to cooperative that are established by policy makers at national level and other others are set within the cooperative. In Rugeramigozi case, Nabahungu and Vesser (2011) argue that farmers feel that they have little or no influence on the policies of their organisation. This may indicate an authoritative style of management where decisions are often taken without member participation or consultation (Nabahungu et al, 2011). In contrary farmers are called to implement these decisions taken by the leaders. Low involvement and lack of inputs in the decisions making from farmers will weaken their participation in implementation of the decisions. Moreover taking into account that about

60% of the population lives on less than US$ 1 per day (World Bank, 2009), farmers should be involved in making decisions especially those regarding fee payment in order to set an affordable amount.

4.4. Stakeholder analysis for allocation and management of water resources

In table 7 of stakeholder analysis, the aspect of Importance/ priority is only analysed on the three water users in order to prioritise the water use from the dam. According to the government policy for water resources management about allocation of water resources, account must be taken of the needs and demands of all water users (MINIRENA, 2011). In the case of Rugeramigozi the users don't know quantitatively and qualitatively their water demands except EWSA. However given that water resources are limited and that all demands cannot be met to the full extent, this policy states that the "*priority must be given to the social functions of water in society. This means, for instance, that domestic uses of water shall be accorded priority in allocation decisions, particularly in times of shortage". (Idem, p.15)*

As said above the main challenge in water allocation can be found in the poor integrated water resources management. The main water users such as agriculture, energy from hydro-power and water supply have been working nearly independently in their own domains without significant coordination with other sectors in using the same source. Each of these big water users has not taken the concerns of the other users seriously into account (Klooster et al, 2011). In this regards at present EWSA treats 30litter/sec but due to a rapid urbanization and modernization of Muhanga city the water supply is expected to be increased to 45litter/sec next year. Klooster et al(2011) argue that the large Rwanda's population growing at a high rate of 2.8% will results in an increasing consumption and quality the domestic water requirements in future.

In the same way, the high population density has left no land unoccupied for food production except marshlands. Therefore the way to increase production addresses the need for rapid agricultural growth. In this way irrigation is seen as a key tool to reach harvest security (MINIRENA, 2011). However this agricultural development will demand for enormous volume of water and have impact in terms of quality like the use of chemical fertilizers and pesticides to boost production (Klooster et al, 2011; MINERENA, 2011).

After all one of the ways to approach and analyse these two scenarios of water demands increase (drinking water supply and agriculture) can be found in the objectives of Rwanda Policy for Water Resources Management "to *manage and develop the water resources of Rwanda in an integrated and sustainable manner, so as to secure and provide water of adequate quantity and quality for all social and economic needs of the present and future generations with the full participation of all stakeholders in decisions affecting water resources management'' (MINERENA, 2011, p13).*

In Rugeramigozi case , this policy recognizes that water allocation to the users would have done with the integrated approach and sustainable use of this limited resources requires a participatory management. This approach provides a framework for considering the different uses and users of water resources and taking decisions and actions which ensure that all relevant factors are taken into account in resource allocation. And the participatory management indicates that best results are achieved where decisions regarding water resources managements are made with the involvement and participation of water users and other stakeholders (MINERENA, 2011). However all water needs from water user will not be met. The ministry of natural resources management needs to be more articulate in the field of IWRM in order to make a fair and equitable distribution of available water resources and balance strong claims from the domestic water supply and the Agriculture sector within the total community of users of water (Klooster et al, 2011).

4.5. Limitations of the study

Lack of updated hydrological data

Weak availability of climatic data. In this regard the climatic data used, are from 1960-1990 because of the damage of hydro-meteorological stations in the war period, and some are still non-operational due to lack of operation and maintenance. For this situation, MININFRA and MINIRENA are required to improve the Meteorological service in order to develop and plan a sustainable integrated water resources management. Moreover the monitoring of groundwater should be carried out in order to see if how its extraction can contribute to water supply in the rain season

Lack of updated info of the scheme

This limitation refers to the fact that :

- The amount of water supply to irrigation by KIABR and VTC is not monitored.
- Irrigation schedules used in irrigation practices are based on estimation rather than calculation
- Lack of updated maps of the irrigation scheme (were produced before irrigation dams)

Absence of these data wouldn't allow the comparison with the models and the ones on in reality. In this way it is difficult to say whether the current irrigation turns and water applied to crop according to the current setting lead to over or under irrigation.

Data collection

Some answers from the responders are biased due to the poor yields (0.22ton/ ha) of the previous seasons in Rugeramigozi. Data collection was done in rain season; it was not possible to see irrigation practices and water management in dry season and their effects on crops.

5. Conclusion and Recommendations

The results in the preceding section was dedicated to describe the water availability, demands and allocation in Rugeramigozi marshland. They also describes the physical system, cultural attributes, irrigation and management rules, actors involved in irrigation, their interaction and irrigation practices and water management within this wetland.

By returning to the research questions, the amount of water available for agriculture was obtained (Table 3). The results illustrate that the current cropping pattern made of 80ha of rice grown in season B is irrigated enough. Given that considerable amount of water flows out from October to May, this shows that there is even enough water to irrigate the whole marshland (120ha) in this season. Moreover in this period all water demands are met. But in other hand the cropping pattern in season A (Figure 3) is not possible because this period is characterised by water scarcity and the reservoir is empty for three months. In this way none of the water demand is met.

The current water users are EWSA with 30 l/s, KIABR with irrigated area of 80ha and rain fed area of 40ha of maize, bean and vegetables, and VTC Mpanda with 1ha of cabbage. The existing system still functions even in dry period because drinking water supply is still 30 l/s and irrigation water from the field is re-used by EWSA located in the downstream of the wetland and in dry period Misizi dam releases water for EWSA. Therefore the findings in this study refers to the new setting of water distribution and cropping pattern of KIABR.

EWSA wants to increase the drinking water supply from 30 l/s to 45 l/s because of rapid development of urban area of Muhanga and takes water directly from the reservoir instead of downstream. RSSP is making effort to irrigate the whole marshland of 120 ha and get to two harvests per year for food security and cost recovery of the dam. But both targets of the water users could be achieved if the problem is solved with the participatory approach: Domestic water supply is prioritised but EWSA should agree to re-use the so called "polluted water" from the fields of farmers; the extension of the reservoir capacity by the water users; realising water from Misizi dam for EWSA. Also RSSP and RAB could find the possibility to introduce crop rotation in season A.

The study also describes the management rules but specifically water management and irrigation rules (Figure 7 and Fig 3a in appendices). These rules are conceived by RSSP in collaboration with the farmers' cooperative and there is tendency to tendency to undermine the existing indigenous knowledge of farmers because of their limited knowledge in irrigation technology especially for rice crop.

Since farmers have been using the wetland in growing rain fed crops and rice in few plots; and rice was introduced in the whole marshland with construction of the irrigation dam in 2010; there is a need of effort in teaching farmers irrigation rules and creating awareness of water management. The strict rules associated with irrigation and water management and their importance are not fully understood by all farmers. This can also be caused by low ability of indigenous peasants to understand irrigation technology faster. Farmers feel that there is enough water for their crops and the lack of awareness of water use efficiency draw back their attention during irrigation. But this kind of irrigation practices aggravates the water shortage in season A.

Most of irrigation rules comply with practices at the scheme and zone level except maintenance works which need to base on the needs of the system rather than a routine activity. At field level, numerous practices don't correspond with irrigation and water management rules and sensitization and rules enforcement to correct them are still poor. In short, regarding irrigation practices in most cases, farmers are interested in irrigation not in water management but willing to participate in the maintenance program leading to a sustainable and efficient water use.

From the above results and discussions the recommendations in terms of water availability and uses, participatory management, water use efficiency, irrigation practices are suggested below:

Water availability and uses

- Re-use of irrigation water from the field and irrigation canal by EWSA: this will contribute to water saving and minimizing water demands especially in drought period. This water can be treated and supplied for domestic uses.

- EWSA and RSSP as main users of the reservoirs could expand its storage volume. In this enough water can be retained and used when water becomes scarce.

- Allowing crop rotation: RAB as a research organization could find other crop consuming water which can be growing in season A and rice can be grown in wet season.

- VTC Mpanda should grow rice like other big landowners. This will minimize water conflict and facilitate the management of the resources for WUA. Rice is more profitable than vegetables even though it will increase the water needs in season A in the wetland.

Participatory management, water use efficiency, irrigation practices

- The new farming technology and practices should include and build on the existing indigenous knowledge. These can be introduced and explained at block level (8 farmers) rather than at zone level (300 farmers). In this way indigenous farmers will have opportunity to give their views on them and the evaluation on the practicability by field staff could be done easily.

- Awareness of irrigation practices and water management need to be created among farmer. This could be could be improved by delegating responsibilities and enforcing collaboration between Irrigators and the Leader of the Block. This can be done if the landowners and their leader make a rotation schedule of irrigation in such a way one or two farmers could irrigate the whole block (8 plots) and they rotate on the next irrigation day. In this way the farmers in charge of irrigation should make sure that they irrigate according to the rules and the Leader of the block should come in the evening to check if the irrigation has been done accordingly.

- Given that maintenance of watercourses and the dam seems to be left in the hand of farmers of KIABR, I suggest that each member who claims to use water of the dam should contribute to the maintenance of the system. In this way the WUA when doing the water balance to the users should do the same on the contribution of each user to maintenance of the system. EWSA and VTC could hire workforce to participate in "Umuganda" as other big landowners (Sisters cathedral) do.

- New approaches recognizing the relationship among water users and close communication of stakeholders should be developed and implemented in Rugeramigozi. This includes monitoring the water needs and supply in Rugeramigozi, adoption of integrated water resources management and Ecosystem Approach.

Further research

- Efficiency analysis of surface irrigation in Rugeramigozi wetland.

- Water resources monitoring both qualitative and quantitative for is recommended to control, regulate and distribute this limited resource. This includes especially the groundwater monitoring and how it can be used as another source of water.

References

Allen G., Luis S. Pereira, Dirk Raes D., Smith M., 1998; Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56; Rome, available at http://www.fao.org/docrep/X0490E/X0490E00.htm (Accessed:22.08.2011)

Allen, R.G, Pereira, L.S., Raes, D. and Smith,M., 1998: Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56, FAO, Rome.

Australian National Committee on Irrigation and Drainage, 2001, Rural Water Industry Terminology and Units, (2nd ed.), Classification**:** Water Resource Terms

Brouwer C., Hoevenaars J.P.M., van Bosch,B.E., Hatcho N., Heibloem M., 1992; Irrigation Water Management: Training Manual No. 6 - Scheme Irrigation Water Needs and Supply, FAO Rome; available at: http://www.fao.org/docrep/U5835E/u5835e04.htm#3.3%20cropping%20pattern (accessed 23.08.2011)

Bronwen Golder, WWF-US and Meg Gawler, ARTEMIS Services, 2005, Cross-Cutting Tool Stakeholder Analysis,

Brouwer C., Prins K., Heibloem M., 1989; Irrigation Water Management: Irrigation Scheduling: Training manual no. 4; FAO Rome; available at: http://www.fao.org/docrep/T7202E/t7202e04.htm#chapter%201:%20introduction; (accessed: 23.08.2011)

BUTTERWORTH, J.; SOUSSAN, J. (2001): Water Supply and Sanitation and Integrated Water Resources Management: why seek better integration?. Andhra Pradesh: Water, Households and Rural Livelihoods Project. URL [Accessed: 10.10.2011].

City of Springfield, 2007 *DRAINAGE CRITERIA MANUAL*, Missouri

Diao X, Fan S., Kanyarukiga S. Yu b., 2009; "Technical Assistance for Public Expenditure Management", Background Paper 5: Agricultural Growth and Investment (Options for Poverty Reduction); Rwanda

DK Rao & JJ Kaur, 2007, Living Science Biology, India

Eden, C. and Ackermann, F. (1998) Makina Strate8J:T heJ ourneyo f StrateaicM anaaementL, ondon: Sage Publications.

Enote.com,2012, culture-impunity, Available : http://www.enotes.com/history/q-and-a/what-culture-impunity-how-does-relate-rule-law-135419/_(Accessed:2011, July,15)

Gunter Wriedt G., Van der Velde M., Aloe A., Bouraoui F., 2008; Water Requirements for Irrigation in the European Union; A model based assessment of irrigation water requirements and regional water demands in Europe; Luxembourg.

Heng L. K., Steduto P., Theodore C., Hsiao, Raes D., Fereres E., 2009; "AquaCrop- The FAO Crop Model to Simulate Yield

FAO, 1992, CROPWAT A computer program for irrigation planning and management by Martin Smith, Rome. p.32

FAO, 1986, Irrigation Water Management: Irrigation water needs, available at http://www.fao.org/docrep/S2022E/S2022E00.htm, (accessed: 2012, June, 25)

FAO SAFR, 1998, Wetland characterization and classification for sustainable agricultural development
IFAD, 2009, Making Rice a Cash Cow in Rwanda

IFAD,2009, Rural Poverty portal, Available: http://operations.ifad.org/web/guest/country/home/tags/rwanda(Accessed: 2011, July 25)

Index Mundi, 2011, Rwanda Demographics Profile, Available : http://www.indexmundi.com/rwanda/demographics_profile.html (Accessed: 2011,July, 20)

Ker & Downey, 2008; Rwanda Country Information

MINAGRI/RSSP, April, 2009 Resettlement action plan of construction of an irrigation dam in Rugeramigozi marshland, Muhanga district.

Ministry of Agriculture and Animal Resources, 2009, Resettlement Action Plan of Construction of an Irrigation dam in Rugeramigozi Marshland, Kigali

MINIJUST, 2007, Codes and Laws of Rwanda Volume 2: Administrative Law, Law n° 53/2007 of 17/11/2007 establishing community works in Rwanda.

Ministry of Finance and Economic Planning,2002; Poverty Reduction Strategy Paper, Kigali, Rwanda

Ministry of Local government, 2008, Community development policy, revised version

Mountain Empire Community College, 2012, *Lesson 11: Rational method*; available at: http://water.me.vccs.edu/courses/CIV246/lesson11_print.htm, accessed at 2nd, July, 2012

Murekashungwe E., 2007, Performance evaluation of water distribution in Rugeramigozi irrigation scheme, NUR, Rwanda

MINAGRI, AGCD-Belgique, 2001, *La Carte Pédologique du Rwanda (CPR)*, Kigali

National unity and reconciliation commission, 2009, Itorero ryígihugu, Making national and community service Work in Rwanda, Kigali-Rwanda.

NABAHUNGU1 N. L. AND S. M. VISSER, 2011, Farmers' Knowledge And Perception Of Agricultural Wetland Management In Rwanda, Wageningen UR

OECD, 1997, Glossary of Environment Statistics, Studies in Methods, Series F, No. 67, United Nations, New York,.

Official Gazette of the Republic of Rwanda, 2003; The constitution of the Republic of Rwanda, , Article 8; Kigali Rwanda.

Ostrom, E., 2011. “Background on the Institutional Analysis and Development Framework”. The Policy Studies Journal 39 (1): pp. 7-27.

Ostrom, E. 2005. “Doing Institutional Analysis: Digging Deeper than Markets and Hierarchies”. In Handbook of New Institutional Economics. C. Menard and M.M. Shirley (eds.)

Paul Schiariti, P.E., CPESC, 2008; *Basic Hydrology Runoff Curve Numbers*, Mercer County Soil Conservation District

RSSP, 2011; achievement”, Available: http://www.rssp.gov.rw/index.php?option=com_content&view=article&id=23&Itemid=38 (Accessed: 2011, July 27)

Rap, E., 2006, The success of a policy model: Irrigation management transfer in Mexico. Wageningen Universiteit, The Netherlands.

REMA, 2009, *Rwanda State of Environment and Outlook Report*”, Kigali, Rwanda.

Resource Library, 2011, Mutual help groups and the rehabilitation process, available at http://findarticles.com/p/articles/mi_m0842/is_n3_v16/ai_11008731/?tag=content;col1, accessed:17th July, 2012

The Rwanda focus, 2011, Say no to the hoe: how irrigation and mechanization boost agriculture available: http://focus.rw/wp/2011/06/say-no-to-the-hoe-how-irrigation-and-mechanization-boost-agriculture/ (Accessed: 2011, 23 July)

Thomas, J. C., 1993, 'Public Involvement and Governmental Effectiveness: A Decision-Making Model for Public Managers. Administration and Society, 24:4 pp444-69.

UNFFC, 2011; Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change available at: http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5403.php (Accessed:29-08-2011)

USAID/Rwanda, 2010, Rwanda districts, Available: http://www.usaid.gov/rw/our_work/district/districts_main.html (Accessed: 2011, July 27)

Welthungerhilfe , 2010. Annual report, Rwanda

Wester, P., 2008, Shedding the waters : institutional change and water control in the Lerma-Chapala Basin, Mexico; WUR Wageningen UR

World Bank, 2009, Technical Assistance For Public Expenditure Management, Background Paper 5: Agricultural Growth and Investment (Options for Poverty Reduction).

APPENDICES

Table1a: Runoff CN for urban areas

Table 2-2a Runoff curve numbers for urban areas [1]

Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

(Column group heading: Cover description; Curve numbers for hydrologic soil group A, B, C, D.)

1 Average runoff condition, and $I_a = 0.2S$.

2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Source: Paul Schiariti et al, 2008

Table2a: Runoff CN for Cultivated agricultural land (source: Paul Schiariti et al, 2008)

Table 2-2b Runoff curve numbers for cultivated agricultural lands [1]

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

[1] Average runoff condition, and I_a=0.2S

[2] Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

[3] Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

HSG	*Soil textures*
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

Table3a: Soil characteristics

Table 4,5a: K_c values of different crops for growing stages

Table 12 continued

Crop	$K_{c\ ini}$ [1]	$K_{c\ mid}$	$K_{c\ end}$	Maximum Crop Height (h) (m)
e. Legumes (*Leguminosae*)	**0.4**	**1.15**	**0.55**	
Beans, green	0.5	1.05[2]	0.90	0.4
Beans, dry and Pulses	0.4	1.15[2]	0.35	0.4
Chick pea		1.00	0.35	0.4
Fababean (broad bean) – Fresh	0.5	1.15[2]	1.10	0.8
– Dry/Seed	0.5	1.15[2]	0.30	0.8
Grabanzo	0.4	1.15	0.35	0.8
Green Gram and Cowpeas		1.05	0.60-0.35[6]	0.4
Groundnut (Peanut)		1.15	0.60	0.4
Lentil		1.10	0.30	0.5
Peas – Fresh	0.5	1.15[2]	1.10	0.5
– Dry/Seed		1.15	0.30	0.5
Soybeans		1.15	0.50	0.5-1.0
f. Perennial Vegetables (with winter dormancy and initially bare or mulched soil)	**0.5**	1.00	0.80	
Artichokes	0.5	1.00	0.95	0.7
Asparagus	0.5	0.95[7]	0.30	0.2-0.8
Mint	0.60	1.15	1.10	0.6-0.8
Strawberries	0.40	0.85	0.75	0.2
g. Fibre Crops	**0.35**			
Cotton		1.15-1.20	0.70-0.50	1.2-1.5
Flax		1.10	0.25	1.2
Sisal[8]		0.4-0.7	0.4-0.7	1.5
h. Oil Crops	**0.35**	**1.15**	**0.35**	
Castorbean (*Ricinus*)		1.15	0.55	0.3
Rapeseed, Canola		1.0-1.15[9]	0.35	0.6
Safflower		1.0-1.15[9]	0.25	0.8
Sesame		1.10	0.25	1.0
Sunflower		1.0-1.15[9]	0.35	2.0
i. Cereals	**0.3**	**1.15**	**0.4**	
Barley		1.15	0.25	1
Oats		1.15	0.25	1
Spring Wheat		1.15	0.25-0.4[10]	1
Winter Wheat - with frozen soils	0.4	1.15	0.25-0.4[10]	1
- with non-frozen soils	0.7	1.15	0.25-0.4[10]	
Maize, Field (grain) *(field corn)*		1.20	0.60,0.35[11]	2
Maize, Sweet *(sweet corn)*		1.15	1.05[12]	1.5
Millet		1.00	0.30	1.5
Sorghum – grain		1.00-1.10	0.55	1-2
– sweet		1.20	1.05	2-4
Rice	1.05	1.20	0.90-0.60	1

Table A.5 Values of the Crop factor (Kc) for various crops and growth stages

Crop	Initial stage	Crop dev. stage	Mid-season stage	Late season stage
Barley/Oats/Wheat	0.35	0.75	1.15	0.45
Bean, green	0.35	0.70	1.10	0.90
Bean, dry	0.35	0.70	1.10	0.30
Cabbage/Carrot	0.45	0.75	1.05	0.90
Cotton/Flax	0.45	0.75	1.15	0.75
Cucumber/Squash	0.45	0.70	0.90	0.75
Eggplant/Tomato	0.45	0.75	1.15	0.80
Grain/small	0.35	0.75	1.10	0.65
Lentil/Pulses	0.45	0.75	1.10	0.50
Lettuce/Spinach	0.45	0.60	1.00	0.90
Maize, sweet	0.40	0.80	1.15	1.00
Maize, grain	0.40	0.80	1.15	0.70
Melon	0.45	0.75	1.00	0.75
Millet	0.35	0.70	1.10	0.65
Onion, green	0.50	0.70	1.00	1.00
Onion, dry	0.50	0.75	1.05	0.85
Peanut/Groundnut	0.45	0.75	1.05	0.70
Pea, fresh	0.45	0.80	1.15	1.05
Pepper, fresh	0.35	0.70	1.05	0.90
Potato	0.45	0.75	1.15	0.85
Radish	0.45	0.60	0.90	0.90
Sorghum	0.35	0.75	1.10	0.65
Soybean	0.35	0.75	1.10	0.60
Sugar beet	0.45	0.80	1.15	0.80
Sunflower	0.35	0.75	1.15	0.55
Tobacco	0.35	0.75	1.10	0.90

Source: (FAO, 1986)

Table 11 continued

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
Sorghum	20	35	40	30	130	May/June	USA, Pakis., Med.
	20	35	45	30	140	Mar/April	Arid Region
Rice	30	30	60	30	150	Dec; May	Tropics; Mediterranean
	30	30	80	40	180	May	Tropics

Table6a: Length of growing stages for different crops

Table (7&8)a: Crop water requirement for rice in season A and B

CROP WATER REQUIREMENTS

ETo station: Byimana
Rain station: Byimana

Crop: Rice_A
Planting date: 20/06

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
May	3	Nurs/LPr	1.06	3.42	3.4	2.1	107.3
Jun	1	Nurs/LPr	1.06	3.62	36.2	10.6	25.6
Jun	2	Init	1.07	3.83	38.3	0.3	224.8
Jun	3	Init	1.10	4.01	40.1	0.5	39.6
Jul	1	Init	1.10	4.08	40.8	1.3	39.4
Jul	2	Deve	1.10	4.14	41.4	0.1	41.3
Jul	3	Deve	1.12	4.38	48.1	1.8	46.4
Aug	1	Deve	1.16	4.66	46.6	3.2	43.5
Aug	2	Mid	1.19	4.95	49.5	4.2	45.2
Aug	3	Mid	1.20	4.97	54.6	8.0	46.6
Sep	1	Mid	1.20	4.95	49.5	12.8	36.7
Sep	2	Mid	1.20	4.93	49.3	16.7	32.7
Sep	3	Late	1.19	4.84	48.4	17.4	30.9
Oct	1	Late	1.15	4.59	45.9	17.2	28.6
Oct	2	Late	1.10	4.30	43.0	18.0	25.0
Oct	3	Late	1.05	3.92	27.5	14.0	5.5
					662.6	128.2	819.1

CROP WATER REQUIREMENTS

ETo station: Byimana
Rain station: Byimana

Crop: Rice_B
Planting date: 01/12

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	2	Nurs/LPr	1.06	3.57	35.7	32.7	106.9
Nov	3	Nurs/LPr	1.06	3.58	35.8	28.9	193.9
Dec	1	Init	1.10	3.71	37.1	23.6	13.5
Dec	2	Init	1.10	3.72	37.2	20.4	16.8
Dec	3	Deve	1.10	3.78	41.5	20.2	21.3
Jan	1	Deve	1.12	3.89	38.9	19.8	19.1
Jan	2	Deve	1.14	4.03	40.3	19.0	21.3
Jan	3	Mid	1.17	4.14	45.6	20.7	24.9
Feb	1	Mid	1.17	4.20	42.0	22.7	19.3
Feb	2	Mid	1.17	4.22	42.2	24.1	18.1
Feb	3	Mid	1.17	4.21	33.7	25.1	8.6
Mar	1	Mid	1.17	4.20	42.0	24.5	17.5
Mar	2	Late	1.15	4.08	40.8	24.7	16.1
Mar	3	Late	1.09	3.68	40.4	32.2	8.3
Apr	1	Late	1.04	3.30	29.7	39.4	0.0
					582.9	377.8	505.7

Note: CROPWAT model provides CWR for 10days as irrigation interval.

Table 9a: Crop water requirement for Cabbage in season C

CROP WATER REQUIREMENTS

ETo station: Byimana
Rain station: Byimana

Crop: Cabbage_C
Planting date: 20/06

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jun	2	Init	0.45	1.61	1.6	0.0	1.6
Jun	3	Init	0.45	1.64	16.4	0.5	15.9
Jul	1	Deve	0.45	1.68	16.8	1.3	15.4
Jul	2	Deve	0.61	2.28	22.8	0.1	22.7
Jul	3	Deve	0.86	3.34	36.7	1.8	35.0
Aug	1	Mid	1.04	4.20	42.0	3.2	38.8
Aug	2	Mid	1.05	4.36	43.6	4.2	39.4
Aug	3	Mid	1.05	4.35	47.8	8.0	39.8
Sep	1	Mid	1.05	4.33	43.3	12.8	30.5
Sep	2	Mid	1.05	4.32	43.2	16.7	26.5
Sep	3	Mid	1.05	4.25	42.5	17.4	25.0
Oct	1	Late	1.01	4.02	40.2	17.2	23.0
Oct	2	Late	0.92	3.61	25.2	12.6	7.3
					422.2	95.9	321.0

Note: CROPWAT model provides CWR for 10days as irrigation interval.

Depth(cm)	CLAY	SAND	SILT	Soil Texture Class
		← % →		
Profile 1				
0-20	10.6	78.04	11.4	Loamy sand
20-40	32.88	59.12	8	Sandy clay loam
40-60	24.88	65.12	10	Sand clay loam
Average	22.79	67.43	9.8	Sandy clay loam
Profile 2				
0-20	6.88	83.12	10	Loamy sand
20-40	6.88	71.12	22	Sandy loam
40-60	7.88	82.12	10	Loam sand
Average	7.21	78.79	14	Loamy sand
Profile 3				
0-20	5.88	77.12	17	Sandy loam
20-40	27.6	63.4	9	Sandy clay loam
40-60	7.88	78.12	14	Sandy loam
Average	13.79	72.88	13.3	Sandy loam
Profile 4				
0-20	15.24	72.12	12.6	Sandy loam
20-40	20.88	74.48	4.64	Sandy clay loam
40-60	25.88	62.12	12	Sandy clay loam
Average	20.67	69.57	9.75	Sandy clay loam

Table10a: Textural classes in Rugeramigozi wetland
Source: Murenzi et al, May 2010(unpublished)

Table 11a: Rainfall records for Rugeramigozi wetland

Meteorological Station of Byimana 1960 – 1990

Geographic coordinates: 29°44'E, 2°11'S

Altitude :1750m

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	P(mm)
1960	112.2	97.6	137.3	273.7	39	1.6	3.5	25.2	52.5	110.2	71.7	45.2	969.7
1961	69.3	121.2	150.9	96.5	99.2	2.1	7	0.8	120.7	144.6	222.2	199.3	1233.8
1962	168.5	31.4	130.4	123.2	199.3	15.5	18.4	93.4	104.4	272.4	124.2	131.1	1412.2
1963	167.4	99.9	80.2	205.7	408.4	47.5	0	43.8	146.7	33.7	110.8	205.9	1550
1964	83.4	162.5	106.5	272	68.7	42.3	66	22.1	44.5	134.8	144.6	70.4	1227.8
1965	87.9	69	102.4	282.9	141	8	0	42.5	103.7	111.5	146.4	48.1	1143.4
1966	30.7	164.5	163	179.8	61.9	22.7	0	100.8	72.2	65.2	136.4	65.2	1062.4
1967	40	63	111.3	169.3	283.6	47.4	24	7.8	130	30.9	143.4	193.9	1244.6
1968	128.1	171.8	213.8	187.8	91.6	67.8	8.8	0.2	36.7	65.4	170.6	96.1	1238.7
1969	88.9	85.7	123.1	131.7	135.4	1.4	0.3	0	65.5	65.3	106.9	44.2	838.4
1970	265.2	152.7	170.9	232	56.3	19.7	17.3	56.2	56.8	103	169.2	64.4	1363.7
1971	103.7	132.3	80.8	193.3	197.6	0	16.8	126.6	51.6	42.9	115.2	121.2	1182
1972	63.3	225.2	68.3	84	103.2	115.5	0	35	52.2	106.9	223.4	83.4	1160.4
1973	85.5	104.2	84	258.9	232.7	4.7	0	38.4	204.8	105.3	189.5	73.1	1379.1
1974	88.5	32.6	276.5	173.3	202.4	105.9	87.9	7.8	84.7	34.5	121.7	55.4	1252.2
1975	136.5	82.6	73.9	231.8	142.7	3.4	52.4	14.6	136.2	151.1	92	160.5	1276.7
1976	84.9	99.6	113.9	118.5	143.6	31.5	0	82.6	90	94.6	74.3	82.5	1016
1977	116.3	87.2	105.4	237.4	98.6	7.2	5.5	66.3	119.3	121.7	161.6	109.2	1235.7
1978	125.2	85.1	237.1	173	127.8	22	0	39.5	37.1	55.4	106.1	106.9	1115.2
1979	210.1	150.3	36.3	186.6	234.7	52.3	0	21.5	5.5	28.8	140.9	129.9	1196.9
1980	81.9	96.9	86.2	204.5	160.1	3.8	0	8.9	153.6	110.4	182.9	122.5	1211.7
1981	62.2	69.7	150.2	186.9	174.2	0.2	0	148.8	107.5	79.7	82.4	77.4	1119.2
1982	68.2	83.3	45.3	247.5	224.6	41.3	0	6.1	89.9	89.1	183.6	240.9	1299.8
1983	12	200.7	131.4	283.7	70.5	3.3	18.6	36.7	46.4	124.7	177.4	151.4	1266.8
1984	78	88	97.5	181.5	26	0.2	65.9	42.2	24.9	171.6	149.1	68.9	993.8
1985	83	126.7	163.7	263.9	65.8	30.6	0	0.2	181.8	116.5	157.9	143.3	1333.4
1986	169.6	155.4	128	412.8	183.6	51.2	0	25.1	43.1	145.5	97.5	130.1	1541.9
1987	153.1	226.6	111.5	190.5	220.7	87.4	0	32.8	167.7	163.3	344.3	80.8	1778.7
1988	70.3	172.3	216.6	218.4	113.1	4.6	0.3	105.4	91.7	97.4	102.9	56.1	1249.1
1989	143.5	160.5	190.5	220.4	153.5	53.9	21.1	57.9	38.9	76.9	65.2	143.4	1325.7
1990	65.9	120.9	191.3	187.2	59.2	0	0	24.4	88.9	90.8	136.5	110.3	1075.4
Average	104.2	120	131.6	206.4	146.8	35.6	21.8	42.3	88.7	101.4	142.3	110	1235

Source: Rwanda Meteorological Agency

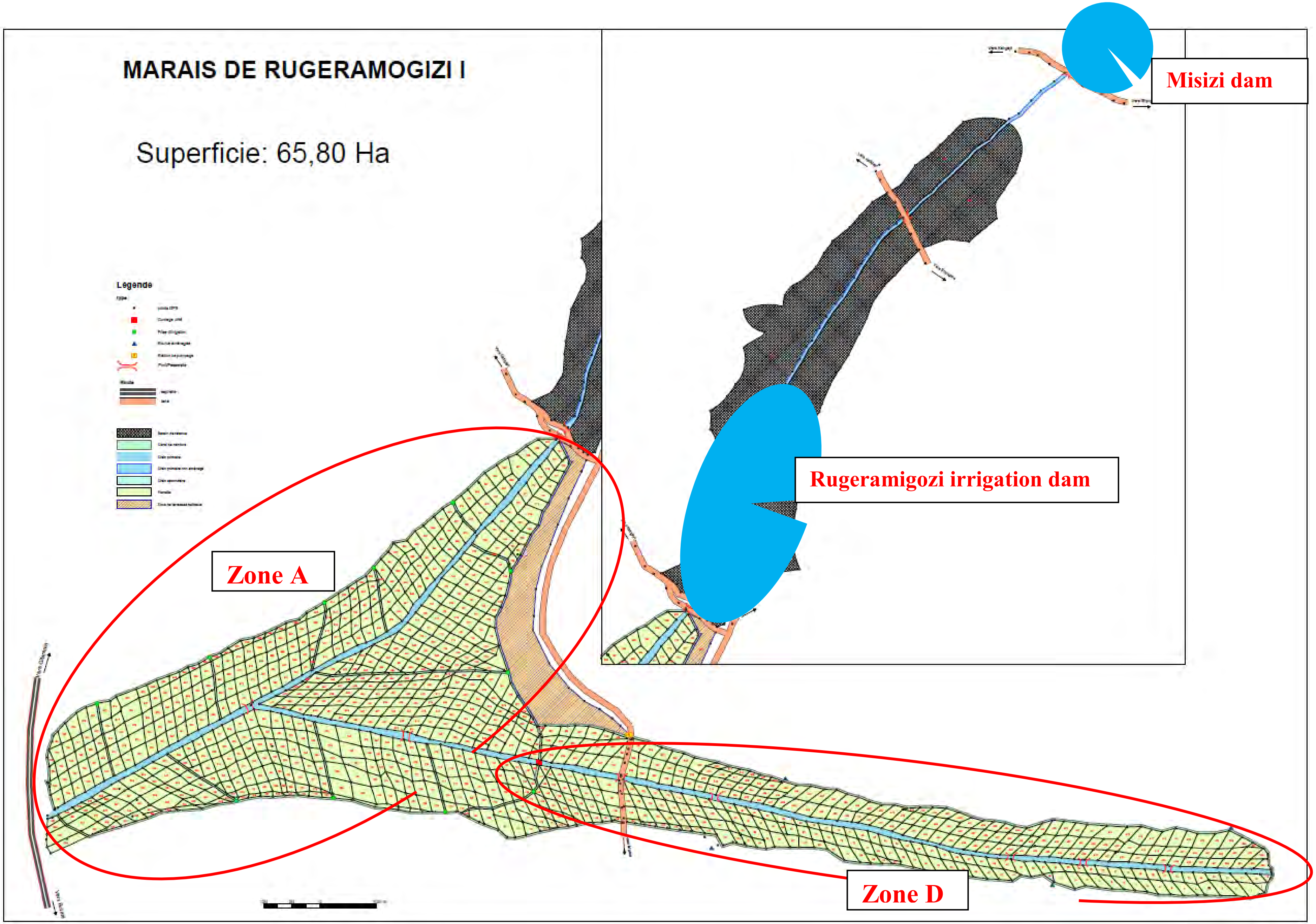


Fig 1a:Rugeramigozi marshland, Zone A and D

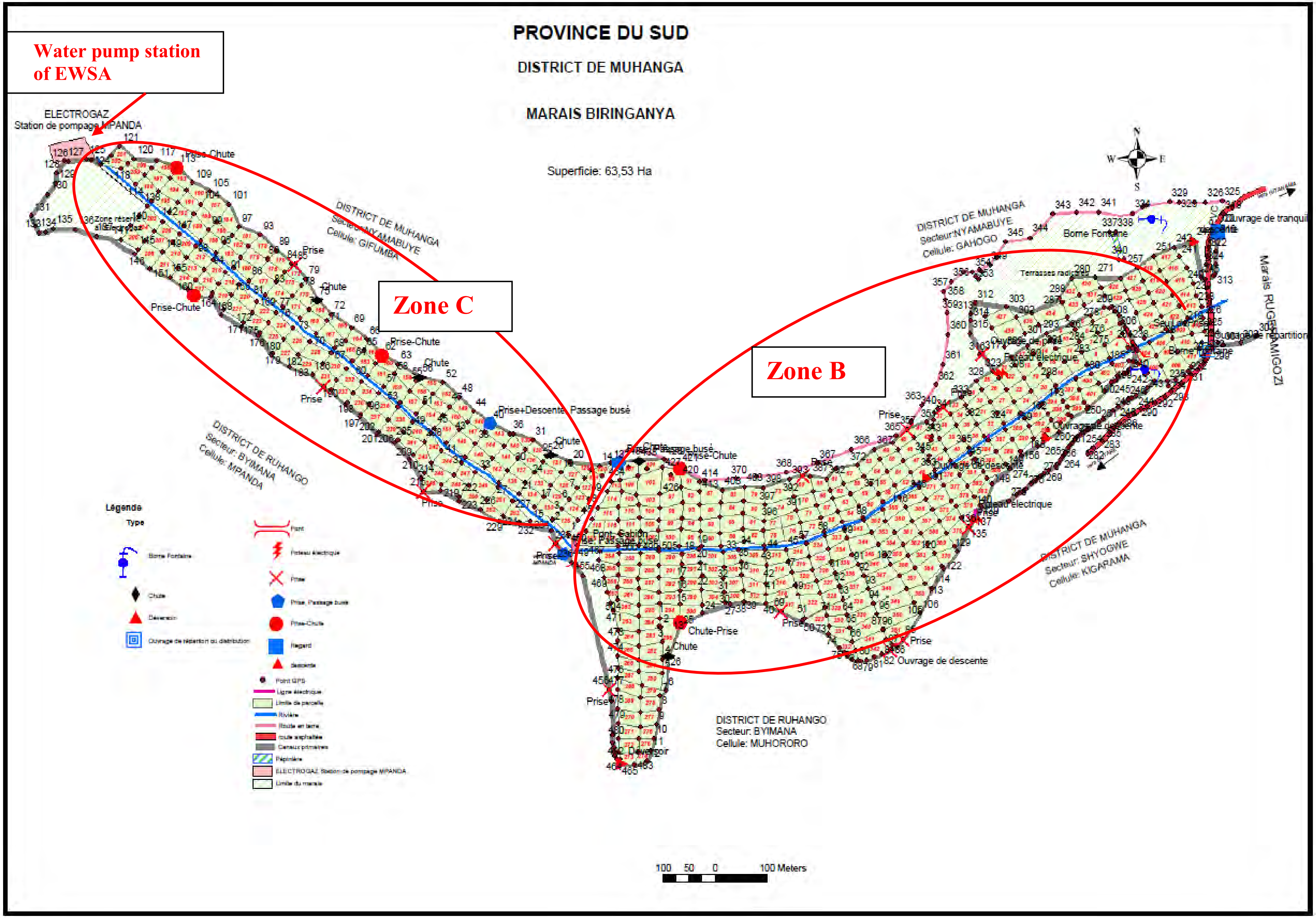


Figure 2a:Rugeramigozi marshland, zone B and C

Fig 3a: Management rules in Rugeramigozi marshland

1. Boundary rules

- A,B and C grow rice while D grows rain fed crops.
- Wetland is divided in 4 zones ABC & D
- There zone is made of Blocks there are 57 blocks.
- Each block is composed by 8 or more plots
- The community work is done at zone level
- All the farmers should grow the crop agreed
- Irrigators are in charge of the zone and opening the dam
- IS work closely with leaders of the zone and WUA
- FIEng. is employed and paid by RSSP
- FIEng. Supervises irrigation works of the scheme
- Each member should own a plot

2. Position rules

- KIABR is led by Administrative, Inspectorate and TC
- The leaders are elected by GA
- Everyone can be a candidate
- There is no limit of re-election
- If the committee doesn't comply with the law the GA can elect a new one.
- The maintenance is done in community works.
- FIEng. supervises the maintenance works
- FIEng. reports to the Office Irrigation engineer
- OIEng. is employed by RSSP
- OIEng. is in charge of irrigation in the Province
- OIEng. reports to the coordinator of RSSP in Province
- Representative of KIABR in WUA represents the cooperative interests.
- The WUS is led by the Administrative, Inspectorate Committee and Conflict resolution Council.
- The GA vote or reject the law made by AC

3. Authority rules(choice rules)

- Provision of seeds, fertilizers, pesticides, and technical support (RAB)
- Local authority can intervene in conflict resolution
- Farmers irrigate their fields by taking water from tertiary canal.
- Special irrigation water is approved by FIEng.
- The farmers maintain and level their fields themselves
- While irrigating farmers should wait for water to cover the plot as instructed
- Farmer is free to irrigate any time on irrigation day.
- The irrigators are only hired in irrigation period.
- FIEng. proposes the maintenance and extension works.
- Release of less water in drought (FIEng.)
- The Tender committee looks for the markets of the yields
- The T.C weighs and records the harvest of farmers under their presence.
- Opening of the prices should be in public.
- Agreement on fee deducted from harvest for cooperative (Farmers- TC)

4. Aggregation rules

- FIEng. supervise maintenance and leveling of the fields
- Opening and conveyance of water to zone(irrigators)
- Checking for the water theft (Irrigators)
- FIEng. supervises operation and maintenance of the system.
- FIEng. determines the irrigation needs for the zone
- FIEng. addresses water needs for the cooperative to WUA
- Implementation of decisions of OIEng. On the field(FIEng.).
- Provision of irrigation schedules (OIEng.),
- Preparation of maintenance and extension works(OIEng.)
- A weekly meeting of OIEng. and FIEng.
- A month meeting of WUA on water distribution and management

5. Information rules

- Provision of irrigation instructions to farmers (FIEng.)
- Information flow to Irrigators(FIEng)
- Selling the yield KIABR is allowed to farmers
- Irrigators report to the field irrigation Eng.
- Farmers must know about their irrigation turns
- The field which isn't used according to rules can be given to others

6. Payoff rules

- Absence in maintenance works is fined ≈0.83USD
- WUA collects the water fee.
- Water fee is 500FRW(≈0.83USD) per field/season
- Water fees is for the payment of the temporary staff
- The water fee and its use should be agreed on in G A.
- KIABR sells the harvest to RAB and private company
- RAB provides the improved seeds at harvest.

7. Scope rules

Abbreviations:
FIEng: Field irrigation engineer
OIEng: Office irrigation Eng.
TC: Tender committee
GA: General assembly

Management rules by Ostrom(2005, p.835)

Position Rules

- Positions of owner, seller, buyer, police, suspects, judge, and members of a jury are defined.

Boundary Rules

- Licensing requirements for individuals to become buyers and sellers are minimal.
- Buyers and sellers may enter and exit the market at their own initiative.

Authority Rules

- Sellers are authorized to decide how many legally owned goods to offer for sale at a price.
- Buyers are authorized to decide how much of a commodity to offer to buy at a price.
- Police are authorized to arrest those suspected of unlawful use of goods owned by others.
- Judges are authorized to determine rights and obligations of buyers and sellers in civil proceedings and of suspected thieves in criminal proceedings.
- Members of juries are authorized to determine guilt or innocence of those accused of theft.

Scope Rules

- Actors are limited in regard to the costs they can externalize on others. (Scope rules related to externalities vary substantially from market to market.)

Aggregation Rules

- Whenever any two actors agree to exchange goods they own, that transaction occurs.
- Police may make an arrest after a request or on their own initiative.
- Decisions made by a judge must be final unless challenged in a higher court.
- Members of a jury must vote before their decisions are official.

Information Rules

- Prices of current offers to buy and sell must be made available.
- No one is authorized to force information from others regarding preferences or costs.
- In some jurisdictions, seller may be required to provide specific information on content of goods.

Payoff Rules

- Seller retains profit, if any, after payment for inputs, interest, and taxes.
- Buyer retains consumer surplus, if any, after payment for goods.
- Suspects pay fines, or spend time in jail, if judged guilty of criminal acts.
- Buyers and/or sellers pay damages and costs to other parties if ordered to do so by judge.