SPATIO-TEMPORAL VARIABILITY OF WATER QUALITY AND ITS RESPONSE ON GROWTH OF IRRIGATED RICE IN RUSURIRWAMUJYINGA SUB-CATCHMENT, RWANDA

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DECLARATION

This thesis is my original work and has not been presented for a degree or any other award in any other university.

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DEDICATION

Dedicated to my wife, Espérance Munganyinka, my daughter, Gadièla R. Urusaro and my son, Aubin G. Ruhakana.

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ACRONYMS AND ABBREVIATIONS

ANOVA: Analysis of Variance

AP: Available Phosphorus

APHA: American Public Health Association

BMPs: Best Management Practices

CEC: Cations Exchange Capacity

CV: Coefficient of Variation

DDP: District Development Plan

D.F: Degree of Freedom

EC_w: Electrical Conductivity of Water

EC_s: Electrical Conductivity of Soil

FAO: Food and Agriculture Organization

GIS: Geographical Information System

GPS: Geographical Positioning System

HCl: Hydrogen Chloride

ISAR: Rwanda Agriculture Research Institute

IWM: Integrated Watershed Management

IWRM: Integrated Water Resources Management

LSD: Least Significant Difference

MINAGRI: Ministry of Agriculture and Animal Husbandry

Max: Maximum

MS: Mean Square

Min: Minimum

NUR: National University of Rwanda

OC: Organic Carbon

pH: Hydrogen Ion Concentration

RCGIS: Rwanda Centre of Geographical Information Systems

RNBS: Rwanda National Bureau of Statistics

RSSP: Rural Sector Support Project

SAR: Sodium Adsorption Ratio

SED: Standard Error of Difference Means

SEM: Standard Error of the Mean

SS: Sum of Square

STDEV: Standard Deviation

T^o: Temperature

TDS: Total Dissolved Solids

TN: Total Nitrogen

UNEP: United Nations Environment Program

US-EPA: United States - Environmental Protection Agency

WHO: World Health Organization.

VR: Variance Ration

ABSTRACT

The water quality used for irrigation is essential for the yield and quantity of crops, maintenance of soil productivity, and protection of the environment. Irrigation water quality has a profound effect on soil and plant health. A major concern with water used for irrigation is decreased crop yields and land degradation as a result of poor water and soil management which lead to irrigation induced problems, such as salinity and water-logging capacity. The Rusurirwamujyinga rice irrigation scheme of Rusurirwamujyinga sub-catchment in Rwanda was subjected to a study of its water quality and its response on growth of rice. The aim of this study was to assess spatial and temporal water quality variability and its response on growth of irrigated rice in Rusurirwamujyinga sub-catchment. Specifically, this study analysed physico-chemical parameter in the water used for rice irrigation by considering stream positions (upstream, middle and downstream) and seasonal variation (dry season, moderate and rainy season) in order to find out the variation of irrigation water quality within time and space. The study also analysed the status of soil fertility and rice plant nutrients in order to determine the trend of relationship between water quality, soil and plant nutrients. Data collection methods used included the primary data obtained from water, soil and plant through analytical laboratory and field measurements and secondary data was obtained from the meteorological station, topo sheet maps and review of available literature. The statistical tools used to analyse data were mainly descriptive statistics and correlation analysis in order to determine central tendency, dispersion, reliability and variability of the data. The index of water quality for irrigation and general ANOVA and regression ANOVA LSD at ($P < 0.05$) was used to estimate the significant difference of water quality between seasons (dry season, short rainy and short dry season and rainy season), between stream positions (upstream, middle and downstream) and to estimate interrelationship between water quality, soil and plant nutrients. The experimental results showed significant variation of irrigation water quality both in season and in stream positions. No significant interrelationship between water quality, soil and plant nutrients was observed in all variables tested in water, soil and rice plants. All parameters measured were recommendable for use without any impact to crops when compared with the FAO guidelines of evaluation water quality for irrigation. The correlation matrix between water quality parameters showed moderate positive and negative correlation ($r = 0.4 – 0.6$), weak positive and negative correlation ($r = 0.2 – 0.4$) and no correlation ($r = 0 – 0.2$) between parameters. The study makes the following recommendations: Rusurirwamujyinga sub-catchment needs to be sustained by reducing the negative impact which causes water pollution. The recommendations were given to the management of Rusurirwamujyiga dam as well as the whole irrigation infrastucture, which is used for supplying and regulation of water for irrigation. The use of Best Management Practices (BMPs) to reduce agriculture's impact on water quality while enhancing agricultural production in the irrigation scheme will be the best way of soil and water management by ensuring quality and equitable sharing of the water resource in the study area.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The water quality used for irrigation is essential for the yield and quantity of crops, maintenance of soil productivity, and protection of the environment. For example, the physical and mechanical properties of the soil, soil structure (stability of aggregates) and permeability are very sensitive to the type of exchangeable ions present in irrigation waters (Emamgholizadeh, 2008). Defining background conditions of water quality is important for water and land managers in assessing the effects of human activities, such as land use, on water resources (Stoner *et al.*, 1998).

It has been recognized that the quality of water changes continuously and many different anthropogenic factors and activities in a watershed via point sources, as wastewater treatment facilities, and non-point sources, as run-off from farm land and urban area affect the quality of receiving waters (Antonopoulos *et al.*, 2001). A strong relationship between stream flow and stream-water chemistry at different spatial and temporal scales has been identified for rivers and streams (Larsen *et al.*, 1999). Huang and Foo (2002) claim that engineering and management modifications in a river system may change the water quality characteristics of the river.

Agriculture demands more water than any other single activity, requiring 69% of the world's water supply (Holden and Thobani, 1996). In Rwanda, of the amount of water used for different purposes, 94 % is used for agriculture (FAO, 2003). In many countries, efforts to raise levels of agricultural production through increases in cultivated land, cropping intensity and yields have led to a greater dependence on irrigation. Where irrigated agriculture is developed, 90% of water used during the dry season (Hurand and Tardieu, 1998). Water used for irrigation can vary greatly in quality, depending upon the type and quantity of dissolved salts. Salts are present in irrigation water in relatively small but significant amounts. They originate from dissolution or weathering of the rocks and soil, including dissolution of lime, gypsum and other slowly dissolved soil minerals (Longenecker and Lyerly, 1994). Good management of irrigated land is therefore an important factor in insuring sustainable production (Rhoades *et al.*, 1999).

Rice (*Oryza sativa*) is not only the staple food for nearly half of the world's population, but also a key source of employment and income for the rural people, most of whom live in developing countries. The crop occupies one third of the world's total area planted under cereals and provides 35-60 percent of the calories consumed by 2.7 billion people (Guera *et al.*, 1998). It is the most widely grown crop under irrigation. During the last decade, rice has seen consistent increases in demand and its growing importance is evident in the strategic food security planning policies of many countries (FAO, 2003). With the development of human society, rice irrigation systems combined with their commanded areas have evolved into complex agro-ecosystems distinct from rain fed or upland systems, sustaining both the livelihood of the populations and a rich biodiversity, which have also shaped the hydrology of the watershed (Zhijun Chen (2005). Throughout the rice producing regions of Southeast Asia, the integration of rice cultivation and local cultures has been evolving for thousands of years.

Rice irrigation was introduced into Rwanda in the 1950s, with simple trials being made by the Chinese, through their mission known as "Formose", in the regions of Bugarama in

Cyangugu and Kabuye. By 1967, significant progress had been made which resulted in the development of several rice schemes across the country. At present, there are seven formal rice-producing schemes in Rwanda and the total production area covers about 5,500 hectares (Jagwe *et al.,* 2003). Water regulation problems, irrigation and drainage system, reservoirs management which lead to the shortage of quantity and degradation of the quality are among the major constraints to rice production in Rwanda (MINAGRI, 2001; Jagwe et al., 2003).
This is particularly burdensome in Rusurirwamujyinga rice irrigation scheme, where rice production seems to be lowered due to lack of water management.

Phil e*t al.* (2000) noted that irrigation water is necessary for a productive rice crop, and poor quality water can cause soil-related problems that negatively impact rice. Some of the predominant soil-related problems that affect rice include salinity (high soluble salts), zinc deficiency, phosphorus deficiency and excessive sodium, which cause poor physical soil conditions. Yutaka (2008) reported irrigation water quality guidelines for paddy rice system in Japan where heavy metals are, of course, a concern for the health of consumers. Nitrogen concentration is also of concern due to a potential of over nutrition that may result in fertilizer and pesticide management, drainage control and recycling of irrigation water. Hoffman et al. (1983), Guy (1995) and Harvand (1999) highlighted the guidelines for irrigation water quality standard and salinity management strategy for enhancing agriculture production. Nevertheless, water quality testing is an important step in diagnosing existing problems and identifying potential problems.

1.2 Statement of the Problem

In most irrigation situations the primary water quality concern is salinity levels since salts can affect both the soil structure and crop yield (Guy, 1995). Salinity is one of the most important problems for irrigation agriculture. Both irrigation water and soil composition can help to increase salinity, which in turn decrease crop output (Ananavas, 2002). Salinity is discussed from the standpoint of a reduction in soil-water availability to the crop (FAO, 1985). A paddy field has a dynamic and complex environment with much interaction of water, soil and the rice crop. Different management systems have contrasting effects of soil biology, physical and chemical properties which reflect in yield differences. Several crops are destroyed each year by toxicity and salinity of irrigation water (Maas, 1984). Since 2001 the government of Rwanda has maintained its overall goal is to improve food security in Rwanda by putting in place a National Rice Development and Promotion Board and irrigation system to encourage increased production with an aim of rice becoming a staple food by year 2015. One of the implementation strategies is water control by setting up better irrigation and drainage systems with construction and rehabilitation of dams and water reservoirs for the management of water for irrigation schemes (MINAGRI, 2001). The problem of water quality for crop irrigation is one of the major constraints to crop production within the world where salinity and toxicity cause crop damage or reduced yields.

Rice cultivated in Rusurirwamujyinga irrigation scheme is experiencing loss of crop yields. However, due to demographic pressure in the catchment area and the country's economic growth, Rusurirwamujyinga sub-catchment is surrounded by an environmental crisis related to anthropogenic activities such agricultural, deforestation, livestock population, brick making, fuel wood cutting and tile making. These activities have led to lowering of water levels, depletion of water quality and degradation of biodiversity in the catchment area. The water used for irrigation is polluted by siltation fed from up river by soil erosion and the application of fertilisers and pesticides.

This study was undertaken to the physico-chemical parameters which may endanger the quality of water used for rice irrigation in Rusurirwamujyinga sub-catchment and to show the interrelationship between water quality parameters, soil nutrients and rice plant tissue nutrients sampled in water, soil and plant.

1.3 Justification of the Study

The study was motivated by several reasons. The first one is the low production of rice cultivated under the irrigation scheme in Rusurirwamujyinga sub-catchment, which may be caused by the quality of water used for crop irrigation. The study assessed the quality of water for rice irrigation through physico-chemical analysis to find out whether or not it is suitable for crop irrigation.

It is thus very important that this study be carried out especially during this period when the national irrigation policy is still being developed and focusing on increasing of agricultural rice irrigation production. Rusurirwamujyinga sub-catchment is among the selected areas in Southern Province for rice irrigation scheme for improving food security and livelihood in the province. Since there has not been any clear information on the water quality for rice irrigation status, especially in the study area, it was thus necessary to analyse the quality of water used for irrigation in Rusurirwamujyinga sub-catchment to determine its suitability for rice production.

The study could be useful to decision-makers, planners, scientists and farmers as a basis for decision-making in the management of the quality of water used for rice irrigation within the study area, and similar schemes.

1.4 Research Questions

The guided by the following research questions:

(i) Does water quality vary significantly as one moves from upstream to downstream of the irrigation rice scheme?

(ii) Is there a significant seasonal variability in irrigation water quality within the rice irrigation scheme?

(iii) Is there any interrelationship between water parameters, soil nutrients and rice plant tissues nutrients within the rice irrigation scheme?

1.5 The Objectives of the Study

1.5.1 General Objective

The main objective of this study is to find out the quality of water for rice irrigation in Rusurirwamujyinga sub-catchment and to analyse the interaction within water-soil-plant interface that may cause loss in crop yield in the irrigation scheme.

1.5.2 Specific Objectives

Following specific objectives have been addressed:

(i) To evaluate the differences in water quality for the upper, middle and downstream sections of the rice scheme.

(ii) To determine the seasonal variability of water quality within rice irrigation scheme.

(iii) To find out the interrelationship in water quality parameters, soil nutrients and rice plant tissue nutrients within the rice irrigation scheme

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1.6 Significance and Expected Output

Water quality for rice irrigation is very important during this period where there is extension of irrigation agriculture in Rwanda for ensuring food security and where water quality control is among the constraints which may decline the production of rice. This study will provide information on the quality of water used for rice irrigation in comparison with FAO standard norms of water quality for rice irrigation and formulate plans and priorities for water quality management, which will help mitigate the water quality problem within the irrigation scheme and water resource in the catchment area.

The quality of water used for rice farming in Rusurirwamujyinga has not been studied. It is important to evaluate the quality of water for irrigating rice in the study area and show the interrelationship between water quality parameters, soil nutrients, rice plant tissue nutrients sampled within the rice irrigation scheme. The study will contribute to improved rice yields through recommendations that may enhance sub-catchment management interventions leading to sustainable water quality in the scheme.

1.7 Scope and Limitations of the Study

The study was confined to the evaluation of the following: (i) water physico-chemical parameters: temperature, electrical conductivity; total dissolved solids, sodium; potassium; magnesium; calcium; bicarbonate, carbonate; chloride; boron; hydrogen ion concentration; nitrate, sulphate, copper and zinc, (ii) soil nutrients: sand, silt, clay, electrical conductivity, hydrogen ion concentration, sodium; potassium, magnesium; calcium, sodium; potassium, cation exchangeable capacity, organic carbon, total nitrogen and available phosphorus, (iii) rice plant tissue: total nitrogen, Total phosphorus, Potassium, copper and zinc. Furthermore, the study was limited by lack of published literature on water quality for irrigation in the study area and lack of some materials and reagents.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Freshwater is a finite resource, essential for agriculture, industry and human existence. Without freshwater in adequate quantity and quality sustainable development will not be possible (Bartram and Ballance, 1996). Water represents one of the basic elements supporting life and the natural environment, a primary component for industry, a consumer item for humans and animals, and a vector for domestic and industrial pollution (Quevauviller, 2002). The quality and amount of the various (natural or anthropogenic) constituents actually form the basis for the definition of the quality of water, upon which the adequacy for various uses will be decided such as human and domestic animal consumption, domestic or industrial use, irrigation and so on (Wells and Cofino, 1995).

Discharge of toxic chemicals, over-pumping of aquifers, long-range atmospheric transport of pollutants and contamination of water bodies with substances that promote algal growth (possibly leading to eutrophication) are some of today's major cause of water quality degradation. It has been unequivocally demonstrated that water of good quality is crucial to sustainable socio-economic development (Bartram and Ballance, 1996). Colin and Quevauviller (1998) reported that European Directives already provide a framework for the control of aquatic substances, the quality of bathing, surface and drinking water, and effluent control. Such regulatory measures are closely related to 'classical' analytical measurements (involving sample collection and laboratory analysis) (Boelee *et al.*, 2005).

2.2 Factors Affecting Irrigation Water Management

To determine the suitability of water for irrigation, the following factors should be considered: (i) the quality of water, (ii) the soil quality, (iii) the climate, (iv) the crops, (v) the irrigation and drainage conditions and (vi) the management practices of the farmer**.**

2.2.1 Quality of Water

Defining background conditions of water quality is important for water and land managers in assessing the effects of human activities such as land use, on water resources (Emamgholizadeh, 2008**).** Irrigated agriculture is dependent on an adequate water supply of usable quality. The total salt content of irrigation water indicates the total dissolved salts whereby Ca, Mg, K, Na, CI, SO_4, HCO_3, and occasionally NO_3, account for 99 per cent of the salt content of most waters (Assidjo *et al.*, 2006). The total salt content of irrigation water strongly influences the salinity of the soil (Howard, 2002). Water quality is in the world deteriorating fast due to increasing population pressure, rapid urbanization and industrialization, and inadequate sanitation facilities, with water resources being contaminated by a variety of hazardous chemicals and virulent pathogens. These pollutants are mainly untreated human and animal waste, garbage and industrial waste (Choi *et al.*, 2007).

2.2.2 Soil quality

The key point of the percolation process is that the permeability of the soil must make it possible to wash the soil and leach the salts from the root zone (Howard, 2002). The extra quantities of water needed for leaching can be calculated, but if the permeability of the soil is low, this extra water may stagnate on the surface, causing the crops to suffer from water logging without any leaching taking place (Johns *et al.*, 1994). The structure and permeability of the soil must be good and remain good under long periods of irrigation. If the Sodium Adsorption Ratio (SAR) of the soil moisture increases through an unfavourable chemical composition of the irrigation water, it may be necessary to restrict the use of such water to soils with low clay content. Such soils will have a small adsorption complex and their structure will, therefore, hardly be affected by the composition of the soil moisture (Weert *et al.*, 2009). Owing to their structure, heavy and medium-heavy clay soils may originally have a fair permeability, but if their structure deteriorates, it will strongly affect their permeability. As the total salt content of the irrigation water increases, so too does the leaching requirement, and with that the permeability requirement of the soil. The poorer the quality of the water, the higher the requirements of the soil structure to maintain a fair to good permeability. These requirements explain why the use of saline water or water of poor chemical composition is generally restricted to light soils with a good permeability. Calcium in some form is often used to reclaim sodic soils, the most common form being gypsum (Clermont-Dauphin *et al.*, 2010).

2.2.3 Climate

Evaporation, rainfall, and temperature are the most important climatological components to be considered in determining the suitability of water for irrigation. A high evaporation rate means that more water and thus more salt will be applied than when evaporation is low (Glenn, 1997). In general, this will cause a higher salt content in the soil, notwithstanding leaching. If water with a high salt content is used, it may be wise to grow winter crops or crops that do not need irrigation during periods of maximum evaporation. (Little *et al.*, 2010)

2.2.4 Crops

The osmotic potential of the soil moisture increases as the salt content of the soil moisture increases. If this happens, less water will be available to the plant, thus reducing its growth and causing a yield depression. Usually the vegetative growth is more seriously hampered than the formation of seed (Francisco, 2010). Apart from the osmotic effect, the salt can exert a toxic effect on crop growth. In principle, the relation between yield depression and salt content is a shaped curve, in the yield depression range of 5 to75 per cent (Guy, 1995).

2.2.5 The Irrigation and Drainage Conditions.

With frequent irrigation the soil moisture content will be higher and the salt concentration of the soil solution lower than with less frequent irrigations. The osmotic potential will thus remain lower, by there favouring crop growth (Umaru, 2006). This procedure produces a more marked effect on light textured soils than on medium and heavy textured soil, where smaller fluctuations in moisture content occur. Surface irrigation is the oldest and most wide-spread irrigation method and can be also used for saline water. Its disadvantage is that soil surface serves as the transport medium and water quantity cannot be precisely controlled because of differences in the soil infiltration rate. The quantity of water applied must be large enough to cover the whole field, but if applied frequently, the crop must suffer from excess water, especially on medium and heavy textured soil (Richard et al., 2000). The drainage serves to dispose of the leaching water that percolates through root zone. Drainage can be either natural, as when river levees are drained by the adjacent river, or artificial, either through canals, ditches, and pipes (horizontal drainage) or through a system of tube wells fitted with pumps (vertical drainage) (Umaru, 2006). Drainage is the necessary complement to irrigation. This is true for all types of irrigation, not only for irrigation with saline water. But, if drainage is poor and the irrigation water saline, soil salinity problems will be created sooner than when the irrigation water is fresh. If saline water is to be used in new irrigation project, the installation of drainage system is more urgent than otherwise. Postponing the drainage in such a project can lead to disaster (Jinan, 1997).

2.2.6 Management Practices of the Farmer

Good management practices aim at obtaining a good stand of the crop by a rapid and homogeneous germination of the seed and emergence of the seedlings. A failure at this stage generally leads to poor stand and considerable yield decrease (Zial *et al.*, 2006). If the irrigation water has a composition that negatively affects the soil structure, the application of gypsum or organic manure may improve matters. Since the infiltration rate strongly depends on the structure of the top layer, tillage should aim at keeping this layer open (Haq et al., 2001). To prevent its structure from deteriorating, irrigation methods that allow small quantities of water to be applied should be chosen. It is obvious that management practices depend on the skills of the farmers and on the implements they have at their disposal. When deciding whether saline water can be used under local conditions, these two factors must also be considered (Ullrich and Volk, 2009).

2.3 Concept of Water Quality for Irrigation

Water used for irrigation can vary greatly in quality depending upon the type and quantity of dissolved salts (Harlin, 1980). These originate from the dissolution or weathering of the rocks and soil, including dissolution of lime, gypsum and other slowly dissolving soil minerals. These salts are carried by water to wherever it is used. In the case of irrigation, the salts are applied with the water and remain behind in the soil as water evaporates or is used up by the crop (Prichard, 1983). The suitability of water for irrigation is determined, not only by the total amount of salt present, but also by the kind of salt. Various soil and cropping problems develop as the total salt content increases, and special management practices may be required to maintain acceptable crop yields. Water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long-term use (Roundy, 1984). The problems that result vary both in kind and degree, and are modified by soil, climate and crop, as well as by the skill and knowledge of the water user. As a result, there is no set limit on water quality; rather, its suitability for use is determined by the conditions of use which affect the accumulation of the water constituents and which may restrict crop yield. The soil problems most commonly encountered and used as a basis to evaluate water quality are those related to salinity, water infiltration rate, toxicity and a group of other miscellaneous problems (Tanji, 1990).

2.4 Empirical Studies on Water Quality for Irrigation

Guy (1995) examined, irrigation water quality standards and salinity management strategy in the state of Texas. He elucidated that when taking water samples for laboratory analysis, on must keep in mind that water from the same source can vary in quality with time. Therefore, samples should be tested at intervals throughout the year, particularly during the potential irrigation period. He figured out the terms, units, and useful conversions for understanding water quality analysis reports and types of salinity problems and Soil salinity tolerance levels for different crops. This study did look at variability of the spatial and temporal water quality and their effect.

Kumar *et al.* (2011), in the study on "Assessment of seasonal variation and water quality index of sabarmati river and Kharicut Canal at Ahmedabad, Gujarat" India. The concluded that the river water quality varies with season changes but they did not consider water quality at different stream positions of the river. The present study fills this gap by assessing the spatial and temporal variability of water quality and its impact on rice irrigated in Rusurirwamujyinga sub-catchment.

Emongor *et al.* (2005) studied "The suitability of Treated Secondary Sewage Effluent for Irrigation of Horticultural Crops in Botswana. In their study they relied solely on FAO guidelines for water quality for irrigation. They neither investigated the variability of water quality within time and space nor about its impact on crop yield. Our study addressed questions related to variability of water quality for irrigation within time and space and its impact on rice yield in Rusurirwamujyinga sub-catchment.

Gordon and Hailin (2004) in the Oklahoma State University Water Testing Laboratory, developed chemical procedures for determining water quality. The two most important measures for determining irrigation water quality are: The total amount of dissolved salts in the water and the amount of sodium (Na) in the water compared to calcium (Ca) plus magnesium (Mg). Oklahoma irrigation water is grouped into six classes on the basis of soluble salt content and sodium percentage. Interpretation of these classes in relation to their use is as follows:

Class 1: Excellent. The total soluble salt content and sodium percentage of this water are low enough so that no problems should result from its use.

Class 2: Good. This water is suitable for use on most crops under most conditions. Extensive use of Class 2 water on clay soils where little or no leaching occurs may eventually cause a saline or sodic soil problem. Normal rainfall will usually dilute the soluble salts and eliminate the risk of salt accumulation. If the water's sodium percentage is high (above 30 percent), gypsum can be used periodically to remedy the problem.

Class 3: Fair. This water can be used successfully for most crops if care is taken to prevent accumulation of soluble salts, including sodium, in the soil. Good soil management and irrigation practices must be followed. The Class 3 water can be used with little danger to permeable, well-drained soils. The water table should be at least 10 feet below the surface to allow accumulated salts to be leached below the root zone by excessive irrigation when rainfall is limited.

Class 4: Poor. Use of this water is restricted to well drained permeable soils for production of salt tolerant crops. Irrigation practices must receive careful attention to avoid salt accumulation. Excess water must be applied when rainfall is not adequate to cause periodic salt leaching. Good soil management practices must be used to maintain good physical condition of the soil. Soil fertility levels must be maintained at adequate levels. Use of this water on medium textured soils may cause soil salinity problems if good practices are not followed. This water is not recommended for use on fine textured soils.

Class 5: Very Poor. Use of this water is restricted to irrigation of sandy, well-drained soils in areas of the state which receive at least 30 inches of rainfall. This water should not be used without advice from a trained irrigation expert.

Class 6: Unsuitable. Water of this quality is not recommended for crop irrigation. From these different salt water classes, Oklahoma State University Water Testing Laboratory developed the diagram for classifying irrigation water in Oklahoma as general guidelines for water quality use for irrigation but this did not incorporate the specified crops.

Longenercker and Lyerly (1994) listed the kinds of salt normally found in irrigation waters, with chemical symbols and approximate proportions of each salt (Table 2.1)

Table 2.1: Silts found in irrigation waters

Chemical name	Chemical symbol	Approximate proportion of total salt content
Sodium chloride	$NaCl$	Moderate to large
Sodium sulphate	Na_2SO_4	Moderate to large
Calcium chloride	$CaCl_2$	Moderate
Calcium sulphate	$CaSO_4\ 2H_2O$	Moderate to small
Magnesium chloride	$MgCl_2$	Moderate
Magnesium sulphate	$MgSO_4$	Moderate to small
Potassium chloride	KCl	Small
Potassium sulphate	K_2SO_4	Small
Sodium bicarbonate	$NaHCO_3$	Small
Calcium carbonate	$CaCO_3$	Very Small
Sodium carbonate	Na_2CO_3	Trace to none
Borates	BO^-_3	Trace to none
Nitrates	NO^-_3	Small to none

Source: Longenercker and Lyerly (1994)

They state that water quality varies greatly in amounts and kinds of dissolved salts but they did not take into consideration the different levels of the quality of water and their impact on crop yield.

This study bridged the gap between different variations of water quality and its impact on rice growth in Rusurirwamujyinga irrigation scheme using FAO guideline to interpret the standards of water quality suitable for irrigation.

2.5 The Empirical Studies on Water Quality for Rice Irrigation

In the standardisation of water quality for rice irrigation in Arkansas, rice farm cooperative Phil *et al.* (2000) confirmed that irrigation water is necessary for a productive rice crop. Poor quality water can cause soil-related problems that negatively impact rice growth. Some of the predominant soil-related problems that affect rice include salinity (high soluble salts), zinc deficiency, phosphorus deficiency and excessive sodium, which cause poor physical soil conditions. On the other hand, Yutaka (2008) in the study of monitoring management of irrigation water quality in Japan, reported irrigation water quality guidelines for paddy rice system in Japan where heavy metals are of concern for the health of consumers. Nitrogen concentration is also of concern due to a potential of over nutrition that may result in fertilizer and pesticide management, drainage control, recycling of irrigation water. In their studies, Phil *et al.* (2000) and Yutaka, (2008) did not go through the guidelines set by FAO of water quality for irrigation and were not interested in the relationship to water quality, soil quality and rice crop nutrients. Our study is about water variability and its impact on rice irrigation.

Similarly, Papadopoulos *et al.* (2008), in their study of reclaimed municipal wastewater Application on Rice Cultivation in Thessaloniki, Greece. They assessed the quality of water use for irrigating rice and microbial pathogens by guidelines of the standards of US Environmental Protection Agency (EPA, 1994), but they did not relate this to water quality, soil nutrients or rice plant nutrients.

Opoku- Duah *et al.* (1999) studied “The water quality for irrigated rice based cropping system in the Oda river valley bottom at Besease, Ghana”. They analysed both surface water and ground water and compared the results with FAO guidelines of water quality for irrigation but they never considered soil nutrients and rice plant nutrients complementary to water quality or the variation of water quality for irrigation within time and space.

This study evaluated the special and temporal variation of water quality and its response on growth of irrigated rice in Rusurirwamujyinga irrigation scheme.

2.6 Source of Pollution in Rusurirwamujyinga Rice Irrigation Scheme

As it rains, water falls to earth and moves along the ground to a nearby river, lake, or stream, taking with it whatever happens to be on the soil in a farm field, a construction site, or your lawn. This is called non-point source pollution. Non-point pollutants include: sediment (silt, suspended solids), pathogens (animal waste) from agriculture, improperly managed construction sites, eroded stream banks, residential and urban areas, forest lands, fertilizer (nutrients), herbicides and insecticides from agricultural. Agriculture contributes more to non-point source pollution at certain times of the year, for example during spring when there is less crop vegetation and when there may be more rainfall.

Rusurirwamujyinga is threatened by environmental degradation due to agricultural and other human activities which may be the cause of river and dam pollution.

2.7 Water Quality Parameters Measured in Rusurirwamujyinga Rice Irrigation Scheme

2.7.1 The Physical Parameters (T^oC, pH, EC_w and TDS)

2.7.1.1 Temperature (T^oC)

Temperature is referred to as the master factor among environmental factors affecting aquatic life (Niyotwambaza, 2009). Temperature must be measured *in situ* because a water sample will gradually reach the same temperature as the surrounding air. If it is not possible to measure the temperature *in situ*, a sample must be taken from the correct location and depth, its temperature measured immediately it is brought to the surface (Bartram and Ballance, 1996).

2.7.1.2 Hydrogen Ion Concentration (pH)

The pH of water is measured in terms of the acidity or alkalinity of irrigation water. It is expressed as pH (< 7.0 acidic; > 7.0 alkaline). Irrigation water with a pH between 6.5 to 8.5 is generally considered satisfactory (Assidjo et al., 2006). Acidic water tends to be corrosive to plumbing and faucets, particularly, if the pH is below 6. Alkaline waters are less corrosive; water with a pH above 8.5 may tend to have a biter or soda-like taste (Obiefuna and Sheriff, 2011). Determination of the pH of water should, if possible, be made in situ. If this is not possible, for example with well water or when access to a lake or river is very difficult, the measurement should be made immediately after the sample has been obtained (Bartram and Ballance, 1996).

2.7.1.3 Electrical Conductivity (EC_w) (Salinity Hazard)

Conductivity is a measure of the ability of water to conduct an electric current. It is used to estimate the amount of dissolved solids. It increases as the amount of dissolved mineral (ions) increases (Obiefuna and Sheriff, 2011). The measurement should be made in situ or in the field immediately after a water sample has been obtained, because conductivity change with storage time. Conductivity is also temperature-dependent. It is important to record the temperature once you have measured the conductivity of the water.

2.7.1.4 Total Dissolved Solids

Total Dissolved Solid (TDS) generally reflects the amount of minerals that are dissolved in the water, since this controls its suitability for use. A high concentration of dissolved solids may cause adverse taste effects. Highly mineralized water may also damage domestic plumbing and appliances. Total Dissolved Solids (TDS) may have an influence on the acceptability of the water in general. High TDS values may be an indication of the presence of excessive concentrations of some specific substance not included in the Safe Drinking Water Act, which would make the water aesthetically objectionable to the consumer (Obropta and Goodrow, 2005).

2.7.2 The Anions (Cl^-, CO_3^{--}, HCO_3^- , NO_3^-, SO_4^{--} and B^-)

The anions are any ion negatively charged. The important anions found in irrigation waters are chlorides, carbonates, bicarbonates, Nitrates, sulphates and borons.

2.7.2.1 Alkalinity (HCO_3^-, CO_3^{--})

The alkalinity of water is its capacity to neutralise acid. The amount of strong acid needed to neutralise the alkalinity, the alkalinity is reported in mg/L as $CaCO_3$. The alkalinity of some waters is due only to the bicarbonates of calcium and magnesium. The presence of carbonate and bicarbonate ions makes the irrigation water slightly alkaline, raising its pH to more than 7.5. Because this causes corrosion in boilers and metallic pipes, its determination is also important for agricultural as well as industrial purposes (Geeta, 2005). High pH's above 8.5 are often caused by high bicarbonate (HCO_3^-) and carbonate (CO_3^{--}) concentrations, known as alkalinity. High carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution. This alkaline water could intensify sodic soil conditions (Bauder *et al.,* 2003).

2.7.2.2 Boron (B^-)

Metalloid extracted from borax and rosorite ores. It does not exist in its elementary state in nature, but in the form of boric acid (used **as** an antiseptic), and borates (used in the glass and ceramic industries). It is frequently found in urban and industrial waste-waters (Quevauviller, 2002). The concentration of boron varying from trace to several ppm, is essential in low amounts, but toxic at higher concentrations. In fact, toxicity can occur on sensitive crops at concentrations less than 1.0 ppm. Although boron is an essential micronutrient for plant growth, its concentration >2.0 mg/L (ppm) in irrigation waters is harmful to most crops. Boron is usually high in saline ground waters of the arid and semi arid regions (Geeta, 2005).

2.7.2.3 Chloride (Cl^-)

Chloride is present in all natural waters, usually in relatively small amounts; however, chloride also can be derived from human sources (Quevauviller, 2002). Chloride concentrations in waters are very variable depending on soil leaching. Chloride is among the important anions found in irrigation water (Geeta, 2005). Irrigation water with a chloride content greater than 350 mg/L is toxic when absorbed by roots. Chloride is essential to plants in very low amounts (less than 70 ppm). It can cause toxicity to sensitive crops at high concentrations (Table 2.2). Like sodium, high chloride concentrations cause more problems when applied by sprinkler irrigation. Leaf burn under sprinkler irrigation, from both sodium and chloride can be reduced by night time irrigation or application on cool, cloudy days. Drop nozzles and drag hoses are also recommended when applying any saline irrigation water through a sprinkler system to avoid direct contact with leaf surfaces. (Harivandi, 1999 and Bauder *et al.,* 2003).

Table 2.2 Chloride classification of irrigation water

Chloride (ppm)	**Effect on crop**
Below 70	Generally safe for all plant
70-140	Sensitive show injury
141-350	Moderately tolerant plants show injury
Above 350	Can cause severe problems

Source: Bauder *et al.* (2003)

2.7.2.4 Nitrate (NO_3^-)

Sources of nitrate in water include human activity such as application of fertilizer in farming practices, human and animal waste (which relate to population). Nitrate is the most highly oxidised form of nitrogen compounds commonly present in surface and ground waters. Significant source of nitrate are chemical fertilisers from cultivated land and drainage from livestock feedlots, as well as domestic and some industrial waters (Edwin, 1996). The determination of nitrate helps the assessment of the character and degree of oxidation in surface waters, in groundwater penetrating through soil layers, in biological processes, and in the advanced treatment of wastewater. In surface water, nitrate is a nutrient taken up by plants and assimilated into cell protein. Stimulation of plant growth, especially of algae, may cause water problems associated with eutrophication (Bartram and Ballance, 1996).

2.7.2.5 Sulphate (SO_4^{--})

Sulphate is an abundant ion in the earth's crust and its concentration in water can range from a few mg to several thousand mg/L. Industrial wastes and mine drainage may contain high concentrations of sulphate. Sulphate occurs in water as the inorganic sulphate salts as well as dissolved gas (H_2S). Sulphate is not a noxious substance although high sulphate in water may have a laxative effect. The sulphate ion is a major contributor to salinity in irrigation water, however, toxicity is rarely a problem, except at very high concentrations where high sulphate may interfere with uptake of other nutrients (Obiefuna and Sheriff, 2010).

2.7.3 The Cations (Ca^{++}, Mg^{++}, Na^+, K^+, Cu^{++} and Zn^{++})

The cations are any ion that are positively charged. Ca^{++}, Mg^{++}, Na^+ and K^+, are the important cations present in irrigation water whilst Cu^{++} and Zn^{++} are the heavy metal cations which can also be found in small amounts (traces elements) in irrigation water.

2.7.3.1 Calcium (Ca^{++})

An element widespread in nature, in particular in calcareous rocks in the form of carbonates ($CaCO_3$). In water, it exists mainly in the form of hydrogen carbonates and, in lesser amounts, as sulphates, chlorides and others. Calcium oxide is used in construction works, the paper industry and water treatment (Quevauviller, 2002). Calcium contributes to the hardness of water and it is the fifth most common element found in most natural waters. The sources of calcium in ground water especially in sedimentary rocks are calcite, aragonite, gypsum and anhydrite.

2. 7.3.2 Magnesium (Mg^{++})

Magnesium is one of the most widespread elements in nature (2.1% of the earth's crust). Most of the magnesium salts are water-soluble. This element is present in the forms of carbonates and hydrogen carbonates. Like calcium, it constitutes a significant element in water hardness (Quevauviller, 2002).

2.7.3.3 Sodium (Na^{+})

Sodium is a common element, the sixth most abundant, and present to some extent in most natural waters. Concentrations vary: from negligible in fresh water to considerable in sea water and brackish water. The permeability of agricultural soil is harmed by a high ratio of sodium ions to total cations. Sodium concentrations higher than a few mg/L are undesirable in feed water for high- pressure boilers. Sodium constitutes 50% or more of total cations in saline and sodic water. The classification of irrigation water with respect to Sodium Adsorption Ratio (SAR) is based primarily on the effect of exchangeable sodium on the physical condition of the soil (Bartram and Ballance, 1996, Geeta, 2005). High concentrations of sodium in irrigation water can result in the degradation of soil structure.

This will reduce water infiltration into the soil surface and down the profile, and limit aeration, leading to reduced crop growth (Bauder *et al.*, 2003).

2.7.3.4 Potassium (K^+)

Although potassium is a relatively abundant element, its concentration in natural fresh waters is usually less than 20 mg/L. Brines and seawater, however, may contain as much as 400 mg/L of potassium or more. Potassium generally constitutes a small fraction of cations in irrigation water. The concentration of potassium can be determined directly by using a Flame Photometer (Bartram and Ballance, 1996).

2.7.3.5 Trace Elements (Cu^{++}, Zn^{++})

Copper and zinc are among the long chain of trace elements or heavy metals which are encountered in natural water in small amounts. These elements may be toxic to sensitive crops if highly concentrated. Toxic trace elements concentration in some irrigation water samples are undesirably high, and hence it becomes necessary sometime to estimate their qualities in an irrigation water sample (Moshood, 2009).

(a) Copper (Cu^{++})

The element is present in nature in the form of native copper ore oxides or sulphides it is a constituent of alloys such as, brass (copper and zinc) and bronze (copper and tin), being largely employed owing to its thermal and electrical conductivity properties. Copper salts (sulphates, acetates and organic derivatives) are used as fungicides in agriculture, for skin tanning, paint formulations and ceramics. In addition to industrial or agricultural pollution, this metal mainly originates from corrosion of water pipes. Copper is an essential nutrient, but at high doses has been shown to cause stomach and intestinal distress, liver and kidney damage, and anemia (Obropta and Goodrow, 2005).

(b) Zinc (Zn^{++})

An element present in rocks in the forms of sulphides, with the most widespread being zinc blende. It forms a constituent of numerous alloys, and it is used in the galvanization of metallic articles, the production of paint pigments, varnish and phytosanitary products. In the form of orthophosphate, it is used as a corrosion inhibitor in lead pipes. This metal is often found in association with cadmium and lead. Zinc is found in some natural waters, most frequently in areas where it is mined. It is not considered detrimental to health unless it occurs in very high concentrations. It imparts an undesirable taste to drinking water (Obropta and Goodrow, 2005).

2.7.4 Sodium Hazard

The sodium hazard can be expressed based on the sodium adsorption ratio (SAR). This index quantifies the proportion of sodium (Na^+) to calcium (Ca^{++}) and magnesium (Mg^{++}) ions in a sample.

$$SAR= \frac{[Na^+]}{\sqrt{\frac{\{[ca^{++}]+[Mg^{++}]\}}{2}}} \qquad (2.1)$$

Calcium will flocculate (hold together), while sodium disperses (pushes apart) soil particles. This dispersed soil will readily crust and have water infiltration and permeability problems. High concentrations of sodium in irrigation water can result in the degradation of well-structured soils. This will limit aeration and soil permeability to water, leading to reduced crop growth (DeHayr *et al.*, 2006). Sodium in irrigation water can also cause toxicity problems for some crops, especially when sprinkler applied (Bauder *et al.*, 2003). Table 2.3 below shows the acceptance limits of sodium hazard in irrigation water quality.

Table 2.3: General classifications of irrigation water based upon SAR

SAR values	Sodium hazard of water	Comments
1-9	Low	Use on sodium sensitive crops must be cautioned
10-17	Medium	Amendments (such as gypsum) and leaching needed.
18-25	High	Generally unsuitable for continuous use.
≥ 26	Very High	Generally unsuitable for use.

Source: Bauder *et al.*, (2003)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The aim of the study was to estimate the spatial and temporal variability of the quality of water and its response on growth of irrigated rice in Rusurirwamujyinga Sub-catchment, Huye District, Southern Province, upper Mwogo catchment area. An extensive literature review was done in order to set up the theoretical basis of the study. The data was collected depending on the seasons and streams. They were analysed statistically and compared to establish the spatial and temporal variation of water quality used for irrigating rice and to understand the interrelationships between water, soil and rice plant tissues.

3.2 Study Area

3.2.1 Location

Rusurirwamujyinga Sub-catchment occupies an area of 67.171 Km^2 and has population of 84,313 who reside within Rusatira, Ruhashya, Rwaniro and Kinazi sector of Huye District in the Southern Province of Rwanda, upper Mwogo catchment area, which plays major role in regulation of water flow to Nile basin (RCGIS, 2010, Huye DDP 2007). Geographically, it lies between longitudes 29^o 40’ 0” and 29^o 48’ 0” East of Greenwich and between latitude 2^o 23’50” and 2^o 31’58”S South of the Equator (Figure 3.1). Altitude varies between 1200-1700 m above sea level and the average annual precipitation is 1171mm (Nahayo, 2009). The sub-catchment area is drained by Rusurirwamujyinga River which has several tributaries such us Gasuma, Akogo, Gahama, Gatare, Nyakagezi and Umwaro. The whole drainage area covers about 608 ha and the rice irrigated area covers about 400 ha.

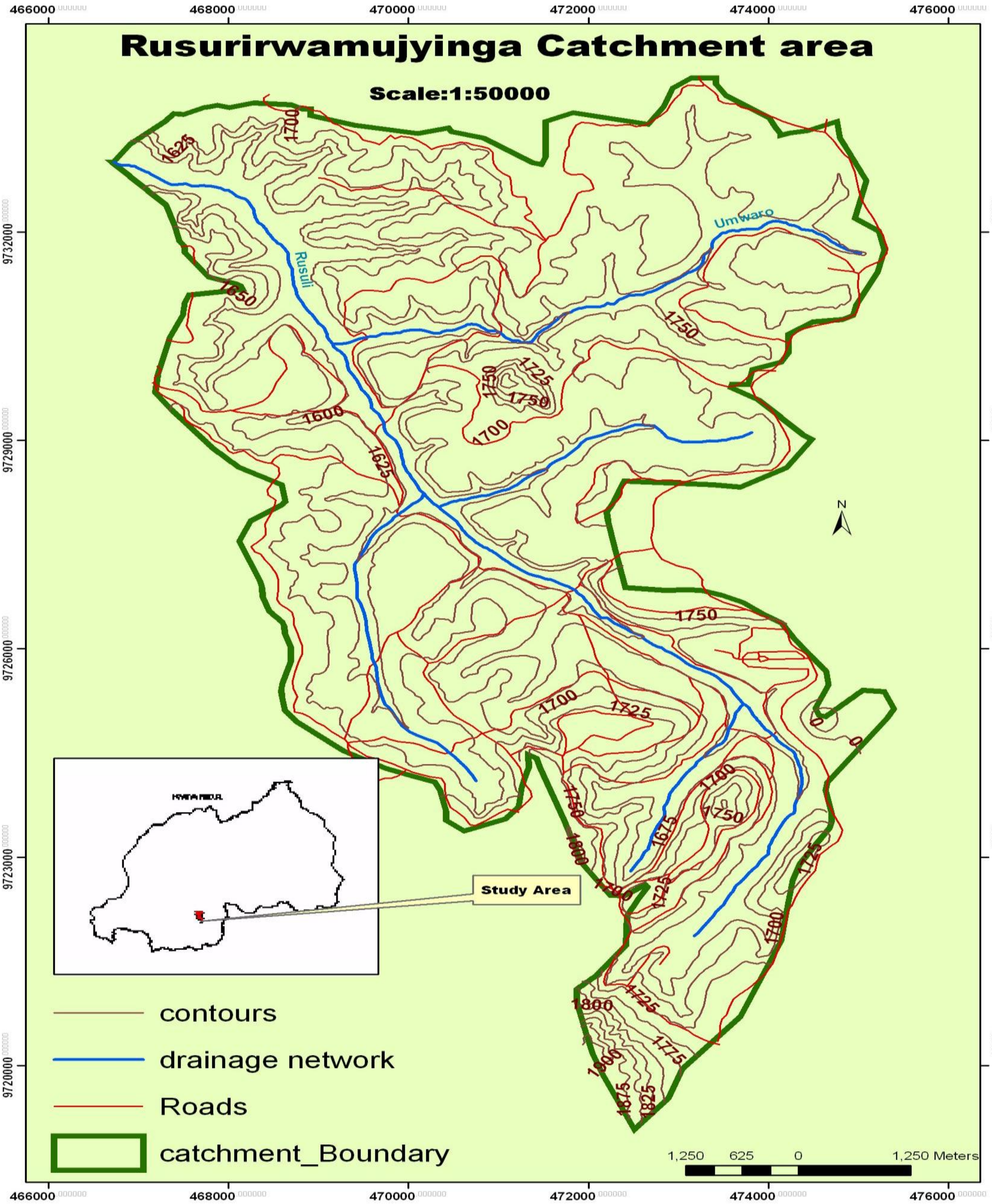


Figure 3.1: Map of the study area

Climatic conditions

The climate of the country is characterized by four seasons of which two are wet and the other two are dry depending on the month of the year: a short rainy season occur from October to November; a short dry season from December to January, a long rainy season from February to May bringing and a long dry season from June to September (Twagiramungu, 2006 and Nahayo, 2009). The study is characterised by sub-equatorial temperate climate with an average temperature fluctuating around 20 °C (Huye DDP, 2007). The rainfall data recorded from Rubona Meteorological Station from 1997 to 2010 shows the fluctuation of rainfall within the sub-catchment area with highest amount of rainfall recorded in year 2001 and the lowest in year 2000 (Figure 3.2). The average rainfall is estimated as 1140 mm per year.

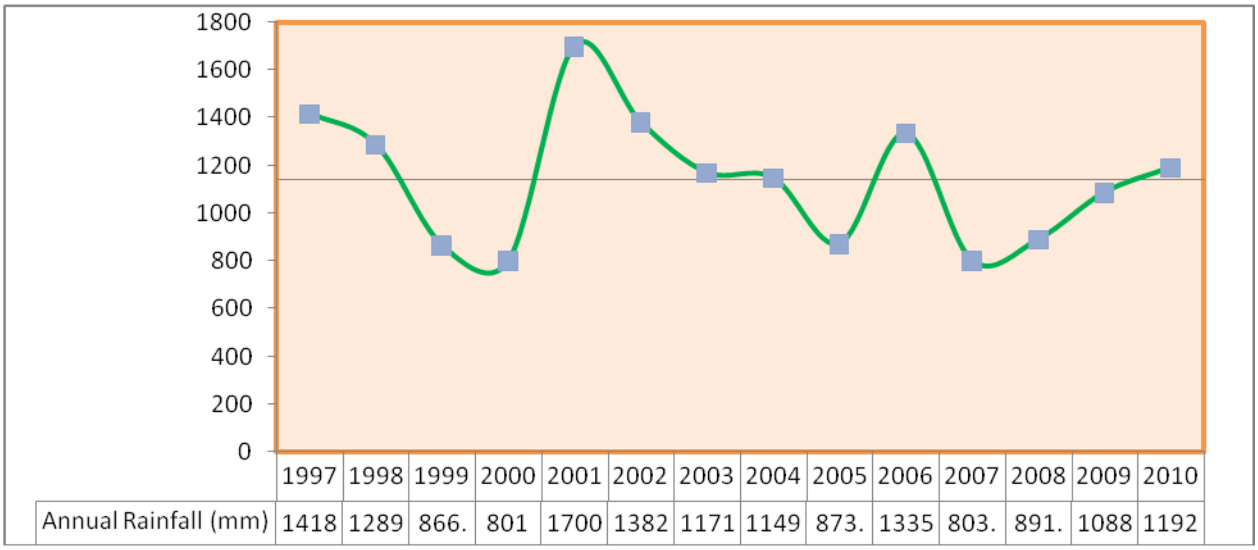


Figure 3.2: Distribution of average annual rainfall (1997-2010)
Source: (Rubona meteorological station, 2011)

The main agro-climatic parameters which are temperature, radiation, potential evaporation and rainfall regimes that influence crop production are derived from Rubona (station 2°29' S; 29°46' E; 1,706 m) which is located within the catchment area. The problems that decrease crop production are soil erosion and flooding during the rainy season and water shortage in during dry season. These as a result of the topographic conditions with an inclination (slope) which varies between 2 and 3% (Nahayo, 2009).

3.2.3 Agricultural Potential

Land productivity depends on the chemical and physical properties of the soil. These properties vary with the underlying parent material that weathers into mineral soil upon the impact of climatic elements such as temperature and rainfall. The nature of this substrate, the slope gradient, the altitude, the natural vegetation and the management practices further influence the degree of soil conservation or erosion. The agricultural potential of a region results from the interaction of all these interdependent factors. Verdoodt and Van Ranst (2003) identified twelve agricultural zones in Rwanda, based on differences in altitude, rainfall regime and soil properties. The twelve agricultural zones are the following: Imbo, Impara, Kivu Lake borders, Birunga, Congo Nile Watershed Divide, Buberuka highlands, Central Plateau, Granitic Ridge, Mayaga, Bugesera, Eastern Plateau, Eastern Savana. Each zone has a unique combination of land resources that determines the range of well-adapted crops.

Rusurirwamujyinga sub-catchment is within the Central plateau agricultural zone of the country in the large region of hills and valleys between the Congo-Nile mountain chain and the Granitic Ridge, at the centre of the country. If the humus-bearing horizons are conserved, the soils can be used for the cultivation of a whole range of climatically adapted crops (Verdoodt and Van Ranst, 2003).

3.2.4 Soil Characteristics

According to Twagiramungu (2006), the Rwandan pedology is characterized by six types of soils, namely: (i) Soils derived from schistose, sandstones and quartzite formations (50%); (ii) Soils derived from granite and gneissic formations (20%); (iii) Soils derived from basic intrusive rocks (10%); (iv) Soils derived from recent volcanic materials (10%); (v) Soils derived from old volcanic materials (4%); and (vi) Alluvial and colluvial soils (6%). The impressive geologic and geomorphologic history of Rwanda resulted in a high diversity of parent materials. Pure shale and quartzite intervening with shale dominate the lithology of the country with a real extent exceeding 50 %. Granite is the third most important parent material, covering 11 % of the land (Verdoodt and Van Ranst, 2003). The sub-catchment soil types are hill ferro soils and valley histosoils (MINAGRI, 2004). The sub-catchment soil map (Figure 3.3) extracted from Rwanda digital soil map produced by MINAGRI in 2004 shows that the Rusurirwamujyinga sub-catchment area possesses thirty one series of soils. The soil within the irrigation scheme is dominated by a series of fluventic humitropept in US soil taxonomy (1975) and distric (humic), cambisols (heptic humic) and Alisol in FAO soil taxonomy (1990) (Appendix 4).

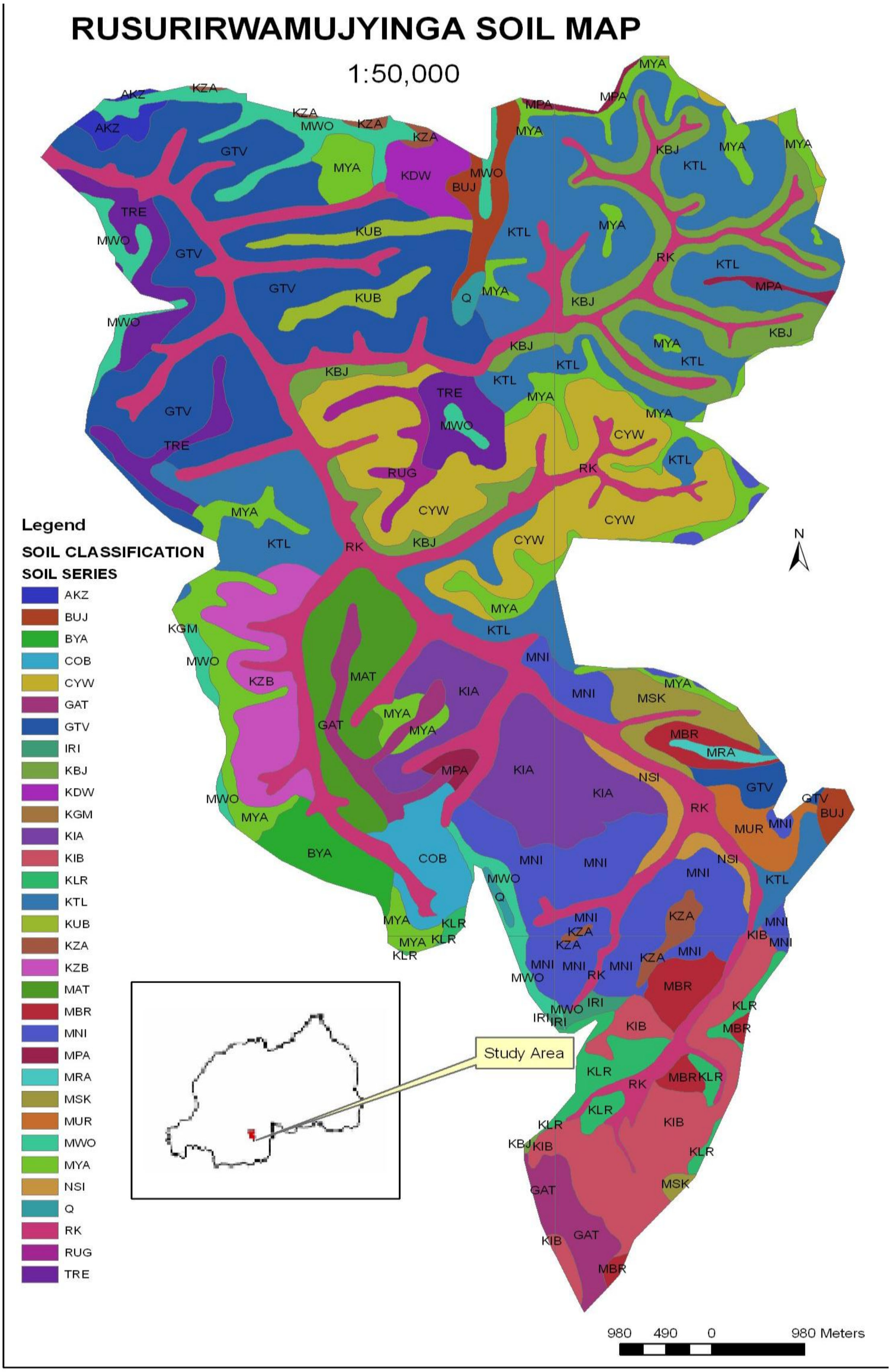


Figure 3.3: Soil map of the study area

3.2.5 Hydrological Networks

The Republic of Rwanda has a very dense hydrographical network of 2km/km² (length of the superficial out-flow network by Km² of surface). Rwanda possesses water in abundant quantities. The country area under water (lakes, rivers, reservoirs, swamps and ground water) is about 211,000 ha, about 8% of the national territory (Mukasa *et al.*, 2005).

Although the country is endowed with abundant surface and groundwater resources, the utilisation and management of this resource has remained critical. One of the main challenges in managing the water resources is land and ecosystem degradation, namely forests, wetlands and savannah. These factors are aggravated by demographic pressures that implies the constant land development, and new land reclamation in order to increase food security (Twagiramungu, 2006). Rusurirwamujyinga sub-catchment drainage area has some hydrologic network such as Agatare, Agasuma, Agatare and Mwarara which almost dry up in the dry season.

3.3 Sampling Method and Techniques

3.3.1 Location of Sampling Points

Three homogenous zones were demarcated from the study area, namely, the lower zone, the middle zone and the upper zone according to drainage distribution and topography. Samples were taken at different points of the rice irrigation scheme as shown in Figure 3.4 and Table 3.1. The sampling sites started from S_o in-let dam (not irrigated) and ended at S_{11} also (not irrigated), which is at Mwogo, the main river in the catchment area.

Table 3.1: Sampling point details

N^o	Sub-catchment area	Sampling point	Geographical Coordinate	Physical Observation
1	Up stream	So	S: 2^o 30’36.4” E: 29^o 45’52.9”	Inlet dam
2		S1	S: 2^o 30’17.4’’ E: 29^o 46’03.8’’	Outlet dam
3		S2	S: 2^o 30’08.3” E: 29^o 46’08.7”	Bandagure bridge
4		S3	S: 2^o 29’31.6’’ E: 29^o 46’01.7’’	Mugogwe bridge
5		S4	S: 2^o 29’15.8’’ E: 29^o 45’50.2’’	Agatare stream
6	Middle stream	S5	S: 2^o 28’49.8’’ E: 29^o 45’21.8’’	Musasu bridge
7		S6	S: 2^o 28’22.3’’ E: 29^o 44’50.7’’	Kiruhura bridge
8		S7	S: 2^o 28’04.6’’ E: 29^o 44’21.3’’	Ruhashya stream
9		S8	S: 2^o 27’40.6’’ E: 29^o 43’59.3’’	Bweramana bridge
10	Down stream	S9	S: 2^o 26’52.5’’ E: 29^o 43’39.8’’	Gahama stream
11		S10	S: 2^o 26’25.6’’ E: 29^o43’22.5’’	Agasuma stream
12		S11	S: 2^o 25’00.3’’ E: 29^o 42’03.6’’	Enter Mwogo River

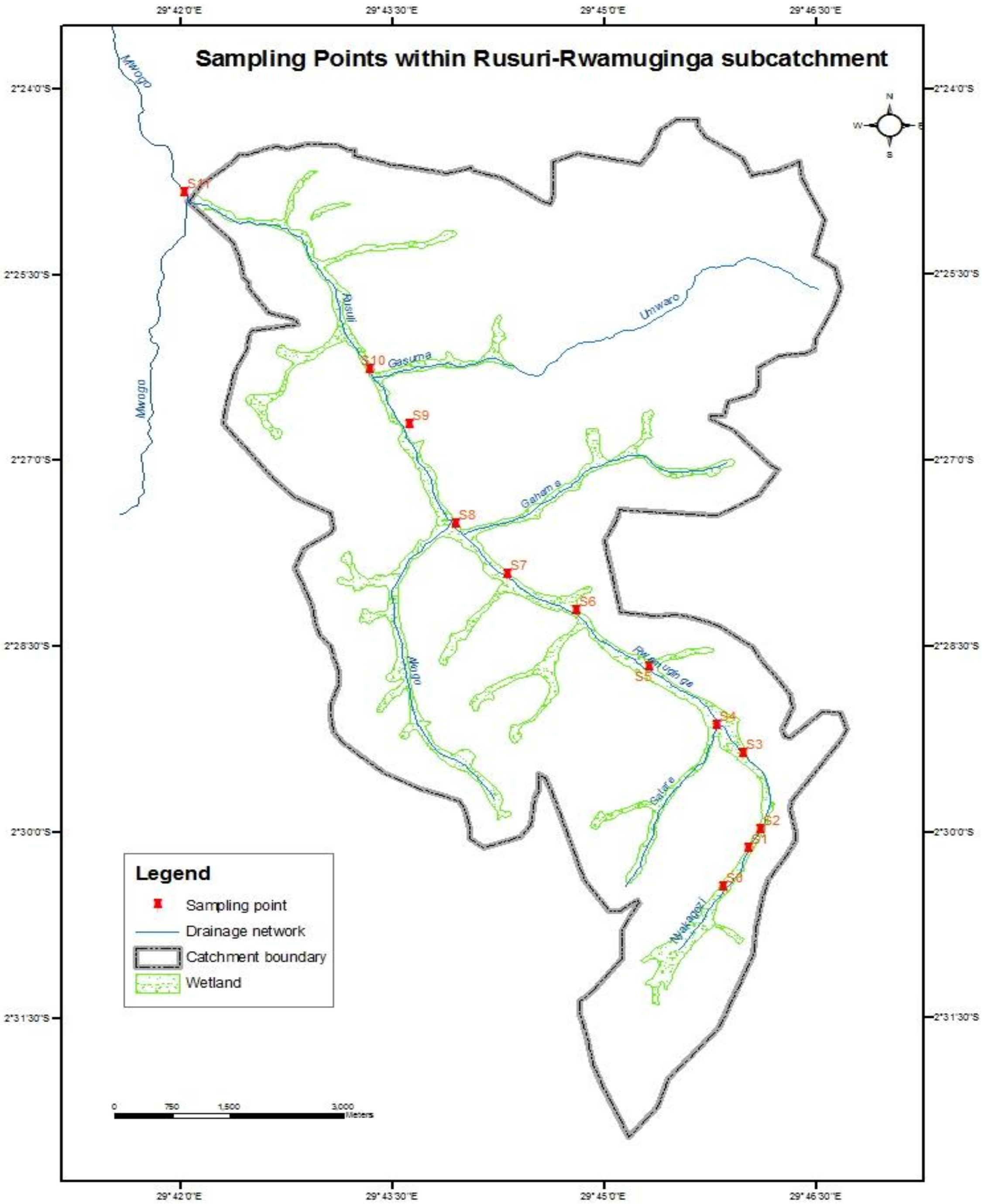


Figure 3.4: Sampling point within the study area

3.3.2 Sampling Procedures

Seventy two surface water samples were collected six times from August 2010 to April 2011 depending on the seasonal variability (dry, moderate and rainy season). Dry season data were taken in August and September 2010; moderate season data were taken in November 2010 and January 2011; and rainy season data taken in March and April 2011 within rice plots, Rusurirwamujyinga river and their tributaries. Each sample was a composite of 5 to 10 sub-samples to minimize error and heterogeneity. Polyethylene bottles were used for sampling and each sample was one litre.

Twenty soil samples were taken from the top soil at a depth of 0-30cm randomly across rice irrigated plots using an auger (Figure 3.5). This was done before planting and after harvesting rice in August 2010 and January 2011. Each sample was a composite of 5 to 10 sub-samples taken at the same area where water and plant tissue were sampled.

Ten rice plant tissue samples, each sample having about 500 g of the most common vegetation were collected at the sites near where the water samples and soil samples were taken. The standard procedures and materials recommended for environmental sampling of water, soil and plants were followed (Kisamo, 2003).

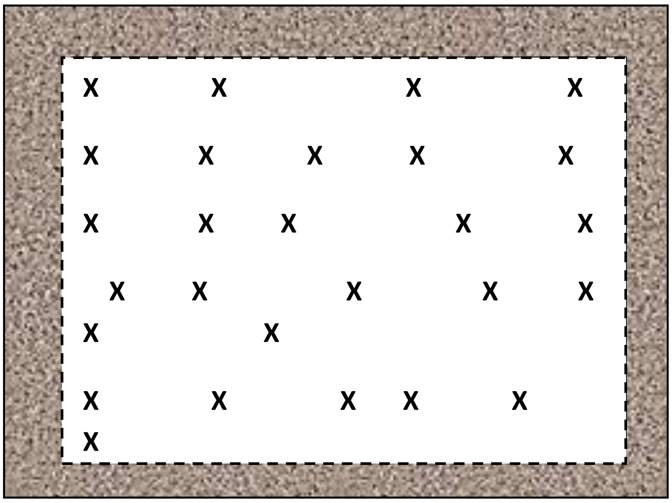


Figure 3.5: Drown of simple randomly sampling of water soil and plant within rice irrigation scheme

3.3.3 Sample collection and preservation

The water samples were taken for a period of nine months every 25th day of the month from August 2010 to April 2011. Depending on the seasonal variability of the country, sampling was frequently done two time per season in the dry season (August and September), moderate season (November and January) and rainy season (March and April). Plastic bottles were used for collecting water samples. These were washed with phosphorus free detergents and rinsed with 1M HCl 24 hours before sample collection. They were again rinsed twice with sample water before final sample collection. The plastic bottles were labelled properly for identification according to the point number before sample collection to avoid confusion of samples. Samples collected from study area were carefully transported to the laboratory and kepted in a refrigerator at 4^{o}C before analysis (Islam and Shamsad, 2009; Niyotwambaza, 2009). Table 3.2 below shows the water sample preservation and storage before analysis in laboratory.

Table 3.2: Preservative treatments and maximum permissible storage of water samples

Variable	Recommended container	Preservative	Max. Permissible storage time
pH	polyethylene	None	6 hrs
EC_w	polyethylene	cool 4 ^oC	24 hrs
NO_3^-	Polyethylene	cool 4 ^oC	24 hrs
SO_4^{--}	Polyethylene	cool 4 ^oC	7 days
Cl^-	Polyethylene	cool 4 ^oC	7 days
B^-	Polyethylene	cool 4 ^oC	6 months
HCO_3^-	Polyethylene	cool 4 ^oC	24 hrs
CO_3^{--}	Polyethylene	cool 4 ^oC	24 hrs
Ca^{++}	Polyethylene	cool 4 ^oC	7 days
Mg^{++}	Polyethylene	cool 4 ^oC	7 days
K^+	Polyethylene	cool 4 ^oC	7 days
Na^+	Polyethylene	cool 4 ^oC	7 days
Cu^{++}	Polyethylene	2 ml Conc. HNO_3/L sample	6 months
Zn^{++}	Polyethylene	2 ml Conc. HNO_3/L sample	6 months

Source: APHA (2005) and Bartram and Ballance (1996)

Proper soil sampling techniques are critical in determining the average nutrient status in a field as well as the nutrient variability across a field. Each sample was clearly labelled twice, one on the outside of the sample container and the other inside. Soil samples were best collected in plastic bags and transported in the laboratory where they were immediately air-dried for seven day before grinding, sieving and analysis.

After sampling, the rice plant tissues were placed in a paper bag and were transported to the sampling location and relevant information of each sample was included. The samples were then transported to the laboratory for processing. Samples were dried immediately or as soon as possible upon reception in the laboratory to de-activate the enzymes and stop biochemical changes taking place. The samples were rinsed again with distilled water to remove dust or soil contamination. The next action after rinsing was to dry them at 60-70 ^oC in a forced-draught stainless lined oven, which allowed adequate air circulation. After the sample had been dried, roots were removed with scissors and then ground before analysis as indicated in the protocol.

3.3.4. Sample Log-in

Sample log-in is a very important step in any laboratory work for the purpose of retracing a sample that may have been lost. A manual log-in is done in intern laboratories registers immediately upon reception of the samples, however other laboratories may use computer log-in, but in either way should carry detailed information (Okalebo *et al.,* 2002). In this study we used computer log-in by using alphanumeric notation for sample identification and detailed information as follows:

(i) Designate water sample we used (S_w) and indicated the date and time of sampling

(ii) Designate soil sample we used (S_s) and indicated the date and time of sampling

(iii) Designate rice plant tissue sample we used (S_p) and indicate time and date of sampling

In general, the log-in information helped to display more detailed records of sample collection that included the labelling code, sampling points, sampling depth, sampling time, treatment conditions and so on.

Figure 3.6 is a flow diagram of the methodology adopted in sample collection, handling, storage, analysis and interpretation of results in this study.

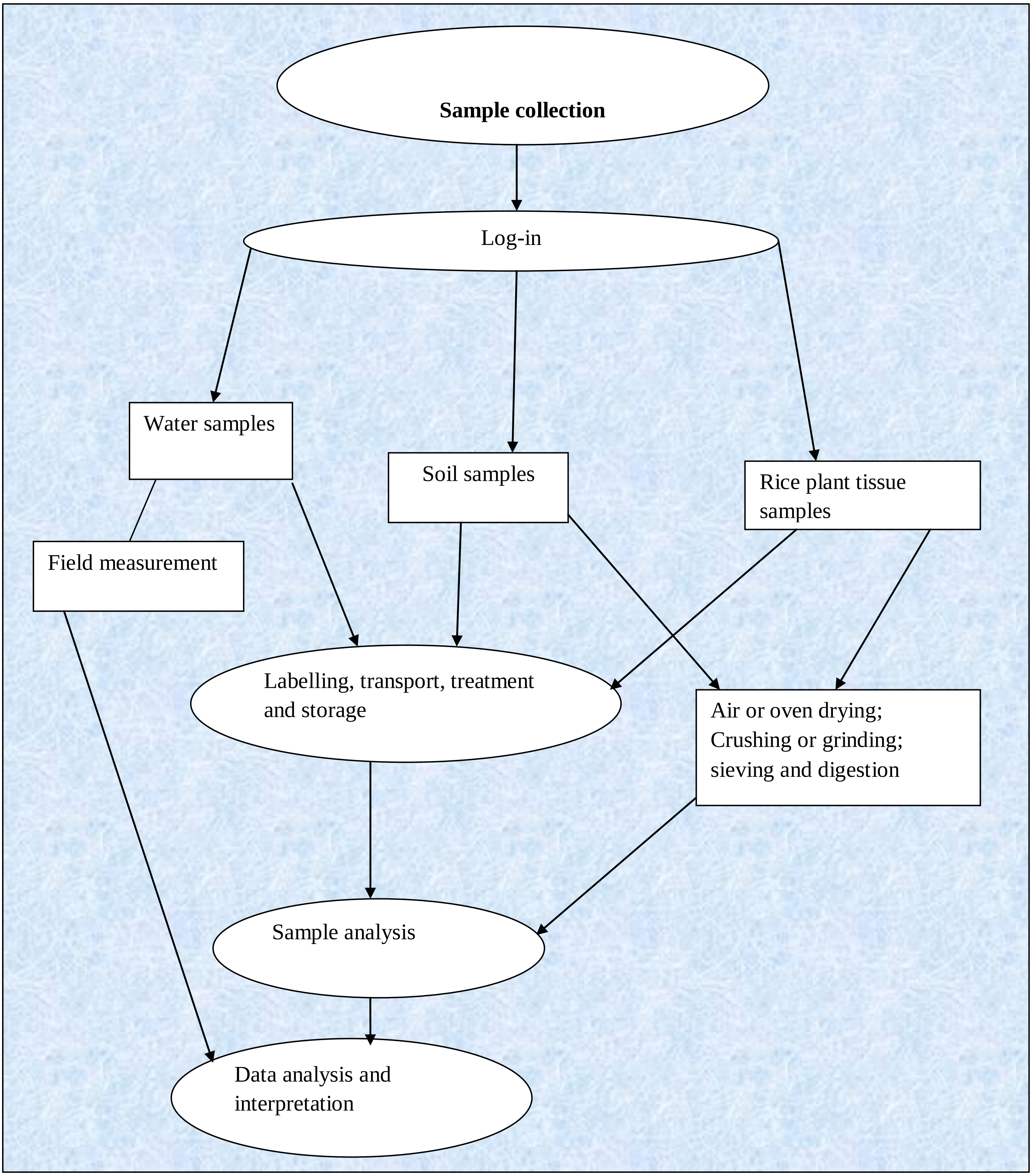


Figure 3.6: Flow diagrams of sample collection, handling, storage and analysis: Adopted from Okalebo *et al.* (2002)

3.4 Data Collection

The primary data were obtained from the laboratories. Samples collected from the study area were analysed jointly in a chemistry and water analytical laboratory of the National University of Rwanda (NUR) and soil and plant analysis laboratory of Rwanda Agriculture Research Institute (ISAR). Rainfall data (the secondary data) collected from Rubona Meteorological Station is placed within the sub-catchment area.

The geographical coordinate data were collected using Handheld GPS (Garmin Venture HC-GPS receiver) to determine the sub-catchment demarcation and sampling points. The map of study area, sampling points, and soil series map were processed using arc GIS (Arc Map version 9.3) in order to illustrate the biophysical status of the study area. A digital camera was used to record some meaningful facets which would give the real status of water management in study area, for example the availability of water in term of quantity in rice plots upstream and downstream, encroachment activities surrounding the irrigation scheme and spatial and temporal variation of water level in the study area. Several parameters were tested simultaneously regarding water, soil and rice plant tissues in order to find out the interrelationship between water quality, soil fertility and rice plant tissue nutrients.

3.4.1 Water

To evaluate the quality of water used for rice irrigation, some parameters were tested such as Temperature (T^0C), Electrical Conductivity ($EC_{w,}$), Total Dissolved Solid (TDS), Hydrogen ion concentration (pH), Sodium (Na^+), Potassium (K^+), Calcium (Ca^{++}), Magnesium (Mg^{++}), Boron (B^-), Chloride (Cl^-), Nitrate (NO_3^-), Sulphate (SO_4^{--}), Bicarbonate (HCO_3^-), Carbonate (CO^{--}), Copper (Cu^{++}), Zinc (Zn^{++}). The pH, Temperature, EC_w and TDS were determined directly on-site electrometrically using digital pH and digital conductivity meter (Model Hanna Conductivity meter)

Calcium (Ca^{++}), Magnesium (Mg^{++}), Copper (Cu^{++}) and Zinc (Zn^{++}) are the cations, were analysed by atomic absorption spectrophotometer (Model Perkin Elmer, Analyst 200). Sodium (Na^{+}), Potassium (K^{+}), also cations elements were determined by flame photometer (Models PFP7). Bicarbonate (HCO_3^{-}), carbonate (CO^{-}) were determined by acidimetric titration method while chloride (Cl^{-}) was determined by argentometric titration method. Boron (B^{-}) and nitrate (NO_3^{-}) were determined by calorimetric method whereas sulphate (SO_4^{--}) was analyzed turbid metrically.

3.4.2 Soil

Soil samples were air-dried and crushed to pass a 2 mm sieve before analysis for pH, Electrical conductivity (Ecs), Available Phosphorus (AP), Cations Exchangeable Capacity (CEC), Potassium (K^{+}), Calcium (Ca^{++}), Magnesium (Mg^{++}), Sodium (Na^{+}) and soil texture (Sand, Silt, Clay). Determination of Total Nitrogen (TN) and Organic Carbon (OC) required a subsample of soil ground to pass a 50-mesh sieve (about 0.5 mm).

To identify the status of soil in the study area, some parameters were tested such as soil texture (sand, silt and clay), Hydrogen ion concentration (pH), Electrical conductivity (EC_s), Total Nitrogen (TN), Available Phosphorus (AP), Potassium (K^{+}), Calcium (Ca^{++}), Magnesium (Mg^{++}), Sodium (Na^{+}), Cations Exchange Capacity (CEC) and Organic Carbon (OC)

3.4.3 Rice Plant Tissues

Plant analysis indicates the nutritional status of the plant. It is used to check for what is hidden in good-looking crop as well as nutrient deficiencies in a poor crop. Nutrient deficiency can occur in the plant due to that nutrient being low in the soil, environmental conditions or herbicide residue or disease. Plant analysis is an agronomic tool that enhances the soil test. To estimate the availability of nutrients and micronutrients in rice plant tissues, the same parameters were tested such as Nitrogen (N), Phosphorus (P), Potassium (K^{+}), Copper (Cu^{++}) and Zinc (Zn^{++}). Table 3.3 gives a summary of the methods used to analyse water, soil and rice plant tissue in the laboratory.

Table 3.3: Summarized method used for collecting quantitative data in the laboratory

Sample	Sample preparation	Parameters	Analytical Method
	Storage in polyethylene bottles		
Water	Kept quite in refrigerator at indicated temperature (4^oC) or concentrated acid	T^o; EC_w; TDS, pH	Electrometric method
	Filtrated before testing	Ca^{++}, Mg^{++}; Cu^{++}; Zn^{++}	Atomic Absorption spectrophotometer
		K^+; Na^+	Flame photometer
		NO_3^-; B;	Colorimetric method
		Cl^-	Argentometric method
		SO_4^{--}	Turbid metric method
		HCO_3^-; CO_3^-	Titrimetric method
Soil	Dried in air for 7 days	pH; ECs	Electrometric method
		Particle size analysis (clay, silt, sand)	Hydrometric method
	Crushed with pestle and mortar	TN	Kjeldhal method (Volumetric)
	sieved by mesh 2mm diameter and 0.5mm for TN and O.C	AP	Bray P1 method
		K^+; Na^+	Flame photometric
		Ca^{++}; Mg^{++}; Zn^{++}; Cu^{++}	Atomic Absorption spectrophotometer
		CEC	Titrimetric method
		OC	Colorimetric method
		N	Kjeldhal method (Volumetric)
Rice plant tissue	Cleaned with deionised water	P	Colorimetric method
	Dried in oven at 70 ^oC	K^+	Flame photometric
	Ground with electronic milling machine and then digested with conc. acid	Cu^{++}; Zn^{++}	Atomic Absorption spectrophotometer

Source*:* Adopted from APHA (2005), Okalebo *et al.* (2002), Geeta (2005), Bartram and Ballance (1996),

3.5 Quality Control and Analytical Assurance

The quality of analytical results is important, because many decisions are based on the data generated by laboratory results. Each step in the sampling, analysis and reporting of data is important, and the quality of the data must be assured at each step in the process (Okalebo *et al.,* 2002). It is also important that procedures be standardized, that they are not only done correctly, but also done the same way each time. The importance of standardized procedures is basic to the quality of results produced by the laboratory. Quality control in the laboratory encompasses a variety of topics. These may be broadly divided into (1) issues dealing with variability in sampling and analytical procedures, and (2) data handling, calculations and reporting of results (Okalebo, 2002; Bartram and Ballance, 1996).

3.6 Parameters Analysed in Irrigation Water Quality

Natural waters are never pure; they always contain varying amounts of dissolved gases and solids (Shaki and Adeloye, 2006). The major ionic species in most natural waters were analysed in irrigation scheme and compared with water quality standards for irrigation set by FAO, US-EPA and many other scholars worldwide. In data analysis, the following points were considered:

(i) The water quality variability within time and space (seasonal variability and from upstream to downstream).

(ii) The physical parameters data directed measured in the field such as $T^{o}C$, pH, EC_w and TDS

(iii) The variation of ions among others anions and cations within the irrigation scheme.

3.7 Data Analysis

Water quality data were analysed in three different stages:

(i) In the first step was to determine the variability of the quality of water as its move from upstream to downstream. The data were assigned to the groups in each classification based on site location and hydrological attribute.

(ii) The second step was to determine seasonal variability of the quality of water used for irrigation. The data were grouped according to season: dry season (August, September); moderate season (November, January); and the rainy season (March, April).

(iii) The third step was to classify the irrigation water quality grouping elements according to FAO guidelines classification of water quality for irrigation; such as: salinity, infiltration and permeability, specific ion toxicity, trace element toxicity and miscellaneous impacts on sensitive crops.

The data were statistically performed using Gen Stat 12th edition software and Microsoft Excel.

3.7.1 Descriptive Statistics

Descriptive statistic (Univariate Analysis) deals with the collection, summarisation, presentation and description of data. This study dealt with central tendencies (mean, mode, median) and dispersions (standard deviation, standard deviation of the mean) in order to display the variability of the quality of water in time and space**.**

The irrigation water quality parameters tested from the laboratory were displayed spatially temporally by applying the following statistical formula (Table 4.1 and Table 4.4):

(i) **Mean ($\bar{X}$):** Σ Xi/n is the average value where the X is X1, X2, X3,............X value of observation and n is the number of observations

(ii) **Maximum (Max):** the maximum is the largest value of the observations

(iii) **Minimum (Min):** the minimum is the smallest value of the observations

(iv) **Median:** the median was obtained by arranging observations in order smallest to largest value and the median is the middle value.

(v) **Standard deviation (STDEV):** $\sqrt{S^2}$ where S^2 is the variance of the samples

(vi) **Mean plus or minus (±) standard error of the mean**: $\bar{X}$±SEM which is the reporting value of variable. SEM is the standard error the estimator used. It tells us within what distance of the estimated parameter we can expect the true value of the parameter.

3.7.2 Inferential Statistics

Inferential statistics were used to make judgments of the probability that were observed between different groups of data analysed. Hence the above statistics were used to test the hypotheses of the study and to make inferences from our data to more general conditions about the spatial temporal variability of water quality and water- soil-plant relationship within the irrigation scheme.

The null hypothesis and alternative hypothesis (Ho and Ha) were formulated as follows:

(i) **Ho: $\mu_1=\mu_2=\mu_3$** There is no significance difference variation of water quality and its impact on rice irrigation in Rusurirwamujyinga sub-catchment.

(ii) **Ha: $\mu_1\neq\mu_2\neq\mu_3$** There is significance difference variation of water quality and its impact on rice irrigation in Rusurirwamujyinga sub-catchment.

The multiple comparisons of general ANOVA by Fisher's protected LSD at 0.05 Significant Level ($P<0.05$) were used to test the hypotheses of the means of samples. The bellow table of ANOVA was used either to accept or to reject our hypothesis. Table 3.6 below, ANOVA table, was used either to accept or to reject our hypothesis.

Table 3.4: ANOVA Table

Source of variation	Degrees of freedom	Sum of squares	Mean square	$F(\alpha)_{calculated}$	$F(\alpha)_{0.05\ LSD}$
Treatment	t-1	SSTrt	MS Trt		
Replication	t-1	SS_{Rep}	MS Rep		
Residual	n-t	SSE	MSE		
Total	n-1	SSTot			

Source: *Osuga (2010)*

(i) **Treatment**: upstream, middle stream, downstream for objective one and dry season, middle season and rainy season for objective two.

(ii) **Replication:** repetition of sampling or time of sampling

(iii) **Residual :** source of errors made in experimental design

(iv) **Total:** total number of treatment, replication and residual in the experiment

3.7.3 Irrigation Water Quality Classification

In irrigation water quality monitoring, priority should be given to those parameters which are known to be of importance to plant growth and which are known to be present in significant concentrations in the water source.

Abdul Jabbar, 2010) stated that the quality of irrigation water resource is associated with five main groups of limitations which are:

(i) Salinity limitation: Electrical conductivity and total dissolved solids.

(ii) Infiltration and permeability limitation: Sodium Adsorption Ratio (SAR) and Electrical Conductivity (ECw).

(iii) Specific ion toxicity: Sodium, Chloride and Boron.

(iv) Trace element toxicity: Copper and zinc.

(v) Miscellaneous impacts on sensitive crops: Nitrate, Sulphate, Carbonate, Bicarbonate and Hydrogen ion concentrations.

These limitations have a negative impact on soil quality and crop yield and were analysed in Rusurirwamujyinga rice irrigation scheme. The water quality parameters forming these groups are selected according to guidelines presented by Ayers and Westcot (1985) and Abdul Jabbar (2010).

3.7.4 Correlation Analysis

Correlation analysis was used to relate x and y in order to verify if x increases or decreases, what will y do (increase, decrease, no change). The correlation between x and y is expressed by the correlation coefficient "**r**" which can be calculated from the following equation.

$$r = \frac{\Sigma(Xi-\overline{X})(Yi-\overline{Y})}{\sqrt{\Sigma(Xi-\overline{X})^2 \Sigma(Yi-\overline{Y})^2}} \quad (3.1)$$

where

$\mathbf{x_i}$ = data **x**; $\bar{\mathbf{x}}$= mean of data **x**; yi = data y; $\bar{\mathbf{y}}$**=** mean of data y

r varies between 1 to -1

r = 1 perfect positive linear correlation

r = 0 no linear correlation

r = -1 perfect negative linear correlation

Correlation coefficient "**r**" is also expressed as "$\mathbf{r}^2$", the coefficient of determination or coefficient of variance. The advantage of "$\mathbf{r}^2$" is that when multiplied by 100, it indicates the percentage of variation in **y** associated with variation in **x**.

The correlation coefficient "**r**" was used to describe statistically the relationship between water quality variables (x and y) but it did not prove cause and effect between independent and dependent variables (x and y).

3.8 Interpretation and Presentation of Results

After the analysis of the data by descriptive, inferential statistics and irrigation water quality index, the results were presented in a tabular, mathematical equation and graphical and text forms for easy interpretation. The results were triangulated with work done by scholars in the area of the assessment of water quality for irrigation in general to compare the relevance of the findings made. This procedure helped in drawing meaningful conclusions from the results obtained and making recommendations for sustainable irrigation water management in Rusurirwamujyinga sub-catchment, upper Mwogo Catchment. The results and discussion, summary of findings, conclusions and recommendations are presented in the subsequent chapters of the study.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and discusses the findings from the research conducted in Rusurirwamujyinga Sub-catchment, Upper Mwogo Catchment. The study used laboratory techniques to extract information about the quality of water used in irrigation and its response on growth of rice in Rusurirwamujyinga irrigation scheme. The results of water quality variability within time and space and its response to growth rice irrigation in the study area are presented statistically by Gen Stat 12th Edition software and Excel spreadsheet. Physical measurements, cations and anions analysis as well as the guide of interpretation of water quality used for irrigation are discussed in this chapter.

4.2 Stream Irrigation Water Quality

The variation of the quality of water was assessed by considering upstream samples (So, S1, S2, S3 and S4), middle Stream (S5, S6, S7 and S8) and downstream (S9, S10 and S11). The results are summarised (Table 4.1). Results from stream variation and their replication (ANOVA table) are presented (Table 4.2).

Table 4.1: The Streams Variability of Irrigation Water Quality

No	Parameter	Up stream Min	Up stream Max	Up stream Mean n=30	Up stream Median	Up stream STDEV	Middle stream Min	Middle stream Max	Middle stream Mean n=24	Middle stream Median	Middle stream STDEV	Down stream Min	Down stream Max	Down stream Mean n=18	Down stream Median	Down stream STDEV
1	T^o (^oC)	19.1	24	21.52	21.55	1.33	21.5	28	24.45	24.2	1.67	22.5	25.3	23.8	23.95	0.82
2	pH	6.24	7.63	7.02	7.07	0.25	6.88	7.6	7.17	7.14	0.17	6.49	7.39	7.01	7.07	0.24
3	TDS (ppm)	37.9	116	75.45	76.3	25.98	37.6	140	80.83	76.75	32.33	22.3	111	75.9	80.65	29.99
4	EC_w (µs/cm)	76.6	147.7	104.7	101.95	16.59	74.8	142.5	110.75	111.2	19.3	75.1	150.6	108.55	110.35	20.25
5	NO_3^- (mg/L)	1.1	5.2	2.12	1.85	0.98	1.5	6.5	2.65	2.2	1.24	1.3	8.1	2.7	2	1.54
6	SO_4^{--} (mg/L)	7	14	9.16	9	1.68	9	14	11.16	11	1.27	10	30	15.55	15	4.87
7	Cl^- (mg/L)	4	19	9.76	9.5	3.98	0.9	32	13.93	15	9.14	1.2	32	13.01	9.5	8.44
8	B^- (mg/L)	0	0.5	0.09	0.07	0.11	0	0.5	0.19	0.15	0.14	0.06	0.15	0.09	0.09	0.02
9	HCO_3^-(mg/L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	CO_3^{--}(mg/L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Ca^{++} (mg/L)	4.4	12	6.9	6.37	1.86	1.75	14.2	6.57	6.04	2.87	1.55	11.8	5.18	4.6	2.75
12	Mg^{++} (mg/L)	0.14	4.44	2.64	3.08	1.03	0.92	5.66	3.05	3.17	1.11	0.16	3.88	2.6	2.85	1.06
13	K^+ (mg/L)	1.01	18.9	4.7	1.95	5.4	1.01	21.6	6.03	2.3	5.99	1.01	18.8	7.12	2.8	6.68
14	Na^+ (mg/L)	2.6	10	5.58	5.03	1.48	4.6	12.5	7.36	6.92	2.11	4.6	12.5	6.91	11.25	2.6
15	Cu^{++} (mg/L)	0.007	0.124	0.047	0.038	0.037	0	0.117	0.036	0.016	0.042	0.003	0.124	0.037	0.017	0.044
16	Zn^{++} (mg/L)	0	0.095	0.023	0.018	0.022	0	0.061	0.022	0.019	0.02	0	0.084	0.022	0.014	0.027

Values of all parameters are in mg/L except pH, Temperature (^oC), Total TDS (ppm) and ECw (µs/cm)

The chemical composition of groundwater and surface water is related to the solid product of rock weathering and changes with respect to time and space. Therefore, the variation on the concentration levels of the different hydro-geochemical constituents dissolved in water determines its usefulness for domestic, industrial and agricultural purposes. However, the use of water for any purpose is guided by the standards set by the FAO, UNESCO, WHO and other related agencies (Obiefuna and Sheriff, 2011). In this study, the results of the analysed chemical parameters were correlated with those of the FAO (1985).

The stream's water quality parameters show means results of parameters measured in the upstream, middle-stream and downstream sections for the rice irrigation scheme (Table 4.1). Several parameters (T^o, pH, TDS, ECw, Cl^-, B^-, Na^+, Mg^{++}) were found increasing more in the middle stream than in the upstream and downstream sections.

The parameters (Ca^{++}, Cu^{++}, Zn^{++}) were high in the upstream while NO^-_3, SO^{--}_4 and K^+ were found to be higher in the downstream section. These measurements show inequitable distribution of physico- chemical parameters within the irrigation scheme due to various encroachment activities surrounding the irrigation scheme. Obiefuna and Sheriff (2011) emphasised the same issue in their study of" Assessment of Shallow Ground Water Quality of Pindiga Gombe Area, Yola Area in Nigeria". They found that the geochemical concentrations vary from one settlement to the other depending on the local geology of the area and other human related factors. The temperature has direct effect on certain chemical and biological activities of the organism in aquatic media (Kumar *et al.*, 2011). The water temperature in middle stream ranged between 21.5 and 28^{o}C. The high temperature in the middle stream is related to several human activities compared to up and downstream sections such as agriculture under pressure, brick making, deforestation on the hillside bordering middle stream (Plate 4.2). The biophysical profile changes dramatically in the middle stream, hence TDS and EC_w were concentrated more here than up and downstream and once increasing EC_w and TDS increasing also, these parameters are dependent each on other. Emamgholizadeh (2008) plotted Electric conductivity and Total Dissolved Solid in Kopal River, Iran. He concluded that reduced flows can cause accelerated increases of Total Dissolved Solids (TDS) concentrations and Electric Conductivity (EC_w) of the river. The same scenario was observed in the study area where stream flows seemed to be reduced in middle stream than upstream and resulted in the soaring of Electric Conductivity and Total Dissolved Solids.

Water pH regulates aquatic chemistry and can impact water use and habitat. The normal pH range for irrigation water is from 6.5 to 8.4 (Emamgholizadeh, 2008). A pH above 8.5 is often caused by high bicarbonate (HCO_3^-) and carbonate (CO^{--}_3) concentrations, known as alkalinity. High carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution. This alkaline water could intensify sodic soil conditions (Bauder *et al.*, 2003). The behaviour of pH in middle stream ranged between (6.88-7.6) with an average of 7.17. This mean that pH has a tendency of floating on acid and alkalinity from upstream to downstream and because of unavailability (under limit of detection) of carbonate and bicarbonate at the moment, leading to disproportion of calcium and magnesium and the presence of sodium ions as the dominant ion in solution (Table 4.1).

Chloride and boron were also found concentrated more in middle stream than up and downstream because of a dynamic significant encroachment activities occurring in the middle stream. Likewise, the presence of calcium, copper and zinc emphasizes the dynamic of heavy metal (Copper and zinc) of leaching by underground water in the upstream section whilst calcium may have originated from sedimentary rock weathering and changes when constructing dam upstream. Such rocks may be calcite, aragonite, gypsum and anhydride. Downstream of the scheme, there was high concentration of nitrate, sulphate and potassium ions. It was observed that there was heavy agricultural activity going on and other encroachments (Plate 4.3). Therefore, it is noted that the flow of fertilisers (Urea and NPK) actually used by rice farmer's cooperative in farming activities which lead to Nitrate, potassium and sulphate is being deposited in downstream.

According to Hayal and Seyoum (2009), nitrate, potassium and sulphate ions are among the highly soluble chemicals and may quickly reach water bodies from soil, organic matter, manures, and artificial fertilisers. On the other hand, Bauder *et al.* (2003) stated that the sulphate ion is a major contributor to salinity in Colorado irrigation waters and sulphate in irrigation water has fertility benefits and may interfere with the uptake of other nutrients. However, the sulphate precipitates easily and settles to the bottom sediment of the river. According to Manyaneza *et al.* (2010), sulphate silicate and phosphate are the hydro-chemical tracers which used to explain the impact of water quality with surface runoff and inform the processes that occur within the catchment, and to estimate the sediment deposit in the stream. The same scenarios were observed in the study area where the hillsides in downstream were shaped by human induced activity which accelerates the erosion and sediment deposit in downstream (Plate 4.3).

The stream variations and their replication in the variables tested showed the least significant difference in water quality as one moves from upstream to downstream (Table 4.2).

Table 4.2: ANOVA table by Fisher's protected LSD at (P< 0.05)

Source of variation	DF	To	pH	E_C	TDS	NO^-_3	SO^{--}_4	CL^-	B^-
Replication	5	8.117***	0.19264**	2063.3***	10383.2***	8.8038***	6.447^{NS}	363.11***	0.00476^{NS}
Streams	2	66.385***	0.19989*	255.3^{NS}	218.7^{NS}	2.4848^{NS}	230.854***	129.03*	0.07471**
Residual	64	1.378	0.04257	206.4	109.6	0.9682	7.683	27.88	0.00171

(*), (**), (***): Significance respectively at $\alpha: 0.05, 0.01$ *and* 0.001
(N.S): No significant difference

(Continuous Table 4.2)

Source of variation	DF	Ca^{++}	Mg^{++}	K^+	Na+	Cu^{++}	Zn^{++}
Replication	5	36.3***	9.664***	276.04***	37.3623***	0.02199042***	0.00633297***
Streams	2	17.474*	1.4261^{NS}	34.47^{NS}	23.2437***	0.00091102***	0.00000609^{NS}
Residual	64	3.733	0.4766	17.59	0.9676	0.00007784	0.00008216

(*), (**), (***): Significance respectively at $\alpha: 0.05, 0.01$ *and* 0.001
(N.S): No significant difference

Using Gen Stat 12th Edition software, by multiple comparisons of general ANOVA table by Fisher's protected Least Significant Difference (LSD) at 0.05 probability [P(α)]. The summarised results were found almost the significant different (Table 4.2). These prove dynamic variation of stream sections (upstream, middle stream, downstream) in term of water quality because of different encroachments by human being in the study area. The least significant difference at probability (α) at 0.05 (95%), 0.01 (99%) and 0.001 (99.9%) were observed almost in stream variation and their replication (Table 4.3). Using Microsoft Excel we reached to computerise the probability of variation stream and their replications in order to test the hypothesis formulated in Objective One.

Table 4.3: Comparison between probability value P(α) calculated of streams and replications and P(α) LSD at 0.05, 0.01 and 0.001

Stream and Replication	Variables	P(α) Calculated	P(α)< 0.05, 0.01 and 0.001
Streams Replication	T^o	$1.72.10^{-13}$ $1.54.10^{-4}$	< 0.001 < 0.001
Streams Replication	pH	$1.3.10^{-3}$ $1.3.10^{-2}$	< 0.01 < 0.05
Streams Replication	EC_w	0.29 4.10^{-7}	> 0.05 < 0.001
Streams Replication	TDS	0.144 0	> 0.05 < 0.001
Streams Replication	NO_3^-	0.084 1.10^{-6}	> 0.05 < 0.001
Streams Replication	SO_4^{--}	6.10^{-10} 0.52	< 0.001 > 0.05
Streams Replication	Cl^-	0.013 9.10^{-9}	< 0.05 < 0.001
Streams Replication	B^-	5.10^{-3} 0.088	< 0.01 > 0.05
Streams Replication	Ca^{++}	0.013 6.10^{-7}	< 0.05 < 0.001
Streams Replication	Mg^{++}	0.057 $4.54.10^{-12}$	> 0.05 < 0.001
Streams Replication	K^+	0.149 $4.64.10^{-10}$	> 0.05 < 0.001
Streams Replication	Na^+	$1.65.^{10-8}$ $4.45.^{10-8}$	< 0.001 < 0.001
Streams Replication	Cu^{++}	$4.67.10^{-5}$ $3.25.10^{-42}$	< 0.001 < 0.001
Streams Replication	Zn^{++}	0.929 $9.45.10^{-26}$	> 0.05 < 0.001

Most of values calculated (Table 4.3) proved the significant difference P (α) probability less than 0.05, 0.01 and 0.001. The stream probability [P(α)] calculated showed that the variables (T^o, SO_4^{--}, Na^+, Cu^{++}) were significantly different at P<0.001 (99.9 %) and (pH, Cl^-, Ca^{++}) were significantly different at P< 0.05 (95%) while B^- was significantly different at 0.01

(99%) (Table4.3). The above results showed the change in water quality from upstream to downstream. The replication of sampling (six time of sampling for each stream) at the same points also emphasised this situation because of (T^o, ECw, TDS, NO^-_3, Cl^-, Ca^{++}, Mg^{++}, Na^+, K^+, Cu^{++} and Zn^{++}) were significantly different at $P<0.001$ (99.9%) while pH was significantly different at $P< 0.01$ (99%) (Table 4.3).

It can be argued that the parameters tested at different stream positions (upstream middle and downstream) and replications of sampling within the streams (six replications for each position) showed that there is a significant difference in water quality when one moves from upstream to downstream and when samples are taken at different times. As for Objective One, it was very important to use inferential statistical results (Table 4.2 and Table 4.3) and testing Null (Ho) and the Alternative Hypothesis (Ha). The Null hypothesis (Ho) was formulated as following: Ho: $\mu_1=\mu_2=\mu_3$, that there is no significant difference variation of water quality as it moves from upstream, middle stream to downstream, while the alternative hypothesis (Ha) formulated: Ha: $\mu_1\neq\mu_2\neq\mu_3$ there is significant difference variation of water quality as it moves from upstream, middle stream to downstream. In general, the alternative hypothesis was accepted and the null hypothesis was rejected because all the variables showed some least significant difference.

To understand the distribution of physico-chemical parameters measured for irrigation water quality, we considered three important groups, such as the group of physical parameters, which were directly measured in the field: (Temperature (T^oC), Electrical Conductivity (ECw), Total Dissolved Solids (TDS) and Hydrogen ion concentration (pH). The Group of anions (NO_3^-, SO_4^{--}, Cl^-, B^-,) and cations (Ca^{++}, Mg^{++}, Na^+, K^+, Cu^{++} and Zn^{++}) were also considered in ensuring the meaningfulness of the graph plotted. Emongor et al. (2005)

studied the irrigation water in Bostwana. The water contained varying amounts of cations and anions. Among them, the main soluble cations were Ca^{++}, Mg^{++}, Na^{+} and K^{+}, and anions were Cl^{-}, SO_4^{--}, CO_3^{--} and HCO_3^{-}. Out of the soluble constituents, Ca^{++}, Mg^{++}, Na^{++}, Cl^{-}, SO_4^{--}, HCO^{-}_3 and B^{-} are of prime importance in judging the water quality for irrigation. Therefore, the results of irrigation water quality from the study area were grouped and plotted, looking on three consecutive groups as physical parameters, anions and cations. Figure 4.1 shows the distribution of T^{o}, ECw, TDS, and pH.

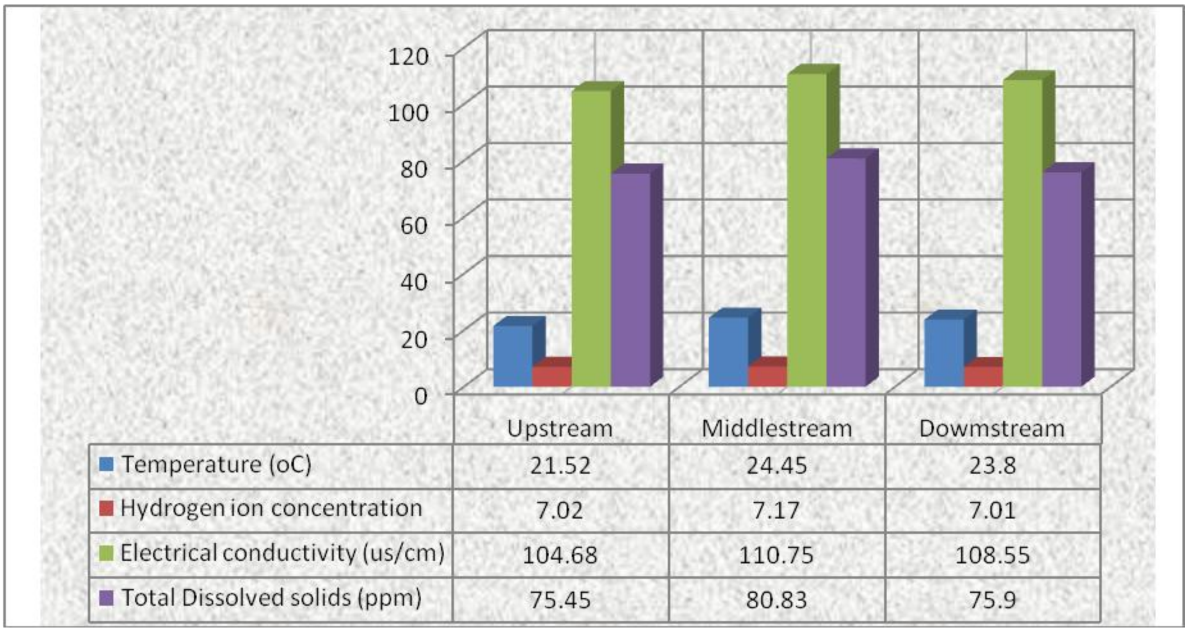


Figure 4.1: Streams distribution of the physical water parameters measured in Rusurirwamujyinga rice irrigation scheme.

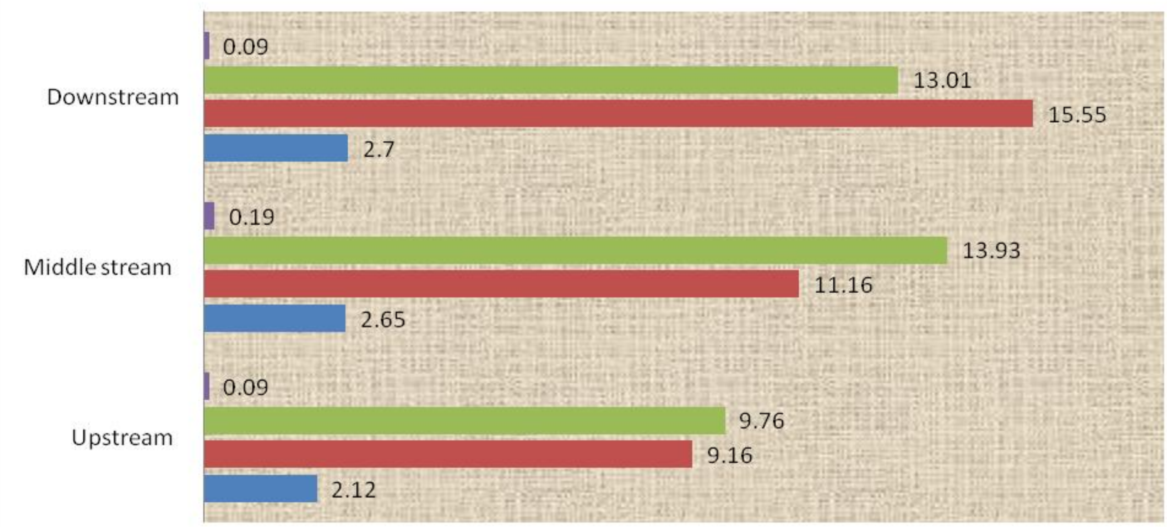
The physical parameters directly measured within Rusurirwamujyinga rice irrigation scheme showed the expected significant interconnectivity between ECw and TDS where if one increases causes the other to increase and if one decreases causes the other to decrease simultaneously. Based on research done by other scholars we tested and we proved that when the electrical conductivity and total dissolved solids increase the river flow decreases. Emamgholizadeh (2008), Plotted Electric Conductivity and Total Dissolved Solid versus Flow Discharge and concluded that reduced flows can cause accelerated increases of Total

Dissolved Solids (TDS) concentrations and Electrical Conductivity (EC) in downstream reaches of the river. In the study area, the middle stream flows physically seemed to be reduced more by human encroachment (Plate 4.2) than upstream where water from the dam concentrates in the rice canals and plots (Plate 4.1). All physical parameters measured *in situ* (T^o, EC, TDS and pH) seemed to be higher in the middle stream and downstream than upstream. The main causes of this occurrence is human encroachment through several activities such as agricultural under pressure, deforestation, brick making and other human activities which are concentrated more in the middle and downstream than upstream (Plate 4.1, Plate 4.2 and Plate 4.3).

Plate 4.1*:* Rusurirwamujyinga rice plot and dam (upstream) used for rice irrigation

Plate 4.2: Human encroachment in middle stream of irrigation scheme

Figure 4.4 illustrates the status of anions within the scheme, where NO_3^- and SO_4^{--} were found dominant in downstream while Cl^- and B^- were concentrated in middle stream.



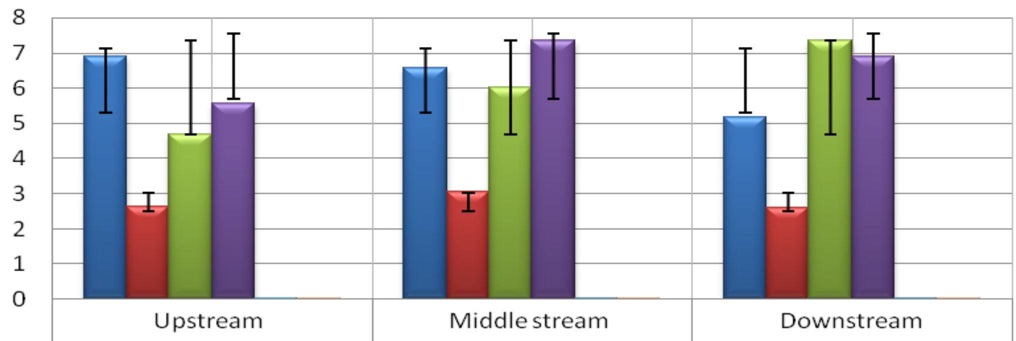
	Upstream	Middle stream	Downstream
Boron (mg/L)	0.09	0.19	0.09
Chloride (mg/L)	9.76	13.93	13.01
Sulphate (mg/L)	9.16	11.16	15.55
Nitrate (mg/L)	2.12	2.65	2.7

Figure 4.2: Streams distribution of the anions in Rusurirwamujyinga rice irrigation scheme

The nitrate and sulphate anions were found concentrated in the downstream as indication of the loss of fertilisers and sediment loaded in downstream. Farming activities using organic and inorganic fertiliser were observed in the scheme and on hills surrounding the scheme which may be the common source of nitrate increasing toward the direction of Rusurirwamujyinga River (upstream, middle and down). Edwin (1996) observed that nitrate from the soil is soluble and mobilised through soil profile. Nitrate is also observed in surface runoff during rainfall events and in groundwater during periods of rain by the process of leaching. Likewise, Sulphate is normally associated with nutrients and absolved by plant. This explains the flow of Sulphate and Nitrate from upstream to downstream. Sulphate is also an indicator of estimating erosion and sediment in the river. The scenario was observed in downstream by soil erosion and encroachment surrounding the irrigation scheme (Plate 4.3).

Plate 4.3: Tiles making and soil erosion surrounding downstream of irrigation scheme

The chloride and boron were dominant in middle stream because of dynamic significance of encroachment activities, loss of biodiversity and increase of water pollutants from upstream to downstream. The scenario was assessed by physical observation where the middle and downstream show signs of environmental degradation, soil erosion, bare soil, deforestation, brick and tile making and many other human induced activities. These lead to inaccessibility of water required and poor production of rice. Figure 4.3 shows the cations distribution within the irrigation scheme. The Ca^{++}, Cu^{++} and Zn^{++} are found in high concentration in the upstream while Mg^{++} and Na^{+} found concentrate in middle stream and K^{+} is high in downstream.



	Upstream	Middle stream	Downstream
Calcium (mg/L)	6.9	6.57	5.18
Magnesium (mg/L)	2.64	3.05	2.6
Potassium (mg/L)	4.7	6.03	7.36
Sodium (mg/L)	5.58	7.36	6.91
Copper(mg/L)	0.047	0.036	0.037
Zinc (mg/L	0.023	0.022	0.022

Figure 4.3: Streams distribution of the cations in Rusurirwamujyinga rice irrigation scheme

Calcium, copper and Zinc were found slightly higher in upstream than middle and down. The presence of calcium upstream is explained by calcite rocks and gypsum rocks and other sedimentary rocks which may be weathered and changed and remain in water source upstream. The same applies for copper and zinc which are trace elements found normally in nature but whose high concentration may be very harmful to crops, animals and human being. Copper and Zinc are also among the group of heavy metals which are the results of geo accumulation and bioaccumulation because they are associated with geological rock and biological species. The source of their presence in upstream is the same as middle and downstream because their concentration is very low. They were found as trace elements in the rice irrigation scheme. Potassium is among the nutrients taken up by plants, the same as nitrate. It increases from upstream to downstream going in the direction of river flow. Potassium comes from fertilisers (NPK) applied by farmers and flows downstream and is interconnected with nitrate and sulphate in the scheme (Figure 4.2 and Figure 4.3). Sodium is the cation which characterises poor soil. High concentrations of sodium in irrigation water can result in the degradation of soil structure. This will reduce water infiltration into the soil surface and down the profile, and limit aeration, leading to reduced crop growth (Bauder et al., 2003). The presence of sodium in middle stream is supported the argument which pointed up to the dramatic encroachment of middle stream of the rice irrigation scheme.

4.3 Seasonal Irrigation Water Quality

The seasonal variation of the quality of water was assessed by considering Rwandan climate which has an annual cycle of four seasons: two rainy seasons and two dry seasons (Twagiramungu, 2006 and Nahayo 2009). These are:

(i) A short rainy season (October - November); only the month of November is characterized by heavy precipitation.

(ii) A short dry season (December - January).

(iii) A long rainy season (February - May) bringing 14 to 61% of the annual precipitation.

(iv) A long dry season (June - September).

Figure 4.4 illustrates the long term average monthly rainfall distribution from 1997 to 2010 in Rusurirwamujyinga sub-catchment which is characterised by an annual cycle of rainy season, dry season and short rainy season and short dry season.

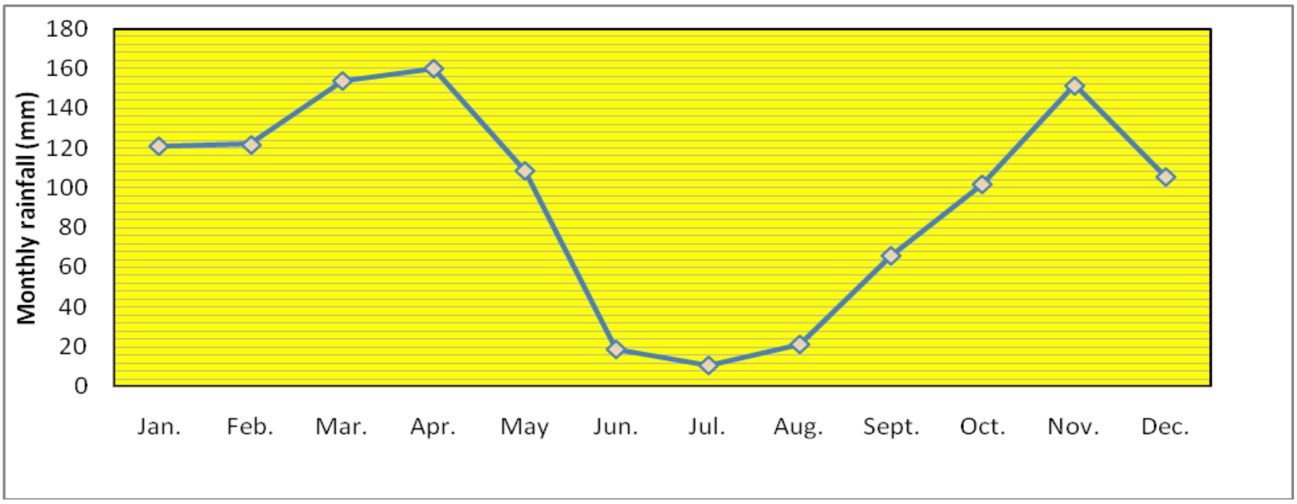


Figure 4.4: Long term average monthly rainfall trend in the study area (1997-2010)
Source: Rubona meteorological station (2011)

We sampled water using the above guide of annual cycle of four seasons where two time of sampling were taken per season.

The seasonal variation of the quality of water was assessed by considering the samples taken in the dry season (August and September), the short rainy and dry season (November and January) and the rainy season (March and April). The descriptive statistics (min, max, mean, median and standard deviation) results are summarised in Table 4.4.

Table 4.4: The season variability of irrigation water quality

		Dry season (August and September)					Short rainy and short dry season (November and January)					Rainy season (March and April)				
No	Parameter	Min	Max	Mean n=24	Median	STDEV	Min	Max	Mean n=24	Median	STDEV	Min	Max	Mean n=24	Median	STDEV
1	$T^o(^oC)$	19.1	26.8	22.63	22.45	1.92	20	26.8	22.6	21.85	1.7	20.5	28	24.02	23.9	1.74
2	pH	6.73	7.63	7.21	7.12	0.23	6.67	7.63	7.14	7.05	0.25	6.24	7.3	7.04	7.11	0.23
3	TDS (mg/L)	78	132	101.08	100.5	12.85	37.6	140	74.4	70.3	35.05	37.6	74.6	52.7	50.1	11.8
4	ECw (µs/cm)	85	150.6	115.6	129.05	19.8	81	136	108.6	110.9	13.03	74.8	142.5	98.7	103	18.12
5	NO_3^- (mg/L)	1.3	5.2	2.3	2	0.99	1.1	8.1	3.01	2.45	1.73	1.3	3.3	1.97	1.95	0.46
6	SO_4^{--} (mg/L)	7	30	12.04	11	5.31	7	17	11.04	10.5	2.78	8	18	11.2	11	2.5
7	Cl^- (mg/L)	6	32	16.58	15	7.69	8	27	13.38	12.5	5.33	0.9	10	5.14	5.5	2.29
8	B^- (mg/L)	0	0.5	0.13	0.09	0.15	0	0.33	0.11	0.09	0.09	0.04	0.5	0.13	0.1	0.11
9	HCO_3^- (mg/L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	CO_3^{--} (mg/L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Ca^{++} (mg/L)	3.88	7.44	5.82	5.76	0.72	1.7	12	7.92	8.12	2.49	1.55	14.2	5.33	4.62	3.01
12	Mg^{++} (mg/L)	2.46	3.88	3.32	3.27	0.32	0.14	5.66	2.74	3.05	1.44	1.26	4.16	2.23	2.01	0.86
13	Na^+ (mg/L)	4.64	12.5	8.12	7.5	2.36	2.6	7.15	5.35	4.95	1.15	4.2	8.2	6.04	5.67	1.24
14	K^+ (mg/L)	1.3	21.6	8.4	5.94	6.29	1.01	18.9	7	2	6.85	1.24	4.06	1.84	1.88	0.55
15	Cu^{++}(mg/L)	0	0.054	0.024	0.025	0.01	0.003	0.018	0.008	0.007	0.003	0.059	0.124	0.091	0.09	0.02
16	Zn^{++} (mg/L)	0	0.009	0.001	0	0.002	0.011	0.05	0.025	0.02	0.01	0.012	0.095	0.04	0.034	0.02

Value of all parameters are in mg/L except pH, Temperature (^oC), Total TDS (ppm) and ECw (µs/cm)

The seasonal water quality parameters are shown by different mean results of parameters measured in the dry season, the short dry and rainy season and the rainy season in irrigation scheme. Several parameters (pH, ECw, TDS, SO_4^{--}, Cl^-, Mg^{++}, Na^+, K^+ and Cu^{++}) were found to be higher in the dry season than in the rainy and short dry and rainy seasons. NO_3^-, Ca^{++} and Zn^{++} were concentrated in the dry and rainy season while (T^o) was highest in the rainy season. The B^- showed the same concentration both in dry season and rainy season. According to Obiefuna and Sheriff (2011) the chemical composition of groundwater and surface irrigation water is related to the solid product of rock weathering and changes with respect to time and space. It had been observed that the ECw and TDS are two elements that were interconnected which were found to increase in the dry season when Rusurirwamujyinga river flow decreased. This is why ECw and TDS soared in the dry season.

Similarly, SO_4^{--}, Cl^- , Mg^{++}, Na^+ and K^+ were found concentrated in the dry season because of the process of evaporation which is very high in the dry season and allows chemical and solid compounds to accumulated greater in water and soil in the dry season than in the rainy season when the dilution occurs. The Cu^{++} and Zn^{++} were found in very small amounts both in the dry and rainy season. Insignificant amounts in variation were found in the dry season, short dry and rainy season and rainy season. The NO_3^- and Ca^{++} were found increased in moderate period because of NO_3^- accumulated in the farming season which is characterised by organic and inorganic fertiliser, by runoff NO_3^- could leach easier the rivers. The increase in the moderate season of Ca^{++} concentration was due to sedimentary rocks such as calcite rocks and gypsum rocks and which may be weathered by the runoff in the moderate season.

The seasonal variations and their replication in almost all variables tested showed the least significant difference in water quality (Table 4.5).

Table 4.5: ANOVA table by Fisher's protected LSD at (P< 0.05)

Source of variation	DF	T°	PH	EC	TDS	NO_3^-	SO_4^{--}	Cl^-	B^-
REP	1	0.405^{NS}	0.00222^{NS}	4741.8***	10870.8***	15.217***	6.13^{NS}	0.45^{NS}	0.00007^{NS}
SEASONS	2	17.145**	0.09583^{NS}	1745.4**	12033.1***	6.772**	6.89^{NS}	872.57***	0.0034^{NS}
Residual	68	3.336	0.05725	232.4	359.3	1.209	14.2	31.06	0.01553

(*), (**), (***): Significance respectively at $\alpha: 0.05, 0.01$ *and* 0.001

$^{(N.S)}$: No significant difference

(Continuous Table 4.5)

Source of variation	DF	Ca^{++}	Mg^{++}	K^+	Na^+	Cu^{++}	Zn^{++}
REP	1	63.638***	0.7575^{NS}	230.19**	70.053***	0.00585***	0.0032805***
SEASONS	2	45.478***	7.159**	286.46***	50.033***	0.0462205***	0.009482***
Residual	68	4.423	0.9794	26.06	1.84	0.0002715	0.000216

(*), (**), (***): Significance respectively at $\alpha: 0.05, 0.01$ *and* 0.001

$^{(N.S)}$: No significant difference

Source: *Author (2011)*

Gen Stat 12th Edition software, by multiple comparisons of general ANOVA table by Fisher's protected Least Significant Difference (LSD) at 0.05 probability [P($\boldsymbol{\alpha}$)]. The summarised results were found almost the significant different (Table 4.5). These prove the change in seasons in term of water quality with climate variability. The least significantly different results at probability (**$\boldsymbol{\alpha}$)** at 0.05 (95%), 0.01 (99%) and 0.001 (99.9%) were observed in almost all seasonal variations and their replications (Table 4.6). Using Microsoft Excel, we computerised the probability of seasonal variations and their replications in order to test the hypothesis formulated in Objective Two.

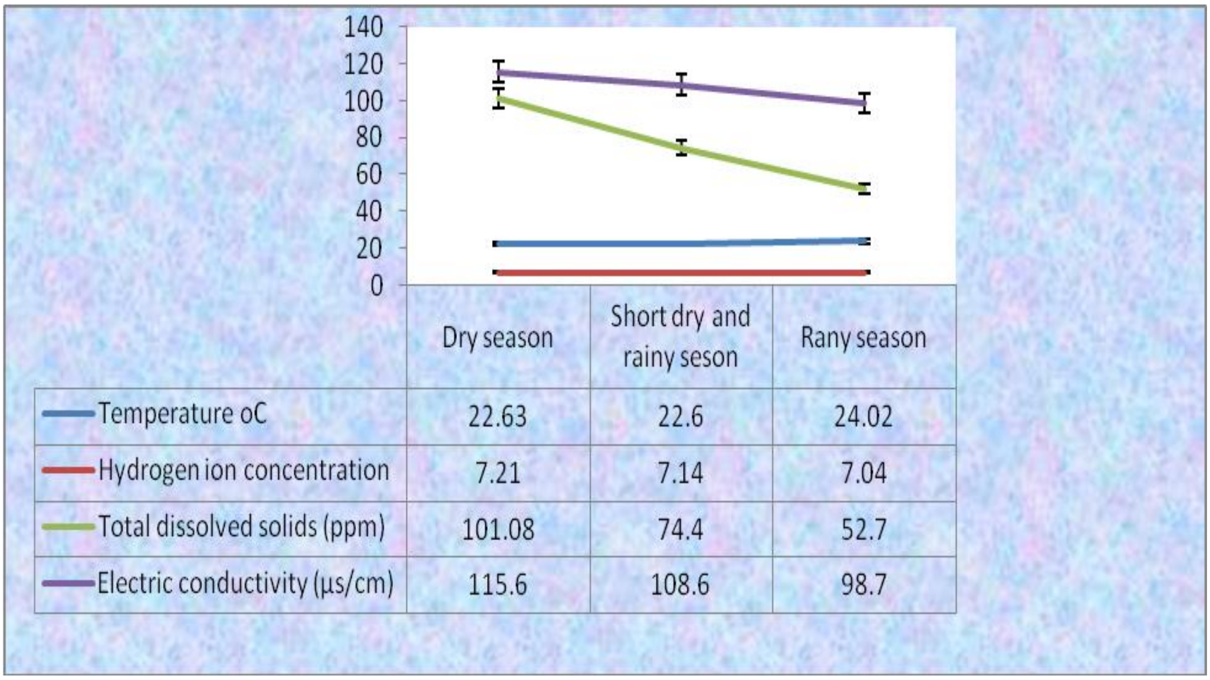
Table 4.6: Comparison between probability value P (α) calculated by seasons and replications and P (α) LSD at 0.05, 0.01 and 0.001

Season and replication	variables	P(α) calculated	P(α) < 0.05, 0.01 and 0.001
Seasons Replications	T^{o}	0.008 0.73	<0.01 > 0.05
Seasons Replications	pH	0.195 0.842	> 0.05 > 0.05
Seasons Replications	EC_w	0.01 $2.55.10^{-7}$	< 0.01 < 0.001
Seasons Replications	TDS	$7.51.10^{-11}$ $6.185.10^{-7}$	< 0.001 < 0.001
Seasons Replications	NO_3^-	0.006 $7.08.10^{-4}$	< 0.01 < 0.001
Seasons Replications	SO_4^{--}	0.168 0.518	> 0.05 >0.05
Seasons Replications	Cl^-	$1.28.10^{-9}$ 0.920	< 0.001 > 0.05
Seasons Replications	B^-	0.804 1	> 0.05 > 0.05
Seasons Replications	Ca^{++}	$1.26.10^{-4}$ $3.18.10^{-4}$	< 0.001 < 0.001
Seasons Replications	Mg^{++}	0.001 0.383	< 0.01 >0.05
Seasons Replications	K^+	$7.31.10^{-5}$ 0.004	< 0.001 < 0.01
Seasons Replications	Na^+	$2.09.10^{-9}$ $4.26.10^{-8}$	< 0.001 < 0.001
Seasons Replications	Cu^{++}	$3.36.10^{-27}$ $1.63.10^{-5}$	< 0.001 < 0.001
Seasons Replications	Zn^{++}	$5.75.10^{-13}$ $2.26.10^{-4}$	< 0.001 < 0.001

The exact values calculated (Table 4.6) proved the significant difference of P (α) probability less than 0.05, 0.01 and 0.001. The season probability [P(α)] calculated showed that the variables (TDS, Cl^-, Ca^{++}, K^+, Na^+, Cu^{++} and Zn^{++}) were significantly different at P<0.001 (99.9 %) whilst (T^o, ECw, NO_3^-, Mg^{++}) were significantly different at P< 0.01 (99%) (Table 4.6). Results showed seasonal replication changes in water quality, with season replication of sampling (two time of sampling of each season) also emphasised this situation because the ECw, TDS, NO_3^-, Ca^{++}, Na^+, Cu^{++} and Zn^{++} concentration were significantly different at $P<0.001$ (99.9%) and K^+ was significant difference at $P< 0.01$ (99%) (Table 4.6).

It can be argued that the parameters tested at different seasons (dry season,short dry and rainy season and rainy season) and replications of sampling within the seasons (two replications for each season) showed that there is almost significant difference in water quality from dry season short rainy and dry season and rainy season. To investigate Objective Two it was very important to use inferential statistical results (Table 4.5 and Table 4.6) and end up by deciding on the Null Hypothesis (Ho) and the Alternative Hypothesis (Ha). The Null Hypothesis (Ho) was formulated as following: Ho: $\mu_1=\mu_2=\mu_3$: that there is no significant difference in seasonal variability in water quality within rice irrigation scheme, while the alternative hypothesis (Ha) formulated: Ha: $\mu_1\neq\mu_2\neq\mu_3$: that there is significant difference in seasonal variability in water quality within the rice irrigation scheme. The alternative hypothesis was accepted and the null hypothesis was rejected because of all the variables showed some significance difference.

To understand well the meaning of the graph plotted for seasonal water quality variability within the rice irrigation scheme, we considered three important groups such as the group of physico parameters measured *in situ*, group of anions and group of cations. Figure 4.5 shows the seasonal variation of physico parameters measured *in situ*.



	Dry season	Short dry and rainy seson	Rany season
Temperature oC	22.63	22.6	24.02
Hydrogen ion concentration	7.21	7.14	7.04
Total dissolved solids (ppm)	101.08	74.4	52.7
Electric conductivity (μs/cm)	115.6	108.6	98.7

Figure 4.5: Seasons distribution of the physical parameters measured in Rusurirwamujyinga rice irrigation scheme

The mean value of ECw and TDS and pH were found increased in the dry season than in the short dry and rainy season and rainy season. The trend shows decrease in concentration from dry season to rainy season. Generally, in the dry season high evaporation occurs and concentrates the chemical and solids compound in the water and the river flow reduced. These showed how ECw and TDS increased in the dry season when Rusurirwamujyinga River and discharge from the dam is reduced in the dry season (plate 4.4). The important physical observation in the field was that the river flow slows in the dry season due to the problem of water irrigation management and encroachment activities and the discharge could be insignificant compared to that observed in the rainy season and activate the increasing of ECw and TDS. Increased of pH occurs because evaporation in the study area in the dry season facilitated the hydroxide ion to concentrate (OH^-) in water body and increased the alkalinity slightly within the scheme in the dry season.

Temperature measured in the dry season was slightly lower. The mean temperature was between 22.63 and 24°C in the rainy season because the study area is characterised by sub-equatorial temperate climate where the temperature fluctuates around 20°C.

Plate 4.4: Rusurirwamujyinga outlet dam (the main canal upstream) in the rainy and dry seasons

Figure 4.6 shows how the anions were seasonally distributed within the rice irrigation scheme

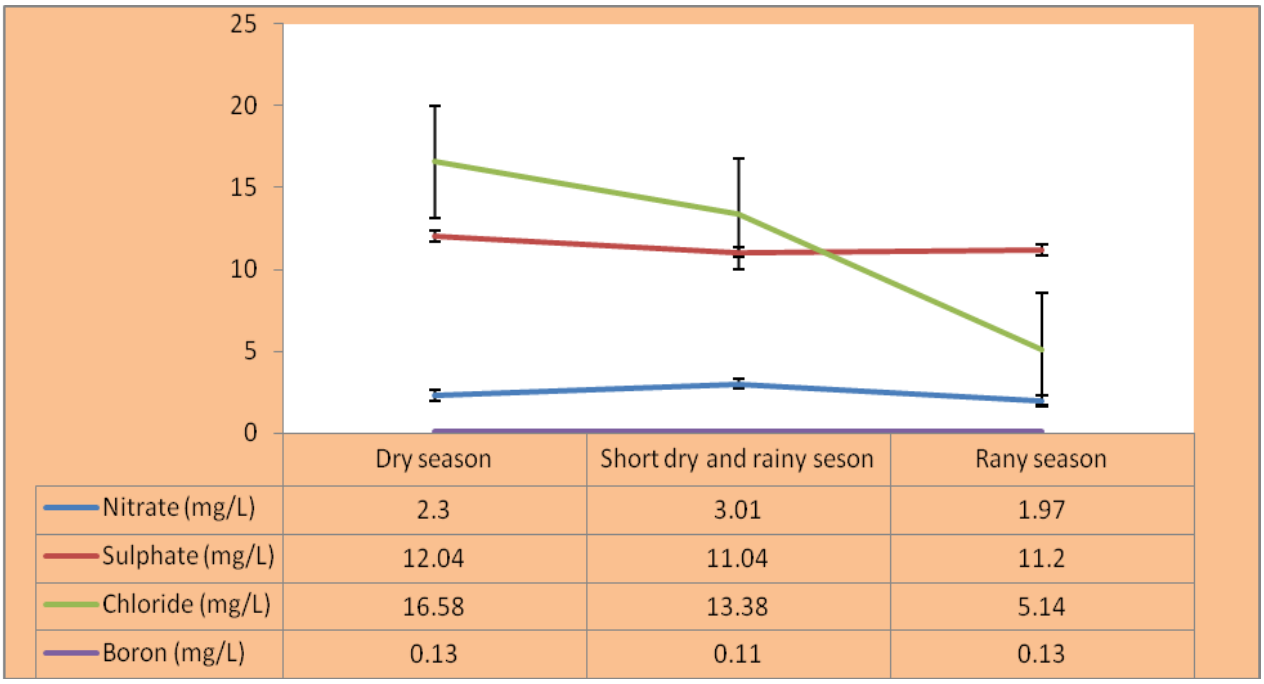
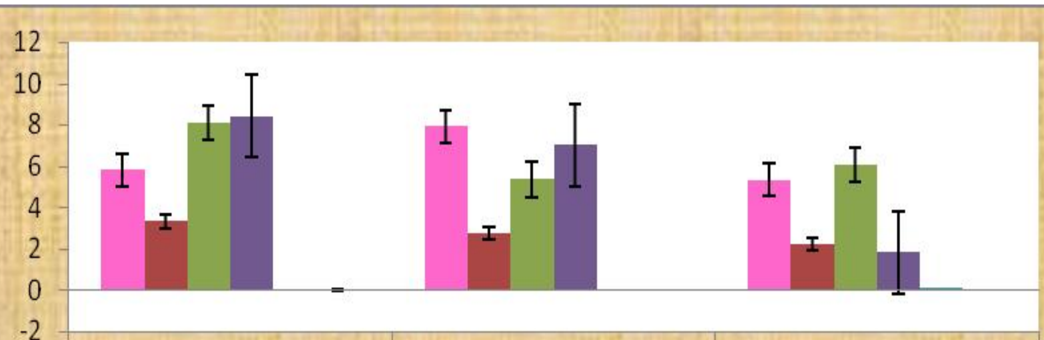


Figure 4.6: Seasons distribution of the anions in Rusurirwamujyinga rice irrigation scheme

The mean season anions compounds were totally different in concentration where chlorides were shiftily decreased from dry season to rainy season because high evaporation facilitated the chloride to concentrate in surface and ground water. The presence of chloride in dry season explained the residue of non-point source of pollution from agricultural activities and other human activities. These were deposited by evaporation in the dry season and diluted in the rain season. The same scenario was observed by Kumar *et al.* (2011) in the assessment of seasonal variation and water quality index of Sabarmati River and Kharicut, India, found that high values of chloride in summer months may be associated with high temperature which enhances the evaporation, reducing the volume of water, thus resulting in the high concentration of salts. The sulphates were slightly decreased from the dry season to the rainy season because of sulphate is associated with sediments and nutrients from erosion found concentrated by evaporation in the dry season and diluted in the rainy season. The seasonal distribution of nitrate in the scheme was slightly increase from dry season to short dry and rainy season and decreased in rainy season. This phenomenon justified by rice planting period (July-August) accompanied by the application of fertilisers and leaching in water surface and ground water and increased in short dry and rainy season where others crops are being farmed upland around the irrigation scheme and decreased in harvesting period. Boron remained in very small amounts in all seasons. As a trace element it could neither be concentrated by evaporation nor diluted by the rain within the irrigation scheme. Figure 4.7 shows the seasonal distribution of cations in rice irrigation.



	Dry season	Short dry and rainy seson	Rany season
Calcium (mg/L)	5.82	7.92	5.33
Magnesium (mg/L)	3.32	2.74	2.23
Potassium (mg/L)	8.12	5.35	6.04
Sodium (mg/L)	8.4	7	1.84
Copper (mg/L)	0.024	0.008	0.091
Zinc (mg/L)	0.001	0.025	0.04

Figure 4.7: Seasons distribution of the cations in Rusurirwamujyinga rice irrigation scheme

The mean distribution of cations in rice scheme were justified by almost cations have the capacity of accumulating in water body by evaporation in the dry season and diluted in the rainy season. Because the soil texture in irrigation scheme is mostly clay (Appendix 5 and 6), the process evaporation is very high in the dry season and allows the cations to be more heavily accumulated in water and soil in the dry season than in the rainy season. This is because potassium; magnesium and sodium were increased more in the dry season than in the rainy season. This does not occur with copper, zinc and calcium. Copper and zinc are found in very small amount, they neither have the capacity to concentrate by evaporation in the dry season nor to be diluted by rain in the rainy season within the scheme. Another complex exception is the significant concentration of calcium in the short dry and rainy season because calcium is concentrated upstream it comes from sedimentary rocks such as calcite rocks and gypsum rocks and others which may be weathered by several activities including dam construction and residual deposit in the area which in the dry season has little significance about water level and the significance availability of calcium was exception understood in short dry and rainy season because water flowing and extends the area.

4.4 Water Soil and Plant Interrelationship

To fulfil this objective, we considered the parameters tested alternatively in water, soil and plant rice tissues to show their distribution in Rusurirwamujyinga rice irrigation scheme. The water- soil- plant parameters comparatively measured were:

Nitrogen compounds (total nitrogen in soil and plant tissue and nitrate in water); potassium, copper and zinc in soil, water and plants. The samples in water were measured in milligram per litre; the sample in soil were measured in milligram per kilogram potassium, copper and zinc and in percentage (%) the total nitrogen; the samples in plants were measured in percentage (%) for total nitrogen and potassium, in milligram per litre for copper and in microgram per litre for zinc (Table 4.7).

Table 4.7: Water quality parameters, soil nutrients and rice plant tissues nutrients in Rusurirwamujyinga rice irrigation scheme

	Nitrogen			Potassium			Copper			Zinc		
Sample	TN-Soil (%)	TN-Plant (%)	N-NO_3 water (mg/L)	K-Soil (mg/kg)	K-Plant (%)	K-Water (mg/L)	Cu-Soil (mg/Kg)	Cu-Plant (mg/Kg)	Cu-Water (mg/L)	Zn-Soil (mg/kg)	Zn-Plant (µg/kg)	Zn-Water (mg/L)
S1	0.295	1.51	1.71	1.03	0.78	5.08	1.75	0.02	0.04	2.375	0.011	0.02
S2	0.28	1.3	2.68	1.25	0.86	5.37	2.16	0.02	0.04	0.46	0.024	0.02
S3	0.3	1.43	2.35	1.145	1.01	4.65	3.91	0.023	0.04	0.838	0.012	0.02
S4	0.295	1.27	2.26	1.145	0.87	3.74	3.63	0.04	0.04	1.5	0.015	0.02
S5	0.285	0.97	2.91	1.035	0.91	4.81	2.98	0.019	0.04	0.425	0.013	0.02
S6	0.315	1.54	2.9	1.365	0.8	4.44	2.78	0.041	0.03	0.503	0.016	0.02
S7	0.335	1.09	2.41	1.77	0.83	6.46	4	0.021	0.03	0.255	0.039	0.02
S8	0.325	1.31	2.23	1.33	0.65	8.43	5.06	0.044	0.03	0.265	0.011	0.02
S9	0.31	1.51	2.33	1.285	0.86	9.4	3.2	0.048	0.03	0.525	0.062	0.02
S10	0.31	1.43	2.03	1.225	0.96	5.8	3.1	0.003	0.03	0.74	0.012	0.02

Soil water plant relationship is very important because it gives the picture of how nutrients from soil are being dissolved and taken up by plant at their different growth cycle and how nutrients are washed in soil by runoff and down to rivers, lakes and reservoirs of water. This study considered the same parameters measured at the same time in same sampling points. The distribution of results is illustrated in figure 4.7.

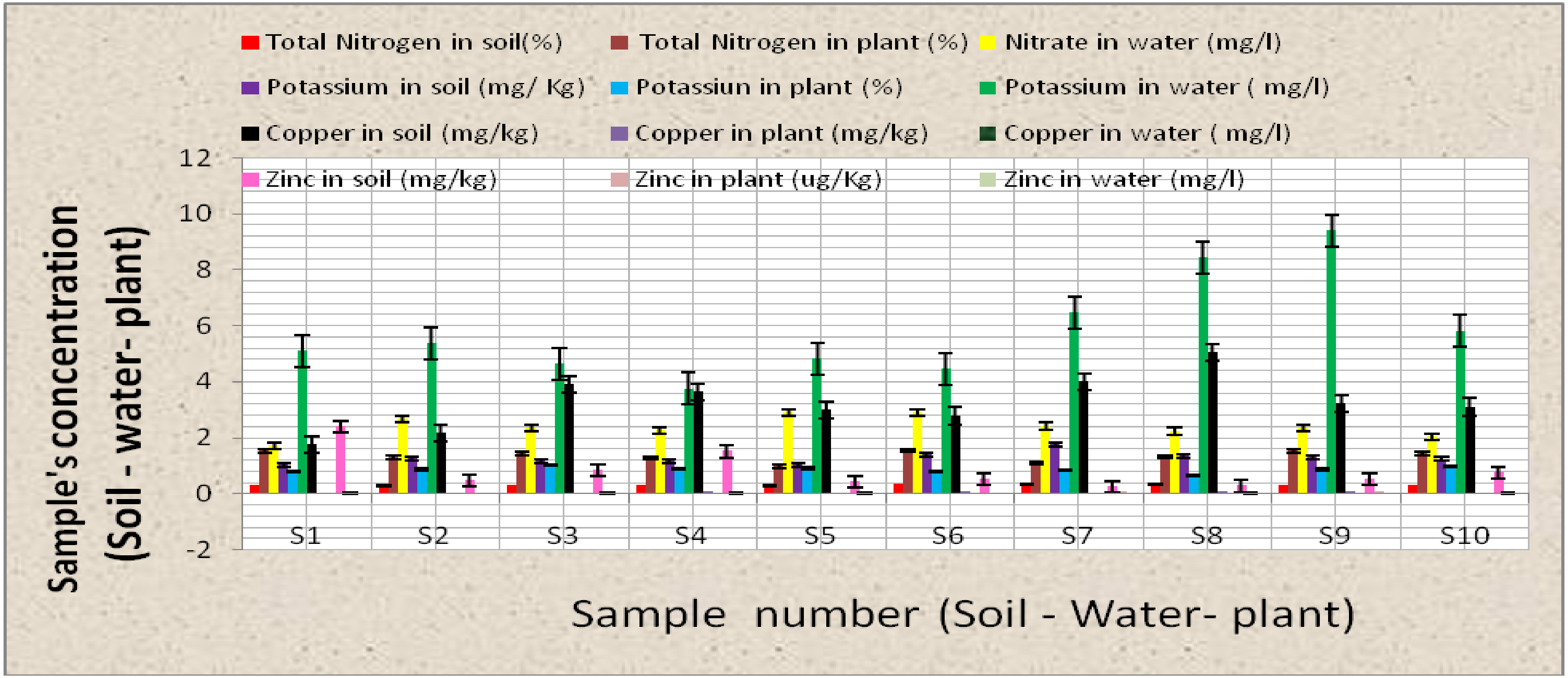


Figure 4.8: Concentration of selected soil nutrients, plant tissue nutrients and water quality parameters in rice irrigation scheme

The samples taken upstream, middle and downstream in the rice irrigation scheme. The nitrogen was varied between (0.28 and 0.335%) in soil, (0.97 and 1.54%) in rice plant tissue and (1.71 and 2.91 mg/l) in water. The potassium was found to be between (1.03 and 1.77 mg/kg) in soil, (0.65 to 1.01%) rice plant tissue and (3.74 and 9.4 mg/kg) in water. The copper varied between (1.75 and 5.06 mg/kg) in soil, (0.02 and 0.048 mg/kg) in rice plant tissue and between 0.03 and 0.04 mg/l) in water. The zinc was found to be between (0.255 and 2.375 mg/kg) in soil, (0.011 and 0.062 μg/kg) in rice plant tissue and found equal at 0.02 mg/kg in all water sample taken. Nitrogen recommended in soil varies between (0.12 - 0.25%) and (3.5 - 5%) in plant tissue potassium varies between (50 – 175 mg/kg) in soil and (2.5 – 4%) in plant tissue, (Okalebo and *al.*, 2002).

According to Moshood (2009) the recommended values of plant growth are 100 mg/kg of copper in soil and 400 mg/kg of zinc in soil. The rice plant nutrients deficient was stated by Shouichi *et al.* (1976) as follows: nitrogen at 2.5%, phosphorus at 0.1% potassium at 1%, zinc at 10 ppm and copper at less than 6 ppm. By comparison with nutrients recommended, nitrogen was found moderate in the soil but was very deficient in the rice plant tissue, potassium was found deficient in soil and rice plant tissue and copper and zinc were very low in soil and very deficient in rice plant tissue. These results helped to understand the lack of sufficient soil and rice plant nutrients and poor production in the Rusurirwamujyinga rice irrigation scheme.

The regression ANOVA was used to test the interaction among the three parameters (water, soil and plant nutrients), All data showed no significant relationship for water quality parameters, soil and plant nutrients (Table 4.8).

Table 4.8: Regression ANOVA at LSD (P<0.05) of soil-water-plant relationship and P(α) results calculated

Regression ANOVA of nitrogen in soil-water-plant					
Sources of variation	**DF**	**SS**	**MS**	**VR**	**P(α) calculated**
TN_plant	1	2.7	2.7	0.21	0.693
N-NO_3_water	1	9.9	9.9	0.76	0.475
TN_soil	1	34.94	34.94	2.69	0.243
TN_plant x N-NO^-_3_water	1	0.56	0.56	0.04	0.855
TN_ plant x TN_soil	1	2.79	2.79	0.21	0.689
N-NO^-_3_water x TN_soil	1	0.63	0.63	0.05	0.846
TN_plant x N-NO^-_3_water x TN_soil	1	5.03	5.03	0.39	0.597
Residual	2	25.96	12.98		
Total	9	82.5	9.17		

Regression ANOVA of copper in soil-water-plant					
Sources of variation	**DF**	**SS**	**MS**	**VR**	**P(α) calculated**
Cu^{++}_plant	1	44.346	44.346	10.44	0.084
Cu^{++}_soil	1	11.61	11.61	2.73	0.240
Cu^{++}_water	1	7.713	7.713	1.82	0.310
Cu^{++}_plant x Cu_soil	1	2.625	2.625	0.62	0.514
Cu^{++}_plant x Cu_water	1	5.521	5.521	1.3	0.372
Cu^{++}_soil x Cu_water	1	2.022	2.022	0.48	0.561
Cu^{++}_plant x Cu_soil x Cu_water	1	0.17	0.17	0.04	0.860
Residual	2	8.493	4.247		
Total	9	82.5	9.167		

Regression ANOVA of potassium in soil-water-plant					
Sources of variation	**DF**	**SS**	**MS**	**VR**	**P(α) calculated**
K^+_plant	1	13.38	13.38	4.85	0.159
K^+_soil	1	16.04	16.04	5.81	0.137
K^+_water	1	14.196	14.196	5.14	0.151
K^+_plant x K^+_soil	1	12.676	12.676	4.59	0.165
K^+_plant x K^+_water	1	14.45	14.45	5.24	0.149
K^+_soil_x K^+-water	1	1.675	1.675	0.61	0.518
K^+_plant x K^+_soil_ x K^+_water	1	4.563	4.563	1.65	0.327
Residual	2	5.52	2.76		
Total	9	82.5	9.167		

Regression ANOVA of zinc soil-water-plant					
Sources of variation	**DF**	**SS**	**MS**	**VR**	**P(α) calculated**
Zn^{++}_Plant	1	28.854	28.854	5.13	0.064
Zn^{++}_Soil	1	18.407	18.407	3.27	0.121
Zn^{++}-Plant x Zn^{++}_Soil	1	1.465	1.465	0.26	0.628
Residual	6	33.774	5.629		
Total	9	82.5	9.167		

The results from regression ANOVA at LSD ($P<0.05$) were used to calculate the values of probability [P (α)] which helped to test the hypothesis of interaction of soil-water-plant. Statistically, all parameters tested proved that no significant relationship between water quality parameters, soil nutrients and rice plant tissue nutrients (Table 4.8). These helped to determine and to decide to the objective three by accepting or rejecting the Null Hypothesis (Ho) or the Alternative Hypothesis (Ha). The Null Hypothesis (Ho) was formulated as follows: Ho: $\mu_1=\mu_2=\mu_3$ that there is no significant difference in interrelationship in water quality parameters, soil nutrients and rice plant tissue within rice irrigation scheme, while the alternative hypothesis (Ha) formulated: Ha: $\mu_1\neq\mu_2\neq\mu_3$ that there is significant difference interrelationship in water quality parameters, soil nutrients and rice plant tissue within rice irrigation scheme. The null hypothesis was accepted and the alternative hypothesis was rejected because all parameters tested in soil, water and plant showed that no significance interrelationship among them, it implies that no interrelationship among water, soil and rice plant tissue nutrients.

The conclusion from this objective is that because of the encroachment observed in Rusurirwamujyinga rice irrigation scheme, due to negative impact caused by mismanaging water and soil, there is a deficiency in plant rice nutrients because water is the basic transport medium for carrying essential plant nutrients from solid soil particles into plant roots and to the farthest reaches of the plant's leaf structure.

4.5 Irrigation Water Quality

In irrigation water quality monitoring, priority should be given to those parameters which are known to be of importance to plant growth and which are known to be present in significant concentrations in the water source. However, in general and as mentioned by Ayers and Westcot (1985) and Abdul Jabbar (2010), the quality of irrigation water resource is associated with five main groups of limitations which are:

(i) Salinity limitation: EC and TDS.

(ii) Infiltration and permeability limitation: SAR and EC.

(iii) Specific ion toxicity: Na^{+}, Cl^{-} and B^{-}.

(iv) Trace element toxicity: Cu^{++} and Zn^{++}.

(v) Miscellaneous impacts on sensitive crops: NO_3^{-}, SO_4^{--} and pH.

Table 4.9 illustrates experimental results from the laboratory which compared the FAO guidelines of evaluation of water quality for irrigation. The experimental results showed that all parameters measured were recommendable for use without any impact on crops.

Table 4.9: Comparison of irrigation water quality experimental results with FAO standards of irrigation water quality

No	Group of limitation	parameters	Experimental results	FAO Standards	Recommendation
1	Salinity	EC TDS	101.3-115.85 µs/cm 69.98 - 85.36 mg/l	≤ 250 µs/cm ≤450 mg/l	Good Good
2	Infiltration and permeability	SAR EC	2.26-3.84 101.3-115.85 µs/cm	≤ 9 ≤250 µs/cm	Good Good
3	Specific ions toxicity	Na^+ Cl^- B^-	4.71- 7.93 mg/l 8.2- 17.7 mg/l 00.3- 0.38 mg/l	≤70 mg/l ≤70 mg/l ≤0.7mg/l	Good Good Good
4	Trace elements toxicity	Cu^{++} Zn^{++}	0.03-0.05 mg/l 0.02-0.03mg/l	≤ 0.2 mg/l ≤2 mg/l	Good Good
5	Miscellanious impact on sensitive crops	NO_3^- SO_4^{--} pH	1.6-3.73 mg/l 8.33-17.16 mg/l 6.81-7.28	≤10 mg/l ≤ 960 mg/l 6.5-8.4	Good Good Good

The initial experimental results showed that all parameters tested in the rice irrigation scheme meet the criteria laid down by of FAO for irrigation. However, variability was observed in time and space. That is that the quality of water seemed to change in quality as one moved from upstream to downstream and from the dry to rainy season. These dramatic spatial and temporal variations in quality are aggravated by the encroachment of human activities surrounding the scheme.

4.6 Correlation Analysis between Physico-Chemical Constituents

The correlation analysis between physico-chemical parameters of irrigation water quality was used to illustrate the relationship between variables measured in irrigation water quality. The correlation coefficient (r) between variables x and y where both represent all variables measured in the irrigation scheme was used. It means that x and y have the same variable and explained how they correlated to each other. According to Salkind (2002), the correlation is the coefficient that reflects the linear relationship of two variables but both of which variables are continuous in nature. The absolute value of the coefficient reflects the strength of the correlation. It can range in value from -1 to +1. Value in the range from 0.8 to 1.0 are interpreted as very strong relationships, 0.6 to 0.8 are strong relationships, 0.4 to 0.6 are moderate relationships, 0.2 to 0.4 weak relationships, while 0 to 0.2 is a very weak or no relationship. If the variables change in the same direction, the correlation is called direct or positive correlation. If the variables changes in the opposite direction, the correlation is called indirect or negative correlation. The correlation analysis are also justified by the coefficient of variance (r^2) which shows the percentage of variation of variables x and y. The r value, r^2 value, x and value, percentage of variation and linear correlation were summarised in the (Appendix 3). Table 4.9 shows the matrix inter-correlation among sixteen variables assumed to be of prime importance in judging the water quality for irrigation.

Table 4.10*:* The Correlation matrix between the chemical constituents of irrigation water quality in the rice irrigation scheme

	B^-	CO_3^{--}	Cl^-	Ca^{++}	Cu^{++}	ECw	HCO_3^-	K^+	Mg^{++}	NO_3^-	Na^+	SO_4^{--}	T^oC	TDS	Zn^{++}	pH
B-	1															
CO_3^{--}	0	1														
Cl^-	0.028	0	1													
Ca^{++}	-0.04	0	0.200	1												
Cu^{++}	0.027	0	-0.653	-0.399	1											
ECw	-0.020	0	0.148	-0.151	0.091	1										
HCO_3^-	0	0	0	0	0	0	1									
K^+	-0.120	0	0.626	0.343	-0.443	-0.027	0	1								
Mg^{++}	0.125	0	0.355	0.093	-0.427	0.302	0	-0.160	1							
NO_3^-	0.062	0	0.005	0.265	-0.222	-0.381	0	0.223	-0.240	1						
Na^+	0.185	0	0.424	0.004	-0.226	0.083	0	0.367	0.321	0.060	1					
SO_4^{--}	-0.003	0	0.08	-0.227	-0.107	0.031	0	0.170	0.001	0.135	0.210	1				
T^oC	0.278	0	-0.021	-0.246	0.237	0.042	0	-0.072	-0.034	0.085	0.314	0.288	1			
TDS	0.077	0	-0.359	-0.235	0.430	0.428	0	-0.645	0.206	-0.446	-0.340	-0.062	0.268	1		
Zn^{++}	0.006	0	-0.443	-0.186	0.667	-0.141	0	-0.281	-0.541	-0.047	-0.478	-0.080	0.216	0.348	1	
pH	-0.05	0	-0.231	0.176	-0.054	-0.205	0	-0.015	-0.129	0.413	-0.182	0.013	0.076	-0.204	0.150	1

The inspection of the correlation matrix shows that there is a moderate positive correlation between K^+ and Cl^- , Zn^{++} and Cu^{++}, TDS and Cu^{++}, pH and NO^-_3 (Table 4.9). This positive moderate correlation (0.4 to 0.6) showed the linkage of these parameters which lead to several natural factors such as season, stream climate and human activities within the irrigation scheme. The moderate negative correlation were observed between Cu^{++} and Cl^-, Zn^{++} and Cl^-, K^+ and Cu^{++}, TDS and K^+, Mg^{++} and Cu^{++}, Zn^{++} and Mg, TDS and NO^-_3 (Table 4.9). This negative moderate correlation (0.4 to 0.6) showed the opposite linkage of these parameters emanating from several natural factors such as season, stream climate and human activities in the study area.

A weak positive correlation was observed for several variable such as Ca^{++} and Cl^-, T^{o}C and B^-, Mg^{++} and Cl^-, Cu^{++} and Ca^{++}, K^+ and Ca^{++}, NO^-_3 and Ca^{++}, T^{o}C and Cu^{++}, Mg^{++} and ECw, pH and ECw, NO^-_3 and K^+, Na^+ and K^+, Na^+ and Mg^{++}, TDS and Mg^{++}, Na^{++} and SO^{--}_4 T^{o}C and Na+, T^{o}C and TDS Zn^{++} and T^{o}C, Zn^{++} and TDS (Table 4.9). This positive weak correlation (0.2 to 0.4) showed the weak linkage of these parameters linked to several natural factors such as season, stream climate and human activities and many other uncontrolled factors which change water quality in the study area. The weak negative correlation were observed between TDS and Cl^-, pH and Cl^-, SO^{--}_4 and Cl^-, TDS and Ca^{++}, NO^-_3 and Cu^{++}, Na^+ and Cu^{++}, NO^-_3 and ECw, Zn^{++} and K^+, NO^-_3 and Mg^{++}, TDS and Na^+, pH and TDS. This negative weak correlation (0.2 to 0.4) showed the weak linkage of these parameters coming from several natural factors such as season, stream climate and human activities and many other uncontrolled factors which change water quality in the study area. All other parameters remained very weak or showed no relationship between them because they were found to be between 0 to 0.2 (Table 4.9).

CHAPTER FIVE:

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Key Findings

The main objective of the study was to assess the spatial and temporal variability in quality of water used for rice irrigation in Rusurirwamujyinga sub-catchment to enhance irrigation water management practices which seemed to be weak. To this end, a comparison of the seasonal water quality variability, streams water quality variability, as well as relationship of soil nutrients, plant tissues nutrients and water chemical parameters was made.

The specific objectives of the study were:

(i) To evaluate the differences in water quality for the upper, middle and downstream sections of the rice irrigation scheme.

(ii) To determine the seasonal variability of water quality within the scheme

(iii) To find out the interrelationship between water quality parameters, soil nutrients and rice plant tissue nutrients within the rice irrigation scheme

The experimental tools used in conducting this research were: Several materials and reagents from water, soil and plant laboratory, GPS, Digital camera and top sheet maps were used to design the study area. The analytic tools were mainly descriptive statistics and correlation analysis to analyse the central tendency, dispersion, reliability and variability of the data and general ANOVA and regression ANOVA to determine whether there is a significant difference of water quality variables between seasons and between streams and to estimate any significant interrelationship between water quality, soil and plant nutrients, to accept or reject the hypothesis.

All the analytic tools were triangulated quantitatively with results of scientific research on irrigation water quality for better interpretation. This helped to answer the following research questions:

(i) Does water quality vary significantly as it moves from upstream to downstream sections of the irrigation rice scheme?

(ii) Is there a significant seasonal variability in irrigation water quality within the scheme?

(iii) Is there any interrelationship in water quality parameters, soil nutrients and rice plant tissue within the rice irrigation scheme?

The results from general ANOVA and regression ANOVA showed that most of variables showed a significant difference at all stream positions and different seasons and showed no significant interrelationship between water quality parameters, soil nutrients and rice plant tissue nutrients. The correlation analysis showed that some variables were moderately positive and negative correlation (0.4-0.6) while other showed weak positive and negative correlation (0.2-0.4). Still others showed no relationship among them (0-0.2). On the other hand, water used in the Rusurirwamujyinga rice irrigation scheme was classified according to FAO guidelines for water quality for irrigation and found to be as follows:

(i) **Salinity limitation:** Electrical Conductivity (101.3-115.85 µs/cm) and Total Dissolved Solids (69.98 - 85.36 mg/l).

(ii) **Infiltration and permeability limitation:** Sodium Adsorption Ratio (2.26-3.84) and Electrical Conductivity (101.3-115.85 µs/cm).

(iii) **Specific ion toxicity:** Sodium (4.71- 7.93 mg/l) and Chloride (8.2- 17.7 mg/l) and Boron

(00.3- 0.38 mg/l).

(iv) **Trace element toxicity:** Zinc (0.02-0.03mg/l) and Copper (0.03-0.05 mg/l).

(v) **Miscellaneous impacts on sensitive crops:** Nitrate (1.6-3.73 mg/l) and Sulphate (8.33-17.16 mg/l) and Hydrogen ion concentration (6.81-7.28).

5.2 Conclusions

The study on spatial and temporal variability of water quality and its response on growth of irrigated rice in Rusurirwamujyinga sub-catchment showed that it was suitable for irrigation. Significant differences were observed for all variables assessed. There is a significant difference in water quality among stream positions (upstream, middle and downstream) and there is also a significant difference between seasons (dry season, short rainy and season and rainy season) and no significant interrelationship between water quality parameters, soil nutrients and rice plant tissue nutrients. Due to the pressure of human encroachment surrounding the irrigation scheme, from upstream to downstream, several pollutants, sediment loss, dam siltation along the river and canals were observed as signals of resource degradation in the catchment. The unequal distribution of irrigation water from upstream to downstream was also assessed as the main cause of decreasing production, dryness in middle and downstream section, especially in the dry season and this cause some conflicts among farmers.

If interventions are not effected to control and monitor water quality and quantity in the irrigation scheme, pollution and siltation will render the water unsuitable in future. The middle stream and the downstream will continue to suffer from water quality risk and water shortages because of over encroachment. These conclusions were justified by the significant change of water quality observed in different stream positions and seasons and the deficiency soil and rice plant nutrients.

5.3 Recommendations

From the study findings, the following recommendations were made:

(i) In order to monitor the irrigation water and water resource in general, it is a good to establish a hydrological and hydro-chemical station so that the irrigation managers and farmers could mitigate water pollution, water withdrawal, and be able to account for the irrigation water used in the scheme.

(ii) The irrigation scheme should have a buffer, it is currently surrounded by human activities and the hillside surrounding the irrigation scheme should be rehabilitated so as to protect the river channel, thus improving soil health and restoring the ecosystem.

(iii) Because of the vast amount of water withdrawal especially in the rainy season, it is highly recommended to establish means of consumption water metering of dam for agricultural use.

(iv) The practice of the principles of Integrated Water Resources Management (IWRM) and Integrated Watershed Management (IWM) throughout the catchment will help to establish a system of equitable distribution of water for upstream, middle stream and downstream through rotational use. All stakeholders would know that water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels and watershed, management is continuous and needs multi-disciplinary approach in order to sustain socio-economic living by managing natural resources among others.

(v) Agriculture contributes more to non-point source pollution at certain times of the year, such as spring when there is less crop vegetation and when there also may be more rainfall. There are several accepted Best Management Practices (BMPs) that have been developed by scientists and other professionals that are frequently used in controlling soil erosion, and protecting environmental and human health. BMPs range from better use of the natural environment to the construction of artificial devices, but all can be effective in minimizing runoff and protecting water quality. Building farmers' capabilities in BMPs will be a very important solution to water and soil management in the study area.

(vi) Rusurirwamujyinga rice irrigation scheme lies under some other jurisdictions among others Ministry of Agriculture, Rural Sector Support Project, Rusurirwamujyinga rice's farmers Cooperative, Agriculture Research and Extension Institutions and National Irrigation Task Force. A legal framework is recommended for implementing, managing and sustaining Rusurirwamujyinga rice irrigation scheme and the whole catchment area in general.

(vii) In order to achieve social equity, economic efficiency, and environmental sustainability, the management of Rusurirwamujyinga sub-catchment needs to be considered first by setting a committee in charge of water resource and forming water resource users associations which would insure daily management of water resources both upstream and downstream so that the water resource in the study area will be equitably distributed.

(viii) The following mitigation measures are highly recommended. Water management in Rusurirwamujyinga sub-catchment needs to be sustained in order to reduce the negative impact which causes water pollution. The former must be presented to the management of Rusurirwamujyiga dam as well as the whole irrigation infrastuctures which are used for supply and regulation of water for irrigation. The use of Best Management Practices (BMPs) to reduce agriculture's impact on water quality while also enhancing agricultural production in irrigation scheme will be the best way of achieving soil and water management by ensuring quality and equitable sharing of water resource in the study area.

5.4 Further Research in the Study Area

This study was mainly based on the assessment of the spatial and temporal water quality variability and its response to the growth of rice irrigation in Rusurirwamujyinga sub-catchment. This study was the pioneer research ever conducted in Rusurirwamujyinga sub-catchment, especially irrigation water quality and no comparison whatsoever, for the purpose of comparability has ever been done. The research can be replicated in the study area by extending sampling time and testing bio-organic, microbial and bacteriological parameters.

The potential areas for research in the catchment area include:

(i) Assessment of the effect of fertiliser and pesticide use for farming rice in Rusurirwamujyinga rice irrigation scheme.

(ii) Assessment of impact of pesticide and fertiliser loss in Rusurirwamujyinga River.

(iii) Water balance and its impact on crop production in Rusurirwamujyinga sub-catchment area.

(iv) Impact of land use change and its impact on water quality in Rusurirwamujyinga sub-catchment.

(vi) Modelling nutrients and sediments loss in Rusurirwamujyinga dam.

(vii) Livelihood change and effect of optimising Rusurirwamujyinga water’s dam for agricultural use and fishpond farming.

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APPENDICES

Appendix 1: Water Results from Laboratory

S/ Catchment location	Sample location	Geographical Coordinate	$T^o(^oC)$	pH	EC (µs/cm)	TDS (ppm)	NO^-_3 (mg/l)	SO^{--}_4 (mg/l)	Cl^- (mg/l)	B^- (mg/l)
Upstream	In let dam (So)	2^o 30'36.4"S and 29^o 45'52.9"E	21.16 ±0.54	7.05±0.08	108.25 ± 9.61	71.25±8.09	1.60± 0.15	9 ± 0.62	10.16 ± 1.84	0.03 ± 0.00
	Outlet dam (S1)	2^o 30' 17.4"S and 29^o 46'03.8"E	21.3±0.53	6.92±0.05	101.65± 5.25	71.25±9.10	1.71± 0.26	9.16 ± 0.74	10 ± 2.20	0.06 ± 0.00
	Bandagure bridge (S2	2^o 30' 08.3"S and 29^o 46'08.7"E	21.3±0.61	7.10±0.09	106.98 ± 7.36	72.03± 10.36	2.68 ± 0.55	10.33 ± 0.49	8.2 ± 0.99	0.08 ± 0.01
	Mugogwe bridge (S3)	2^o 29' 31.6"S and 29^o 46'01.7"E	21.3 ±0.69	7.01±0.05	104.53 ± 6.77	76.33±13.90	2.35 ± 0.57	9 ± 1.02	10.96 ± 2.03	0.04 ± 0.01
	Agatare stream (S4)	2^o 29' 15.8"S and 29^o 45'50.2"E	22.28 ± 0.35	7.03±0.05	102 ± 6.42	79.96± 1386	2.26 ±0.20	8.33 ± 0.20	9.50 ± 1.05	0.26 ± 0.07
Meddle stream	Musasu bridge (S5)	2^o 28' 49.8"S and 29^o 45'21.8"E	23.21 ±0.51	7.28±0.06	115.85 ± 9.69	85.36± 16.95	2.91± 0.50	12.33 ± 0.42	13.16 ± 2.54	0.20 ± 0.01
	Kiruhura bridge(S6)	2^o 28' 22.3"S and 29^o 44'50.7"E	25.36 ±0.86	7.17±0.06	103.78 ± 6.14	77.20± 12.96	2.90 ± 0.73	11.5 ± 0.55	12.20 ± 3.50	0.38 ± 0.05
	Ruhashya stream (S7)	2^o 28' 04.6"S and 29^o 44'21.3"E	24.6± 0.52	7.20±0.05	111.06± 7.59	79.73± 13.27	2.41± 0.50	10.50 ± 0.22	13.23 ± 3.69	0.07 ± 0.03
	Bweramana bridge(S8)	2^o 27' 40.6"S and 29^o 43'59.3"E	24.65 ± 0.62	7.04±0.07	112.33 ± 8.97	81.03± 12.75	2.23 ± 0.34	10.33 ± 0.42	17.15 ± 5.36	0.11 ± 0.00
Downstream	Gahama stream (S9)	2^o 26' 52.5"S and 29^o 43'39.8"E	23.8±0.35	6.81±0.08	109.65 ± 9.39	75.98± 15.65	2.33 ± 0.38	12.66 ± 0.33	17.70 ± 4.82	0.11 ± 0.00
	Agasuma stream (S10)	2^o 26' 25.6"S and 29^o 43'22.5"E	23.81± 0.33	7.00±0.08	114.71 ± 9.65	81.73± 12.09	2.03 ± 0.26	17.16 ± 2.85	10.50 ± 2.55	0.08 ± 0.00
	Enter Mwogo river (S11)	2^o 25' 00.3"S and 29^o 42'03.6"E	23.8±0.38	7.21±0.05	101.30 ± 5.59	69.98± 10.25	3.73 ± 0.89	16.83 ± 1.64	10.83 ±1.98	0.07 ± 0.00

Continuous

S/ Catchment location	Sample location	Geographical Coordinate	HCO^{-}_{3} (mg/l)	CO^{--}_{3} (mg/l)	Ca^{++} (mg/l)	Mg^{++} (mg/l)	K^{+} (mg/l)	Na^{+} (mg/l)	Cu^{++} (mg/l)	Zn^{++} (mg/l)	SAR
Upstream	In let dam (So)	2° 30'36.4"S and 29° 45'52.9"E	0	0	6.75 ± 0.42	2.38 ± 0.53	4.64±1.71	4.71 ± 0.66	0.05±0.01	0.03±0.00	2.26
	Outlet dam (S1)	2° 30' 17.4"S and 29° 46'03.8"E	0	0	6.26 ± 0.67	2.39 ± 0.34	5.08±2.61	5.17 ± 0.46	0.04±0.01	0.02±0.00	2.49
	Bandagure bridge (S2	2° 30' 08.3"S and 29° 46'08.7"E	0	0	7.26 ± 0.84	2.26 ± 0.44	5.37±2.75	5.72 ± 0.49	0.04±0.01	0.02±0.00	2.62
	Mugogwe bridge (S3)	2° 29' 31.6"S and 29° 46'01.7"E	0	0	7.30 ± 1.13	2.97 ± 0.34	4.65±2.60	5.73 ± 0.44	0.04±0.01	0.02±0.00	2.53
	Agatare stream (S4)	2° 29' 15.8"S and 29° 45'50.2"E	0	0	6.93 ± 0.75	3.22 ± 0.40	3.74±1.95	6.56 ± 0.79	0.04±0.01	0.02±0.00	2.91
Meddle stream	Musasu bridge (S5)	2° 28' 49.8"S and 29° 45'21.8"E	0	0	9.50 ± 1.33	3.21 ± 0.69	4.81±1.57	7.02 ± 0.68	0.04±0.01	0.02±0.00	2.78
	Kiruhura bridge(S6)	2° 28' 22.3"S and 29° 44'50.7"E	0	0	5.35 ± 0.78	2.83 ± 0.34	4.44±2.26	6.98 ± 0.75	0.03±0.01	0.02±0.00	3.35
	Ruhashya stream (S7)	2° 28' 04.6"S and 29° 44'21.3"E	0	0	5.81 ± 0.89	3.22 ± 0.43	6.46±2.49	7.93 ± 0.99	0.03±0.01	0.02±0.00	3.74
	Bweramana bridge(S8)	2° 27' 40.6"S and 29° 43'59.3"E	0	0	5.63 ± 0.89	2.92 ± 0.35	8.43±3.42	7.53 ± 1.13	0.03±0.01	0.02±0.00	3.65
Downstream	Gahama stream (S9)	2° 26' 52.5"S and 29° 43'39.8"E	0	0	5.45 ± 1.06	2.57 ± 0.57	9.40 ±3.57	7.69 ± 1.09	0.03±0.01	0.02±0.00	3.84
	Agasuma stream (S10)	2° 26' 25.6"S and 29° 43'22.5"E	0	0	5.59 ± 1.35	2.81 ± 0.32	5.80 ± 2.78	6.78 ± 0.77	0.03±0.01	0.02±0.00	3.32
	Enter Mwogo river (S11)	2° 25' 00.3"S and 29° 42'03.6"E	0	0	4.49 ± 1.08	2.42 ± 0.44	6.15 ± 2.35	6.25 ± 0.83	0.03±0.01	0.02±0.00	3.37

Appendix 2: ANOVA Table of Means

Mean Streams

STREAMS	T^o	PH	EC	TDS	NO^-_3	SO^{--}_4	Cl^-	B^-	Ca^{++}	Mg^{++}	K^+	Na^+	Cu^{++}	Zn^{++}
Up	21.47	7.012	104.683	75.45	2.12333	9.17	9.77	0.099	6.901	2.648	4.7	5.581	0.0474	0.0474
Down	23.81	7.028	108.556	75.9	2.7	15.56	13.01	0.192	5.181	2.6017	7.12167	6.911	0.03767	0.03767
Middle	24.46	7.179	110.758	80.8333	2.61667	11.17	13.94	0.092	6.576	3.051	6.03875	7.368	0.03688	0.03688
SEM	0.246	0.043	3.005	2.19	0.206	0.579	1.104	0.0493	0.404	0.144	0.877	0.206	0.0018	0.0019
SED	0.35	0.061	4.28	3.12	0.293	0.826	1.574	0.0352	0.576	0.206	1.25	0.293	0.0026	0.0027
LSD	0.696	0.123	8.56	6.24	0.586	1.651	3.145	0.0702	1.151	0.411	2.498	0.586	0.0052	0.0054
CV (%)	5.1	2.9	13.3	13.5	40.5	24.2	44.1	92	30.4	24.9	72.9	15.1	21.3	40.4

Means seasons

SEASONS	T^O	PH	EC	TDS	NO^-_3	SO^{--}_4	Cl^-	B^-	Ca^{++}	Mg^{++}	K^+	Na^+	Cu^{++}	Zn^{++}
Dry	22.52	7.035	115.7	56.6	2.3	12.04	16.58	0.133	5.83	3.33	8.4	8.13	0.0245	0.00129
Middle	22.6	7.147	98.7	74.4	3.02	11.04	14.18	0.115	7.93	2.75	7.01	5.35	0.0086	0.02521
Rainy	24.02	7.04	108.7	101.1	1.98	11.21	5.15	0.137	5.33	2.24	1.84	6.05	0.0913	0.04075
SEM							1.138	0.0254						
SED	0.527	0.069	4.4	5.47	0.317	1.088	1.609	0.036	0.607	0.286	1.474	0.392	0.005	0.004
LSD	1.052	0.138	8.78	10.92	0.633	2.171	3.211	0.0718	1.212	0.57	2.94	0.781	0.009	0.008
CV (%)	7.9	3.4	14.2	24.5	45.2	33	46.9	97.2	33.1	35.7	88.7	20.8	39.7	65.6

Appendix 3: Inter-correlation between Variables

x	y	r	r^2	Percentage of variation (%)	Linear correlation
T^o	pH	0.076	0.005776	0.57	positive
	EC	0.042	0.001764	0.17	positive
	TDS	0.268	0.071824	7.18	positive
	NO^-_3	0.085	0.007225	0.722	positive
	SO^-_4	0.289	0.083521	8.35	positive
	B^-	0.278	0.077284	7.72	positive
	Cl^-	-0.021	0.000441	0.04	negative
	Ca^{++}	-0.246	0.060516	6.05	negative
	Mg^{++}	-0.034	0.001156	0.11	negative
	K^+	-0.073	0.005329	0.55	negative
	Na^+	0.314	0.098596	9.85	positive
	Cu^{++}	0.238	0.056644	5.66	positive
	Zn^{++}	0.218	0.047524	4.75	positive
pH	EC	-0.2053	0.04214809	4.21	negative
	TDS	-0.204	0.041616	4.16	negative
	NO^-_3	0.4137	0.17114769	17.11	positive
	SO^{--}_4	0.0132	0.00017424	0.01	positive
	B^-	-0.0501	0.00251001	0.25	negative
	Cl^-	-0.2313	0.05349969	5.34	negative
	Ca^{++}	0.1765	0.03115225	3.11	positive
	Mg^{++}	-0.1297	0.01682209	1.68	negative
	K^+	-0.0154	0.00023716	0.02	negative
	Na^+	-0.1821	0.03316041	3.31	negative
	Cu^{++}	-0.0543	0.00294849	0.29	negative
	Zn^{++}	0.1484	0.02202256	2.2	positive
EC	TDS	0.4281	0.18326961	18.32	positive
	NO^-_3	-0.3817	0.14569489	14.56	negative
	SO^{--}_4	0.0312	0.00097344	0.097	positive
	B^-	-0.0155	0.00024025	0.024	negative
	Cl^-	0.1485	0.02205225	2.2	positive
	Ca^{++}	-0.1518	0.02304324	2.3	negative
	Mg^{++}	0.3029	0.09174841	9.17	positive
	K^+	-0.0275	0.00075625	0.07	negative
	Na^+	0.083	0.006889	0.68	positive
	Cu^{++}	0.0916	0.00839056	0.83	positive
	Zn^{++}	-0.2053	0.04214809	4.21	negative
TDS	NO^-_3	-0.4465	0.19936225	19.93	negative
	SO^{--}_4	-0.0624	0.00389376	0.38	negative
	B^-	0.0765	0.00585225	0.58	positive
	Cl^-	-0.3591	0.12895281	12.89	negative

	Ca^{++}	-0.2354	0.05541316	5.54	negative
	Mg^{++}	0.2064	0.04260096	4.26	positive
	K^{+}	-0.6458	0.41705764	41.7	negative
	Na^{+}	-0.34	0.1156	11.56	negative
	Cu^{++}	0.4303	0.18515809	18.51	positive
	Zn^{++}	0.3482	0.12124324	12.12	positive
NO^{-}_{3}	SO^{--}_{4}	0.1358	0.01844164	1.84	positive
	B^{-}	0.062	0.003844	0.38	positive
	Cl^{-}	0.0052	0.00002704	0.002	positive
	Ca^{++}	0.2652	0.07033104	7.03	positive
	Mg^{++}	-0.2405	0.05784025	5.78	negative
	K^{+}	0.2235	0.04995225	4.99	positive
	Na^{+}	0.0604	0.00364816	0.36	positive
	Cu^{++}	-0.2224	0.04946176	4.94	negative
	Zn^{++}	0.4137	0.17114769	17.11	positive
SO^{--}_{4}	B^{-}	-0.0026	0.00000676	0.0006	negative
	Cl^{-}	0.082	0.006724	0.67	positive
	Ca^{++}	-0.2276	0.05180176	5.18	negative
	Mg^{++}	0.0012	0.00000144	0.00014	positive
	K^{+}	0.1708	0.02917264	2.91	positive
	Na^{+}	0.2109	0.04447881	4.44	positive
	Cu^{++}	-0.1078	0.01162084	1.16	negative
	Zn^{++}	-0.0809	0.00654481	0.65	negative
B^{-}	Cl^{-}	0.028	0.000784	0.07	positive
	Ca^{++}	-0.0405	0.00164025	0.16	negative
	Mg^{++}	0.125	0.015625	1.56	positive
	K^{+}	-0.1244	0.01547536	1.54	negative
	Na+	0.1853	0.03433609	3.43	positive
	Cu^{++}	0.0273	0.00074529	0.074	positive
	Zn^{++}	0.0061	0.00003721	0.007	positive
Cl^{-}	Ca^{++}	0.2004	0.04016016	4.01	positive
	Mg^{++}	0.3557	0.12652249	12.65	positive
	K^{+}	0.6265	0.39250225	39.25	positive
	Na^{+}	0.4245	0.18020025	18.02	positive
	Cu^{++}	-0.6536	0.42719296	42.71	negative
	Zn^{++}	-0.4432	0.19642624	19.64	negative
Ca^{++}	Mg^{++}	0.0931	0.00866761	0.86	positive
	K^{+}	0.3435	0.11799225	11.7	positive
	Na^{+}	0.0045	0.00002025	0.002	positive
	Cu^{++}	-0.3997	0.15976009	15.97	negative
	Zn^{++}	-0.1862	0.03467044	3.46	negative
Mg^{++}	K^{+}	-0.1604	0.02572816	2.57	negative
	Na^{+}	0.3216	0.10342656	10.34	positive
	Cu^{++}	-0.4273	0.18258529	18.25	negative

	Zn^{++}	-0.5413	0.29300569	29.3	negative
K^+	Na^+	0.3675	0.13505625	13.5	positive
	Cu^{++}	-0.443	0.196249	19.62	negative
	Zn^{++}	-0.2816	0.07929856	7.92	negative
Na^+	Cu^{++}	-0.226	0.051076	5.1	negative
	Zn^{++}	-0.4787	0.22915369	22.9	negative
Cu^+	Zn^{++}	0.6679	0.44609041	44.6	positive

Appendix4: Soil Series found in Rusurirwamujyinga Sub-catchment

SERIS (LOCAL NAME)	SYMBOL	LEGENDE	US (1975) TAXONOMY	FAO (1990) TAXONOMY
AKAZI	AKZ	I.E4s*/5sr	Lithic Humitropept	Dystric Regosols / Dystric Leptosols
BUJUMU	BUJ	IQ.E4f*/5sr	Lithic Troporthent	Dystric Regosols / Dystric Leptosols
BYUMBA	BYA	QI.A9s*/5	Orthoxic Tropudult	Ferric Acrisols
CYAMBWE	CYW	G.A8*/5zq	Oxic Tropudalf	Haplic Lixisols
CYOBO	COB	G.Ac12*/4	Typic Eutropept	Eutric Cambisols (à Haplic Phaeozems)
GATONDE	GAT	G.E7*/5zr	Lithic Troporthent	Eutric Regosols /Eutric Leptosols
GATOVU	GTV	I.Ap6/5	Typic Paleudalf	Ferric Lixisols
IRIBA	IRI	G.O12*/7	Oxic Ustic Dystropept	Ferralic Cambisols
KABIRA	KIA	I.A6/5	Humoxic Sombrihumult	Humic Acrisols (sombric)
KANGOMA	KGM	G.K7*/5z	Typic Tropudult	Haplic Alisols
KANTWALI	KTL	G.Ac6*/5	Typic Sombrihumult	Humic Alisols à Rhodic/Haplic Luvisols
KAYANZA	KZA	G.C5*/5zq.s	Typic Humitropept	Humic Cambisols - Humic Alisols
KAYUMBU	KUB	I.A5/5q	Humoxic Tropohumult	Humic Acrisols à Humic Ferralsols
KIBILARO	KLR	Gm.K4/5zj	Typic Humitropept	Humic Alisols à humic Acrisols
KIBILIRA	KIB	Gm.A6/5	Typic Tropohumult	Humic Acrisols
KIBINJA	KBJ	G.K4/5zj	Humoxic Sombrihumult	Rhodic (humic?) Ferralsols à Haplic (humic) Acrisols
KIDAHWE	KDW	G.C4*/4zq.s	Lithic Dystropept	Dystric Cambisols
KIZIBERE	KZB	G.A7*/5z	Typic Tropudalf	Haplic (humic) Alisols
MASAKA	MSK	I.Ap3/4	Oxic Tropudalf	Humic Ferralsols (à Chromic Ferric Luvisols)
MATA	MAT	IQ.K6/5	Sombrihumox	Humic Ferralsols à Humic Acrisols
MBARE	MBR	G.K9/5	Sombriorthox	(Humic?) Rhodic Ferralsols

MPANGA	MPA	G.A4/5zq	Humoxic Tropohumult	Humic Acrisols à Humic Alisols
MUNINI	MNI	G.A5*/5zq	Ultic Tropudalf	Haplic Acrisols
MURAMA	MRA	G.K5/5zq	Tropeptic Umbriorthox	Humic Acrisols (geen ferralsol)
MURAMBA	MUR	B.A3/5	Typic Tropohumult	Humic Alisols
MUYIRA	MYA	G.E4*/5sr	Typic Troporthent	Eutric Regosols / Mollic Leptosols
MWOGO	MWO	QI.E7f*/5sr	Lithic Troporthent	Dystric Regosols / Dystric Leptosols
NSINDA	NSI	I.K6/4	Sombriusthox	Humic Ferralsols
RUGESHI	RUG	IQm.C5s*/6r	Typic Humitropept	Dystric (humic) Cambisols
TARE	TRE	Q.C8f*/5g.r	Typic Dystropept	(Humic) Ferralic Dystric Cambisols
RUKO	RK	CA.C63*/5	Fluventic Humitropept	Dystric (parfois humic) Cambisols à Haplic (humic) Alisols

Source: *MINAGRI (2004)*

Appendix5: Soil results from laboratory Before Harvesting (25/08/2010)

No	Sample,s site	Ec (µS/cm)	pH	Total N (%)	Avail. P (ppm)	Ca^{++} (mg/kg)	Mg^{++} (mg/kg)	K^{+} mg/kg	Na^{+} mg/kg	CEC (Cmole/kg)	Cu^{++} mg/kg	Zn^{++} (mg/kg)	Sand %	Silt (%)	Clay (%)	O.C %
1	S1	57.6	5.62	0.21	26.04	1.7	2.1	0.15	0.13	17.76	1.9	4	42.5	14.8	42.71	2.98
2	S2	60	5.51	0.21	29.9	2.38	0.5	0.3	0.26	12.88	2.7	0.5	53.8	8.95	37.28	3.07
3	S3	79.8	5.41	0.21	26.04	0.56	1.88	0.38	0.33	13.92	6.3	0.875	49.1	13.59	37.36	2.86
4	S4	189.8	4.79	0.21	27.3	0.36	3.62	0.53	0.4	22.4	6	1.5	11.3	37.27	51.43	2.8
5	S5	70.2	5.24	0.21	26.04	1.26	1.12	0.46	0.33	16.56	4.4	0.5	35.3	20.09	44.62	3,23
6	S6	92.2	5.15	0.25	71.5	0.46	3.64	0.38	0.46	19.6	4	0.375	20.9	28.28	50.8	3.03
7	S7	124.4	5.53	0.27	68.9	1.36	0.64	0.46	0.46	13.28	6.5	0.29	35.3	22.37	42.32	3.07
8	S8	101.1	4.97	0.25	74.1	0.94	2.68	0.46	0.4	14.4	8.5	0.25	15	26.54	58.47	3.24
9	S9	108	5.3	0.27	28.7	0.89	2.45	0.52	0.47	15.5	4.8	0.15	17.5	23.44	59.06	2.99
10	S10	104	5.7	0.24	28	0.44	0.9	0.55	0.3	16.8	5.3	0.69	17.1	20.75	62.15	2.66

Appendix 6: Soil results from laboratory After Harvesting (25/01/2011)

Sample,s site	Ec (µS/cm)	pH water	Total N (%)	Avail. P (ppm)	Ca^{++} (mg/kg)	Mg^{++} (mg/kg)	K^{+} (mg/kg)	Na^{+} (mg/kg)	CEC (Cmole/kg)	Cu^{++} (mg/kg)	Zn^{++} (mg/Kg)	sand (%)	Silt (%)	Clay (%)	O C (%)
S1	83.5	5.2	0.38	46.62	4.34	2.9	1.91	1.13	15.44	1.6	0.75	40.4	10.7	48.9	3.44
S2	82	5.5	0.35	29.97	4.64	2.56	2.2	1.23	15.3	1.61	0.42	43.2	9	47.8	3.85
S3	86.8	5.3	0.39	46.62	4.48	2.66	1.91	1.79	15.28	1.52	0.8	41	13.1	45.9	4.21
S4	112	5.43	0.38	33.64	4.9	3.22	1.76	1.89	15.74	1.26	1.5	43.3	12	44.7	4.42
S5	102	5.3	0.36	46.62	4.58	2.62	1.61	1.79	15.52	1.56	0.35	42	10.9	47.1	4.01
S6	99	5.39	0.38	29.97	5.18	3.29	2.35	2.45	17.28	1.56	0.63	36.7	15.9	47.4	4.35
S7	104.3	5.19	0.4	29.97	5.06	2.62	3.08	1.89	21.76	1.5	0.22	15.6	18.8	65.6	4.55
S8	101	5.28	0.4	29.97	4.54	2.58	2.2	1.42	15.36	1.61	0.28	39.1	10.2	50.7	4.08
S9	107	4.9	0.35	29.97	4.16	2.42	2.05	1.32	15.28	1.59	0.9	41.8	9.6	48.6	3.9
S10	105	5.5	0.38	24.5	4.88	2.01	1.9	1.17	15.3	0.9	0.79	33	22.43	44.57	3.7

Appendix 7: Rice Plant Tissue Results from Laboratory

N0	N (%)	P (%)	K (%)	Cu^{++}(mg/kg)	Zn^{++}(μg/kg)
S1	1.51	0.18	0.78	0.02	0.0113
S2	1.29	0.24	0.78	0.022	0.0156
S2	1.31	0.24	0.94	0.018	0.0325
S3	1.43	0.21	1.01	0.023	0.0123
S4	1.29	0.24	0.89	0.05	0.0136
S4	1.26	0.24	0.84	0.033	0.0162
S5	0.97	0.23	0.91	0.019	0.0129
S6	1.54	0.29	0.8	0.041	0.0159
S7	1.09	0.23	0.83	0.021	0.0391
S8	1.31	0.27	0.65	0.044	0.0111
S9	1.51	0.23	0.86	0.048	0.062
S10	1.43	0.23	0.96	0.003	0.0116

Appendix8: Rainfall Data from 1997 to 2010

	Years													
Month	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
January	145.5	202	45	95.5	245	259	59	149	93	60.1	92.3	78.5	83	82.4
February	85	155	34.5	75.5	95.9	73.5	135	161.3	124.5	100	99.4	123.5	148.5	293.5
March	149	238	172	95.2	211.3	186.5	158.5	191	202	157.8	71.8	132	80.6	106.5
April	239	174.5	96	98.5	265.7	274	139.5	158	76.5	182.2	169.4	101	118.5	143.5
May	150	130	66	30	62	203	115.5	63	111.3	219.5	98.9	57.5	109.5	104.5
June	52.5	81.5	11	0	6	0	1.5	2	8.5	0.5	35	42.5	7	15.5
July	0	9.5	0	1.5	91	0	2	9	0	28.5	3.3	2.5	2	0
August	25.5	9	65.7	9	71	10.5	26.5	20.5	42	14.7	0	3.5	0	0
September	8.5	66.5	103	17.5	143	23	108	42	67	48	89.5	47	50	110
October	160.5	62	56	107.3	151	75	181	121.5	76.5	107.5	0	111	118	96
November	224	100.5	143.5	182.5	295	105.5	187.5	124.5	57	233	104.5	99.3	163	101
December	178.5	60	74.2	88.5	63	171.5	56.5	107	15	183.5	39.4	93	208	139.5
Annual rainfall	1418	1288.5	866.9	801	1699.9	1381.5	1170.5	1148.8	873.3	1335.3	803.5	891.3	1088.1	1192.4

Source: Rubona Meteorological station (2011)