ASSESSMENT OF TECHNICAL EFFICACY AND ECONOMIC IMPACT OF BENCH TERRACES USED IN SOIL EROSION CONTROL IN EASTERN RWANDA

ERIC DERRICK BUGENIMANA

A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY OF THE OPEN UNIVERSITY OF TANZANIA

2017

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Open University of Tanzania a thesis titled: "**Assessment of Technical Efficacy and Economic Impact of Bench Terraces used in Soil Erosion Control in Eastern Rwanda"** in fulfillment of the requirements for the Degree of Doctor of Philosophy of the Open University of Tanzania.

....

Dr. John P.A. Msindai

(Supervisor)

....

Date

....

Dr. Emmanuel Patroba Mhache

(Supervisor)

....

Date

COPYRIGHT

DECLARATION

I, **Eric Derrick Bugenimana,** do hereby declare that this thesis titled "Assessment of technical efficacy and economic impact of bench terraces used in soil erosion control in Eastern Rwanda" is my own original work and that it has not been presented elsewhere for any academic award.

……………………..……………

Signature

………………………..…………

Date

DEDICATION

This work is dedicated to my darling Niyonambaza M. Clarisse, my lovely daughter Isimbi Ella ClaDe, who were the main inspiration in joining the program and conducting this study to completion. They endured the demands of this work with patience, love, support and prayer.

ACKNOWLEDGEMENT

Above all, forever and ever, I thank my God for helping me throughout my life and during my studies. First and foremost, I would like to express my deepest gratitude to both supervisors, Dr. John Msindai and Dr. Emmanuel Patroba Mhache for their constructive critiques, scientific and innovative advices, as well as useful recommendations throughout this thesis. Without their constant support and timely help, this thesis would not have been possible.

I am also deeply indebted to Prof. Charles Karemangingo and Dr. Mathusalem Kanobana from The University of Kibungo for their comments, advice and supports during this thesis writing and selection of research theme, modification of methodology. In general, their guidance on how to start and finish the study were great to me. Their intellectual encouragement and help are unforgettable.

I highly appreciate the encouragement of my wife Clarisse Niyonambaza, and my daughter Isimbi Ella ClaDe. I am extremely happy to have a family like you. Moreover, I would like to thank the Government of Rwanda, especially the Eastern Province for allowing me to collect the data with ease. I highly appreciate the hard work of the students of University of Kibungo in Agriculture Engineering, who assisted me in collecting the data for this work.

Thank you all!

ABSTRACT

Soil erosion is one of the most serious problems challenging the wellbeing of the human beings and environmental sustainability. In developing countries like Rwanda, in order to combat soil erosion, conservation practices should be implemented. This research evaluated the technical conformity and cost effectiveness of bench terraces in Rwanda. The Eastern Province of Rwanda was selected for this study as it is the largest, and has a combination of the most populous and the least densely populated areas and compares well with other five provinces. This province experiences insufficient rainfall and serious erosion problems because of its hilly nature and frequent rainstorms. The technical standards and models provided by MINAGRI and FAO were tested on 180 terraces taken as a sample against the current terracing practice. The results showed that many sites have been constructed without consideration of the technical guidelines. In fact, some land slopes are below the 10.7% standards; others are above 44% instead of 15-40% and slope risers of 90% and height of 2.9m. The correlation between vertical interval measured on the field and vertical interval given by FAO formula indicated weak correlation ($r=0.314$; $P<0.01$) and very weak correlation between width measured on the field and width given by FAO formula (0.194;$P<0,05$). Furthermore, some plots have been abandoned and used as pastures and some farmers destroyed the embankment for increasing the cultivable area. The benefit analysis showed that whether farmers use all agricultural technology of farming management the terraces can be economically benefit in second year with 1.15 BCR. Farmers' preferences were investigated through pair-wise ranking approach. The farmers ranked the increasing fodder and soil erosion control at the first rank. If no remedial measures are taken soon to some terraces, landslides and erosion will be carrying more soil than before the construction of bench terraces. The remaining subsoil will not suitable for growing crops; and the increase in agriculture productivity, which was a target while implementing bench terraces will not be met. Therefore, special emphasis should be placed on it by increasing the supervision of implementation on field. MINAGRI should make its effort on construction of them during and after even should continue the monitoring and evaluation till at least 5 years and handover with both implementers and farmers.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOS

LIST OF APPENDICES

LIST OF ABBREVIATIONS

BCR	Benefit Cost Ratio
CBA	Benefit Cost Analysis
CIP	Crop Intensification Program
EC	Erosion control
EM	Easy for maintenance
FAO	Food and Agriculture Organization
FGD	Focus Group Discussions
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Position System
ICA	Increase cultivable area
ICY	Increase crop yield
IF	Increase fodder
ISAR	Institut des Sciences Agronomiques du Rwanda
ISF	Improve soil fertility
LLR	Low labour requirement
LWH	Land Husbandry Water Harvesting and Hillside
MIDIMAR	Ministry of Disaster Management and Refugees Affairs
MINAGRI	Ministry of Agriculture and Animal Resources
MINECOFIN	Ministry of Economic Planning and Finance
MINITERE	Ministry of Land, Forestry, Water and Mines
NAS	National Agriculture Survey

NAS	National Agriculture Survey
NGO	Non-Governmental Organization
NISR	National institute of statistics of Rwanda
NPV	Net present value
OM	Organic Matter
PGRB	Project de Gestion des espaces Ruraux de Buberuka
RDB	Rwanda Development Board
RSM	Retain soil moisture
RSSP	Rural Sector Support Project
SWC	Soil and Water Conservation
USAID	United States Agency for International Development
VUP	Vision Umurenge Programme

CHAPTER ONE

INTRODUCTION

1.1 Background to the Research Problem

Soil erosion is commonly recognized as one of the main factors of land degradation worldwide. Other forms of soil degradation are soil compaction, loss of organic matter, loss of soil structure, poor internal drainage, salinization and soil acidity (Ananda and Herath, 2003; Beskow et al, 2009; Valentin et al. 2005). Terraces are usually reported as a remedy for soil erosion control in regions with combinations of steep slopes, humid climatic conditions and poorly consolidated soils and substrata. Nevertheless, in some cases the effectiveness of terracing is limited, especially in areas with sparse vegetation (Zuazo et al. 2006). Terraces in some areas, especially in rural areas in developing countries, found to be expensive to construct and maintain (Ramos et al. 2007).

Land degradation by water erosion can be measured through three parameters: soil depth, soil organic matter content and soil texture. A degraded soil would have a shallow depth, low organic matter content and low clay fraction (Zuazo *etal*., 2006). Consequently, soil depth, slopes, structure and texture, cropping patterns, rainfall and landscape are key factors to take into consideration prior to any installation of any soil erosion control structure, particularly the installation of bench terraces. The construction of these structures (bench terraces) is expensive and technically complex (Bizoza, 2012). The productivity impacts of land degradation are due to a decline in land quality on site where degradation occurs (erosion) and off site where sediments are deposited (Eswaran et al. 2001). Furthermore, the battle against soil degradation and desertification is also crucial from an economic point of view considering the high productivity impacts and losses. The global monetary loss due to soil erosion has been estimated to be US Dollars 400 billion per year (Eswaran et al. 2001). This is probably an underestimation, given vast tracts of land that are degraded and turned into deserts or desolate land each year.

More than 80% of world's agricultural land suffers soil erosion, from moderate to severe level (Zhang et al. 2008). The mean annual soil erosion rate on cropland worldwide reaches the level of about 30 Mg ha-1, while reported values vary from 0.5 to over 400 Mg ha-1 yr-1 (Pimentel and Kounang, 1998). Several factors influencing the rate of soil erosion by water have been reported by several authors, such as climatic conditions, precipitation and frequency of extreme rainfall events, terrain surface morphology determining the rate of surface runoff generation and flow velocity, hillside slopes' steepness and length, inclination and exposure (Zhang *et al.*, 2008); soil characteristics: particle size, composition and erodibility (Askoy and Kavvas, 2005) and soil usage, manner of agricultural, forestry, engineering or constructional activities.

Bench terraces are one of the proven measures of erosion control. Terracing is an agricultural technique for collecting surface runoff water, thus increasing infiltration and controlling water erosion, known from an ancient history and used to transform landscape to stepped agro-systems in many hilly or mountainous regions of the world (Zuazo *et al*. 2005). The well-known regions of frequent application of terraces in Europe cover Spain, Italy, France, Portugal, Hungary (basically for vineyard cultivation), but they are also employed in such countries like Norway and Poland

(Cots-Folch et al. 2006; Widomski et al. 2010). Terracing is also commonly used in agriculture in Northern and Southern America, Asia (Chinese Loess Plateau, Thailand, India etc.) and in developing countries in arid environment in Africa, i.e. Ethiopia, Rwanda, Tanzania and others (Ramos et al. 2007; Sang-Arun et al. 2006).

Terraces are usually used to cultivate manually or with mechanization, different plants from grains to grapes and various fruit trees such as apples, avocado, mango, loquat, litchi and others (Zuazo et al. 2006). The main purpose of terracing application is to improve the usefulness of steep slope and to increase its agricultural potential. This function is realized by creating the level surfaces according to contour lines of transformed slope (Cots-Folch et al. 2006). The level bench platform allows spreading the surface runoff water, decreases its speed and thus allows more time for water infiltration into soil profile.

Land degradation as a result of soil erosion in Rwanda is well documented as a factor hampering agricultural development and land-based livelihoods (MINAGRI, 2010). The main cause of soil erosion in Rwanda is rainfall since other causes of erosion are not significant. The high slope gradient of Rwanda's landscape (75% of the cultivated land), the fragility of soils, the high rainfall and the way the land is utilized, make Rwanda very susceptible to soil erosion. This type of erosion occurs on the whole national territory at different degrees according to agro-climatic regions and depending on slopes (MINAGRI, 2010).

The agricultural sector constitutes an important part of the Rwandan economy and contributes greatly to the country's overall economic growth. In 2008, the agricultural sector contributed as much as 11.2 per cent to the national economy. The sector provides a means of living for about 80 per cent of the total population (MINECOFIN, 2009). There are many constraints for the promotion of radical terraces in the high altitude regions of Rwanda, including high cost of construction and maintenance, lack of trained manpower to supervise the application on peasant farms, predominance of light soil on schist or quartzite classified as lithosols (ISAR, 1985) and initial reduction of soil fertility which requires, therefore, relatively important quantities of organic and fertilizing amendments unavailable in sufficient quantity in the system.

In Rwanda, a unique method of back-slope terracing originally introduced by missionaries growing wheat in the Northern Province in the 1970s, has been widely adopted by smallholder farmers in many parts of the country (WOCAT, 2014). Other soil and water conservation techniques had been established earlier, such as hedgerows and progressive terraces (trenches coupled with hedges) also known as slow-forming terraces. Both bench and progressive terraces have received a lot of attention from different development interventions in agriculture. Establishing these terrace structures requires a few topographical criteria, including angle of slope. A bench terrace is constructed by breaking up the slope (with a gradient of 25–55%) into different segments in order to maintain the top soils, which are rich in nutrients, and to keep the riser of the terrace intact (Posthumus and Stroosnijder, 2010). The history of bench terraces in Rwanda is linked to policies and regulations by the Government and to interventions by NGOs (Bizoza and Hebinck, 2010).

Rwanda is a mountainous and over-populated country with 477.36 populations per sq. km. Its economy is mainly based on agriculture. The shortage of land for agriculture causes small farmers to cultivate on very steep slopes with no erosion control or using slow forming and bench terraces for soil erosion control, water retention and groundwater recharge. In a changing environment, however, research findings have shown that erosion control structures that increase water infiltration could trigger landslides (Crosta *et al*. 2003; Montrasio and Valentino, 2008; and Gurung et al. 2013). Also Rwandan farmers have linked landslides to heavy rains on bench terraced lands (Bizoza and de Graaff, 2012) while slow-forming terraces have been proven inefficient to control erosion in the high lands (Kagabo et al., 2013). Furthermore, in Rwanda, the bench terraces are constructed by public projects (LWH, VUP) and private companies, as observed some of bench terraces have been abandoned and are not used by farmers after construction; that is why this research focused on the assessment of technical efficacy and economic impact of bench terraces in Rwanda.

1.2 Statement of the Problem

Soil resources are vital assets needed by small-scale farmers in developing countries to produce sufficient crops in order to achieve food security and income (Vlek, 2006). However, in many sub-Saharan African regions, such as in East Africa, rapid population growth and unfavourable economy have exerted great pressures on soil resources. Thus, farmers in East Africa, who cultivate on fragile environments such as steep hill-slopes with high levels of rainfall, have experienced tremendous soil degradation and severe crop yield decline on their lands (Stoorvogel and Smaling, 1990).

Given the continued degradation of the natural resource and high population growth rate, the opportunity to increase production through area expansion is very limited in the country. The greatest potential for increasing agricultural productivity is likely to come from improved land management practices and efficient application of improved agricultural inputs (Kidane, 2001; Assefa, 2009). However, studies have shown that land transformations carried out during terracing are modifying not only the landscape but also the soil physical and chemical properties. In the transformed plots, the acidity has increased and the OM content is also up to 50% lower than in undisturbed plots (Ramos et al. 2007). Catio Exchangeable Capacity (CEC) and Base Saturation (BS) decreased and an increase in exchangeable acidity also occurred (Zhaohua *et al.* 1997).

In Rwanda some of bench terraces are constructed on slopes or cuts with sandy or rocky soils, non-cohesive or highly erodible soils, or decomposing rock including moraines and high slopes and soils are not reorganized and re-fertilized by organic manure and limes after and during bench terracing as recommended by FAO norms. As a consequence, several areas of the country have experienced floods and resulted in landslides on some constructed bench terraces and some terraced lands have been abandoned by farmers after terracing. This suggests that there is need to study the designs of the bench terraces and find out how some of the designs, because of soil infertility and landslides, and some bench terraces are abandoned and not used. The report by National Agriculture Survey (2008) showed that 10% of farm land is uncultivated, and according to (MINAGRI, 2016), survey done in four provinces shown that 32.55% are not underexploited thus this is noteworthy in a land-scarce country such as Rwanda. In that regard, this research was carried out for analyzing technical efficacy vis-a-vis the standards established by FAO and LWH and economic impact of these bench terraces was analysed in order to know if bench terracing is economically benefit to the farmers and the factors explaining current farmers' perception of bench terraces for soil erosion control in Eastern Province of Rwanda was analyzed.

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of this study isto evaluate the technical efficacy and economic impact of bench terraces for soil erosion control in Eastern Rwanda.

1.3.2 Specific Objectives

(i) To compare the technical conformity of bench terraces vis-a-vis the standards established by FAO and LWH for the construction of bench terraces for soil erosion control;

(ii) To examine the cost-benefits of bench terraces for maize and beans;

(iii) To examine farmers' perceptions on bench terraces for soil erosion control in Eastern Province of Rwanda.

1.4 Research questions

(i) Are the standards of construction of bench terraces for soil erosion control used in Rwanda in conformity with the standards established FAO and LWH?

(ii) Is the use of terracing financially cost effective for crop production in the Eastern Province of Rwanda?

(iii) Which factors/criteria do explain the current and future farmers' perception of bench terraces for soil erosion control in Eastern Province of Rwanda.

1.5 Significance and Justification of the Study

The findings of this study would add to the knowledge and understanding in the subject of soil conservation, because soil conservation in Rwanda is very sensitive due to the soil steepness as it is called a country of a thousand hills and leading to the landslides and floods on main hills of the country. In Rwanda, there is no research done on the technical, economic and farmers' perceptions of bench terraces especially in Eastern Province; so there is an urgent need for additional capacity and resources in order to provide the appropriated answers and motivation.

Therefore, the information from this research would help the Rwandan government specially Ministry of Agricultural and Animal Resources (MINAGRI) to take appropriate decisions and establish related policy in soil conservation techniques by promoting and sensitizing the existing measures (maintenance) because some farmers are unaware of soil conservation and many of them want to harvest more without referring to the soils needs. In additional, MINAGRI would increase its supervision on bench terraces constructors, because some of them construct the terraces without taking into consideration of FAO and LWH norms. The target of some constructor companies is to get more money and spend less (less input but get more output) because they are paid according to the surface prepared. Thus, they construct the terraces without applying or following all principles of bench terraces installation (slope, applying the manure or limes, and other more), the Rwandan Government would also know the farmers' 'perceptions of bench terraces project.

This research would inform farmers in land use management and soil management, and it will make them aware of benefits of bench terraces in terms of money. This project is good fit between the government policy of soil and land conservation and fits also with my research interest and natural resource management as my option, the issues of soil conservation and agriculture development are fundamental to promote the agriculture development and environment protection. This study would be significant in the sense that it will be applied by policy makers in soil conservation and agriculture development and successful.

1.6 Scope of the Study

According to Eftekhar (2001), delimitations are boundaries that are set by the researcher in order to control the range of a study. They are created before any investigations are carried out in order to reduce the amount of time spent in certain areas that may be seen to be unnecessary but collect the data needed, and perhaps even unrelated, to the overall study. In that regard, the study was carried out in Eastern Rwanda for analyzing the technical efficacy and economic impact of bench terraces and analyzes the factors explaining current and future farmers’ perception of bench terraces for soil erosion control.

1.7 Organization of the Thesis

This thesis is organized in six chapters. The first chapter contains the introduction, the problem statement, objectives, hypothesis, significance and justification of the study and work organization. The second chapter presents the review of literature and definition of concept, theoretical and empirical literature review, conceptual framework and research gap. The third chapter is research methodology, while the fourth chapter presents the findings and its discussions. The last chapter focus onconclusion and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter gives a brief and precise definition of key concepts, assessment of technical, economic and farmers' perception of bench terraces in Rwanda. It also provides a brief review of previous research findings and attempts to review and analyze the existing facts that may be supportive to the research work. Literature review enabled the selection of the most appropriate methodologies for the study, and provided insights into the strengths and weaknesses of approaches used in previous studies.

2.2 Definition of Concepts

2.2.1 Bench Terraces

A terrace is a channel or bench constructed across the slope to intercept surface runoff water and an artificial land terrace with flat top and nearly vertical side and used especially in series to convert mountainous slopes to arable land (Sheng, 2002). Bench terraces are a series of level or virtually level strips running across the slope at vertical intervals, supported by steep banks or risers (Sheng, 2002). Bench terraces are also defined as level or nearly level steps constructed on the contour and separated by embankments known as risers (Inbar *et al*. 2000). They are finally libelled as horizontal flat bands formed, with variable width according to the slope, disposed like steps on watershed. The role that bench terraces play makes them appropriate for soil conservation in Rwanda (PGERB,2001).

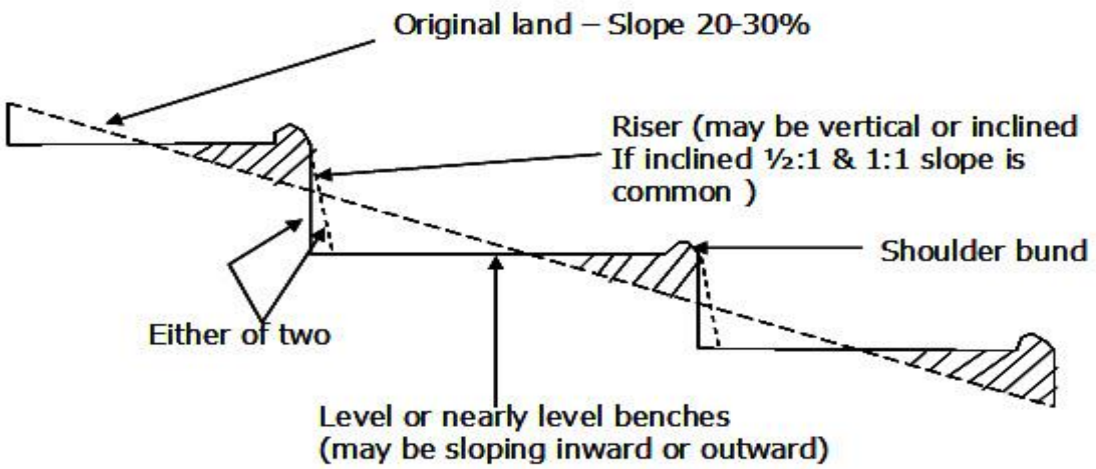


Figure 2.1: Bench Terrace and its Different Components

Source: Mesfin, 2016

2.2.2 Soil Conservation

Soil conservation is the preventing of soil loss from erosion or reduced fertility caused by over usage, acidification, salinization or other chemical soil contamination. Slash-and-burn and other unsustainable methods of subsistence farming are practiced in some lesser developed areas (FAO, 2010).The soil conservation can also be defined as the combination of the appropriate land use and management practices that promotes the productive and sustainable use of soils and, in the process, minimizes soil erosion and other forms of land degradation (Verheye, 2010).

2.2.3 Soil Conservation Farming

Conservation farming is any system or practice which aims to conserve soil and water by using surface cover to minimize runoff and erosion and improve the conditions for plant establishment and growth. It involves planting crops and pastures directly into land which is protected by mulch using minimum or no-tillage techniques (FAO, 2010). Mulch cover protects the soil by absorbing raindrop impact, increasing infiltration and slowing the speed at which water runs over the land, thereby reducing soil movement. A study in the Daly Basin showed that conventionally cultivated areas produced twice the runoff and lost on average 1.5 to 6 times more soil than no-tillage areas despite all areas being protected by soil conservation banks. In some seasons no-tillage areas suffered negligible soil loss while cultivated areas lost up to 8 t/ha (FAO, 2010).

2.2.4 Economic Impact Analysis

An economic impact analysis examines the positive and negative effects of a policy, project, or event on the local economy. An economic impact will quantify the economic value to a local, regional and state economy, including value of production, jobs by sector, jobs by income level, and axe revenue generated (Glen, 2007). A properly designed economic impact assessment will educate others not only on the impact of a project, but also on the opportunity it represents (Elizabeth, 2010).

2.2.5 Efficiency of Terracing in Soil Erosion Control

Terracing is generally reported as successful in limiting the soil erosion by water. Its efficiency in limiting the soil erosion rate is connected to reducing the volume and speed of rain surface runoff because the amount of soil lost is directly related to surface water flow (Zuazo et al. 2005). Concerning the efficiency of terracing in limiting soil erosion compared to erosion rate for untransformed slopes in the same soil and climatic conditions for various regions of the world, it is unquestionable.

On Japanese fruit farm cultivating Satsuma mandarin seedlings compared clean culture and five different methods of soil erosion control: grass cover, straw mulch, grass strips, terraces with bare soil and stone wall terraces for the same slope, soil and climatic conditions for period of 23 months during 1963-1965. Conservation measure soil loss, Mg ha-1 observed total precipitation: 1902 mm clean culture (no control) 157.08 Grass cover 11.32 Straw mulch 1.18 Grass strips 81.63 Bare soil bench terraces 18.49 Stone wall bench terraces 11.98 (Nakao, 2000).

2.3 Theoretical Literature Review

2.3.1 The Law of Diminishing Returns

For 200 years, since it was first expressed (for land) by the French economist Turgot (1767), a law of diminishing returns in the physical output of production has played a central role in the marginal analysis of economic theory, stating in some fashion that the output from production will eventually suffer decreasing increments or decreasing average return if the inputs of some factors of production are fixed and the others are increased indefinitely by some equal increments. Divorced of its reference solely to agriculture, diminishing returns are taken as a fundamental law for technology to support economic theories of equilibrium and price determination.

With the advent of the notion of a production function (Circa, 1910), deductions of the law have followed from mathematical properties assumed for the production function, and most recently by Eichhorn, (1968). Since, the *law* of diminishing returns is a statement concerning technology, from which the production function is a derived concept, a study of the logical relationship between statement of the law and basic concepts in the theory of production should start with a definition of a technology.

A technology is given precise mathematical definition as a family of sets T: L (u), u Ɛ (0, +∞)in the nonnegative domain of an n-dimensional Euclidian space, with certain properties which are presumed to be generally applicable. The members of this family are indexed by a real, nonnegative variable u, denoting output rate, and each set L(u) specifies the set of input vectorsx = (X_1, x_2x 2, ..., Xn) yielding at least the output rate u. The production function ϕ(x) of the technology is then defined on this family of sets for an input vector x as the maximal output rate obtainable with x, giving to it the classical meaning, and the properties of the production function are derived from those of the sets L(u). These formulations permit substitutions between the factors of production, both as alternative and complementary means of production.

The substitutions of primary interest are those on the boundaries of the sets L(u) which are technologically efficient, i.e., input vectors for on output u such that a decrease of any of the inputs without increasing an input will fail to produce the output rate u.One important property (premise) for the input sets L(u) in the definition of the technology is that the efficient subset for each value of u is bounded, i.e, technologically efficient production of an output rate u is not made with an input vector which has infinitely large application of any factor of production.

2.3.2 Carrying Capacity of Land and Productivity

According to Marc (1931), when population density exceeds a certain level in a region where agriculture is based on ploughing with animals, a change to produced fodder in annual rotations is not the only alternative to a grazing shortage. Another solution is to discontinue the cultivation of the poorest land, hitherto used in rotations with short fallow, and leave it as permanent grazings, while the better land is cropped once every year or more with the use of labor-intensive techniques of fertilization and, if necessary, irrigation.

Intensification increases the area that can be cropped in a given year. It may also raise yields per crop hectare, particularly in the cases where a transition from dry to irrigated agriculture is involved. These higher yields per crop hectare are obtained by a much higher labour input per crop hectare, even in cases where the water for irrigation is supplied from canals, built and operated by others than the peasant himself (Stevens,1942). Harvest work per crop hectare is roughly proportionate to yields, and irrigated craps must often be weeded by hand and sometimes transplanted. Total labour input per crop hectare of a given crop may be twice as high as for dry cultivation even where watering is by gravitation and requires very little labour.

Stevens, (1942) reported that the Chinese peasants applying irrigated agriculture sometimes obtain crop yields which are extremely high for cultivation without chemical fertilizers, but in such cases labour input per crop hectare may be up to six hundred working days per crop hectare for a crop of cereals. This is ten to twenty times the usual labour input for dry crops of cereals in extensive plough cultivation of the type applied in underdeveloped countries.

According to Marc, (1931), a model of population growth in which the growth rate is proportional to the size of the population. In the resulting model the population grows exponentially. In reality this model is unrealistic because environments impose limitations to population growth. A more accurate model postulates that the relative growth rate P'/P decreases when P approaches the carrying capacity K of the environment.

The corresponding equation is the so called logistic differential equation:

$$\frac{dP}{dt} = kP\ (1 - \frac{P}{K})$$

2.4 Empirical Literature Review

The technical evaluation of bench terraces has been guided by the FAO and LWH technical standards of bench terrace construction

2.4.1 Design Specifications (Technical of Bench Terraces)

(i) **Length:** The length of a terrace is limited by the size and shape of the field the degree of dissections and the permeability and erodibility of the Soil. The longer the terraces, the more efficient they will be. But it should be borne in mind that long terraces cause accelerated run-off and greater erosion hazards. A maximum of 100 m in one draining direction is recommended for typical conditions in a humid tropical climate. The length can be slightly increased in arid and semi-arid regions**(**http://www.fao.org/docrep/006/ad083e/AD083e07.htm).

(ii) **Width:** The width of the bench (flat part) is determined by soil depth, crop requirements, and tools to be used for cultivation, the land owner's preferences and available resources. The wider the bench, the more cut and fill needed and hence the higher the cost. The optimum width for handmade and manual-cultivated terraces range from 2.5 to 5 m; for machine built and tractor-cultivated terraces, the range is from 3.5 to 8 m. (FAO, 1985) In this research, we consider the handmade and manual-cultivated terraces which range from 2.5 to 5 m because the terraces considered in Eastern Province of Rwanda are made for agriculture and made by other materials rather than being machine built.

(iii) **Gradients:** Horizontal gradients range from 0.5 to 1% depending on the climate and soils. For example, in humid regions and on clay soils, 1% is safe for draining the run-off. In arid or semi-arid regions, the horizontal gradients should be less than 0.5%. The reverse grade for a reverse-sloped terrace is 5% while the outward grade for an outward sloped terrace is 3%. (appendix 1) (FAO, 1985).

(iv) **Slope limit:** If soil depths are adequate, hand-made terraces should be employed on 7 to 25 degree (12%-47%) slopes (FAO, 1985). The bench terraces are constructed in 16 - 40% slope categories but not in higher slope categories than 40%. This is average slope range. Their effectiveness varies in the way we space the bench terraces for each slope category. For 20% slope, at 1.5 m vertical interval, the spacing will be every (100/20) x 1.5 = 7.5 meters while the spacing for 39% slope would be (100/39) x 1.5 = 3.85 meters. **(**Azene B, 2011). If the soil depths and slopes are not adequate for bench terraces, hillside ditches or other types of rehabilitation measures should be used.

(v) **Risers and riser slopes**: Riser material can be either compacted earth -protected with grass, or rocks, so after cutting a terrace, its riser should be shaped and planted with grass as soon as possible (Azene B, 2011). The riser slopes are calculated by the ratio of the horizontal distance to the vertical rise the Hand-made with earth material: 0.75:1(FAO, 1985). In order to ensure easy maintenance, terrace riser height should not exceed 2 m.

(vi) Vertical interval: The vertical interval (VI) gives the height of the terrace; provides basic data for calculating the cross-section and volume of soil to be cut and filled (appendix1) (FAO, 1985).

(vii) Water ways and cut-off-drains: The water ways and cut off drains are made before starting terracing to avoid different problems caused by runoff. The person-made water -ways are receiving water from more than one cut-off drain. The person-made waterways are constructed in the form of inverted trapezoid with average top width of 90cm, depth of 50cm and average bottom floor width of 40 cm with both sides sloping at 2:1 (V: H) ratio respectively.

However, the width and the depth of the waterway would be wider at its outlet and narrow in its beginning. The slope of the waterways is ~ 10 - 15% against the contour. However, the slope orientation could be dictated by orientation of existing drainage system (Azene Bekele-Tesemma, 2011). The outlets should be checked to see whether they are adequately protected. Make sure water flows through the outlets instead of going around them. Any breaks must be mended immediately (Morgan, 1981).

Types of bench terraces and criteria for selection: according to Dennis *(*2008), the following are two main types of bench terraces:

(i) *Irrigation or level bench terraces*: These are used where crops, such as rice, need flood irrigation and impounding water.

(ii) *Upland bench terraces*: These are used mostly for rain-fed crops or crops which only require irrigation during the dry season. They are generally sloped for drainage. In Rwanda the upland bench terraces are used because as used in semi-arid regions.

2.4.2 Bench Terraces Construction Process

The construction of bench terraces requires the techniques and standards to be respected the following are the processes as described by many authors. According to Sheng (2000) using land slope and the width of the bench (flat part) as two starting points, the design proceeds step by step with basic arithmetic that can be easily understood by field workers, land users, or farmers.

(a) Design basics

Use simple arithmetic and a step-by-step approach to design.

(i) Design bench terraces such that the volumes of cut and fill are to be equal for minimizing construction cost.

(ii) Design terraces according to the needs of farmers, crops, climate, and tools to be used for farming.

(b) Execution of bench terracing work

When a particular field/area is to be terraced, the following stepwise procedure should be adopted for execution of the work (Figure 2.4) (Central Soil and Water Conservation Research and Training Institute, 2010).

(i) Determine the land slope prevailing in the selected field. For slope measurement, Abney’s level or a measuring tape can be used.

(ii) Fix the permissible depth of cut based on the depth of soil existing in the field. It should be kept in mind that after cutting, a minimum soil depth of 15 cm should be available for cultivation in that field.

(iii) Select the riser slope either as 0.5:1 or 1:1. It is generally recommended to adopt the former for heavy textured soil and the latter for light textured soil.

(iv) After determining the above three parameters, find out the vertical interval to be provided by choosing from the ready reckoner.

(v) Find out the terrace width using the already determined vertical interval and land slope from the ready reckoner.

(vi) Examine whether the computed terrace width is convenient for cultivation or not. If it is too wide or narrow, then a suitable vertical interval has to be selected by adjusting the permissible depth of cut.

(vii) As depicted in Figure 2.2, compute the total vertical distance (T.V.D. in m) of the field based on sloping length (S.L. in m) and land slope (S in m/m) as follows: T.V.D. = S.L.(0.94S+0.006).

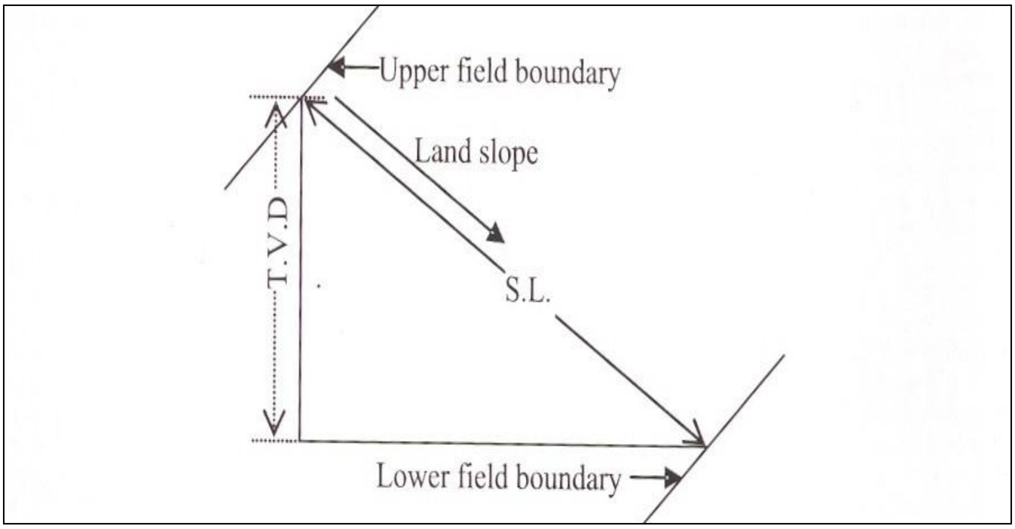


Figure 2.2: Computation of Total Vertical Distance

Source: Central Soil & Water Conservation Research & Training Institute, 2010

(viii) Arrive at the number of terraces which will be formed with the selected V.I. by dividing the T.V.D. by V.I. This may sometimes result in fraction and in such cases round it off to the nearest whole number Divide the T.V.S. by the number of terraces so arrived to get the adjusted vertical interval. This will ensure that a uniform V.I. is followed for the entire field. Alternatively, increase or decrease the V.I. of the first or last terrace and maintain the selected V.I. for the remaining terraces.

(ix) In the field, start from one end and place the peg marks at the selected V.I. with the help of a hand level or dumpy level.

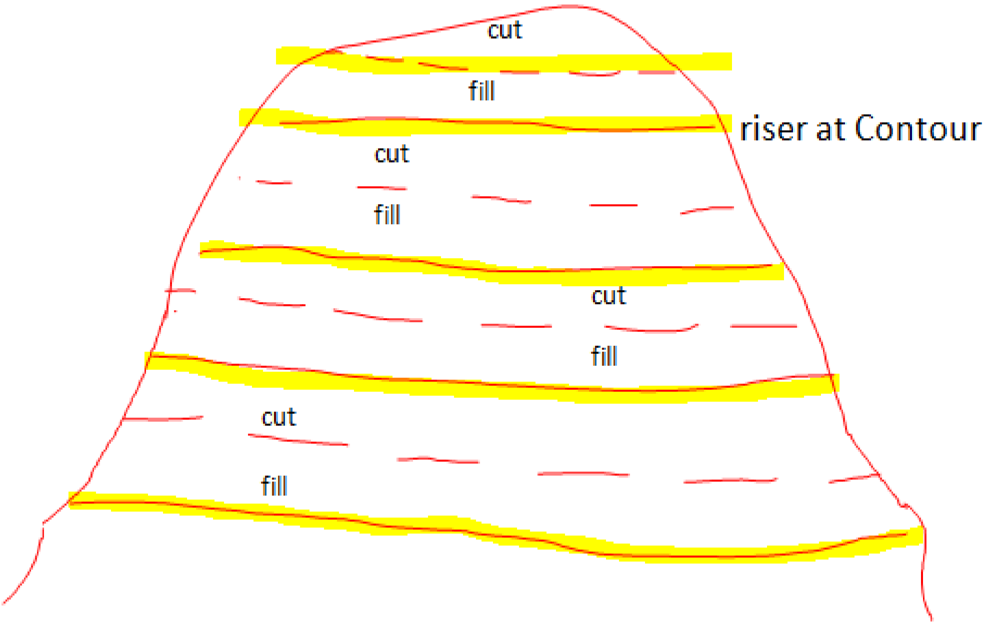


Figure 2.2: Marking Terrace Lines in the Field

Source: Central Soil & Water Conservation Research & Training Institute (2010)

For marking terrace lines in the field using A-frame, anchor one arm of the A-frame at the starting point. Move the other arm either up or down the slope until the plum bob rests at the point of middle arm marked for 1 per cent grade (Fig.2). Proceed again from this point in the same fashion to cover the entire length. In Fig. 2, position 2 indicates A-frame placed with 1 per cent grade between its two arms. Positions 1&3 indicate A-frame with its second arm placed at higher or lower elevations, respectively, than needed for 1 per cent grade

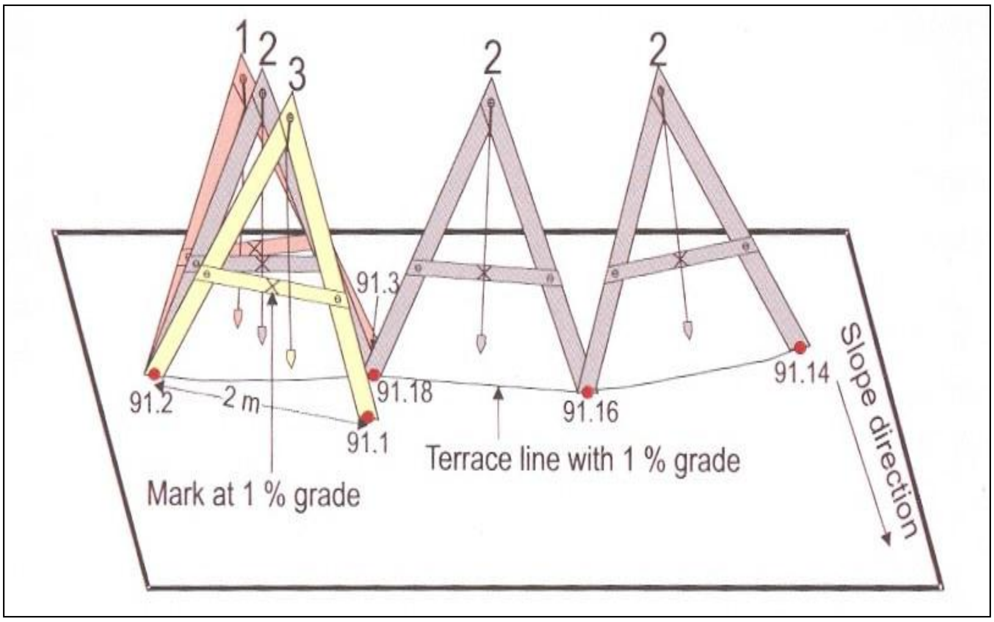


Figure 2.3: Use of A-frame for Marking Contours

Source: Central Soil & Water Conservation Research & Training Institute (2010)

(i) Ease out all sharp and pointed curves deviating from the marked terrace lines, if necessary.

(ii) When the alignment has been finalized, commence the excavation approximately at the middle and push the excavated earth gradually towards the lower slope until the desired level is obtained. After the rough levelling is over, check for the required gradient and carry out the final scraping and levelling.

Basic Construction steps methods

In construction of terraces needs first of all to remove the topsoil and pile it convenient place, digging the foundation and start to construct the riser along the contour, digging the sub soil on the cut section and fill on the fill section, with raising the riser, until it makes level, finally spread the top soil all across the terrace. Figure 2.6 below illustrates clearly the construction steps.

The riser/ terrace wall need to be compacted during construction of earthen raisers/ terrace wall should be inclined at a slope of 1:1 and earthen terrace wall or riser would be stabilized with grass.

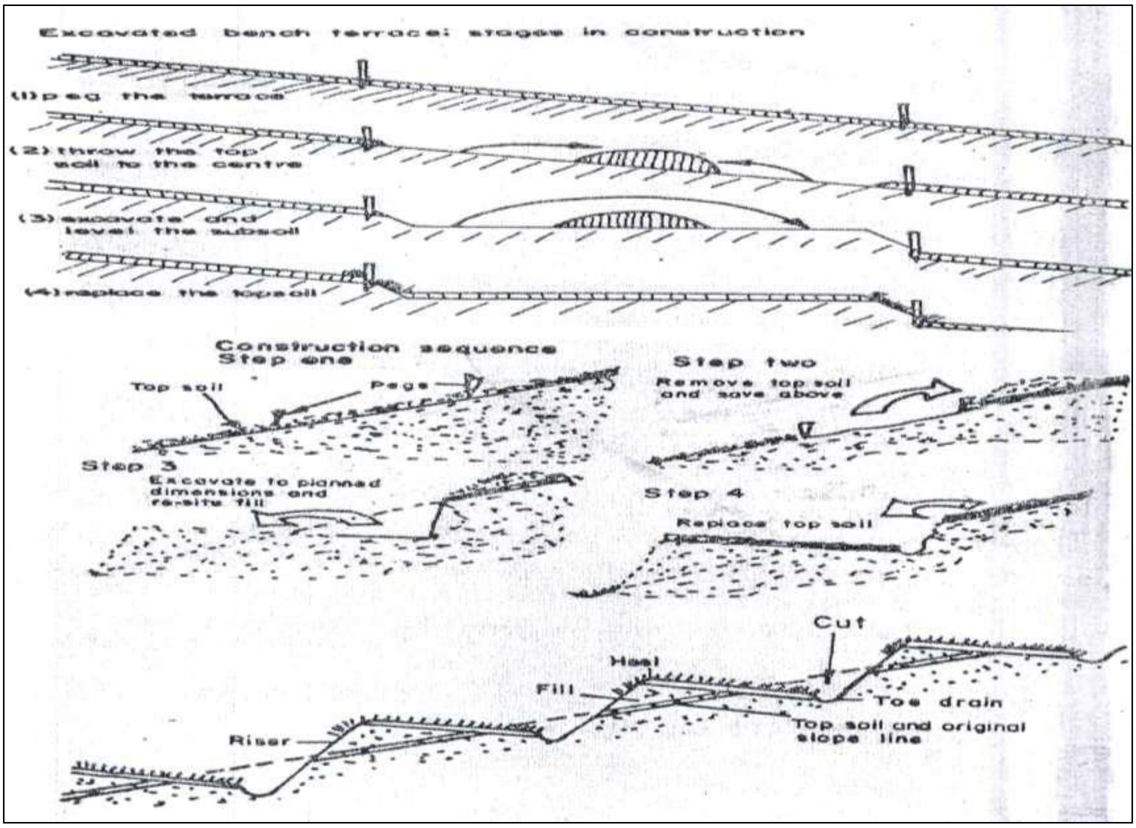


Figure 2. 4: Construction Procedure of Bench Terraces
Sources: Mesfin, 2016

The first method, the terraces should be built from the bottom of the slope upwards. After the bottom terrace is roughly cut, the topsoil from the slope above is then pulled down to the lower bench and spread on its surface. Repeat this procedure for the next terrace up the slope and proceed uphill in this way until the top terrace is built. Of course, the top terrace will not have topsoil unless it is obtained from another place (Mesfin, 2016).

The second method is to push the topsoil off horizontally to-the next section before cutting the terrace. The topsoil should be pushed back when the bench is completed. For hand-made terraces, the topsoil can be piled along the center line provided that the bench is wide enough.

2.4.3 Functioning of Bench Terraces

Bench terracing is an engineering technique for collecting surface runoff water thus increasing infiltration and controlling water erosion known from ancient history and used to transform landscape to steep agro-systems in many hilly or mountainous regions of the world (Zuazo *et al.* 2005). The main purpose of terracing application is to improve the usefulness of steep slopes and to increase its agricultural potential. This function is realized by creating the level surfaces according to contour lines of transformed slope (Cots-Folch *et al.* 2006).

Terracing is also commonly used in agriculture in Northern and Southern America, Asia and in developing countries in arid environment in Africa, i.e. Ethiopia, Rwanda, Tanzania and others (Dabney *et al.* 1999). The high population density averaging 459.73 inhabitants /Km^2 in Rwanda is associated with a number of root causes of land degradation. In fact, a strong cause and effect relation has been recently established between the population density and the soil erosion losses in South Western Rwanda (Karemangingo *et al.* 2014). High population density increased conversion of less-productive and easily erodible marginal lands including land on very steep slopes. This re-conversion is aggravated by the lack of proper land use plans at Districts and Sector levels, since no land capability classification has been established for the country.

(a) Bench terraces and runoff control

The principal objective of terracing is generally to reduce the runoff and the loss of soil, but it also contributes to increasing the soil moisture content through improved infiltration and to reducing peak discharge rates of rivers. Beach and Dunning (1995) stated that, terracing promotes rock weathering and eventually increases soil build up and crop growth. However, Schottman and White (1993), in their studies, showed that there were hardly any figures showing significant increased yields in the first five to ten years after terracing.

On the other hand, the work of Rufino (1989) on technical aspects of the structural competence of terraces suggested that the efficacy of terraces was determined by local conditions along with their dimensions, form and stability. The efficiency of a terrace system increases by applying additional conservation practices, such as appropriate land preparation (contour ploughing and sowing), appropriate cultivation (e.g. strip cropping) and maintenance of a permanent soil cover (Roose *et al*. (1988). Terraces are often promoted as effective soil and water conservation (SWC) measures on sloping land. Hammad et *al.* 2006; Zhang reported that practically the terraces reduce the amounts of runoff and erosion but scientifically is ambivalent on their impacts on crop yield.

Roose *et al*. (1988) specified that the advantage of bench terraces is to reduce the slope and erosion on one hand, and to facilitate the work on soil on the other hand. In fact, radical terraces play an important role, they suppress completely the slope and totally the runoff, increase available water for the plant, capitalizes the acquired fertility through organic and mineral manure and allow establishment of small irrigation schemes on the hills and mountains (Inbar and Al, 2000). Economic vulnerability beyond the potential destruction of infrastructures caused by landslides, erosion such phenomena may induce indirect economic impacts when they block a road or other pathway, destroy an electric line or a water pipe as showing by Figure 2.1, so that the economic activity in the area below must have been stopped.

According to MIDIMAR (2012), at least 17 people were killed and hundreds of houses were destroyed in the North-Western Rwanda. In December 2006, 14 people died and 2,000 were displaced after heavy rains caused flooding in Northern Rwanda. The floodwaters submerged at least 5,000 homes and 3,000 hectares of farmland, forcing farmers to seek refuge on higher ground (MIDIMAR, 2012). Several areas of the country have experienced floods following on-going above normal heavy rains which resulted into landslides in localized areas of the country where steep slopes and mountain valley are presents (Meteorological Services, 2012).

The flooding and landslide cases that happened in the above area impacted heavily on the socio-economic profile of the community in place the Fig 2.1 proof the landslide in Musanze North province of Rwanda. The agricultural sector has been the mostly affected than others. Therefore, comparing the number of households living with agriculture in all over the District (91%), this will impact on food security if nothing done (MIDIMAR, 2012).

Shallow or thick landslides represent constant and common features in the landscape of the Akanyaru sub-catchment, particularly from the central region to the West of Nyaruguru District. They impact on the land resource and they represent serious threats to local communities in the vicinity of their occurrence, runaway, and deposit sites. In general, landslides happen on shallow soils or deep soils on very steep slopes. Most deep slides have been found on very steep slope (above 60% slope) under heavy rain precipitations. They have been generally observed from mid-slope to down slope of the hills.

Existing documentation worldwide indicates that landslides happen when the driving force or shear stress becomes greater than the resisting force or *shear strength* (Ritter, 2004). The rainfall water plays a key role in the disruption of slope stability by increasing the unit weight of material composing the soil; it also creates a pore pressure which opposes the gravity force (normal stress) and so reduces the shear strength of the material (Montrasio and Valentino, 2008; Ritter, 2004).

(b) Terracing and soil fertility

The landscape of Rwanda is characterized by high mountains and hills with very steep slopes. These are major root causes for soil erosion in the country. Up to 77% of all cultivated land in Rwanda have slopes between 13% and 55% and are classified under the category of "moderate to high erosion risk soils (MINITERE, 2007).

In fact, 39% of all cultivated land in Rwanda fall under the high erosion risk categories, 37,5% in the middle risk category and only 23% are classified under the "no or low erosion risk" category. In some cases, land with a slope over 80% is put under seasonal crop cultivation as a result of land scarcity (PSTA, MINAGRI, 2004). The table 2.1 shows erosion hazards according to the slope categories in Rwanda.

Table 2.1: Erosion Risk by Land Category in Rwanda

No	Parameter	% area	'000 Ha	Slope Class
1	Very High Erosion Risk	17.6	358	Slopes class over 55%
2	High Erosion Risk	21.5	437	Slope classes 25-55%
3	Average Erosion Risk	37.5	763	Slope classes s 13-25%
4	Low Erosion Risk	16.7	340	Slope classes 6-13%
5	Very Low Erosion Risk	6.7	137	Slope classes less than 6%

Source: MINITERE, 2007

Crop productivity in Rwanda is declining as a result of intensive farming on steep slopes, which leads to soil loss and declining of soil fertility (Kagabo*et al.* 2013). Bench terraces have been widely adopted in Rwanda to control soil erosion; however, not much has been done to evaluate their efficiency in terms of profitability and technical efficacy. According to Rufino (1989), soil fertility is vital to a productive soil; but a fertile soil is not necessarily a productive soil.

The majority of organic matter, approximately 50 percent of plant-available phosphorus (P) and potassium (K) are concentrated in the topsoil (A-horizon). Losing topsoil to erosion contributes to a loss of inherent soil fertility levels of nitrogen, phosphorus and potassium, and thus to a decline in potential crop yield. The addition of manure and fertilizer can supply needed crop nutrients and help offset some loss of inherent fertility caused by soil erosion. The productivity of eroded soils can be restored by adding inputs only if favourable subsoil material is present (Kagabo*et al.* 2013). Productivity lost by excessive soil erosion cannot be restored with additional inputs when soils have subsoil material with unfavourable physical and chemical properties for plant root growth (subsoil). In soils that have fragile subsoils, limited rooting depth, coarse sand and gravel, or high densities, there is little or no ability to recover yield losses with increased inputs(http://www.ipm.iastate.edu/ipm/icm// ipm/icm/2002/8-19-2002/erosion.html).

Soil erosion in Rwanda causes a total soil loss of about 15 Million tonnes (almost certainly an under-estimate) per year, equivalent to loss of the capacity to feed 40,000 people annually (MINITERE, 2007). The amount of plant nutrients lost annually according to the same source are estimated at about 945,000 tonnes of Organic Matter, 41,210 tonnes of Nitrogen, 3,055 tonnes of Potassium and 280 tonnes of Phosphorous (MINAGRI, 2004).

Soil erosion causes denudation of mountain and hill tops, decreases the soil depth, alters the soil structure and decreases the soil organic matter, thereby reducing the Water Holding Capacity with consequent leaching of nutrients and associated acidification of the soil. Heavy rains frequently occur in the mountainous regions of the country and cause serious erosion and subsequent soil sedimentation in the lower parts of the hillsides, often causing significant damage to crops and destruction of infrastructure such as roads (PSTA, MINAGRI, 2004).

The results from the northern highlands of Rwanda show that because of erosion, the soil in the lower part of the terraces showed as much as 57% more organic carbon content and 31% more available phosphorous than the soil in the upper part. Organic carbon (OC) was higher (OC = 2.1%) on the upper slope than on the hill slope (OC = 1.9%). Less than 2.3 $t.ha^{-1}$ of the mean potato yield ($23t.ha^{-1}$) and only $0.5t.ha^{-1}$of the mean maize yield (5t.ha^{-1}) were recorded on the uppermost third of the terraces on all three landscape positions (Kagabo, *et al.* 2013). Thin top soils mean lower organic matter content, low water holding capacity, and less rooting depth. Textural distribution within the soil profile also determines how much water is available for the plants. Soils with coarse textures tend to drain water more quickly, whereas soils with fine textures hold water too tightly for roots. Poor drainage occurs in medium-textured as well as fine-textured soils on concave landforms, and, in the absence of an artificial drainage system, root development is affected because of the lack of oxygen (Rufino, 1989).

(c) Slope gradient effects on soil loss

The degree of slope of land has long been considered one of the major factors governing the amount of run-off and soil erosion. Few attempts, however, have been made to establish even the simplest mathematical relationships between the degree of slope of land and the amount of run-off and erosion (Duley, 2003).

Many researches indicate that on level land there may be a considerable amount of run-off, but when there is a slight slope the water is less hampered by the very slight depressions and runs off in much greater amounts before it can be absorbed; that is, it will not be held on the land much longer than the duration of the rain (Liu,2015). With a still further increase in slope, the increase in run-off becomes relatively less because the water on any slope is running over the land for the entire duration of the rain and thus time is afforded for absorption. Any run-off that may be taking place at the end of the rain will cease within a short time whether the slope is slight or steep (Duley, 2003).

(d) **Soil conservation and crop profitability**

Increased yields on bench terraced plots are found to be a key stimulus for further adoption of bench terraces (Bizoza, 2012). Other variables like soil properties, farm management, crop and rainfall patterns determine the magnitude of this potential and actual increase of yields. A study by Kassie *et al.* (2008) analyzed the impact of erosion control on the value of crop production in Ethiopia and revealed that their effects on crop productivity differed with agro-ecological settings. Implementing stone bunds increased crop productivity in low rainfall areas whereas in the high rainfall areas this was not the case. Beside the agro-ecological conditions, studies conducted in Kenya by Nyangena and Köhlin (2009) and Otsuki (2010) indicated that the erosion status of the farm was a major determinant of the effect of agro forestry, bunds and terracing on crop productivity.

A study by Bizoza (2012) in Rwanda on a first analysis of costs and benefits, based on farmers' estimates and market prices showed that gross margins on terraced plots are not much higher than those on non-terraced plots and that bench terracing is hardly profitable. However, since the use of labour and manure were found to be the main determinants of profitability and these are mostly available on farm, the cost-benefit analysis was subsequently also undertaken with opportunity costs for labour and manure (both at 50 % of market prices). This plot level cost benefit analysis, using both farmers' estimates and official standard figures, showed that bench terraces in that case were profitable (Posthumus, 2010).

The results from the Peruvian Andes showed that bench terraces have a positive influence on grain yield by modifying the slope. However, crop area is lost because of the construction of terraces as the risers of the terraces occupy space (Nagel, 2010). Based on the dimensions of the terraces, it was calculated that the crop area lost due to the implementation of bench terraces ranged from 16 to 22%, with an average of 20%. This implies that the total yield will be reduced by 20% as less area can be used to grow the crop (Posthumus, 2010).

Bench terracing can be a financially viable option for soil and water conservation, when either costs of labour and manure can be reduced or more intensive use is made of the terraces. Farmers confirm that the terraces are profitable but sometimes they do not consider their efforts put in crop production. During our study and based on farmers' estimates and yield harvested during 2 years the profitability of bench terraces was assessed. Profitability of the technologies appears to be one of the major economic factors which affect the adoption of soil and water conservation technologies (de Graaff *et al*., 2008; Kassie *et al*., 2010; Sattler and Nagel, 2010). The dominant profitability valuation technique in SWC has been mostly cost-benefit analysis (Tenge *et al*. 2005; Bizoza and de Graaff, 2012).

2.4.4 Constraints in Construction of Bench Terraces In Rwanda

Yamoah (1987) finds that there are many constraints for the promotion of radical terraces in the high altitude regions of Rwanda such as:

(i) High cost of construction and maintenance,

(ii) Loss of arable land (already rare which could be more than 50% on slopes higher than 60%);

(iii) Lack of trained manpower to supervise the application on peasant farms;

(iv) Predominance of light soil on schist or quartzite classified as lithosols (ISAR, 1985);

(v) Accumulation of water in terraces causing landslides;

(vi) Difficult in letting out excess water via artificial channels because of the land scarcity and dividing up of farming land.

(vii) Initial reduction of soil fertility which requires therefore relatively important quantities of organic and fertilizing amendments unavailable in sufficient quantity in the system.

Moreover, Ramos *et al* have shown that the land transformations carried out during terracing (in the Priorat area) are modifying not only the landscape but also soil physical, chemical properties by transformation of land relief the acidity increased and the Organic Matter (OM) content went up to 50% lower than in undisturbed plots. Cation Exchangeable Capacity (CEC) and Base Saturation (BS) decreased and an increase in exchangeable acidity occurred (Zhaohua *et al.* 1997).

2.4.5 Perception of Farmers on Bench Terraces

If farmers perceive land degradation as a problem, the chance that they invest in land management measures will be enhanced. The survey results done in Ethiopia by Kassa *et al.* (2013) show that higher proportions (82.7 %) of the sampled households were aware of the problem of soil erosion and majority of these households (54.5 %) perceived erosion on their land as severe. The responses of sampled households about the rate of soil erosion in their area for the last ten years based on their knowledge showed that 37.1 percent were of the opinion that erosion was happening very rapidly, 11.9 percent moderately and 51 percent slowly. They were also asked when erosion becomes severe in their area. Accordingly, 19.6 percent reported that severe erosion started 20 years ago and before, 24.4 percent as 15-20 years, 29.3 percent as 6-14 years and the rest 25.4 percent as the last 5 years, 1.3 percent reported that there is no erosion at all (Karemangingo *et al,* 2014).

The analysis of responses of farm households on the severity of fertility decline on their farm shows, 28.1 percent perceived less severe, 57.9 percent sever and 13.9 percent very severe problem in fertility decline (Karemangingo *et al*, 2014). Concerning the perception of Rwandan farmers on the causes of soil fertility decline on their farms in research done in Nyaruguru District, most of respondents ranked soil erosion, lack of manure and mineral fertilizers the first reasons for the decline of soil fertility (Karemangingo *et al,* 2014).

According to Karemangingo *et al* (2013) during the research in Nyaruguru District of Rwanda, a great majority of respondents /farmers ranked bench terraces at the first position in soil erosion control methods and affirmed that this method improves soil fertility and few of them, they have a bad experience from the bench terraces done in the last years, which were badly done in terms of technique and soil treatment and farmers abandoned their farms or cultivated other resisting crops such as cassava, sweet potatoes and trees on these terraces. Hence, such interventions should consider heterogeneity in the above factors in the design and promotion of the conservation practices. Moreover, to encourage adoption of improved conservation measures, extension institutional support programs and projects which promote soil and water conservation technologies should have strategies which focus on enhancing the willingness of farm households (Kassa *et al*, 2013).

2.5 Soil Erosion and Bench Terraces in Rwanda

Bench terracing was introduced in Rwanda in the 1970s. Other soil and water conservation techniques had been established earlier, such as hedgerows and progressive terraces (trenches coupled with hedges). Both bench and progressive terraces received a lot of attention from different development interventions in agriculture. Establishing these terrace structures requires a few topographical criteria, including angle of slope. A bench terrace is constructed by breaking up the slope (with a gradient of 25–55%) into different segments in order to maintain the top soils, which are rich in nutrients, and to keep the riser of the terrace intact.

Progressive terraces result from tillage practices combined with the planting of hedgerows over a certain period of time, and they are recommended on plots that are less steep (12–25% gradient). These two techniques differ partly in terms of effectiveness to counter run-off, soil erosion control, capacity to conserve water, and the time needed to change soil properties (Kannan et al. 2010). Mountainous areas similar to most parts of Rwanda are very sensitive to rain erosion. In the short term, bench terraces are deemed to be more effective technically at soil erosion control than progressive ones (Posthumus and Stroosnijder, 2010). The layout or ‘bed’ of progressive terraces takes longer to form (about seven years); this explains their technical effectiveness in the long run (Hudson, 1988). Nevertheless, bench terraces call for substantial material and labour inputs in the early, installation stage compared to progressive terraces (Hurni *et al.* 2008).

The history of bench terraces in Rwanda is linked to state policies and regulations and to interventions by NGOs (Bizoza and Hebinck, 2010). The approach used to promote these terraces has shifted over time from top down to somewhat participatory. Various development policies promoted by the current government, such as the ‘performance contracts’ (known as *Imihigo*), collective community work (*Umuganda*) and *Agasozi Ndatwa* (literally meaning a ‘model hill’), entail certain aspects of community-based development, promotion of farmers’ associations and co-operatives, and a self-reliance mentality towards rural development. In the case of soil and water conservation, these policies are geared primarily towards collective awareness and soil erosion control. At the same time farmers operate in small-scale associations and co-operatives from which different forms of social capital originate (e.g. trust, co-operation, and mutual assistance or reciprocity).

Despite theoretical claims that social capital matters for investments in SWC measures, few empirical case-studies exist for Eastern Africa (e.g. Nyangena, 2008; Isham, 2002). Moreover, Graaff *et al*. (2008) present a summary of factors affecting adoption and continued use of SWC measures (including terraces) from recent studies in five developing countries: Tanzania, Ethiopia, Peru, Bolivia, and Mali. Institutional variables considered include land tenure, extension contracts, programme participation, and group participation. These factors measure ‘structural’ social capital. Trust, as part of ‘cognitive’ social capital, is not considered. To the author’s knowledge, no study has related empirically these forms of social capital to the adoption of SWC measures in Rwanda.

This study investigates their impact on the adoption of bench and progressive terraces in the North and Southern provinces of Rwanda. Apart from government interventions, NGOs such as World Vision International played prominent roles in the construction of terraces in the period after the 1994 war and genocide in Rwanda (Bizoza *et al*., 2007). Bench terraces were constructed in some areas using food support from the USAID. The food-for-work programmes have been contested in the literature for nurturing dependency mentality, among other effects. Material incentives and the commoditization of labour may have created paternalistic behaviour and possibly distorted the real sense of existing local institutions such as mutual support.

Despite efforts and progress made, the job of soil erosion control continues. The 2008 National Agriculture Survey (NAS) showed that 62.2 % of the cultivable area (an estimate of 1 280 750 ha) is protected by anti-erosive measures. Furthermore, 4.2 % of the protected area is provided by bench (radical) terraces compared to 69.2 % by anti-erosion ditches of which progressive terraces are formed. Kannan et al. (2010) indicate that 93.2% of the total potentially cultivable area is positioned on hillsides under rain-fed conditions. Current results of soil erosion shown that in last few years, Rwanda has put more efforts in soil erosion control by using the two main system which are progress terraces and radical terraces, the status on soil conservation in Rwanda 1,013,454 ha are protected against soil erosion out of 1,502,727 arable land. The table 1 illustrates current erosion control covered in 2016.

From private perspective, bench terracing is not obviously an optimal soil conservation option (Hurni *et al.* 2008, Saint-Macary *et al*. 2010). As indicated above, bench terracing leads to higher investments, which take longer for farmers to pay back unless they are coupled with additional, improved agricultural practices (Posthumus and Graaff, 2005; Bizoza and Graaff, 2010). Since the top soils of these terraces have been disturbed from an early stage, it has resulted in low soil fertility and high inputs.

Typically, in places like Rwanda where per capita land holdings are very small (less than 1 ha), farmers hesitate easily to invest in such technology. Unless measures to use terraced plots effectively are provided by governmental organizations and NGOs, farmers are rational not to construct terraces on small plots, much of which they depend on for their livelihoods. Indeed, this case-study proves that some smallholders abandon their terraced plots or fail to use them productively (approximately 10%). Results from Bizoza and Graaff (2010) in the same research area show that bench terraces built with help of support projects could well have been established on plots that are too large (and thus underused) and on less suitable soils, resulting in less than expected benefits. Equally, the same NAS (2008) shows that 10% 1of farm land is uncultivated and according to MINAGRI (2016) survey done in four provinces shown that 32.55% are not underexploited shows by table 2 the results of abandoned area in surveyed districts. This is noteworthy in a land-scarce country such as Rwanda.

Therefore, the government intends to further promote terracing through different public and private initiatives. Hence, it is important to learn more about the characteristics of the adopters and the role of local institutions in fostering the adoption. For this purpose, a distinction is made here between bench and progressive terraces to guide policy to tailor future interventions by responding to which types of terrace are demanded by which categories of farmers in rural Rwanda.

2.6 Soil Erosion in Rwanda

At present, the agricultural sector is failing to meet the demands of a rapidly growing population. It is also at the heart of one of the country’s most serious environmental problems: land degradation. Land degradation in Rwanda is characterised by soil erosion and declining soil fertility and is driven by unsustainable land use practices, namely deforestation, over cultivation including on steep slopes without appropriate soil conservation measures, and overgrazing (UNEP 2011).

Soil erosion results in a significant decline in soil fertility, which is the primary cause of low agricultural productivity in Rwanda. Heavily degraded soils are incapable of supporting a large plant biomass because of low or depleted soil nutrients and soil organic matter (SOM). Organic matter is important for maintaining soil structure and maximizing nutrient retention. It is the glue that holds soil nutrients, namely nitrogen and phosphorus, in place until they are accessed by cultivated crops. Frequent, continuous cultivation has accelerated the rate of SOM depletion in the country. Moreover, soil erosion has important downstream impacts. High sediment loads reduce the size of river channels and water-holding capacities of lakes, choke water harvesting and storage systems, and exacerbate flooding. In addition, erosion is a major cause of progressive eutrophication in many of the country's lakes, promoting the proliferation of algal blooms and water hyacinth (*Eichhornia crassipes*), which reduce the amount of dissolved oxygen in water (UNEP 2011).

2.7 Research Gap

Before a problem can be addressed, it must be perceived. Addressing soil erosion with the adoption of conservation practices is no exception. The literature on the technical, economic and farmer's perception of bench terraces in Rwanda has given little attention to perception variables especially in Eastern province. Considering the findings reported in the literature reviewed above it is still not comprehensible whether the technical and how farmers perceive the bench terraces as shown in different studies carried out on soil conservation, farmers' participation in soil conservation rather on technical, economic and farmers' in worldwide as well as in Rwanda.

As reported by Yamoah, (1987), there are many constraints for the promotion of radical terraces in the high altitude regions of Rwanda. Sheng, T.C.(2000) also stated that using land slope and the width of the bench (flat part) as two starting points, the design proceeds step by step with basic arithmetic that can be easily understood by field workers, land users, or farmers. The findings of Bizoza, (2012) and Eswaran *et al.*, (200).The global monetary loss due to soil erosion has been estimated to be US Dollars 400 billion per year. This is probably an underestimation, given vast tracts of land that are degraded and turned into deserts or desolate land each year. Land degradation as a result of soil erosion in Rwanda is well documented as a factor hampering agricultural development and land-based livelihoods (MINAGRI, 2010). The data given by researchers are very general in Rwanda not in eastern province which is a big gap in technical and economic evaluation of bench terraces in Eastern province.

According to the Hurni*et al.*,(2008), Rwanda has invested in hillsides protection with bench terraces; nonetheless some of them have been abandoned by the farmers because of infertility. After these big investments, there was no study conducted for coming up with the reasons why of those mentioned problems and make clear also the benefit cost analysis of soil conservation especially bench terraces system. This research will make clear if the constructors of the bench terraces in Rwanda respect the FAO or LWH /standard/norms, this research will also make clear the profitability of bench terraces in terms of money and make out the farmers' judgment towards the role of bench terraces in their fields. So far, no studies have been conducted on technical conformity and benefit cost analysis on bench terraces in Rwanda and this is a big gap.

2.8 Conceptual Framework

Conceptual Model Figure 2.8 illustrates the research variables, the technical standard and model provided by MINAGRI and LWH were tested against the current terracing practice.

(a) The independent variables

The independent variables are related to the natural factor.

(***Topography and rainfall:*** The major factors of soil erosion are the level of slope land and the amount of rainfall, the rugged topography and steep slopes affect soil erosion rate through its morphological characteristics. On sloping lands, more than one-half of the soil particles that are dislodged by raindrops during rainfall are carried downhill.

(b) The dependent variables

Soil erosion/soil degradation control: Erosion increases dramatically because the increased angle facilitates water flow and soil movement means *Soil erosion:* this soil movement cause serious problem of *soil degradation* these interactive components are used to identify and express the degree of soil deterioration/degradation by changing in soil physical and chemical properties and cause the soil infertility.

Measure of soil conservation /topography management: It is well recognized that soil nutrient content varies across the landscape, but the nature and degree of that variability with respect to landscape position is still poorly understood and documented (Shaoliang Zhang et all, 2010). Slope aspect and steepness, climate and land management are known to affect soil nutrient distribution in a field, but the relative and cumulative strengths of these effects can be managed by famers for erosion control. *Land slope determination is the imperative criteria in selecting what type of soil conservation and management practices to put in place for soil erosion contro.*

Socio Economic and bench terraces: Water is globally known as capital product not only for consumption but also for agricultural production (Rokstrom et al, 2003). Part of reasons is the unsuitability of proposed technologies and the prevailing social, economic, cultural milieu; and partly due to delivery systems of these technologies by development officials (Jostein and Richard 1996). In developing countries like Rwanda, most of agricultural farming systems are rain fed; crop and animal production depend heavily on natural precipitation. In addition, rain fed technologies claimed to be technically sound, economically viable and resource neutral, have not been widely accepted by small scale farmers.

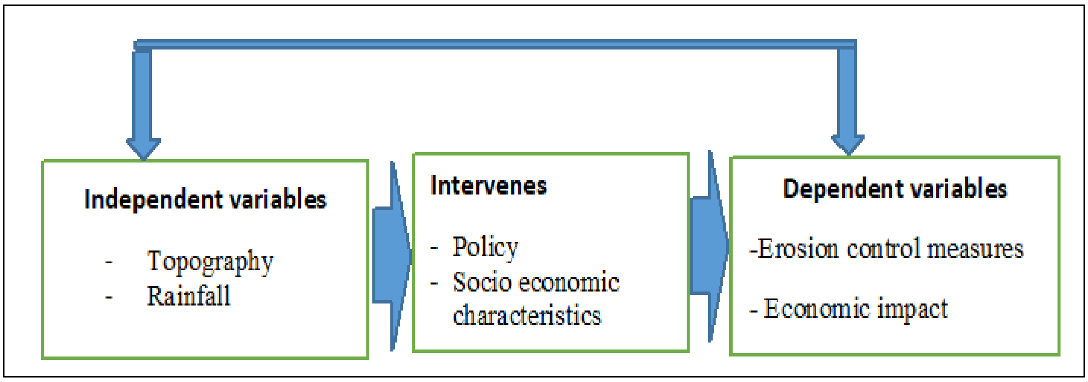


Figure 2.5: The Conceptual Statement of Soil Conservation

Source: Author, 2014

As reported by Bizoza and Hebinck, (2010). The history of bench terraces in Rwanda is linked to state policies and regulations and to interventions by NGOs. The approach used to promote these terraces has shifted over time from top down to somewhat participatory. Various development policies promoted by the current government, such as the 'performance contracts' (known as *Imihigo*), collective communal work (*Umuganda*) and *Agasozi Ndatwa* (literally meaning a 'model hill'), entail certain aspects of community-based development, promotion of farmers' associations and co-operatives, and a self-reliance mentality towards rural development

2.9 Summary

This chapter on literature has outlined definitions of terms and concepts of bench terraces, and has discussed motivating factors to the adoption, negative and positive impacts, technical assessment and famers' perceptions in relation to the bench terraces. Bench terraces are a series of level or virtually level strips running across the slope at vertical intervals, supported by steep banks or risers. Terraces belong to the type of soil management practices that aim to protect an area against runoff by systematic land planning.

The efficiency of a terrace system increases by applying additional conservation practices, such as appropriate land preparation (contour ploughing and sowing), appropriate cultivation of crops (e.g. strip cropping) and maintaining a permanent soil cover. Crop productivity in Rwanda is declining as a result of intensive farming on steep slopes, which leads to soil loss and declining soil fertility. Bench terraces have been widely adopted in Rwanda to control soil erosion; however, not much has been done to evaluate their efficiency in terms of profitability. If farmers perceive land degradation as a problem, the chance that they invest in land management measures will be enhanced. The survey result done in Ethiopia shows that higher proportions 82.7 % of the sampled households were aware of about the problem of soil erosion and majority of these households 54.5 % perceived erosion on their land as severe.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the study areas where the research was conducted, indicating its geographical location in relation to activities; explains what methodologies and materials used, as well as how the process of testing the research hypothesis were carried out. The methodological of research of this study was controlled investigation of the theoretical and applied aspects of measurements, statistics, and ways of obtaining and analyzing data. It was primarily intended to make description and assessment of the technical and economic evaluation of bench terraces in Rwanda. For this reason, this study is an exploratory study because there has not been a similar study before.

3.2 The Study Area

3.2.1 Climate of Eastern Rwanda

The temperature of eastern province of Rwanda is more or less constant throughout the year 20^0C - 24^0C. It has an equatorial-continental temperate type of climate classified as AW3, according to the Köppen classification. The province has four seasons which are determined by the variability of rainfall. However, the rainfall is quite irregular and gives rise to prolonged drought periods, causing serious setbacks to agricultural activities that are totally dependent on rainfall.

3.2.2 Soils in Eastern Rwanda

The soils are naturally fragile (Figure 3.1). They are a result of the physical and chemical alteration of schistose, quartzite, gneiss, granite, and volcanic rocks which form the surface geology of the country. According to the soil map of Rwanda, which was published in 1992, there are six types of soils: soils derived from schistose, sandstone and quartzite which cover almost 50% of the national territory, soils derived from granite and gneiss which make up about 20% of the national territory, soils originating from intrusive basic rocks that hardly cover 10% of the national territory, soils originating from recent volcanic materials that cover 10% of the national territory, soils originating from ancient volcanic materials that cover 4% of the national territory and illuvial and colluvial soils which are typical of Rwanda's swamps occupy 6% of the national territory. The map of soil capacity, which is complementary to the soil map, shows that more than half of Rwanda's soils are unsuitable for crops that are particularly demanding. The very good soils occupy a very small area and are found mostly in densely populated areas (MINERENA,2004).

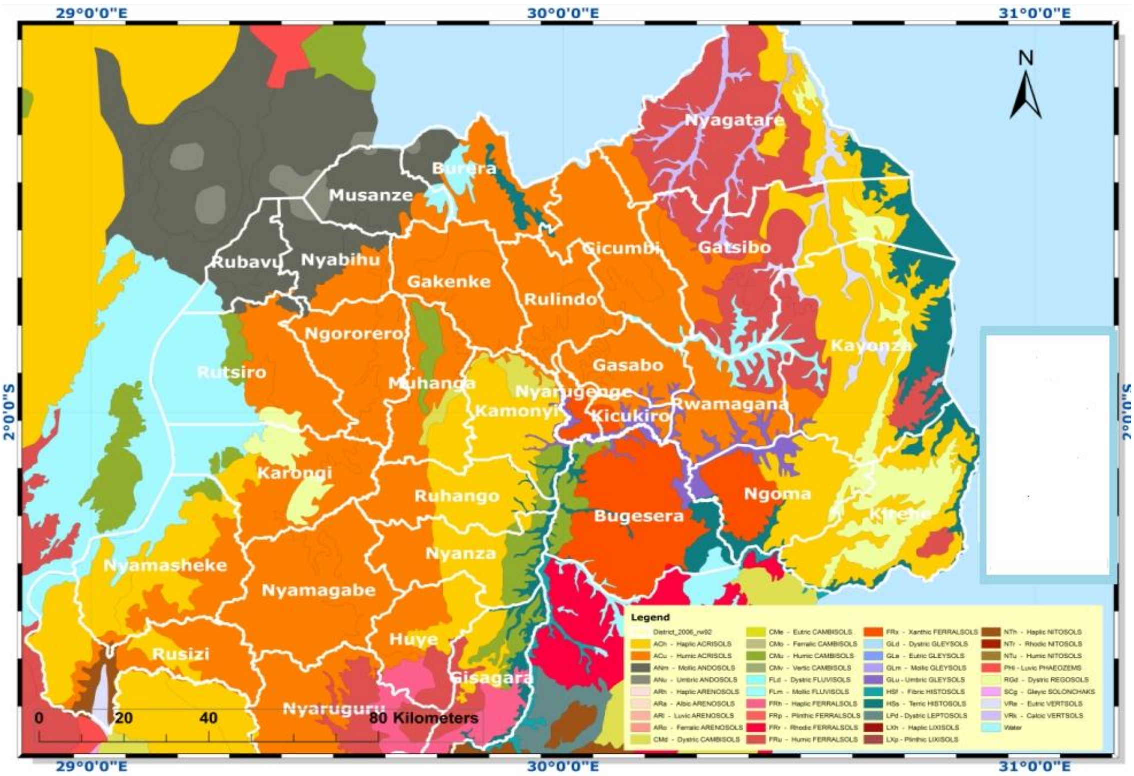


Figure 3.1: Rwanda Soil Map
Source: Ishimwe, 2013

3.2.3 Population of Rwanda

According to the World Statistics, Rwanda in 2012 had 11.78 million people and a population density of 415 persons per sq. km (Figure 3.2). The least densely populated districts are found in the Eastern Province where this research was carried out. The most densely populated districts are Nyarugenge (2,124), Kicukiro (1,911) and Gasabo (1,234). Rubavu in the Western Province has the highest population density outside Kigali City with 1,039 inhabitants per square kilometre.

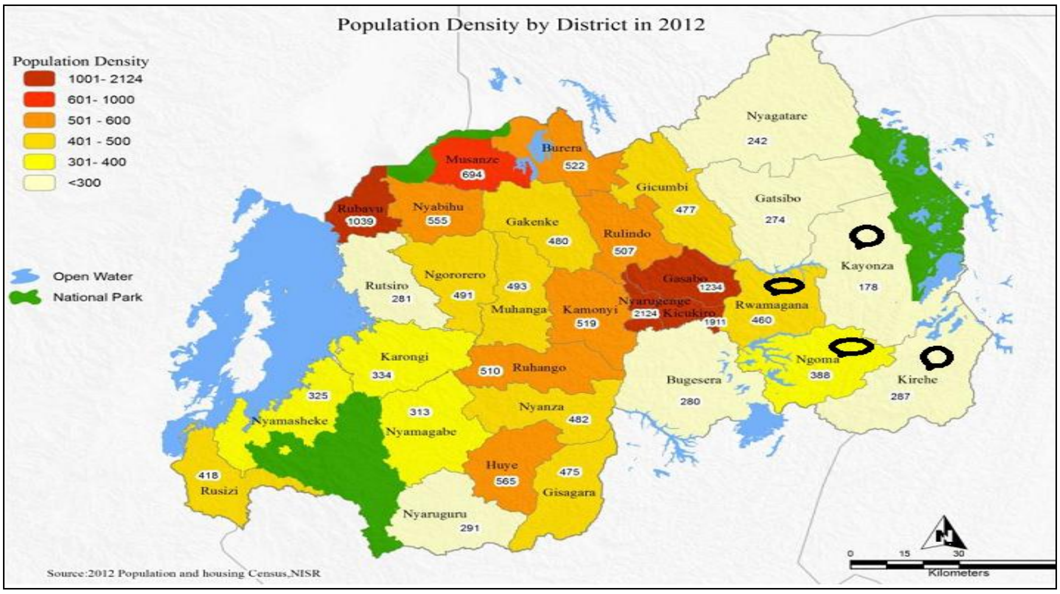


Figure 3.2: Population Density by District
Source: NISR, 2012

: Study area

In May 2000, the Rwandan Government initiated the decentralization policy aiming at involving the entire population in decision making on national development, and in 2006, Rwanda was subdivided into 4 provinces, 30 Districts, 416 sectors and 2148 cells. The province was established by the Organic Law No 29/2005 of 31/12/2005 establishing organization of administrative entities of the Republic of Rwanda, and it is governed by the Law No. 01/2006 No. of 24/01 / 2006 establishing organization and functioning of the Province (Official Gazette of the Republic of Rwanda Nº 29/2005 of 31/12/2005).

Eastern Province (Kinyarwanda: *Intara y'Iburasirazuba*; French: *Province de l'Est*) is the largest, the most populated and the least densely populated of Rwanda's five provinces. It was created in early January 2006 as part of a government decentralization program that re-organized the country's local government structures. It has seven districts namely Bugesera, Gatsibo, Kayonza, Ngoma, Kirehe, Nyagatare and Rwamaganaas shown by Table 3.1. The capital city of Eastern Province is Rwamagana.

Table 3.1: List of the Eastern Province Districts by Population in 2012

Rank in Eastern Province Districts, 2012	**Rank in Rwanda Districts, 2012**	**District**	**Population August 15, 2012**	**Population, August 15, 2002**	**Population Change 2002-2012 (%)**	**Population Density 2012 (sq km)**	**Population Density Rank, Eastern Province 2012**
1	2	Nyagatare	466,944	255,104	83.0	243	6
2	3	Gatsibo	433,997	283,456	53.1	275	5
3	9	Bugesera	363,339	266,775	36.2	282	4
4	10	Kayonza	346,751	209,723	65.3	179	7
5	13	Ngoma	340,983	235,109	44.0	390	2
6	15	Kirehe	338,562	229,468	48.6	288	3
7	26	Rwamagana	310,238	220,502	40.7	455	1
Total	**-**		**2,660,814**	**1,700,137**	**53.0**	**275**	**-**

Source: NISR, 2013

3.2.4 Geologyof Rwanda

Rwanda is largely underlain by the Kibaran Orogeny rock system which consists predominantly of basement and mezoproterozoic rocks that have been intruded by different generations of granitic and mafic rocks. The Kibaran Belt extends from Northern Tanzania, through South Western Uganda, underlying almost the whole of Rwanda and Burundi, then through South Eastern DRC up to Angola (MINIRENA 2010).

The geology of Rwanda consists of Middle (Meso) Proterozoic formations, with Tertiary age, East African Rift, volcanic cover in South Kivu, Cyangugu and in the north western Birunga mountains. The Meso-Proterozoic formations comprise three lithologies: low-to-medium grade metavolcanic and metasedimentary sequences, large granite batholiths (with inliers of basic and metsedimentary rocks) and large complexes of high grade metasediments to amphibolites with granite / gneisses and migmatites.

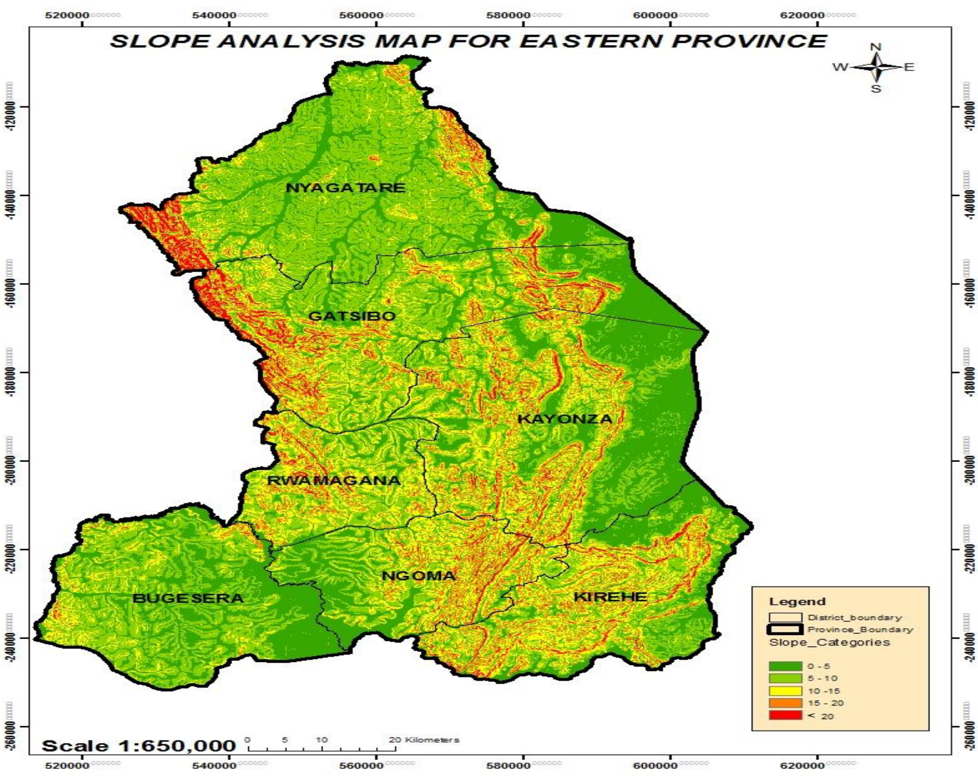


Figure 3.3: Slope Analysis Map of the Eastern Province

Source: Author, 2015

The sediments within Rwanda have been subdivided into four groups, from youngest to oldest. Those are: Rugezi, Cyohoha, Pindura, and Gikoro group. The general pattern of the Kibaran, or Meso-Proterozoic in Rwanda comprises resistant cores (Appendix2: Rwanda geological map) (high-grade units) characterized by weak deformation separated by "Intensely Deformed Zones," noted as Shear Zones (RDB, 2012**).**

3.3 Research Design

This research is the first of its kind in the study area, and such being the case, it is exploratory cross sectional in design. A lot of descriptive data were involved coupled with qualitative and quantitative information collected for comparative purposes. The FAO and LWH standards of terraces were used for correlation with the qualitative and quantitative data collected from the field. Random and purposive sampling techniques were employed.

3.4 Sampling Procedures

Based on population density, the largest and food basket, the Eastern province was selected from four Rwandan Province, then after Eastern Province's slopes analysis (Figure 3.3)we came up with 4 districts out of seven. The selection of sites for sampling and study was guided by topography, availability of terraces in the mountain slopes, accessibility and population density. The materials and methods used during data collection on technical evaluation of bench terraces, farmers' perceptions and benefit cost analysis are described.

After selection of province and district, the sites were selected based on the four most important criteria: firstly, districts of Eastern Province of Rwanda (Table 3.2) were identified it means one of four selected districts. Secondly, the implementers cum supervisors of the construction of terraces were determined and fell into one of following categories: Land and Water Husbandry (LWH), private companies and Vision Umurenge Programme (VUP). Thirdly, the land size under terraces had to be above 50 ha. Fourthly, the terraces abandoned and those terraces actually in use.

In total, 3 sites were identified for each district totalling 12 sites. Lastly the sites were segregated according to who built the terraces i.e. a private company LWH, and VIUP. After selection of districts and sites for research, the researcher contacted the districts officially and sought permission in order to visit the sites have an access to the data**.**

Table 3.2: Selection of Study Sites in the Eastern Province

Districts	**Total sites**
Ngoma	(3)Mugesera/Jalama/Rurenge
Kirehe	(3)Gatore/Mahama/Kirehe
Rwamagana	(3) Gahengeri/Murire/Musha
Kayonza	(3)Mukarange/Murundi/Kabare
Total site	**12**

Source: Field Data, 2015

3.5 Data Collection

To carry out this study, the methodology which was used consisted in field visiting, observation and technical evaluation of implemented bench terraces with reference to FAO standards and LWH standards and Focus Groups for economic evaluation of the bench terraces. Data was collected on site slope bed slope, terrace widths, vertical interval, heights of risers, riser slope, farmers' perceptions of bench terraces in their land.

In data collection, one part of land was taken to be studied, the slope of land was measured by measuring the horizontal distance of the land, and the vertical distance after the calculation of the slope was made. For slope of risers, slope of bed, Vertical interval and width of the bed were measured on 15 terraces of the up as the samples, the medium terraces and the lower terraces means 5 terraces for each level and 180 terraces in of 4 districts then calculation was made.

3.5.1 Evaluation of Technical Standards of Bench Terraces

In order to achieve the first objective of this study, the following technical parameters were considered and evaluated against the FAO standards norms and LWH checklist for terraces construction:

(i) **Slope of the land:** The measurements of site slope is crucial and fundamental in judging whether bench terraces were the most comprehensive land use management option to fight against soil deterioration problems; such as soil erosion, nutrient depletion; and thus slope measurements were carried out according to the following steps shown in Figure 3.4.

Place various succeeding pegs on a straight line from the top to the bottom of the hill;

Then from the bottom to top, calculate the length between succeeding points;

Measure the total length of the hill by summing up length used between succeeding points from the bottom to top of the hill;

Make summation and record(L);

Measure the length of the hill from the top to bottom end by deferrer altitude recorded by GPS(DH);

Then calculate the slope of the hill using the formula below:

The data of risers' slope was measured on 15 terraces taken as samples of five terraces sampled on up, middle and lower levels of each site.

$$\textbf{Slope} = \frac{\text{Vertical distance of riser}}{\text{Horizontal distance of riser}} x100 \qquad \text{Equation (1)}$$

Improved bench terraces are constructed in 16 - 40% slope categories Tesemma, A (2011) and for 12% to 47% slope categories (FAO, 2009).

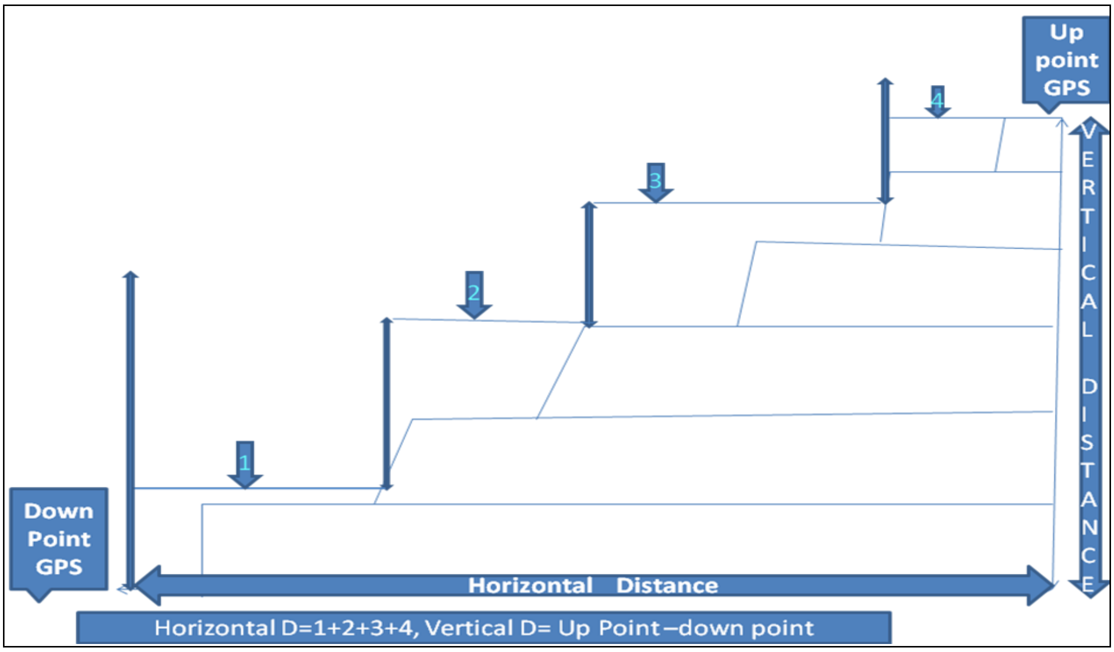


Figure 3.4: Site Slope Measurement

Source: Author, 2015

(ii) **The width of benches:** in order to find the average width of benches for selected terraces, the total length of the terrace was firstly measured. Then, the average width of the bench was calculated by taking different width measurements along that terrace at 10m interval. So, the sum of the different width was taken along the length of the bench at 10m interval was divided by the number of measurements to give the average width of the bench.

The following are the ways to be observed:

Place a tape measure at the beginning to the end of a terrace and record the length. Then for this study, the measurement was done at three levels of the hill/terraces namely at the top hill, middle hill and downhill levels and at each levels were chosen.

At the end, according to the FAO formula, the width measured is then compared to that expected for the measured slope and the vertical interval was used according to the LWH checklist.

Formula used:

$\boldsymbol{Wb = VI \times (100 - (S \times U))/S}$ Equation (2)

VI: vertical interval, in m

S: slope in percentage (%)

Wb: Width of bench (flat strip), in m

U: Slope of riser (using value 1 for machine-built terraces, 0.75 for hand-made earth risers and 0.5 for rock risers)

(iii) **The vertical interval:** According to the LWH checklist, the vertical interval that was used for the slope of 16% to 40% is 1.5m (Azene,2011). But, according to FAO standard norms, the width of benches on a specific slope category correspond to the vertical interval used. Then, with the help of FAO formula, we determined the vertical interval that should correspond to those widths of benches to study if there was a difference between that calculated vertical interval and that of 1.5m used within all studied sites as they adopted the LWH checklist. By using the below formula we calculated the vertical interval:

$$VI = \frac{S \quad x \quad Wb}{100 \quad - \quad (S \ x \ U)}$$ **Equation (2)**

VI: vertical interval, in m

S: slope in percentage (%)

Wb: Width of bench (flat strip), in m

U: Slope of riser (using value 1 for machine-built terraces, 0.75 for hand-made earth risers and 0.5 for rock risers.

For our case we used 0.75 because the bench terraces of our case study made by hand.

(iv) Heights of Riser: After vertical interval was obtained it is easy to figure out the height of riser of the terraces. For level terrace, *VI* equals the height of the riser**.**

For reverse sloped terraces, the *VI* needs to add a reverse height to get the total height. The reverse height was calculated by the following equation:

$$Hr = Wb \, x0.05$$ **Equation** (3)

Where:

RH is reverse height,

Wb is width of bench,

5% is the reverse slope.

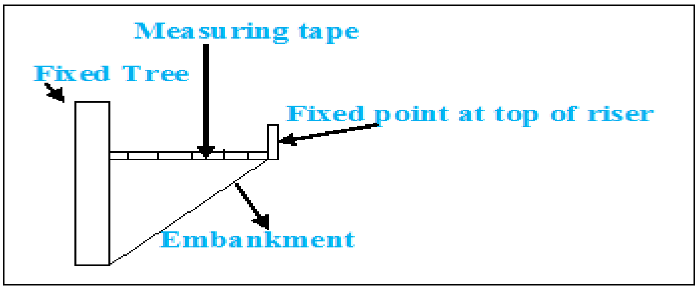


Figure 3.5: Measuring of Embankment Slope

Source: Author, 2015

The materials used for measuring the slope of risers were pegs, a measuring tape and a water level for right angle verification were used. The peg was fixed at the base of the riser measuring tape was connected to the peg fixed at the base of the riser until a right angle was observed with the help of water level. The vertical distance between the base and the point at which the right angle is made along the peg fixed at the base of the embankment is measured; also the horizontal distance between the base of the peg enforced at the top of the riser and the point at which the right angle is made on the peg enforced at the base of the embankment is measured (FAO, 1977).

$$\text{Slope} = \frac{\text{Vertical distance of riser}}{\text{Horizontal distance of riser}} x100 \quad \text{Equation (4)}$$

(i) **Water ways:** in order to verify if the waterways are respected the FAO or LWH standard a measuring tape and a string were used. The top width, the bottom width, depth and slope of the waterways were calculated by measuring three times by 10m of interval and then average was calculated.

(ii) **Terraces maintenance, and land management:** by observation technique, we observed on all sites if the terraces installed are good maintained as recommended by FAO and LWH. During observation, we focused on the following items: Cut-off-drains, check dams, Grass strips, protection of terraces by the security channels against water from up and strengthening improved radical terrace embankments.

3.5.2 Economic Evaluation of Bench Terraces

3.5.2.1 Crop Yield Monitoring and Analysis

Selected sites were evaluated yield wise on four sites: two of Ngoma District (Mugesera and Jalama), one in Kayonza District (Murundi) and one in Rwamagana District (Musha), which means 9 plots on each site and 36 in total and each plot has 10m long bed width were selected from each site as shown by Figure 3.6. For yield monitoring in two years that means four agricultural seasons by using the hybrid maize rotating with bush beans as main crops in study area and contracts were signed with farmers (owner of plots) to protect the integrity of these plots until harvest time and yield evaluation, in order to have good results. The prices were collected in local market found nearby study area in two years.

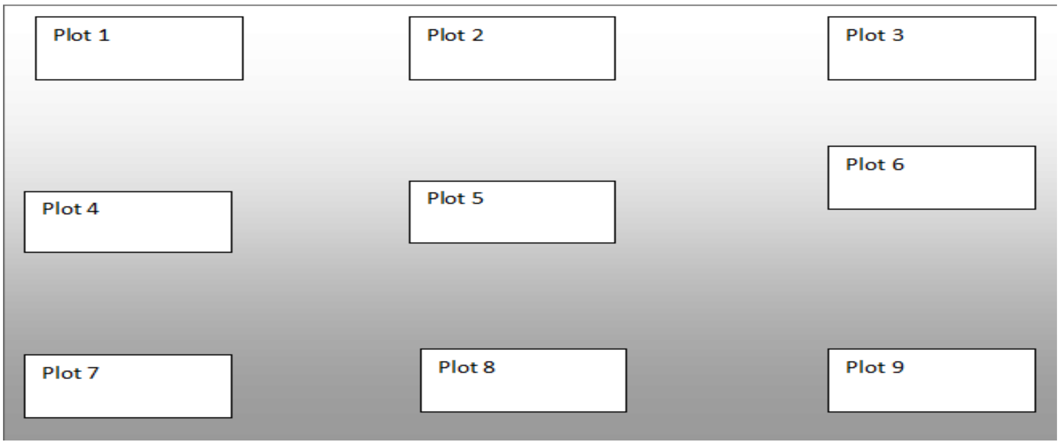


Figure 3.6: Each Sites had Nine Plots

Source: Author, 2015

3.5.2.2 Benefit Cost Analysis of Bench Terraces Project

The cost benefit analysis (CBA) is one of the most widely accepted and applied methods for project, is a prescriptive method that provides guidance on the criteria to take into account in decision making, ensuring that the net aggregate benefits to society outweigh net aggregate costs.

This part of our research involved the identification of economically relevant impacts of bench terraces in Rwanda. Here the question was what to count. This question is bound up in new welfare economics, in particular in the welfare function where the farmer is interested in maximizing profit. What is counted as benefits in this study will be increased in quantity of harvests or a reduction in damages due to soil erosion that generates positive welfare/utility. The costs include any decreases in quantity of goods (e.g. decrease in yield). The negative effects also included using up resource (inputs in production) in the project (establishment and maintenance investments) (Gerald, 2014).

The cost for two years, seasons A and B of 2016 and 2017 calculated for maize and beans crops according to the Crop Intensification Program (CIP) in each site was examined, this means the production costs which include labour and materials require in crop production: land preparation, seeds, planting, weeding, spraying, fertilization, harvesting, and harvesting and transportation, this was compared with the cost of bench terraces construction in Rwanda. This part of BCR was calculated in terms of money only.

- The net present value (NPV) which is the difference between the present value of the costs and the present value of the benefits:

NPV=PV (b)-PV(c), Equation (5)

Where;

b: benefits, c: costs, PV: present value.

If NPV is greater than zero, then the adaptation approach can be implemented and a high

NPV indicates the most efficient and economic adaptation approach.

- The benefit - cost ratio (BCR) the ratio of the present value of benefits and the present value of costs.

BCR=PV (b)/PV(c), Equation (5)

The benefit-cost ratio shows the overall value for money of the project. If the ratio is greater than 1, the project is acceptable. Another reason to study the profitability at field level is that the impact of bench terraces is highly site-specific and can thus vary within small areas (Lutz et al., 1994b; Shiferaw and Holden, 2001).

This chapter will therefore focus on the application of financial CBA only determining the costs is often a straightforward exercise, unless costs have to be divided into financial and economic costs. Identification of the benefits might be more complicated, especially when they are intangible (i.e. impossible to quantify the benefit in monetary terms), like social issues, impact of erosion on yield or secondary benefits to the community (Bojö, 1992).

3.5.3 Farmers' Perceptions of Bench Terraces

The study used a combination of quantitative and qualitative research methodologies in order to meet the study objectives. After selection of districts and sites to be used in this research, we contacted the Province and District officially in order to have access to the farmers who are cultivating on these bench terraces for surveying (focus group discussions with the key informants)19-25 of farmers with the following criteria: to have a big land of terraces site, the president of a cooperative (because all farmers cultivating on bench terraces subsided by government of Rwanda are grouped in cooperatives) on the site and a pilot farmer were chosen on each site and we met with them on field. The participatory rural appraisal approach and pair wise ranking technique were used in order to exhaust all information needed in our research. Each group discussion had around 60 and 90 minutes. The observation techniques were used also to view events on the field in the study area, and photos were taken as evidence from the fields.

The group discussion and field observation were the main sources of primary data collection. Those methods were selected because they provided the criteria of understanding of farmers' preferences of bench terraces and they also helped to gain the interviewee trust in discussion and verification on the field by observation. The group discussions were useful in order to clarify a number of issues in the questionnaire and to make the results of this study more reliable.

(a) Ranking the criteria

Using Focus Group Discussions (FGD), the list of criteria from the farmers' perspective was developed. A pair-wise ranking matrix approach was used for weighing these criteria. The list of criteria was written on both the top and the left side of the matrix. The criteria were weighted in pairs each at a time and the dominant ones were written in the matrix**.**

Table 3.3: Number Focus Group

District	Number of people
Ngoma	43
Kirehe	30
Rwamagana	51
Kayonza	47
Total	171

Source: Author,2016

In each district, we selected 2 focus group discussions. In total, we had 8 FGD of 171 participants and were asked to make comparative judgments on the relative importance of each pair of criteria the group members should vote by raising hands. This was repeated for each pair until the end of entire matrix (the used pair wise matrix for Economic criteria ranking). The results of ranking were expressed as weight (percentage), which is the ratio of the total scores for individual criteria to the overall scores for all criteria (Howard 1991; Zanakis *et al*., 1998).

Table 3.4: The Considered Criteria

a. Economic Criteria	b. Technical criteria
Increasing the cultivable area: increase the cultivable land after terracing	Erosion control: if terraces reduce erosion in farmers 'land
Low labour requirement: cultivate on terraces is easy than hillside	Improve soil fertility : if soil fertility has been raised or decreased after terraces
Increased fodder : if farmers harvest more fodders than before terracing	Retain soil moisture
Increased crop yield: if farmers now harvest more yield than before terraces	Easy for maintenance: if land preparation and crops maintenance are easy or hard after terraces)

Source: Author, 2016

3.6 Data Analysis, Interpretation and Presentation

To complete this study properly, it was necessary to analyse the data collected in order to test the hypothesis and answer the research questions. This part comprised the analysis, presentation and interpretation of the findings. The analysis and interpretation of data carried out in two phases. The first part, which is based on the results of the technical evaluation of bench terraces, mathematical calculation and comparison and analysis of data. The second, which is based on the results of the focus group discussions, is a qualitative interpretation.

To accomplish the analysis of the data for better understanding of the issues covered in the study, we analyzed by using descriptive statistical techniques (like percentage, frequency, mean, ratio and correlation matrix) provided by the Statistical Package for Social Sciences (SPSS) Version 16.0, used while comparing technical aspects of the supervision work (LWH against private companies and VUP). The findings of our study were presented in tables, figures and charts.

3.7 Validity and Reliability of Research Instruments

3.7.1 Validity

The validity is described as the degree to which a research study measures what it intends to do. Reliability is a measure of how well the study actually measures what it is supposed to measure, i.e. the absence of random errors (Bryman, 2004). The research conducted needed to be valid to be able to answer the research question. However, the optimal situation is to conduct research that is both reliable and valid (Blumberg *et al.* 2005).

Therefore, for validity and reliability of research instruments, data collected was coded in order to stay away from the confusion during data recording and interpretation. Some questions could be complicated to some respondents; this problem was corrected by more explaining because we used the group discussion and researcher pre-tested before undertaking the research per se. Researcher's poor memory as human being, during the discussion with focused group researcher taken notes during the discussion and then data were compiled and transformed into valuable information.

3.7.2 Ethical Consideration of the Study

The researcher had the authorization letters for data collection from Open University of Tanzania and letter from Province and Districts (appendix8), the first letter was presented to the District level in order to have the district letter. The letter from District was testimonials to the different local government levels during the data collection such as at sectors level and Sector Agronomist helped us to be trusted by the farmers on the field.

The main purpose is to avoid going into unanticipated ethical circumstances in the respective sites. This became useful in questionnaire data collection and technical efficacy evaluation as it was involved in surveying the farm plots of the small holder farmers. The participants had rights to deny participation or answering any questions or stop the discussions at any time. All participants were guaranteed confidentiality and anonymity. Although the interview transcripts will not be disclosed, informants may still worry that people can identify them by some information. The respondents were assured that their identity would not be revealed by the study and only the codes sites were used to present the quotes. The study also maintained confidentiality of the participants during discussion sessions. For this purpose, each survey instrument was introduced the purpose of the study to the respondents by seeking their consent. This was addressed in every item of the research instrument. The main purpose was to ensure full participation of participants without any fear, arrogance and lack of confidence. Participants were not remunerated for the information they have given and gained no direct benefits from this study.

CHAPTER FOUR

DATA PRESENTATION AND FINDINGS

4.1 Introduction

This chapter presents detailed findings of technical evaluation of bench terraces according to slope of land, slope of riser, width of the bench, vertical interval, height of embankment and maintenance of terraces and economic evaluation. It also presents cost benefit analysis of bench terraces and farmers' perception on bench terraces by using the pair wise ranking matrix with two major criteria such as economic criteria (maximize cultivable area, low labour requirement, increase in fodders and increase yield) and technical criteria (erosion control, improved soil fertility, retention of soil moisture and ease land maintenance.

4.2 Technical Evaluation of Bench Terraces

4.2.1 Land Slope

Land slope determination is the imperative criteria in selecting what type of soil conservation and management practices to put in place for soil erosion control. Figure 4.1 presents the results of land slopes calculated from the field measurements for each implementer (LWH, VUP and CP) by district.

Figure 4.1 illustrates the calculated mean land slopes of bench terraces from twelve sites in eastern part of Rwanda. The land slope of bench terrace sites constructed by Land and Water Husbandry (LWH) 37% of land slopes in Ngoma District, 26.30% of land slopes on site of Kirehe District, 20.5% of site slopes in Kirehe District and 22% for land slope of Rwamagana sites; the land slopes found on Private Companies (PC) sites are 30% of land slope in Ngoma, 22.8% site slope in Kirehe, 10.7% land slope in Kayonza and 30% of land slope in Rwamagana sites. Vision Umurenge Programme (VUP) 34%, 35.35%, 44%, and 28% of land slopes in Ngoma, Kirehe, Kayonza and Rwamagana districts respectively.

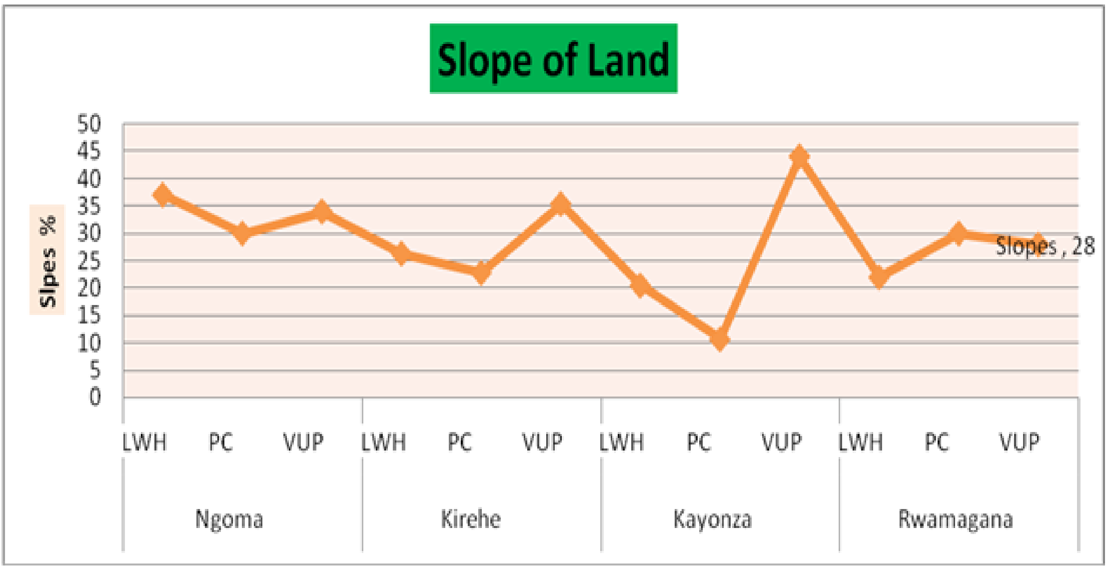


Figure 4.1: The Means of Land Slopes of Bench Terraces

Source: Field Data (2015)

Photo 4.1: (1) The Terraces Well Protected Done by LWH (2) no Protected Risers Constructed by VUP (Photo taken on Musha and Mugesera Fields)

Source: Field Data (2016)

4.2.2 Slope of Bed and Height of Embankment

Slopes of bed and heights of risers are essential for embankment stability and are common methods of slope stability analysis of natural slopes and slopes formed by cutting and filling based on limiting equilibrium. Table 4.1 and Photo 4.1 show the results obtained.

Table 4.1: Slope of Bed and Height of Risers

District	Implementer	Slope of Bed (SB)%	Slope of Riser (SR)%	Height of Riser (HR)m
Ngoma	LWH	3.5	61.4	1.7
	PC	4.1	61.3	1.1
	VUP	2.2	66.0	2.2
Mean		3.26	62.9	1.83
Kayonza	LWH	4.4	68	1.2
	PC	3.47	90	0.88
	VUP	3.07	74.5	2.9
Mean		3.64	77.5	1.6
Kirehe	LWH	2.6	68.87	2.23
	PC	N/A	N/A	N/A
	VUP	2.0	69.63	2.44
Mean		2.3	69.25	2.1
Rwamagana	LWH	4.0	65.1	1.2
	PC	1.8	74.1	1.3
	VUP	2.7	70.6	2.1
Mean		2.83	69.9	1.53

Source: Field Data (2015)

The results from the field revealed that almost implementers did not respect the norms established by FAO or LWH. The standards are: bed slope of terraces should be 3-7%, slope of risers 30-70% and heights of risers should be 1.4-2m. As it can be seen in above table for instance in Kayonza site constructed by VUP the height of riser is 2,9m instead of 1.4-2m, in Rwamagana site done by PC the slopes bed is 1.8 instead of 3-7%. This leads the farmers to destroy the embankments for increasing the arable land Photo 4.1.

Photo 4.2: The First Old and Second New Risers Destroyed by Farmers for Increasing the Cultivation Area (Photo taken on Kayonza and Ngoma fields)

Source: Field Data (2016)

Photo 4.3: Riser's Vertical and Horizontal Distance Measurements (Photo taken on Field)

Source: Author, 2015

4.2.3 Vertical Interval and Width of Bench

The width and vertical interval of bench terraces are crucial part of bench terrace. Quality assessment parameters, which, once inaccurately calculated, affect the position and size of terraces on sites; and there is a very close relationship between both width and vertical interval of bench terrace.

Photo 4.4: The Slopes of Bed are Outward Instead of Inward (Photo taken on Kayonza Sites)

Source: Field Data (2016)

Table 4.2: Vertical Interval and Width of Bench

District	Implementer	VI (m) computed using the FAO formula	VI measured on the field (m)	Width of Bench (m) computed using the FAO formula (WBFAO)	Width of Bench (m) measured on the field (WBF)
Ngoma	**LWH**	**1.4**	**1.6**	**4.6**	**4.7**
	PC	**1.3**	**1.1**	**4.2**	**4.7**
	VUP	**1.3**	**1.4**	**4.8**	**4.4**
Kayonza	**LWH**	**1.0**	**1.2**	**4.22**	**4.2**
	PC	**0.62**	**1.4**	**5.32**	**4.4**
	VUP	**2.7**	**1.9**	**4.2**	**4.0**
Kirehe	**LWH**	**1**	**1.2**	**3.8**	**3.5**
	PC	**N/A**	**N/A**	**N/A**	**N/A**
	VUP	**1.8**	**1.6**	**3.3**	**3.8**
Rwamagana	**LWH**	**1.3**	**0.7**	**4.2**	**4.3**
	PC	**1.4**	**1.5**	**4.7**	**4.5**
	VUP	**1.3**	**2.2**	**4.2**	**4.7**

VI: Vertical Interval

Source: Field Data (2015)

The results on vertical interval of bench terraces show that, the mean calculated by using the FAO formula are 1.4m and 1.4 of vertical interval of bench terraces on both Kirehe and Rwamangana sites and 1.3m of vertical interval on Ngoma and Kayonza sites.

Photo 4.5: (1) the Farmers Started Burning Charcoal on New Terraces, (2) the Cattle Grazing on Bench of Terraces (Photo taken on Mugesera and Musha Sites)

Source: Field Data (2015)

The mean vertical intervals calculated on fields in table above (Tab 4.2) are 1.3m on Ngoma and Kayonza terraces and 1.4m in Kirehe and Rwamangana terraces. On the other hand, the widths of bench terraces calculated using the FAO formula are 4.5m in both Ngoma and Kayonza bench terraces; 3.5m in Kirehe terraces and 4.3m in Rwamagana sites**.**

4.2.4 Pearson Correlations Between the Parameters

Table 4.3 shows the correlation matrix between variables. Vertical interval measured on field (VIF), Vertical interval calculated by using the FAO formula (VIFAO), Width measured on field (WBF), and width calculated by using FAO formula (WBFAO). The correlation used 165 bench terraces as samples from 12 sites of 4 districts.

Table 4.3: Correlations between Parameters

		VI-FAO	VIF	WB-FAO	WBF
VI_FAO	Pearson Correlation	1	.314**	-.071	-.172*
	Sig. (2-tailed)		.000	.364	.028
	N	165	165	165	165
VIF	Pearson Correlation	.314**	1	-.080	.065
	Sig. (2-tailed)	.000		.310	.407
	N	165	165	165	165
WB_FAO	Pearson Correlation	-.071	-.080	1	.194*
	Sig. (2-tailed)	.364	.310		.013
	N	165	165	165	165
WBF	Pearson Correlation	-.172*	.065	.194*	1
	Sig. (2-tailed)	.028	.407	.013	
	N	165	165	165	165

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Source: Field Data (2015)

From the results in Table 4.3, it can be seen that the correlation coefficient(r) between vertical interval measured on the field and Vertical interval calculated by using the FAO formula equals 0.314 with $P<0.001$, indicating a weak relationship; correlation between width measured on the field and width calculated by using the FAO formula is 0.194 with $P<0.05$, representing a very weak correlation between them.

4.2.5 The Results from Observation of Waterway, Cut-Off Drains and Maintenance of Bench Terraces

The construction of bench terraces requires many mechanisms that should be taken into consideration before and even after construction if not the terraces will be destroyed and caused water damages or landslides. In technical evaluation of bench terraces, it was also evaluated how the waterways and cut-off drain have been constructed and maintained, planting the shrubs on risers for stability of terraces. The photos below show the results of observation found on the field related to waterways cut-off drain, risers and their maintenances.

Photo 4.6: The Waterways Destroyed and not Maintained (Photo taken on the Field)

Source: Field data (2016)

Photo 4.7: The Waterways Already Destroyed and not Grassed (The Photo taken 7 Months after Terracing)

Source: Author, 2016

Photo 4.8: **(1)The Embankment Started Cracking few Weeks after Terracing, (2) Terraces are Abandoned by the Farmers are using as Pastures, (3) Terraces without Waterways, and Farmers Destroyed the Embankments for Increasing the Cultivated Areas**

Source: Field Data (2016)

The photos above were taken on the sites and are showing the situation on the field: the first shows the crack of embankment, thus this soil crack may cause the landslides, the second shows the terraces constructed without waterways and cut off drains (located at Musha-Rwamagana District). The last shows embankments attacked by farmers towards waterways, water from waterways will flow easily to terraces. And some terraces have been abandoned by the farmers after terracing photo below showing the field results.

Photo 4.9: (1) Terraces Abandoned is using as Pasture (2) Bench Terraces Destroyed by Livestock (Photos were taken at Gahengeri Sector, Rwamagana District of Eastern Province, the Site Is Located Left Side Toward Kigali from Rwamagana)

Source: Field Data (2015)

4.2.6 Economic Evaluation of Bench Terraces

The data collected in this section were based on yield harvested within 4 agricultural seasons in two years 2015-2016, then the steps of financial benefit cost analysis: determination of evaluation criteria such Net Present Value (NPV) and Internal Rate Return (IRR), and identification of effects of bench terraces (cost and benefits) have been calculated for project analysis by considering different parameters such as operating cost, income, investment cost and benefit cost ratio.

4.3.1 ~~Means~~ Crops Yield According to the Slope Position

The means crops yield were calculated according the land slopes in four agricultural seasons of two years 2016-2017.

Table 4.4: The Mean Maize and bean Yield Tone/Hectare

Position		Yield of Maize t/Ha	Yield of Bean t/Ha
Lower slope	Mean	5.8575	2.1750
	N	4	4
Middle slope	Mean	5.8200	2.1250
	N	4	4
Up slope	Mean	5.7175	2.0750
	N	4	4
Total	Mean	5.7983	2.1250
	N	12	12

Source: Field Data (2014-2016)

The Table 4.4 shows the mean crop yield harvested according to the slope positions (up, middle and lower slopes, statistically there is no significant different between yields harvested according to the slopes. The total yield mean of maize is 5.8 tons per hectare instead of 7 tonnes and 2.13 tons per hectare for beans instead of 2,5 tonnes.

4.3.2 Crop production cost

The crop production costs consist of costs for investment (equipment, infrastructure and building) and operating costs, which are used for the daily activities of farming or daily sustainable farming.

Table 4.5: Crop Production Cost for Selected Crops (USD/hectare)

Crop production (1st year)		**MAIZE**	**BEANS**
Seeds		25kg*0.73$=18.29$	45kg*0.73$= 29.26
Fertilizer	Organic	20t/ha*14.63=292.68$	20t/ha*14.63=292.68$
	Chemical	91.46	91.46$
Pesticides		24.39	24.39$
Drying Costs		182.92	182.92$
Tillage	First	121.92	121.92$
	Second	60.97	60.97$
Planting		60.97	60.97$
Maintenance		121.92	121.92$
Harvesting(Material,		121.95	121.95$
Total of operating cost		1,097.44	1108.41
Investment cost (1h of land terraced)		1,219.51	-
Annually Total Cost		3,425.36	
Crop production(Second year)		**MAIZE**	**BEANS**
Seeds		25kg*0.73$=18.29$	45kg*0.73$= 29.26
Fertilizer	Organic	20t/ha*14.63=292.68$	20t/ha*14.63=292.68$
	Chemical	91.46	91.46$
Pesticides		24.39	24.39$
Drying Costs		182.92	182.92$
Tillage	First	121.92	121.92$
	Second	60.97	60.97$
Planting		60.97	60.97$
Maintenance		121.92	121.92$
Harvesting(Material,		121.95	121.95$
Total of operating cost		121.92	1079.15
Investment cost (rent of 1ha of land)		1219.36	
Annually Total Cost		**2420.43**	
Total expenses in two years		**5,845.79**	
Total return in two years		**6709.74**	
BCR		**1,15**	

Selling price: corn: 0.33 $beans:0.67, 1$=820Rwf

Source: Field Data (2014-2016)

Table 4.5, shows the yield harvested in four agricultural seasons 2015 and 2016, the mean grain yield of maize and beans crops and the price of one kilogram of maize and bean is 0.33 and 0.55 US dollars respectively. The total cost of 1,745 and 1,317 US Dollars respectively in the first year. These prices were collected from local market cost estimates are representative of average costs for farms in the Eastern Province.Based on the results calculated in four agricultural seasons, the gross income is USD 6709.74 while the total cost is USD 5,845.79. After calculation of all required data BCR was calculated based on combination of both crops maize and beans in period of two years and we found the BCR 1.15.

4.4 Farmers' Perception on Bench Terraces

Table 4.6 illustrates the farmers' decisive factors of bench terraces preference in their plots. A pair-wise ranking matrix approach for weighting the criteria was used.

Table 4.6: Farmers' Perception by Pair-Wise Ranking Approach

a. Economic criteria							
Criteria	ICA	LLR	IF	ICY	Score	Percentage	Ranking
ICA	#	LLR	IF	ICY	1	16.6	3
LLR		#	IF	ICY	0	0	4
IF			#	IF	3	50	1
ICY				#	2	33.4	2
b. Technic criteria							
Criteria	ER	ISF	RSM	EM	Score	Percentage	Rank
EC	#	EC	EC	EC	3	50	1
ISF		#	RSM	ISF	1	16.6	3
RSM			#	RSM	2	33.4	2
EM				#	0	0	4

Increase cultivable area (ICA); Low labour requirement (LLR); Increase fodder (IF); Increase crop yield (ICY); Erosion control (EC); Improve soil fertility (ISF); Retain soil moisture (RSM); Easy for maintenance (EM).

Source: Field Data (2015)

The results of farmers' preferences on bench terraces, according to the economic and technical criteria, are grouped in Table 4.6. The values reflected the perceived degree of importance of each, increasing of folder and erosion control by bench terraces preferred at the first rank with the score of 50% and increase crop yield and retain soil moisture are at the second rank with 33.4% and increasing soil fertility on third rank. At the last rank, there is low labour requirement and easy for maintenance with 0% respectively economic and technical criteria**.**

4.5 Summary

In this chapter presents the results of technical evaluation: slope of land, slope of bed, width of the bench, height of embankments and vertical interval and compared with model established by FAO and LWH for bench terraces construction for soil erosion control, and correlation matrix between above parameters was computed. It presents economic evaluation of bench terraces in Rwanda obtained after investment cost and crop production analysis, BCR indicated that, the bench terraces could be profitable in two years. The chapter presents also the farmers' perceptions on bench terrace, through the pairwise ranking matrix techniques.

CHAPTER FIVE

DISCUSSION OF THE FINDINGS

5.1 Introduction

This chapter explores the work characteristics specific to technical evaluation of bench terraces in Eastern Province of Rwanda and also evaluates the benefit cost analysis of terraces on maize and beans crops. Each theme that emerged from the results is discussed, described, and supported with photos from the fields.

5.2 Technical Evaluation

5.2.1 Land Slope and Embankment (Height and Slope)

In Rwanda all bench terraces have been constructed by hand. Inherent slope stability is a critical factor when determining the suitability of slopes for terracing (Brian, 1990).

The site slope (slope of land) determination is the key element in selecting what type of soil conservation and management practices to put in place whether bench terraces, soil bund, hedgerows, forestry or progress terraces. The results obtained in the study as presented in Figure 4.1 indicate that the slopes of some sites are either above or below FAO standards of bench terraces which were found in Kayonza District in two sites where the slopes were 44% and 10.7%. In the first case, the bench terraces were constructed as an erosion control measure instead of forest, while in the second case (10.7% slope) the bench terraces were constructed instead of soil bunds. According to Azene (2011), soil bunds are implemented on soils with slopes ranging between 12% - 15%; whereas those between 16-40% must implement bench terraces; and those between 40-60% are suitable for forestation. FAO (2009) guidelines state that the bench terraces are only recommended for sites whose slope categories range between 12-47%. Nevertheless, the selection also depends on the availability of construction materials and tractors. Otherwise, in the case of Rwanda where all the terraces have been constructed by hand, there is little room for maneuvering.

Concerning the riser (embankment) slopes and height, the results calculated from the field show that about 85% of sites visited were either above or below of embankment slope recommended. The field terraces constructed with the inclination of riser slope between 30% and 60% have remarkably stable and durable embankments; and steeper risers are very unstable and require grass to give them stability (FAO, 2009). The results of studies of riser slopes show that the most of sites constructed by private companies and VUP are well above of the recommendations established by LWH and FAO. For instance, some sites at Rwamagana and Kayonza have embankment slopes of 77% and 90% slopes instead of 60 to 70% as recommended by LWH and 30 to 60% as recommended by FAO.

Therefore, steeper risers are prone embankment to runoff or land slide and is an indicator of poor quality embankments which in the future can lead to sudden embankment landslide or destruction; the embankment gets more fragile as the riser height increases (Critchley and Bruijnzeel, 1995). Tied closely with slope gradient is the overall length and position on the slope. Mismanagement of field’s upslope might occasionally cause serious degradation to down slope fields, a result of concentrated runoff. Gentle slopes receiving storm runoff from above may have a much higher erosion hazard than very steep slopes (Brian, 1990). On the level of land, there may be a considerable amount of run-off, but when there is a slight slope the water is less hampered by the very slight depressions and runs off in much greater amounts before it can be absorbed; that is, it will not be held on the land much longer than the duration of the rain. With a still further increase in slope, the increase in run-off becomes relatively less because the water on any slope is running over the land for the entire duration of the rain and thus time is afforded for absorption. Any run-off that may be taking place at the end of the rain will cease within a short time whether the slope is slight or steep (Duley, 2003).

Furthermore, all sites sampled, the most terraces constructed by VUP have the height of embankment greater than both recommendations of FAO and LWH (Table 4.1), and the recommendations are less than 2m. Experience shows that the overall height of a riser should not exceed 1.8 m to 2 m; above that, the maintenance work will become difficult (Sheng, 2002). According to Critchley (2003), riser material can be either compacted earth, protected with grass, or rocks. In order to ensure easy maintenance, terrace riser height should not exceed 2ms. The height of embankment has a big impact on stability of embankment at the time of maintenance if is high or short.

Hence if the riser is taller, steep and poorly protected it effectively becomes an erosion hazard in itself (Critchley and Bruijnzeel, 1995). Therefore, terrace risers constitute a very important component of terraced hillsides, and their significance increases with steepness of the landscape. Where risers are not protected, they present a distinct erosion hazard (Critchley and Bruijnzeel, 1995). When height of riser is high, it can reduce the cultivable area. Therefore, farmers cut away the base of risers, primarily to increase cultivable area as shown by the Figure 4.1. The farmers destroyed the risers because they needed to increase the cultivable area while cultivating and planting, but this may also trigger some extra erosion through destabilization of the riser.

Secondly, and significantly in certain situations, there are riser failures, where slumping occurs usually when an unstable riser becomes saturated (Euphrat, 1987). Grasses should be grown well on the risers. Weeds and vines which threaten the survival of the grasses should be cut down or uprooted. Grasses should not be allowed to grow too high. Any small break or fall from the riser must be repaired immediately. Cattle should not be allowed to trample on the risers or graze the grasses but on some sampled sites the terraces are using as pastures and run off should are ready to flow over the risers and on bed terraces as shown by Figures 4.5 and 4.7:

It is obligatory to shape and plant grasses after cutting a terrace as soon as possible. By observation on the field during the research, some few sites were well protected for instance ones constructed by LWH, but many constructed by VUP and CP are not protected at all (Figure 4.1). The sites constructed by LWH had fruits and other agro-forestry trees, Sod-forming or rhizome-type grasses are better than those of the tall or bunch-type. Although tall grasses may produce considerable forage for cattle, they require frequent cutting and attention. The rhizome-type of local grass has proved very successful in protecting risers. Stones, when available, can also be used to protect and support the risers (FAO, 2010; Sheng, 2002). Risers require regular care and maintenance. If a small break is neglected, large-scale damage will result (William, 2003).

5.2.2 The Slopes of Bed or Bench

Inward sloping bench terrace, the benches are made with inward slope to drain off excess water as quickly as possible (Suresh, 2009). It is essential to keep the excess runoff towards hill (original ground) rather than on fill slopes. These inward sloping bench terraces have a drain on inner side, which has a grade along its length to convey the excess water to one side, from where it is disposed-off by well stabilized vegetated waterway.

From the results in Table 4.1, the means of inward bed slope values range from 2.3% to 3.6%. However, the results are in a recommended range which is 3% to 7% of slopes but if we consider site by site, some of them constructed by VUP and PC have crucial problem and started to be destroyed because of farmers' activities. Few of benches are outward instead of inward slope Photo 4.4.

The bed slope or inverse slope should be between 3% and 7% (Azene, 2011), and from 3% to 5% (FAO, 2010). This was adopted because inverse slope used for a long term but didn't provide a sustainable land use management answer. Few years after construction, this slope is almost removed due to continuous natural process such as drop and rain borne strong runoff speed, velocity and volume which quickly makes runoffs to move downhill thus destroying embankments of concerned terraces and adversely effecting terraces in its southwards direction (Suresh, 2009). Must be also destroyed by the human activities.

Photo4.5 shows the famers burning the charcoal letting the cattle graze on bench terraces as pastures. Respecting LWH and FAO recommended bed slope, as they play their role in interfering run off and its speed, it means implemented terraces will be sustainable, not destroyed by runoff. Its speed, which will result in their sustainable use over a long time without being destroyed and the soil loss reduced or minimized to the least possible and as runoff water infiltration will be increased, crop yield can also be increased. These suggestions are in line with FAO (2000) reporting that, interfering with runoff and its speed result in increased infiltration rate whichultimately reflect in an increasing crop yield, soil and water conservation and sustainable land use management**.**

5.2.3 Vertical Interval and Width of Bench

Terrace spacing and width of the bench are normally expressed in terms of the vertical interval at which the terraces are constructed. It depends upon factors like slope, soil type and surface condition, grade and agricultural use. Therefore, the width and vertical interval of bench terraces are crucial parts of bench terrace, quality assessment parameters, which once inaccurately calculated, affects the position and size of terraces on sites. There is a very close relationship between both width and vertical interval of bench terrace. According to FFTC (2004), terrace spacing depends mainly upon land slope. However, it also depends upon the soil and climate, the cross section will have some effect on the horizontal spacing, the crops to be grown and the machinery that will be used should also be considered. Based on the formulas we found that the results are in range except few sites for instance on the field we measured the 1,4 m instead of 0,62m given by FAO formula which was found on Kirehe sites and 1,9 instead of 2,7m on Rwamagana site respectively constructed by PC and VUP (Table 4.2).

The correlation between vertical interval and width from Table 4.3 shows the weak and very weak correlation between vertical interval measured on the field and vertical interval calculated by using the FAO formula. It equals 0.314 with $P<0.001$ and width measured on the field and width calculated by using the FAO formula is 0.194 with $P<0.05$. This is evidence that the vertical interval and width constructed on more sites visited do not.

Furthermore, FAO has established theoretical standards (which is range between 12% to 32% of land slope) to refer when one doesn't consider the use of formula. For example, it is the reason why for bench width of 4m the corresponding vertical interval was 0.94m. Appendix 5 on our cases on some sites, did not consider the land slopes standards, but we calculated the vertical interval and width of the bench because few land slopes of our case study comply between 10,7 of PC to 44% of VUP implementer. Unfortunately, FAO and LWH did not specify for sites with slopes categories beyond 32% and below 12 % (Brian, 1990). The area dedicated to growing crops will be reduced and it will reduce the yield which could be obtained from those terraces. According to Sheng (2000), poor vertical interval affects position and sequence of bench terraces to be implemented and interfere with agriculture purpose, of which they were implemented. The effective cultivated length of slope between terraces varies with the type of cross section. The back slope of the broad base cross section can be cultivated and therefore is a part of the effective length (Hamdan et al. 2000). The front slope of either section does not contribute to the effective length. Therefore, terrace spacing can be increased by the horizontal length of the back slope when the grass back slope section is used (Inbar, 2000).

5.2.4 Waterway, Cut-Off Drains and Maintenance of Bench Terraces

Waterways carry the collected runoff in a graded channel to an outlet; waterways are built to protect soil against the erosive forces of concentrated runoff from sloping lands. By collecting and concentrating overland flow, waterways absorb the destructive energy which causes channel erosion and gully formation (NSERL 2014).

Hence, part from sites constructed by LWH, more sites constructed by private companies and VUP programme we found both neither waterway nor cut-off drains. where we found them, they are not respecting the standard and not properly maintained as shown by the Photo 5.5 and some sites without water way and cut-off drains are located below road, water come from road to the terraces. The water will affect terraces in the future if they don't take care off. The toe drains should be always open and properly graded. Water must not be allowed to accumulate in any part of the terrace (Keirle, 2002). All runoff should be allowed to collect at the toe drains for safe disposal to the protected waterway. Obstacles such as continuous mounds or beds must be removed at regular intervals to allow water to pass to the toe drain. Grasses and weeds should be removed from the benches (Wheaton, 200).

Regarding the waterways shapes and cross-section shapes on the field, it was not easy to identify their shapes because the sediments which were deposited in and were destroyed. However, according to the Azene (2011) and KARI/NARL (2010), stated that the width and depth of the waterway would be wider at its outlet and narrow in its beginning. The slope of the waterways is 10 - 15% against the contour and could be in trapezoidal shape.

However, the slope orientation could be dictated by orientation of existing drainage system. When water ways are not well done, crop production in semi-arid areas involves many risks, including flooding, and this makes it difficult for farmers to realize the full benefits of conservation.

The waterways should be maintained and reshaped immediately after crops are harvested, ploughing must be carried out with care so as not to destroy the toe drains and the grade (NRCS, 2010). We observed also that the many waterways are not protected by grass for stabilization. Hence grassed waterways or naturally vegetated drainage ways may be used as a vegetated outlet. It is better to install and stabilize grassed waterways prior to the construction of the terrace so that the terrace will have a stable outlet when it is constructed (NRCS, 2010).

All terraces must have adequate outlets. The outlet must convey runoff water to a point where it will not cause damage. Grassed waterways or naturally vegetated drainage ways may be used as a vegetated outlet but many cases in our study area are not grassed. Photo 4.6 is one of example. Installing and stabilizing grassed waterways prior to the construction of the terrace so that the terrace will have a stable outlet when it is constructed. The capacity of the vegetated outlet must be large enough so that the water surface in the outlet is at or below the water surface in the terrace at the design flow (Morgan, 2004). A waterway must therefore be carefully designed. The most satisfactory location of a waterway is in a well vegetated natural drainage line where the slopes, cross-sections, soil and vegetation have naturally developed to received and carry the runoff it therefore needs only to be protected against deterioration (REMA, 2010).

The side of check dams, it is a big challenge because more of 80% of our case study has any check dams and where we found them, are not maintained. Hence, according to Van et all (2003), the velocity limits for safe flows in a protected waterway are: Grass waterways 1.8 m/sec, ballasted stone waterways 3.0 m/sec, concrete and masonry waterways 6.0 m/se) drop structures. Low check dams or basins are needed to slow down the flow on moderate slopes. It is recommended that low check dams and drop structures be set up every 30 to 40 m to slow down the flows in grass waterways, newly established waterways should be kept free from disturbances. The waterways should be inspected frequently during rain and after ploughing and any minor breaks in the channels or structures should be repaired immediately.

Concerning the bench terraces maintenance in general, we made observation at all sites implemented by VUP, LWH and P C to observe if terraces are well maintained to ensure their sustainability and productivity. Therefore, on PC's and VUP sites, it was visible by naked eye that all maintenance activities were not done as recommended, some waterways were missing many check dams; waterways' banks were destroyed by runoff; some embankments were not totally covered by grasses; some agro forestry trees have not planted and others not pruned and some grasses not harvested and then terraces were abandoned by farmers after construction.

According to (Dorren *et al.* R 2010) the most important aspect of terracing is that it has to be combined with additional soil conservation practices, of which the most important one is the maintenance of a permanent soil cover. This latter is especially needed on the foot slope of the terrace, because terraces themselves could be easily eroded and they generally require a lot of maintenance and repair. By observation also, the farmers do not care about the terraces maintenance where after few days of construction they started destroying the embankment as it is shown on the Photo4.5 and burning charcoal on the bed of bench. Therefore, the humus, content of the soil decreases and overgrazing leads to organically poor, dry, compacted soil and the cattle destroy the terraces (Puja, 2014). So the implementers and agricultural extension workers should explain to the beneficiaries the importance of terraces maintenance before project for sustainability and ownership.

Grazing on the terraces which was softened entails compaction of the soil which makes land preparation a difficult operation or prevents roots from penetrating deep into the soil and another effect is that, once the soil is compacted, pores spaces are enclosed and movement of water and air in the soil are restricted and if water can't move through the soil, nutrients are confined in some areas and are not able to move to the roots of crops and these crops are not able to grow and these results in stunted or poor yield of crops, In terms of quality of maintenance, PC sites ranked at the second after LWH sites and this can be justified by the fact that even if implemented terraces were protected, waterways, cut-off drains and embankments were not protected very well to ensure sustainable use of these terraces.

If no strict measures are taken soon, the landslide and erosion will be carrying more soil than it would be before the implementation of bench terraces. From then, softened and at a great depth compared to before and there will remain the subsoil which is not suitable for growing crops and the increase in agriculture productivity which was a target while implementing bench terraces will be reduced and future generation's wellbeing interfered. In addition, disrespect of contour-lines or direction of farming makes some holes which are areas for water accumulation and unfair distribution in the terrace which is dangerous for some crops growing on these points.

5.3 Economic Evaluation of Bench Terraces

5.3.1 Crop Yield

Maize and beans crops were used in economic evaluation, as shown by the results in Table 4.4. In 2 years, the mean yield is 5,80 t/ha and 2,13 t/ha respectively maize and bean. In Rwanda, the yield of maize and beans, when all agricultural technology applied and climate conditions went well, is in range of 6 to 7 tonnes per hectare for hybrid maize and 2.5 to 3 .5 tone of bush beans. The low yield may be due to stressing moisture manifested at development and midseason the crops stressed by lack of rain.

Moreover, different stress level at different stages affect the yield of maize and even different cultivars have different tolerance level for moisture stress leads to a decrease of chlorophyll content which will reduce the amount of food produced in the plant (Adel et al., 2013). Another results reported by Ersel et al. (2010) also shows moisture stress occurring during vegetative and tasselling stage reduce grain yield significantly.

Generally, the lack of rain showed moisture stress at different crops growth stage. Thus, the yield was lower than expected even in whole country especially in eastern Rwanda. This is supported by FAO (2002) reported on wheat, on bird pepper (Capsicum *annuum* L.) production, Romulus et al. (2009) on spearmint and Huang (2006) on maize production all those researchers reported on decreasing of crop yield due to the drought.

5.3.2 Cost Benefit Analysis

In order to keep away from the under and over yield or profitability estimation with data from the famers, we ourselves grown the bean and maize on four sites of terraces then results from the field and price collected from local market used in benefit cost analysis. The investment costs for the crop farming, which consist of costs for equipment, infrastructure and building were used and operating costs which related to the daily activities of farming. Terraces are however costly when large equipment is used and require large inputs of labour when constructed manually. LWH (2010) reported that terracing requires 1,219.51$ covered by Rwandan government subsidy in programme of soil and water conservation, calculated per hectare including: terracing, liming, fertilization with organic manure and planting grass stabilizers but excluding planting crops, mineral fertilizers and later maintenance.

The national interest in using bench terraces is mostly for soil erosion control. Hence, the reason behind the Rwanda government subsidies or incentives to the construction of terraces for the farmers' plots has been justified by many researchers, Huszar, (1999) incentives, either in the form of subsidies or other measures increasing the profitability of SWC, are likely to be continued in order to sustain conservation measures at the socially and economically optimal level by creation the job in rural areas. If the farmer is the only beneficiary, use of incentives is often justified by the argument that farmers are too poor to take any risks, while the measures involve heavy investment of labour and money.

Therefore, the farmers' income may be reduced in the initial stage of soil conservation (Giger, 1999). Incentives help to compensate this temporary income reduction.

Another justification of the use of incentives is that, since land degradation is often driven by economic incentives, it is necessary to alter these incentives in order to promote soil conservation goals (Enters, 1999). Even if the cost for terracing covered by the government, in cost benefit analysis we added it as investment cost.

Concerning the benefit of cropping on terraces, the results revealed that the break-even point could appear in second year, the total cost of the first year was 3,425.36$ per hectare including the cost for bench terracing while second year was 2420.43$, means excluding the cost for terracing but including the land rent instead of terracing cost which considered for the first year. In our research, we based on tangible or physical scale only because some benefits are complex to measure in money unless estimation of their values for instance social values, soil conservation values, environment pollution, impact of erosion on yield etc… According to Bojö (1992) and Pelt (1993), to be able to apply cost benefit analysis, two requirements have to be met: 1) the impacts of the intervention are measured on a quantitative and physical scale, and 2) (shadow) prices are used to assess the value of the (physical) impact. Therefore, in our research, costs were the investment (cost for terracing) and operating costs for the farmer who cultivates on bench terraces.

Following Gittinger (1982), the selection criterion for projects is to consider those acceptable with a benefit-cost ratio equal or higher to 1, as in the case offered here. The cost benefit analysis has used to evaluate the profitability of bench terraces at field level in eastern Rwanda the cost ratio of bench terraces found is 1.15. Therefore, the results give the impression to confirm that bench terraced can be financially profitable in terms of money when they are considerably intensified and indicate the project's capacity to cover the investment and operating expenditures as also reported by Fleskens, (2007). Terracing is profitable depends on agro-ecological conditions and is thus site-specific and farm management, and how the terraces are constructed. In our case, some terraced plots were found abandoned after terracing. For his neighbour, it is not hence this was observed on some of our study area the most neighbour farmers harvested about a half of our yield due to the bad farming management. Not using the appropriated input and techniques. Similar conclusions were drawn by Lutz et al. (1994b) and Valdivia (2002). The profitability of SWC practices depends on the specific agro-ecological conditions faced, technologies used, prices of inputs used of output produced, and markets (Lutz et al., 1994b; Wiener et al., 2003). Terraces are most likely to be profitable on steep slopes, and farmers will invest in terraces with the highest private benefits (Valdivia, 2002).

The benefit-cost ratios for economic evaluations indicated that the project of bench terraces is able to cover the investment cost and operating expenditures and to obtain an additional return within two years. As Gittinger (1982) stated recommendable as they obtained benefit-cost ratios higher than one. However, the terracing should be accompanied by all farming process and technology.

5.3.3 Farmers' Perception on Bench Terraces

The aim was to evaluate the perceptions of the farmers concerning the bench terraces in their plots. Understanding farmers' perception of soil erosion and its impact is important in promoting soil and water conservation technologies (Chizana and Albrechi, 2006).

In their terraced plots of cropland under their own management, farmers used their own criteria to evaluate the effect or important of bench terraces economically: ICA, LLR, IF and ICY. Technically: ER, ISF, RSM and EM were commonly used for evaluation (Table 4.6) This study reinforced initial discussion that technical and economic factors influence the farmer's decision to adopt or not adopt the terraces. Understanding farmers’ knowledge and their perception and factors that influence their land management practices are of paramount importance for promoting sustainable land management (Alonal, 2008). Even though, the wealth of any farmer plays an important role in his ability to adopt new soil conservation techniques, any conservation techniques that require significant inputs of labour or capital are unlikely to be taken up by the poor farmer strictly because those inputs are unavailable (Wheaton, 2001).

5.3.3.1 Economic Factor

Through the pair-wise ranking approach and focus group discussion, the farmers were requested to rank the selected criteria (Table4.6) in economic accordingly and to discuss the reason why. The increasing of folder ranked on the first place with 50% score. The farmers agreed that they get many fodders from their bench terraces (on risers), they cut them give to their livestock and other sell them to the farmers who have livestock and get money. They emphasized that they could harvest twice a season and added that as you have big plot as you cut more fodder. Thereafter, they ranked the increasing of crop yield at second rank with 33.4%score. Moreover, they reported that with bench terraces they increased the yield harvested from the terraced plots because they started cultivating where they did not before because of erosion.

At the last rank, there is low labour requirement. The farmers said that even they get the fodders for their livestock; the maintenance of terraces requires more attempts. The more profitable the farming system, the more likely that the farmer is willing to invest in its sustainability. As maintenance of bench terraces can be time and efforts consuming on certain landscapes, the farming system must be sufficiently profitable so that the farmer is willing to use and maintain bench terraces

During the research, noticeably, the several participants revealed the problem of terraces abandoned after terracing means were no longer used, the photo 4.8 is showing the sites abandoned by the farmers. The farmers explained that the reasons behind abandoning their terraced plots include that, the farmers explained that during terracing (because some of them participated in construction of terraces as workforces) the implementers did not respect the standards of bench terracing like apply the organic manure and lime or other inputs. Data from the farmers confirmed by our field data related to the technical evaluation showed that some sites did not respect the normal of bench terraces like protection of embankment by planting the folder, respecting the land slopes before choosing the type of erosion control measures to be planted, vertical interval and other more criteria.

The participants reported that after terracing they harvested less than before. Therefore, this disheartened the farmers to continue using the terraced plots in crop farming as before. The results are agreed by the results of MINAGRI 2016 and RAB joint survey executed profiling of radical on 18 sites in the whole country. It reported that around 23.55% out of 1,013,454Ha at national level and 332.91 ha in Eastern Province are not under exploitation means abandoned. According to Mesfin, (2016), bench terraces usually expose the infertile subsoil and this can result in lower production unless some prevention or improvement measures are undertaken. Once such a measure is topsoil treatment or preservation, when fertile topsoil exists, topsoil treatment is always worthwhile.

5.3.3.2 Technical Criteria

Farmers are aware on aspects of erosion indicators, which they observed during their daily farming activities. They also described the extent and distribution of local erosion problems based on their knowledge and experiences. In that regards, they put the erosion control at the first rank. They said that before terraces they had a severity of erosion and/or degradation in their plots but after that the erosion reduced at good level. They added that they were facing high soil erosion and degradation of cultivable land and the yield capacity of all crops declined from year to year. A similar result was reported by Melese, (2010) wo found that farmers are able to know soil erosion and its consequences. So, farmers could identify when soil erosion occurred in their farm lands simply by observing the physical land characteristics and experiences through cultivating over time and were aware of the problem of soil erosion and soil fertility decline and believed that the severity of the problem had increased over time.

At the second rank there is retain soil moisture (RSM), the farmers reported that before terraces their crops suffered from drought but nowadays it drought is not like before. The principal objective of terracing is reducing the runoff and the loss of soil, but it also contributes to increasing the soil moisture content through improved. Therefore, Beach and Dunning (1995) reported that the terraces directly affect local hydrology and consequently runoff characteristics infiltration. In addition, terraces indirectly affect soil moisture and soil characteristics (Chow *et al.* 1999). Terracing has only an effect on water erosion, it does not stop or reduce the impacts of wind erosion.

Besides the increasing of soil fertility as ranked on the third rank, roughly farmers reported that by now they harvest more yield on their plot than before, because of erosion measures. They stated that the plots located on up slope still give less yield than lower slopes this indicates that the nutrients in top-soil flow by the erosion up to lower slope. Results obtained in Paraná (IAPAR, 1984) showed that terracing makes it possible to reduce top-soil losses by half, independently of the used cultivation system. Chow *et al.* (1999) observed dramatic decreases in top-soil loss, from an average of 20t/ha, to less than one t/ha by terracing sloping fields in combination with constructing grassed waterways and contour planting of potatoes.

However, serious run-off from the up-slopes washes away the top and fertile soil during the main rainy season causes to lose it, weakens the strength of the soil structure and facilitates to blowing away through the processes of wind erosion and a loss of topsoil may experience either a loss in land productivity or rise in costs of agricultural production and conservation. Furthermore, Brown and Wolf (1984) affirmed as the apparent increase in soil erosion over the past generation is not the result of a decline in the skills of farmers but rather the result of the pressures on farmers to produce more

5.4 Summary

The purpose of this chapter was to discuss the results of evaluate technical conformity and economic impact of bench terraces in the Eastern Province of Rwanda. Technical standards and models provided by the Ministry of Agriculture and Food and Agriculture Organization were tested on a sample of 180 bench terraces from 12 sites against the current terracing practice. Economic evaluation and farmers' perception results were also discussed according to results from the fields.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The research carried out has led to useful findings, conclusion and recommendations on technical evaluation of bench terraces for soil erosion control and economic evaluation of bench terraces on maize and beans. The objective of this chapter is therefore to recommend to the decision makers and technicians of soil erosion control and suggest ways to address the problems that were found on the field during the study.

6.2 Conclusions

The severity of soil erosion in Rwanda has motivated the government to invest more in soil conservation for sustaining the agricultural production and environment protection. Various agronomic and physical soil conservation measures have been taken as measures and government puts more efforts to reduce its intensively. However, the initiative has met some challenges. This research was carried out in Eastern Rwanda in order to evaluate technical and economical of bench terraces which is one of measures used in soil conservation in Rwanda.

The results revealed that some terraces have been built without taking into consideration recommendations established by Land Husbandry Water Harvesting and Hillside Irrigation (LWH),and Food and Agriculture Organization (FAO). The slopes of land for some sites are over or under norms (standards) of bench terraces for instance on site of Kayonza where slopes is 44% which should use the forest and

10.7% for bench terraces as erosion control measures instead of soil band (Fig 4.1). The slopes and heights of bench riser calculated on the fields show that about of 85% of sites visited are beyond of rise standards and many of them are not good grassed stabilized as recommended except such constructed by LWH.

Therefore, steeper riser is prone embankment runoff or land slide is an indicator of poor quality embankments which in the future can lead to sudden embankment land slide or destruction, the rise gets more fragile as the riser height increases and should not exceed 1.8 m to 2 m. Above that, the maintenance work will become difficult. In general, the bed slope values are in recommendations range from 2.3% to 3.6%. With the calculation we found that vertical interval and width of the bench in general are in range except few sites which have the serious problem of widths, the farmers started increasing the cultivated area by cutting the risers (Figure 5.1) and some burning the charcoal on bench and caws trampled the terraces (Figure 5.4). Several number of sites except those built by LWH have no waterways and nor cut-off drains and some sites without water way and cut-off drains are located below roads, the water from roads flow to the terraces without other deviation. Thus, if no strict measures are taken soon, the landslide and erosion will be carrying more soil than it would be before the implementation of bench terraces.

Moreover, in terms of economy, the results revealed that the break-even point could appear in second year of project with the benefit cost analysis of 1.15 and this gives the impression to conclude that bench terraced can be financially profitable but when all farming systems and technologies are respected and agro-ecological conditions are appropriated.

Concerning the farmers' Perceptions through pair-wise ranking approach, the farmers ranked the increasing the fodder and soil erosion control at the first rank, the farmers used the fodder harvested on risers in livestock farming and selling them, they also ranked retention of soil moisture and increasing the yield as the second rank. They reported that before terraces their crops suffered from drought but nowadays it is not like before. The farmers revealed the problem of some of their terraced plots abandoned after terracing which were no longer used because the terracing has been done without considering the norms and after terracing their plots did not again give the yield as before.

6.3 Recommendations

Based on the results obtained from this research and the role that bench terracing plays, it is an appropriate technique in soil conservation for Rwanda. It has objectives of controlling the velocity of overland flow and checking excessive soil erosion on hill slopes. It also helps to achieve optimum rain water utilization by increasing infiltration opportunity time for it and to ensure equitable soil moisture distribution and for providing required drainage. The following recommendations could be put forward to ensure that the different technical requirements are properly applied through implementation:

To the Government

(i) The severity of soil erosion in Eastern Rwanda area is worsening the wellbeing of community, yet considerable efforts have been made by Rwandan Government to control soil erosion. Although farmers have awareness regarding the important of bench terraces from soil erosion control and its effect on their agricultural live, there is a need for hand- in- hand cooperation with concerned experts while planning and implementation of soil conservation measures and before terracing on farmers' plots, the implementers and local government should sensitize the famers to adapt that newly introduced SWC technologies based on their indigenous knowledge. This may require a long and continuous effort until they accept and implement the technology because while using the top down approach instead of down top or participatory rural appraisal.

(ii) To effectively plan for soil conservation measures application and introduce new farming technology in farmers' land and to manage resources in the right way. It is very necessary to involve local farmers and have knowledge unless that they should be trained in undertaking activities and local concepts such as that of soil management, soil quality, soil fertility and even soil erosion control and bench maintenance. Therefore, this sustains the activities and enhances the farmers' ownership and set also reliable strategies to protect implemented terraces, waterways and cut-off drains.

(iii) As it is not easy to re-terrace, the technicians should increase the supervision of available terracing technicians in order to closely supervise the implementation of terracing activities especially through proper use of recommended criteria such as vertical interval. This is because, at the end, it affects the width of benches for constructed terraces and consequently crop production because benches are those parts of terraces in which crops are planted.

(iv) The technical problem of bench terracing construction was rised. Therefore, special emphasis should be placed on it by increasing the supervision of implementation on field. MINAGRI should make its effort on construction of them during and after even should continue the monitoring and evaluation till at least 5 years and handover with both implementers and farmers.

Recommendations for further studies

(i) Further research could be conducted to determine the efficacy of bench terraces across the country and on all soil erosion control measures.

(ii) Other researchers should carry out the research on level of bench terraces in soil erosion protection.

(iii) Other recommendations for further research include to analyze the benefit cost of other crops across country.

REFERENCES

Amore, E., Modica, C., Nearing, M. A., and Santoro, V. C. (2004). Scale effect in USLE and WEPP application for soil erosion computation from three Sicilian basins. *Journal of Hydrology,293(21),*100 – 114.

Ananda, J., and Herath, G. (2003). Soil erosion in developing countries: A socio-economic appraisal. *Journal of Environmental Management,68(4),* 343-353.

Anderson, J. R., and Thampapillai, J. (1990). *Soil conservation in developing countries: Project and policy intervention*. Washington, D.C: Wold Bank,

Arnanez, J., Larrea V., and Ortigosa, A. (2004). Surface runoff and soil erosion on unpaved forest roads from rainfall simulation tests in North Eastern Spain. *Catena,* 57(1), 1 - 14.

Askoy, H., and Kavvas, M. L. (2005). A review of hill slope and watershed scale erosion and sediment transport models. *Catena* 64(2), 247–271.

Assmo, P., and Eriksson, A. (1994). Soil conservation in Arusha region, Tanzania. Regional soil conservation unit. Nairobi, Kenya. Retrieved on 11th May, 2014 from: http://www.fao.org/library/library-home/en/.

Atampugre, G. (2014). Cost and benefit analysis of the adoption of soil and water conservation methods in Kenya. *International Journal of Scientific and Research Publications, 4(8),* 305 – 318.

Beach, T., and Dunning, N.P., (1995). Ancient Maya terracing and modern conservation in the Peten rain forest of Guatemala. *Journal of Soil and Water Conservation*. *50(2),* 138-145.

Bhuyan, S. J., Kalita, P.K., Janssen., K. A., and Barnes, P. A. (2002). Soil loss predictions with three erosion simulation models. *Environmental Modelling & Software, 17(3),* 137– 146.

Bizoza A. R., and de Graff, J. (2012). Financial cost-benefit analysis of bench terraces in Rwanda. *Land Degradation & Development, 23(2),* 103-115.

Blumberg, B., Cooper, D. R., and Schindler, P. S. (2005). *Business research methods.* London: McGraw- Hill.

Bojö, J. (1992). Cost-benefit Analysis: 20 empirical studies. In: H. Hurni (ed.)Soil conservation for survival. Ankeny (Iowa).*Soil and Water Conservation Society, 21(3),*195-205.

Brian, C. (1990). Terracing re-examined in the light of recent findings in Nepal and Indonesia Research Needs and Applications to Reduce Erosion and Sedimentation. In Tropical Steep lands (Proceedings of the Fiji Symposium, British Columbia, Canada.

Bryman, A. (2004). *Social research methods,* Oxford: Oxford University Press.

Burton, W., and Glen, W. (2007). Assessing the Economic Impact of Projects. *Integrated Environmental Assessment and Management 3(2*), 234-245.

Central Soil & Water Conservation Research & Training Institute, (2010). An Effective Soil Conservation Measure for the Nilgiris, Tamil Nadu, India.

Cots-Folch, R., Martinez-Casasnovas, J. A., and Ramos, M. C. (2006). Land terracing for vineyard plantations in the north-eastern Spanish Mediterranean region: Landscape effects of the EU Council Regulation policy for vineyards' restructuring. Agriculture, *Ecosystems ad Environment, 115(4),* 88-96.

Cots-Folch, R., Martinez-Casasnovas, J. A., and Ramos, M. C. (2006). Land terracing for vineyard plantations in the north-eastern Spanish Mediterranean region: Landscape effects of the EU Council Regulation policy for vineyards' restructuring. *Agriculture, Ecosystems ad Environment, 115(7),* 88-96.

Crosta, G. B., Dal Negro, P.. and Fratinni, P. (2003). Soil slips and debris on terraced slopes. *Nat. Hazards Earth Syst. Sci.3(1),* 31–42.

Dabney, S. M., Liu, Z., Lane, M., Douglas, J., Zhu, J., and Flanagan, D. C. (1999). Lendscape benching from tillage erosion between grass hedges. *Soil & Tillage Research, 51(2),* 219-231.

Duley, F. L., and Hays, O. E., (1932). The effect of the degree of slope on run-off and soil erosion. *Journal of Agricultural Research, 45(6),* 349 – 360.

European Development Fund, (2011). Strategic Environmental Assessment of the Agriculture sector in Rwanda. BOOK 2: ANNEXES to SEA Study Report (draft) – December 2011. Brussels, Belgium.

FFTC, (2004). Soil conservation practices for slopelands. Food and Fertilizer Technology Center. Retrieved on May, 2013 from: http://www.agnet.org/library /abstract/ pt2001024.html.

Food and Agricultural Organization of the United Nations, (2002). Deficit irrigation practice by C. Kirda. Water reports Paper No.22.FAO, Rome, Italy.

Food and Agricultural Organization, (1985). *Method of erosion control*. Rome: FAO.

Food and Agricultural Organization, (2010). Green manure/cover crops and crop rotation in Conservation Agriculture on small farms. Rome, Italy.

Gobin, A., Jones, R., Kirkby, M., Campling, P., Govers, G., Kosmas, C., and Gentile, A. R. (2004). Indicators for Pan-European assessment and monitoring of soil erosion by water. Athens, Greece.

Grigoriev, S. (1981). Les Travertines du Rwanda.-Programme des Nations Unies pour le Développement, Rome, Italy.

Hamdan, J., Burnham, C. P., and Ruhana, B., (2000). Degradation effect of slope terracing on soil quality for Elaeis guineensis Jacq. (oil palm) cultivation. *Land Degradation and Development, 11(2),* 181-193.

Howard, A. (1991). A critical look at multiple criteria decision making techniques with reference to forestry applications. *Canadian Journal of Forest Research* 21(4), 1649-1659.

Huang, R., Birch, C. J., and George, D. L. (2006). Water Use Efficiency in Maize Production – The Challenge and Improvement Strategies. 6th Triennial Conference. Maize Association of Australia, Canberra, Australia.

Inbar, M., and Llerena, C. A., (2000). Erosion processes in high mountain agricultural terraces in Peru. *Mountain Research and Development, 20(1),* 72-79.

Jostein, L., and Richard, P., (1996). *Extension strategy for resource-poor farmers in rainfed agriculture*. New Delhi: Macmillan India Press.

Kagabo D. M., L. Stroosnijder, L., Visser, S. M., and Moore, D. (2013). Soil erosion, soil fertility, and crop yield on slow-forming terraces in the highlands of Buberuka, Rwanda. *Soil and Tillage Research, 128(7),* 23-29.

Kagabo, D. M., Stroosnijder, L., Visser, S. M .http://www.sciencedirect.com/science/article/pii/S0167198712002310 - aff0010, and Moore, D. (2013). Soil erosion, soil fertility and crop yield on slow-forming terraces in the highlands of Buberuka, Wageningen, *Soil and Tillage Research, 128(2),* 23-29.

Karemangingo, C., Bugenimana, E. D., and Bimyebebe, M. (2014). Development of catchment management plan for Akanyaru sub-catchment, Nyaruguru district, Rwanda, Kigali-Rwanda.

Kasai, M., Marutani, T., Reid, L. M., and Trustrum, N. A. (2001). Estimation of temporally averaged sediment delivery ratio using aggadational terraces in headwater catchments of the Waipaoa river, North Island, New Zealand. *Earth Surface Processes and Landforms,26(2),* 1-16.

Kassa, Y., Beyene, F., Haji, J., and Legesse, B. (2013). Farmers' Perception of the Impact of Land Degradation and Soil and Water. Conservation Measures in West Harerghe Zone of Oromia National Regional State, Addis Ababa, Ethiopia.

Kassie, M., Köhlin, G., Bluffstone, R., and Holden, S. (2011). Are soil conservation technologies "win-win?" A case study of Anjeni in the north-western Ethiopian highlands. *Natural Resources Forum, 35(1),* 89–99.

Keirle, R. (2002). Has terracing failed? Report University of Wales, UK.

Kothari C. R. (2009) *Research methodology methods and techniques, second edition,* New Delhi: New age international (P) Ltd publishers.

Kuyvenhoven, A. and L. B. M. Mennes. (1989). *Guidelines for project appraisal: An introduction to the principles of financial, economic and social cost-benefit analysis for developing countries*. New York: The Hague, Government Printing Office.

Liu, B. Y., Nearing, M. A., and Risse, L.M., (1994). Slope gradient effects on soil loss for steep slopes. This paper was peer-reviewed for scientific content. Rome, Italy.

Lutz, E., Pagiola, S., and Reiche, C. (1994b). The costs and benefits of soil conservation: the farmers' viewpoint. *The World Bank Research Observer9*(2), 273-295.

Lutz, E., Pagiola, S., and Reiche, C. (1994a). Economic and institutional analyses of soil conservation projects in Central America and the Caribbean. Environment Paper 8. Washington DC, USA.

Luuk, D., and Freddy, R. (2010). A review of the effect of terracing on erosion Cemagref Grenoble, Paris, France.

Marc, B. (1931). *Les caracteres originaux de l'histoire rurale francaise,* Paris, Sage Publications Inc.

Ministry of Agriculture Government of India January, (2011). A report of Methods Manual Soil Testing in India. Department of Agriculture & Cooperation, New Delhi, India.

Ministry of Disaster Management and Refugees Affairs, (2012). Impacts of floods and landslides on socio-economic development profile. Kigali/ Rwanda.

Ministry of Lands, Environment, Forests, Water and Mines, (2004). National Land Policy, Kigali/Rwanda.

Ministry of Natural Resources, (2010). Mining Policy in Rwanda. Kigali, Rwanda

Monnier, G., (1955). Les terrasses à lit en pente pour l'interception et l'évacuation des eaux. *Fruits 10(7),* 278-283.

Montrasio, L., and Valentino, R. (2008). A model for triggering mechanisms of shallow landslides. *Nat. Hazards Earth Syst. Sci*. 8(1), 1149-1159.

Morgan, G., Powell, A. and McVay, K. A. (2004). *Terrace Maintenance*, Kansas State University, Retrieved on 1st July, 2014 from: https://www.bookstore. ksre.ksu. edu/pubs/C709.pdf.

Morgan, R. P. C. (1986). *Soil erosion and conservation*. London: Longman Group UK Ltd.

Mountjoy, D. C., and Gliessman, S. R. (1988). Traditional management of a hillside agroecosystem in Tlaxcala, Mexico: An ecologically based maintenance system. *American Journal of Alternative Agriculture,* 3(1), 1-10.

National Institute of Statistics Rwanda (NISR), (2012). Rwanda 4th Population and Housing Census report, Kigali/Rwanda.

Nickel, J., Ross, A. M. and Rhodes, D. H., (2009). Comparison of Project Evaluation Using Cost-Benefit Analysis and Multi Attribute Trade space Exploration in the Transportation Domain. *Ecological Modelling,187(5),* 341–351.

Onwuegbuzie, A. J., Collins, K. M. T., Leech, N. L., Dellinger, A. B., and Jiao, Q. G. (2010). A meta-framework for conducting mixed research syntheses for stress and coping researchers and beyond. Retrieved on 19th March 2015 from: http://mmr.sagepub.com/content/4/1/56.abstract.

Pelt, M. J. F. (1993). Sustainability-oriented project appraisal for developing countries. PhD dissertation. Wageningen Agricultural University. Amsterdam, Netherlands.

Philominathan, P. (2013). *Research Methodology*. Tamilnadu, Sage Publications Inc.

Pimentel, D. and Kounang, N. (1998). *Ecology of soil erosion in ecosystems.* New York: Wiley & Sons.

Posthumus, H. (2010). To terrace or not: the short term impact of bench terraces on soil properties and crop response in the Peruvian Andes. See discussions, stats, and author profiles for this publication, Huaraz, Peru.

Ramos, M. C., Cots-Folch, R., and Martinez-Casasnovas, J. A. (2007). Sustainability of modern land terracing for vineyard plantation in a Mediterranean mountain environment. *Geomorphology* 86(3), 1-11.

Rokstroom, J., Barron, J., and Fox, P. (2003). Water productivity in Rain-Fed Agriculture: Challenges and opportunities for smallholder Farmers in Drought-prone tropical Agro ecosystem. In Kjne. J, Barker, R. and Molden D (Eds): *Water productivity in Agriculture; Limits and opportunities for improvement*. London: CAB International Publisher.

Romulus, O., O., Peters, R. T., and Kerry, L. R. (2009). Effect of Sustained Deficit Irrigation on Hay and Oil Yield of Native Spearmint. USCID Fifth International Conference Washington DC, USA.

Ronald, W. S. (1969).*Proof of the law of diminishing returns.* California: California University Bekeley.

Rufino, R. L. (1989). Terraceamento. In: Manual Técnico do Subprograma de Manejoe Conservação do Solo, Curitiba. Secretaria da Agricultura e do Abastecimento, *Paraná*, 2(1), 218-235.

Rwanda Development Board, (2012). Agriculture sector report, Rwanda skills survey, Kigali, Rwanda.

Rwanda Development Board, (2012). Mining sector report Rwanda, skills survey Kigali Rwanda Recherches Minières. Kigali, Rwanda.

Schottman, R. W., and White, J. (1993). *Choosing terrace systems.* Agricultural publication G1500. Department of Agricultural Engineering, University of Missouri-Columbia. Retrieved on 2nd 2014, from: http://muextension.missouri. edu/explore/> gguides/agengin/g01500.htm.

Shaoliang, Z., Xingyi, Z., Ted, H., Xiaobing, L., and Jingyi, Y. (2010). *Influence of topography and land management on soil nutrients variability in Northeast China*. New York: Springer Science and Business Media.

Sheng, C. T. (2002). Bench Terrace Design Made Simple, 12th ISCO Conference, Beijing, China.

Sheng, T. C. (2002). Bench Terrace Design Made Simple. Beijing Department of Earth Resources Colorado State University Fort Collins, his paper introduces a simple but scientific design for bench terraces, Colorado, USA.

Smith, D. D., and Wischmeier, W. H., (1958), Factors affecting sheet and rill erosion. *Am. Geophys. Union Trans. 38(6),* 889–896.

Sobral-Filho, R. M., Madeira-Neto, J., Das, Freitas, P. L. de,, and Silva, R. L. P. (1980). Práticas de conservação de solos. (EMBRAPA-SNCLS, Miscelânea, 3). EMBRAPA-SNCLS, Rio de Janeiro, Brazil.

Stevens, C. E. (1942). *Agriculture and Rural Life in the Later Roman Empire', in The Cambridge Economic History*. Cambridge: Cambridge University

Suresh, N. (2009). *Soil and Water Conservation Engineering*, New Delhi: Standard Publishers.

Ted, C., and Sheng, B. (2002). Bench Terrace Design Made Simple. Department of Earth Resources Colorado State University Fort Collins, USA.

Tesfaye, G., and Debebe, W., (2013).Farmers' perceptions' and participation on Mechanical soil and water conservation techniques in Kembata Tembaro Zone:

International Journal of Advanced Structures and Geotechnical Engineering, 2(4), 118 – 131.

Turgot, A. R. J. (1767), Observations sur le Memoire de 1M. Saint- Puravy," in. *OEUVRES DR TURGOT, Ed. Daire*, *1(2)*,418-433.

United Nations Environment Programme, (2011). Rwanda from Post-Conflict to Environmentally Sustainable Development. Nairobi, Kenya.

Valdivia, R. O. (2002). *The economics of terraces in the Peruvian Andes: an application of sensitivity analysis in an integrated assessment model*. MSc Thesis. Department of Agricultural Economics and Economics, Montana State University. USA.

Van-Beek, L. P. H. (2002). Assessment of the influence of changes in land use and climate on landslide activity in a Mediterranean environment PhD. *Thesis*. Amsterdam, Netherlands.

Van-Dijk, A. I. J. M., and Bruijnzeel, L. A., (2003). Terrace erosion and sediment transport model: a new tool for soil conservation planning in bench-terraced steep lands. *Environmental Modelling & Software 18(3),* 839-850.

Verheye, W. H., and Verheye, W. (2000). Use of Land Evaluation Techniques to Assess the Market Value of Agricultural Land. *Agropedology, Nagpur, 10(2),* 88–100.

Vincent, A. M. C., and Yves Le, B. (2003). Runoff Features for Intensities, slope lengths, and gradients in an agricultural loessial hill slope. *Soil Science Society of America Journal, 67(3),* 844-851.

Wheaton, R. Z., and Monke, E. J. (2001). Terracing as a `Best Management Practice' for controlling erosion and protecting water quality. Retrieved on 4th June, 2016 from: http://www.agcom.purdue.edu/AgCom/Pubs/AE/AE-114.html.

Widomski, M., and Sobczuk, H. (2007). Retentional abilities of soils in eroded environment, In *Environmental Engineering*, Pawłowski L., Dudzińska M. & Pawłowski A., New York: Taylor & Francis.

Wiener, H., Hinojosa, L., Fernandez, W., and Steeb, T. (2003). *Análisis de costo-beneficio de las prácticas de conservación de suelos en Cusco y Apurímac*. Cusco: MASAL, CBC.

Zhao, C., Wang, Y., Chen, X. and Li, B. (2005). Simulation of the effects of groundwater level on vegetation change by combining. *Ecological Modelling* 187(5), 341–351.

Zingg, A. W. (2017), Degree and length of land slope as it affects soil loss in runoff. *Agricultural Engineering, 21(2),* 59–64.

Zuazo, V. H. D., Ruiz, J. A., Raya, A. M., and Tarifa, D. F. (2005). Impact of erosion in taluses of subtropical orchard terraces. *Agriculture, Ecosystems ad Environment,107(2),* 199- 210.

APPENDICES

Appendix I: Results for Technical Evaluation of 180 Terraces

Districts	Implementer	Slope of bed (%)	Slope of riser (%)	Height of riser (m)	VI (m) given by FAO formula	VI measured on the field (m)	Width (m) given by FAO formula	Width (m) measured on the field
Ngoma	**LWH**	**3.50**	**61.40**	**1.70**	**1.4**	**1.6**	**4.6**	**4.7**
	LWH	**4.40**	**68.00**	**1.20**	**1**	**1.2**	**4.2**	**4.2**
	LWH	**2.60**	**68.87**	**2.23**	**1.2**	**1.5**	**3.8**	**3.5**
	LWH	**3.20**	**65.10**	**2.10**	**1.1**	**1.5**	**4.1**	**4.3**
	LWH	**3.20**	**63.40**	**1.90**	**1.2**	**1.8**	**3.2**	**4.2**
	LWH	**4.70**	**68.70**	**1.20**	**1.3**	**1.7**	**3.4**	**4.2**
	LWH	**3.50**	**62.81**	**1.50**	**1.4**	**1.7**	**3.8**	**4.4**
	LWH	**4.40**	**69.20**	**1.20**	**1.4**	**1.3**	**4.4**	**3.6**
	LWH	**2.60**	**61.60**	**1.60**	**1.2**	**1.2**	**4.1**	**3.5**
	LWH	**3.20**	**67.40**	**1.40**	**1**	**1.3**	**4.2**	**3.1**
	LWH	**3.20**	**68.87**	**1.30**	**1**	**1.9**	**3.4**	**3.2**
	LWH	**2.20**	**68.30**	**2.00**	**1.1**	**1.7**	**4.6**	**4.3**
	LWH	**3.90**	**61.40**	**1.80**	**1.3**	**1.3**	**4.1**	**4.5**
	LWH	**2.10**	**59.80**	**1.70**	**1.5**	**1.1**	**4.6**	**4.6**
	LWH	**2.70**	**57.80**	**1.90**	**1.5**	**1.2**	**4.5**	**4.7**
Kayonza								
	LWH	**3.10**	**60.90**	**1.20**	**1.1**	**1.6**	**4.3**	**4.4**
	LWH	**3.40**	**60.10**	**1.10**	**1.1**	**1.2**	**4.2**	**4.6**
	LWH	**3.20**	**63.50**	**1.20**	**1.3**	**1.5**	**4.1**	**4.7**
	LWH	**3.20**	**62.40**	**1.20**	**1.2**	**1.5**	**4.3**	**4.4**
	LWH	**3.10**	**63.00**	**1.50**	**1.3**	**1.8**	**4.1**	**4**
	LWH	**2.70**	**62.10**	**1.80**	**1.4**	**1.7**	**3.3**	**4.1**
	LWH	**2.60**	**61.30**	**1.50**	**1.4**	**1.7**	**3.6**	**4.2**
	LWH	**2.90**	**60.70**	**1.70**	**1.4**	**1.3**	**3.6**	**4.1**
	LWH	**2.50**	**60.20**	**1.90**	**1.3**	**1.2**	**3.2**	**4.2**
	LWH	**2.90**	**67.40**	**1.60**	**1.3**	**1.3**	**3.8**	**3.9**
	LWH	**3.60**	**57.90**	**1.40**	**1.1**	**1.9**	**4.1**	**4**
	LWH	**3.60**	**53.70**	**1.60**	**1.1**	**1.7**	**4.1**	**4.2**
	LWH	**3.90**	**60.00**	**1.50**	**1.2**	**1.3**	**4**	**4.1**
	LWH	**2.80**	**60.00**	**1.40**	**1.2**	**1.1**	**4.3**	**4.2**
	LWH	**2.70**	**58.10**	**1.60**	**1.3**	**1.2**	**4.1**	**4.1**

Kirehe								
	LWH	**3.30**	**50.90**	**2.80**	**0.9**	**1.6**	**2.1**	**4.6**
	LWH	**3.10**	**53.50**	**2.60**	**0.7**	**1.7**	**2.2**	**4.1**
	LWH	**3.20**	**58.00**	**2.70**	**0.9**	**1.5**	**2**	**4.3**
	LWH	**3.40**	**56.40**	**2.40**	**1**	**1.5**	**1.8**	**4.7**
	LWH	**3.30**	**57.10**	**2.80**	**0.9**	**1.4**	**1.9**	**4.2**
	LWH	**3.20**	**57.40**	**1.80**	**1.7**	**1.2**	**4.1**	**3.6**
	LWH	**3.10**	**60.20**	**1.70**	**1.5**	**1.3**	**4.2**	**3.1**
	LWH	**3.10**	**57.50**	**1.80**	**1.2**	**1.2**	**4.3**	**4**
	LWH	**3.20**	**68.90**	**1.80**	**1.5**	**1.4**	**4.3**	**3.6**
	LWH	**3.10**	**80.20**	**1.90**	**1.1**	**1.3**	**3.9**	**3.8**
	LWH	**2.60**	**78.70**	**2.20**	**0.8**	**1**	**4.1**	**3.5**
	LWH	**2.60**	**61.20**	**2.30**	**1.1**	**1**	**4.1**	**3.4**
	LWH	**2.90**	**63.50**	**1.90**	**1.2**	**1.3**	**4**	**3.6**
	LWH	**3.10**	**67.90**	**1.6**	**1.40**	**4.4**	**3.7**	
	LWH	**3.00**	**51.70**	**1.90**	**1.2**	**1.20**	**4**	**3.3**
Rwama gana								
	LWH	**4.00**	**61.40**	**1.30**	**1.3**			
	LWH	**3.20**	**68.00**	**1.20**	**1.2**	**1.3**	**4.1**	**4.3**
	LWH	**3.50**	**68.87**	**1.00**	**1.4**	**1.2**	**4.5**	**4.2**
	LWH	**3.70**	**65.10**	**1.40**	**1.6**	**1.4**	**4.3**	**4.4**
	LWH	**3.70**	**63.40**	**1.20**	**1.1**	**1.2**	**4.1**	**4.3**
	LWH	**4.70**	**68.70**	**1.00**	**1.2**	**1.2**	**4.6**	**4.5**
	LWH	**4.40**	**62.81**	**1.30**	**1.6**	**1**	**3.8**	**4.3**
	LWH	**4.20**	**69.20**	**1.00**	**1.6**	**1.3**	**4.2**	**4.2**
	LWH	**4.70**	**61.60**	**1.40**	**1**	**1.4**	**3.9**	**4.3**
	LWH	**4.00**	**67.40**	**1.20**	**1.5**	**1.3**	**4.2**	**4.1**
	LWH	**4.00**	**68.87**	**1.10**	**1.3**	**1.2**	**4.2**	**4.1**
	LWH	**3.60**	**68.30**	**1.30**	**1.7**	**1.5**	**4.1**	**4.2**
	LWH	**3.80**	**61.40**	**1.20**	**1.3**	**1.4**	**4.2**	**4.3**
	LWH	**4.00**	**59.80**	**1.30**	**1.3**	**1.60**	**4.1**	**4.3**
	LWH	**3.00**	**57.80**	**1.20**	**1.4**	**1.30**	**3.4**	**4.4**
Ngoma	**PC**	**4.20**	**68.80**	**0.70**	**1.4**	**1.00**	**4.3**	**4.5**
	PC	**4.30**	**67.00**	**0.60**	**1.2**	**0.90**	**4.2**	**4.2**
	PC	**4.10**	**57.50**	**0.40**	**1.2**	**1.10**	**4**	**4.7**
	PC	**4.10**	**49.70**	**0.90**	**1.2**	**1.20**	**4.2**	**4.7**
	PC	**3.20**	**65.00**	**1.20**	**1.3**	**1.10**	**4.6**	**3.9**
	PC	**4.70**	**67.90**	**1.10**	**1.5**	**1.00**	**4.5**	**4.7**
	PC	**4.90**	**58.60**	**2.10**	**0.7**	**1.20**	**4.5**	**4.8**

	PC	**3.20**	**68.80**	**0.70**	**1.2**	**1.00**	**4.3**	**4.8**
	PC	**3.50**	**67.40**	**0.80**	**1.3**	**1.00**	**4.2**	**4.8**
	PC	**4.90**	**64.70**	**0.60**	**1.2**	**1.20**	**4.1**	**4.5**
	PC	**6.10**	**65.50**	**0.80**	**1.6**	**1.40**	**3.3**	**4.9**
	PC	**6.90**	**76.90**	**0.90**	**0.8**	**1.00**	**3.4**	**4.8**
	PC	**4.20**	**75.70**	**1.00**	**1.5**	**1.20**	**4.6**	**4.8**
	PC	**3.10**	**60.40**	**0.60**	**1.3**	**1.10**	**4.7**	**4.9**
	PC	**2.10**	**69.50**	**1.00**	**1.2**	**1.10**	**4.8**	**4.7**
Kayonza	**PC**	**3.50**	**80.40**	**1.00**	**0.7**	**1.40**	**4.3**	**4.4**
	PC	**4.50**	**79.40**	**0.90**	**0.6**	**1.70**	**4.2**	**4.3**
	PC	**4.30**	**94.80**	**0.70**	**0.7**	**1.30**	**4.7**	**4.3**
	PC	**2.10**	**94.40**	**0.60**	**0.8**	**1.20**	**4.3**	**4.6**
	PC	**3.20**	**86.40**	**0.90**	**1**	**1.50**	**4**	**4.2**
	PC	**3.10**	**90.40**	**1.40**	**0.5**	**1.30**	**4.9**	**4.3**
	PC	**2.80**	**89.60**	**1.00**	**0.7**	**1.20**	**5.3**	**4.3**
	PC	**2.20**	**98.40**	**0.70**	**0.5**	**1.60**	**5.2**	**4.8**
	PC	**3.00**	**91.70**	**1.60**	**0.7**	**1.30**	**4.7**	**4.6**
	PC	**1.40**	**94.90**	**0.60**	**0.5**	**0.90**	**4.8**	**4.6**
	PC	**4.50**	**89.40**	**0.70**	**0.6**	**0.90**	**5**	**4.7**
	PC	**5.30**	**94.80**	**1.20**	**1.1**	**1.10**	**4.7**	**4.7**
	PC	**4.30**	**95.90**	**0.80**	**0.6**	**1.10**	**4.9**	**4.7**
	PC	**5.80**	**81.80**	**0.90**	**0.7**	**1.90**	**5.4**	**4.4**
	PC	**1.00**	**88.00**	**0.70**	**0.4**	**1.90**	**5.6**	**4.4**
Kirehe	**PC**	**2.4**	**73.1**	**2.3**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**2.3**	**78.3**	**2.2**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**3.2**	**70.5**	**2.1**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**2.1**	**64**	**2.3**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**2.3**	**65.4**	**1.7**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**4.5**	**67.3**	**2.2**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**4**	**73**	**1.5**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**6.2**	**68.2**	**1.4**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**1.9**	**43.8**	**2.8**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**1.8**	**83.9**	**2.8**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**2**	**76.6**	**2.6**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**2.1**	**63.9**	**2.1**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**1.7**	**70**	**2.4**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**1.3**	**71**	**2.1**	**N/A**	**N/A**	**N/A**	**N/A**
	PC	**1.2**	**63**	**2.5**	**N/A**	**N/A**	**N/A**	**N/A**

Rwamagana	**PC**	**4.2**	**82**	**1.3**	**1.2**	**1.6**	**4.2**	**4.3**
	PC	**0**	**78.9**	**1.5**	**1.8**	**1.7**	**4.2**	**4.2**
	PC	**1**	**75.8**	**0.7**	**1.8**	**1.7**	**4.5**	**4.8**
	PC	**2.1**	**89.2**	**1.2**	**1.6**	**1.5**	**4.7**	**4.9**
	PC	**0**	**67.8**	**1.1**	**1.4**	**1.5**	**4.3**	**4.8**
	PC	**1.2**	**57.9**	**2.4**	**1.4**	**1.4**	**3.8**	**5**
	PC	**0**	**59.4**	**2.3**	**1.3**	**1.6**	**3.2**	**5**
	PC	**1.1**	**47.7**	**2.5**	**1.6**	**1.5**	**5.4**	**4.5**
	PC	**1.1**	**73.3**	**1.4**	**1**	**1.6**	**5.7**	**4.3**
	PC	**1.9**	**76.9**	**1.3**	**1.3**	**1.3**	**4.7**	**4.6**
	PC	**2.1**	**87.3**	**1.2**	**1.3**	**1.2**	**4.2**	**3.9**
	PC	**4**	**69.8**	**0.7**	**1.6**	**1.4**	**5.7**	**3.9**
	PC	**4.2**	**79.8**	**1.3**	**1.5**	**1.3**	**5.7**	**3.7**
	PC	**1.1**	**78.6**	**0.8**	**1.4**	**1.4**	**5.4**	**4.7**
	PC	**2.6**	**87**	**0.6**	**1.1**	**1.5**	**4.9**	**4.5**
Ngoma	**VUP**	**-1.2**	**78.7**	**2.3**	**1.2**	**1.4**	**4.5**	**4.2**
	VUP	**1.5**	**69.3**	**2.2**	**1.3**	**1.3**	**5.1**	**4.2**
	VUP	**0.3**	**69.3**	**1.9**	**1.3**	**1.2**	**4.7**	**4.6**
	VUP	**5.3**	**78.3**	**2.1**	**1.4**	**1.3**	**5.4**	**3.4**
	VUP	**4.2**	**78.8**	**2.3**	**1.2**	**1.4**	**4.9**	**4.9**
	VUP	**-1.3**	**73.2**	**2.1**	**1.6**	**1.3**	**4.8**	**4.3**
	VUP	**5.3**	**62.8**	**2.4**	**1.4**	**1.5**	**4.4**	**3.4**
	VUP	**4.2**	**78.4**	**1.3**	**1.1**	**1.3**	**4.7**	**4.5**
	VUP	**6.8**	**65.7**	**2.2**	**1.1**	**1.3**	**4.6**	**5.4**
	VUP	**3.4**	**67.8**	**1.9**	**1.3**	**1.2**	**4.9**	**4.4**
	VUP	**4.3**	**83.1**	**2.1**	**1.5**	**1.4**	**5**	**4.3**
	VUP	**-0.3**	**86.4**	**1.3**	**1.4**	**1.7**	**4.8**	**4.5**
	VUP	**5.7**	**50.2**	**2.1**	**1.5**	**1.6**	**4.6**	**5.4**
	VUP	**-1.1**	**46.3**	**2.3**	**1.3**	**1.7**	**4.7**	**4.3**
	VUP	**3.1**	**71**	**2.6**	**1.4**	**1.4**	**4.5**	**4.5**
Kayonza	**VUP**	**3.9**	**89.7**	**2.3**	**2.8**	**1.7**	**4.2**	**4.1**
	VUP	**2**	**78.3**	**2.6**	**2.5**	**1.8**	**4.1**	**4.3**
	VUP	**1**	**78.3**	**1.6**	**2.5**	**2.4**	**4.4**	**4.6**
	VUP	**1**	**74.3**	**2.5**	**2.8**	**2.6**	**4.6**	**4.9**
	VUP	**4.5**	**78.3**	**2.4**	**2.7**	**2.4**	**4.3**	**3.2**
	VUP	**5.4**	**56.9**	**2.7**	**2.9**	**2.6**	**4.3**	**3.7**
	VUP	**5.9**	**67.3**	**1.6**	**2.7**	**1.4**	**4.2**	**3.7**
	VUP	**-1.4**	**76.8**	**2.4**	**2.8**	**1.6**	**4.4**	**4.3**
	VUP	**-2.4**	**8.9**	**2.7**	**2.9**	**1.7**	**4.3**	**4.9**

	VUP	**5.8**	**87.6**	**2.4**	**2.9**	**1.8**	**4.3**	**5**
	VUP	**4.9**	**88**	**2.3**	**2.7**	**1.4**	**4.1**	**4.2**
	VUP	**6.9**	**82.3**	**1.5**	**2.4**	**2.2**	**4.3**	**4.3**
	VUP	**-0.4**	**88**	**2.5**	**2.4**	**2.3**	**4.1**	**3.2**
	VUP	**4**	**88**	**2.5**	**2.4**	**1**	**4.1**	**3.2**
	VUP	**4.9**	**75.7**	**2.7**	**2.7**	**1.3**	**4.3**	**4.4**
Kirehe	**VUP**	**2.2**	**61.7**	**2.2**	**1.7**	**1.5**	**3.1**	**3.6**
	VUP	**2.1**	**73.6**	**1.7**	**1.6**	**1.5**	**3.3**	**3.4**
	VUP	**2.1**	**71.3**	**1.8**	**1.7**	**1.6**	**3.5**	**4.4**
	VUP	**2.4**	**66.8**	**1.9**	**1.8**	**1.7**	**3.8**	**3.5**
	VUP	**4.3**	**67.4**	**2.6**	**1.9**	**1.7**	**3.2**	**3.1**
	VUP	**5.3**	**80.4**	**2.4**	**1.7**	**1.5**	**3.2**	**3.2**
	VUP	**1.3**	**78**	**2.4**	**1.8**	**1.7**	**2.5**	**3.9**
	VUP	**-1.2**	**70.5**	**2.4**	**1.6**	**1.6**	**2.3**	**4**
	VUP	**-2.1**	**69.7**	**2.4**	**2.3**	**1.5**	**3.5**	**4**
	VUP	**1.1**	**77.7**	**1.8**	**1.9**	**1.7**	**3.2**	**3.8**
	VUP	**2.4**	**64.3**	**2.5**	**1.7**	**1.6**	**3.1**	**3.8**
	VUP	**4.3**	**63.4**	**1.7**	**2.2**	**1.7**	**4.2**	**3.9**
	VUP	**3.3**	**63.2**	**1.9**	**1.6**	**1.9**	**3.2**	**3.9**
	VUP	**4.2**	**67.4**	**1.9**	**1.5**	**1.8**	**3.4**	**3.8**
	VUP	**-0.3**	**69.3**	**2.6**	**1.9**	**1.7**	**3.4**	**4.3**
Rwama gana	**VUP**	**3.2**	**63.2**	**1.8**	**1.2**	**2.3**	**4.4**	**4.6**
	VUP	**4.3**	**70**	**1.7**	**1.5**	**2.1**	**4.3**	**4.6**
	VUP	**2.1**	**69.4**	**2.6**	**1.4**	**1.5**	**4.8**	**4.3**
	VUP	**5.4**	**68.3**	**2.6**	**1.1**	**2.6**	**4.3**	**4.4**
	VUP	**-0.8**	**72**	**2.4**	**1.3**	**1.2**	**4.2**	**5.3**
	VUP	**3.9**	**65.4**	**1.6**	**1.4**	**1.6**	**3.2**	**4.8**
	VUP	**4.8**	**68.4**	**2.4**	**1.4**	**2.7**	**4.7**	**4.4**
	VUP	**4.9**	**67.5**	**2.1**	**1.1**	**2.9**	**4.3**	**5.4**
	VUP	**3.7**	**67.9**	**1.6**	**1.5**	**2.6**	**4.1**	**5**
	VUP	**-2.2**	**78.9**	**1.8**	**1.4**	**2.3**	**4.2**	**4.7**
	VUP	**-1.9**	**70.1**	**1.7**	**1.6**	**2.1**	**4.9**	**4.4**
	VUP	**4.6**	**72.1**	**1.8**	**1.5**	**2.2**	**3.5**	**4.3**
	VUP	**1.3**	**77.3**	**1.7**	**1.5**	**2.2**	**4.3**	**4.3**
	VUP	**-0.4**	**76.8**	**2.7**	**1.2**	**2.6**	**4.3**	**5.1**
	VUP	**-0.9**	**72**	**2.3**	**1.2**	**2.4**	**4.3**	**4.5**

Appendix II: Pair Wise Matrix for Economical Criteria Ranking

Economical							
	Increase cultivable area	Low labour requirement	Increase fodder	Increased crop yield	Score	PERCENTAGE	
Increase cultivable area	#	LLR	IF	ICY	1	16.6	
Low labour requirement		#	IF	ICY	0	0	
Increase fodder			#	IF	3	50	
Increased crop yield				#	2	33.4	

Appendix III: Pair Wise Matrix for Technical Criteria Ranking

Technical criteria						
	Erosion control	Improve soil fertility	Retain soil moisture	Easy for maintenance	Score	PERCENTAGE
Erosion control	#	EC	EC	EC	3	50
Improve soil fertility		#	RSM	ISF	1	16.6
Retain soil moisture			#	RSM	2	33.4
Easy for maintenance				#	0	0

Appendix IV: Specification Tables for Bench Terraces by FAO Approach

BENCH TERRACES (1) (Hand Made)

Riser Slope = 0 .75:1

Reverse Slope = 0.05

Width of the bench (Wb(m)	Slope		S P E C I F I C A T I O N										
	%	Grade	VI m	RH m	Hr m	Dc m	Wr m	Wt m	L m	A m²	Pb %	C m²	V m³
2.50	12	6.8	0.33	0.13	0.46	0.21	0.35	2.85	3509	8773	88	0.14	491
	14	8.0	0.39	0.13	0.52	0.24	0.39	2.89	3460	8650	87	0.16	554
	16	9.1	0.46	0.13	0.59	0.27	0.44	2.94	3401	8503	85	0.18	612
	18	10.2	0.52	0.13	0.65	0.29	0.49	2.99	3345	8363	84	0.20	669
	20	11.3	0.59	0.13	0.72	0.31	0.54	3.04	3290	8225	82	0.23	757
	22	12.4	0.66	0.13	0.79	0.34	0.59	3.09	236	8090	81	0.25	809
	24	13.5	0.73	0.13	0.86	0.37	0.65	3.15	3175	7938	80	0.27	857
	26	14.6	0.81	0.13	0.94	0.39	0.71	3.21	3115	7788	78	0.29	903
	28	15.6	0.89	0.13	1.02	0.41	0.77	3.27	3058	7645	77	0.32	979
	30	16.7	0.97	0.13	1.10	0.44	0.83	3.33	3003	7508	75	0.34	1021
	32	17.7	1.05	0.13	1.18	0.47	0.89	3.39	2950	7375	74	0.37	1092
	34	18.8	1.14	0.13	1.27	0.49	0.95	3.45	2899	7248	73	0.40	1160

	36	19.8	1.23	0.13	1.36	0.51	1.02	3.52	2841	7103	71	0.43	1222
	38	20.8	1.33	0.13	1.46	0.54	1.10	3.60	2778	6945	70	0.46	1278
	40	21.8	1.43	0.13	1.56	0.57	1.17	3.67	2725	6813	68	0.49	1335
	42	22.8	1.53	0.13	1.66	0.59	1.25	3.75	2667	6668	67	0.52	1387
	44	23.7	1.64	0.13	1.77	0.61	1.33	3.83	2610	6525	65	0.55	1436
	46	24.7	1.76	0.13	1.89	0.64	1.42	3.92	2551	6378	64	0.59	1505
	48	25.6	1.88	0.13	2.01	0.67	1.51	4.01	2494	6235	62	0.63	1571
	50	26.6	2.00	0.13	2.13	0.69	1.60	4.10	2439	6098	61	0.67	1634
2.75	12	6.8	0.36	0.14	0.50	0.23	0.38	3.13	3195	8786	88	0.17	543
	14	8.0	0.43	0.14	0.57	0.26	0.43	3.18	3145	8649	87	0.20	629
	16	9.1	0.50	0.14	0.64	0.29	0.48	3.23	3096	8514	85	0.22	681
	18	10.2	0.57	0.14	0.71	0.32	0.53	3.28	3049	8385	84	0.24	732
	20	11.3	0.65	0.14	0.79	0.34	0.59	3.34	2994	8324	82	0.27	808
	22	12.4	0.73	0.14	0.87	0.37	0.65	3.40	2941	8088	81	0.30	882
	24	13.5	0.81	0.14	0.95	0.40	0.71	3.46	2890	7948	80	0.33	954

VI = Vertical Interval; RH - Reverse height; Hr = Height of the riser; Dc = Depth of cut; Wr = Width of the riser; Wt = Width of the terrace; L = Length of the terrace per ha; A = Arca of the benches (flat area) per ha; Pb = Percentage of benches; C = Cross section of the terrace; V = Volume of cut per ha

BENCH TERRACES (2)

(Hand Made)

Width of the bench (Wb(m)	Slope		S P E C I F I C A T I O N										
	%	Grade	VI m	RH m	Hr m	Dc m	Wr m	Wt m	L m	A m²	Pb %	C m²	V m³
2.75	26	14.6	0.89	0.14	1.03	0.43	0.77	3.52	2841	7813	78	0.35	994
	28	15.7	0.98	0.14	1.12	0.46	0.84	3.59	2786	7662	77	0.39	1087
	30	16.7	1.07	0.14	1.21	0.48	0.91	3.66	2732	7513	75	0.42	1147
	32	17.7	1.16	0.14	1.30	0.51	0.98	3.73	2681	7373	74	0.45	1207
	34	18.8	1.26	0.14	1.40	0.54	1.05	3.80	2632	7238	72	0.48	1263
	36	19.8	1.36	0.14	1.50	0.57	1.13	3.88	2577	7086	71	0.52	1340
	38	20.8	1.46	0.14	1.60	0.59	1.20	3.95	2532	6963	70	0.55	1393
	40	21.8	1.57	0.14	1.71	0.62	1.28	4.03	2481	6823	68	0.59	1464
	42	22.8	1.69	0.14	1.83	0.64	1.37	4.12	2427	6674	67	0.63	1529
	44	23.7	1.81	0.14	1.95	0.67	1.46	4.21	2375	6531	65	0.67	1591
	46	24.7	1.93	0.14	2.07	0.70	1.55	4.30	2326	6397	64	0.71	1652
	48	25.6	2.06	0.14	2.20	0.73	1.65	4.40	2273	6251	63	0.76	1728
3.00	12	6.8	0.40	0.15	0.55	0.25	0.41	3.41	2933	8799	88	0.21	616
	14	8.0	0.47	0.15	0.62	0.29	0.47	3.47	2882	8648	87	0.23	663
	16	9.1	0.55	0.15	0.70	0.32	0.53	3.53	2883	8499	85	0.26	737

	18	10.2	0.62	0.15	0.77	0.35	0.58	3.58	2793	8397	84	0.29	810
	20	11.3	0.71	0.15	0.86	0.37	0.65	3.65	2740	8220	82	0.32	877
	22	12.4	0.79	0.15	0.94	0.40	0.71	3.71	2695	8085	81	0.35	943
	24	13.5	0.88	0.15	1.03	0.43	0.77	3.77	2653	7959	80	0.39	1035
	26	14.6	0.97	0.15	1.12	0.47	0.84	3.84	2604	7812	78	0.42	1094
	28	15.6	1.06	0.15	1.21	0.49	0.91	3.91	2558	7674	77	0.45	1151
	30	16.7	1.16	0.15	1.31	0.53	0.98	3.98	2513	7539	75	0.49	1231
	32	17.7	1.26	0.15	1.41	0.55	1.06	4.06	2463	7389	74	0.53	1305
	34	18.8	1.37	0.15	1.52	0.57	1.14	4.14	2416	7248	73	0.57	1377
	36	19.6	1.48	0.15	1.63	0.60	1.22	4.22	2370	7110	71	0.61	1446
	38	20.8	1.59	0.15	1.74	0.63	1.31	4.31	2320	6960	70	0.65	1508
	40	2.18	1.71	0.15	1.86	0.67	1.40	4.40	2273	6819	68	0.70	1591

BENCH TERRACES (3)

(Hand Made)

Width of the bench (Wb(m)	Slope		S P E C I F I C A T I O N										
	%	Grade	VI m	RH m	Hr m	Dc m	Wr m	Wt m	L m	A m^2	Pb %	C m^2	V m^3
3.00	42	22.8	1.84	0.15	1.99	0.71	1.49	4.49	2227	6681	67	0.75	1670

	44	23.7	1.97	0.15	2.12	0.73	1.59	4.59	2179	6537	65	0.80	1743
3.25	12	6.8	0.43	0.16	0.59	0.27	0.44	3.69	2710	8809	88	0.24	650
	14	8.0	0.51	0.16	0.67	0.31	0.50	3.75	2666	8665	87	0.27	720
	16	9.1	0.59	0.16	0.75	0.34	0.57	3.82	2617	8505	85	0.31	811
	18	10.2	0.68	0.16	0.84	0.37	0.63	3.88	2577	8375	84	0.34	876
	20	11.3	0.77	0.16	0.93	0.41	0.70	3.95	2532	8229	82	0.38	962
	22	12.4	0.86	0.16	1.02	0.44	0.77	4.02	2488	8086	81	0.41	1020
	24	13.5	0.95	0.16	1.11	0.47	0.83	4.08	2451	7966	80	0.45	1103
	26	14.6	1.05	0.16	1.21	0.50	0.91	4.16	2404	7813	78	0.49	1178
	28	15.6	1.15	0.16	1.31	0.53	0.98	4.23	2364	7683	77	0.53	1253
	30	16.7	1.26	0.16	1.42	0.57	1.07	4.32	2315	7524	75	0.58	1343
	32	17.7	1.37	0.16	1.53	0.61	1.15	4.40	2273	7387	74	0.62	1409
	34	18.8	1.48	0.16	1.64	0.63	1.23	4.48	2232	7254	73	0.67	1495
	36	19.8	1.60	0.16	1.76	0.67	1.32	4.57	2188	7111	71	0.72	1575
	38	20.8	1.73	0.16	1.89	0.70	1.42	4.67	2141	6958	70	0.77	1649
	40	21.8	1.86	0.16	2.02	0.73	1.52	4.77	2096	6812	68	0.82	1719
	42	22.8	2.00	0.16	2.16	0.76	1.62	4.87	2053	6672	67	0.88	1801
3.50	12	6.8	0.46	0.18	0.64	0.30	0.48	3.98	2513	8796	88	0.28	704
	14	8.0	0.55	0.18	0.73	0.34	0.55	4.05	2469	8642	86	0.32	790
	16	9.1	0.64	0.18	0.82	0.37	0.62	4.12	2427	8495	85	0.36	874

	18	10.2	0.73	0.18	0.91	0.41	0.68	4.18	2392	8372	84	0.40	957
	20	11.3	0.82	0.18	1.00	0.44	0.75	4.25	2353	8236	82	0.44	1035
	22	12.4	0.92	0.18	1.10	0.47	0.83	4.33	2310	8085	81	0.48	1109
	24	13.5	1.02	0.18	1.20	0.51	0.90	4.40	2273	7956	80	0.53	1205
	26	14.6	1.13	0.18	1.31	0.54	0.98	4.48	2232	7812	78	0.57	1272
	28	15.6	1.24	0.18	1.42	0.58	1.07	4.57	2188	7658	77	0.62	1357

BENCH TERRACES (4)

(Hand Made)

Width of the bench (Wb(m)	Slope		S P E C I F I C A T I O N										
	%	Grade	VI m	RH m	Hr m	Dc m	Wr m	Wt m	L m	A m²	Pb %	C m²	V m³
3.50	30	16.7	1.36	0.18	1.54	0.62	1.16	4.66	2146	7511	75	0.67	1438
	32	17.7	1.47	0.18	1.65	0.65	1.24	4.74	2110	7385	74	0.72	1519
	24	18.8	1.60	0.18	1.78	0.69	1.34	4.84	2066	7231	72	0.78	1612
	26	19.8	1.73	0.18	1.91	0.72	1.43	4.93	2028	7098	71	0.84	1704
	28	20.8	1.86	0.18	2.04	0.75	1.53	5.03	1988	6958	70	0.89	1769
	40	21.8	2.00	0.18	2.18	0.79	1.64	5.14	1946	6811	68	0.95	1849
3.75	12	6.8	0.50	0.19	0.69	0.32	0.52	4.27	2342	8783	88	0.32	749
	14	8.0	0.59	0.19	0.78	0.35	0.59	4.34	2304	8640	87	0.37	853
	15	9.1	0.69	0.19	0.88	0.39	0.66	4.41	2268	8505	85	0.41	930

	18	10.2	0.78	0.19	0.97	0.43	0.73	4.48	2232	8370	84	0.46	1027
	20	11.3	0.88	0.19	1.07	0.47	0.80	4.55	2198	8243	82	0.50	1099
	22	12.4	0.99	0.19	1.18	0.51	0.89	4.64	2155	8081	81	0.55	1185
	24	13.5	1.10	0.19	1.29	0.55	0.97	4.72	2119	7946	80	0.61	1293
	26	14.6	1.21	0.19	1.40	0.58	1.05	4.80	2083	7811	78	0.66	1375
	28	15.6	1.33	0.19	1.52	0.62	1.14	4.89	2045	7669	77	0.71	1452
	30	16.7	1.45	0.19	1.64	0.65	1.23	4.98	2008	7530	75	0.77	1546
	32	17.7	1.58	0.19	1.77	0.69	1.33	5.08	1969	7384	74	0.83	1634
	34	18.8	1.71	0.19	1.90	0.73	1.43	5.18	1931	7241	72	0.89	1719
	36	19.8	1.85	0.19	2.04	0.77	1.53	5.28	1894	7103	71	0.96	1818
	38	20.8	1.99	0.19	2.18	0.81	1.64	5.39	1855	6956	70	1.02	1892
4.00	12	6.8	0.53	0.20	0.73	0.34	0.55	4.55	2198	8792	88	0.37	813
	14	8.0	0.63	0.20	0.83	0.38	0.62	4.62	2165	8660	87	0.42	909
	16	9.1	0.73	0.20	0.93	0.42	0.70	4.70	2128	8512	85	0.47	1000
	18	10.2	0.83	0.20	1.03	0.46	0.77	4.77	2096	8384	84	0.52	1090
	20	11.3	0.94	0.20	1.14	0.50	0.86	4.86	2058	8232	82	0.57	1173
	22	12.4	1.05	0.20	1.25	0.54	0.94	4.94	2024	8096	81	0.63	1275
	24	13.5	1.17	0.20	1.37	0.58	1.03	5.03	1988	7952	80	0.69	1372

Soil Erosion Rates by Districts (based on GIS Modelling CGIS/UNEP)

Source: UNEP, 2011

Appendix V: Checklist of Group Discussion

A. Land Exploitation Details of Farmers

1. **Do you own land on this site of bench terraces?**
2. What are the selected crops do you grow in your exploitation land?
    - ✓ Maize
    - ✓ Bean
3. What are the fertilizers, pesticides and amendments used in your land?

- ✓ Liming material
- ✓ Organic manure
- ✓ NPK…………. DAP…………. UREA…………. All
- ✓ Pesticides

B. Adoption Of Bench Terracing Technique

4. **Did you discuss with the implementation actors of terracing project before installing them in your farms?**

- If not, Why

5. Do you remark any social economic impacts of terracing project in your agricultural exploitation?

- Yes
- No
- If yes what are they?
    - ✓ Increase in income generation
    - ✓ Job creation while terracing
    - ✓ Facilitate land use consolidation

6. What are the implementation actors of terracing project?
    - ✓ Ubudehe
    - ✓ Common works (ubudehe, imiganda)
    - ✓ Local government
    - ✓ VUP

- ✓ LWH
- ✓ Private companies: which one?.......................

7. How do you appreciate bench terraces techniques?
8. Do you have adequate capacity and knowledge to maintain the bench terraces?
   - No
   - If yes how did you know that?
9. Is there any improvement of production after terracing project?
   - ✓ Terracing project brings the improvement
   - ✓ The situation is better before the project than after the project
   - ✓ The situation is better after the project than before it.
   - ✓ Others :……………………..
10. If no any improvement what are the constraints?
    - ✓ Low knowledge
    - ✓ Financial problems and insufficiency of agricultural tools
    - ✓ Low motivation of leaders
    - ✓ Others:……………………..
11. Are there any disadvantages of bench terraces?
    - ✓ Loss of arable land
    - ✓ Reduction of productivity in first years of cultivation
    - ✓ Hard work (installation) and time consuming
    - ✓ Bad construction of bench terraces
    - ✓ Others:……………………..
12. Are there any advantages of bench terraces?
    - ✓ Maximize cultivable area……………….. How much?
    - ✓ Low labour requirement…………. explain how?
    - ✓ Increase fodder for their livestock
13. Are you using fertilizer on bench terraces, when were you first started using (after terracing)?
14. Before using the fertilizers how the soil fertility was (first seasons after terracing)?
15. If you have been using fertilizers before bench terracing in your farms, is there any change in the quantity of fertilizer you are using?

- ✓ If yes how much?
- ✓ What do you think is the reason?

16. Decrease or increase of soil erosion in their farms (Comparison before and after bench terraces)

17. Do you know what soil erosion is? Yes

- ✓ If yes; what are the problems you have observed before and after bench terrace in your farms
    - ✓ Loss in production
    - ✓ Land dissection
    - ✓ Gully formation
    - ✓ Loss of soil fertility-
    - ✓ Damage in infrastructure

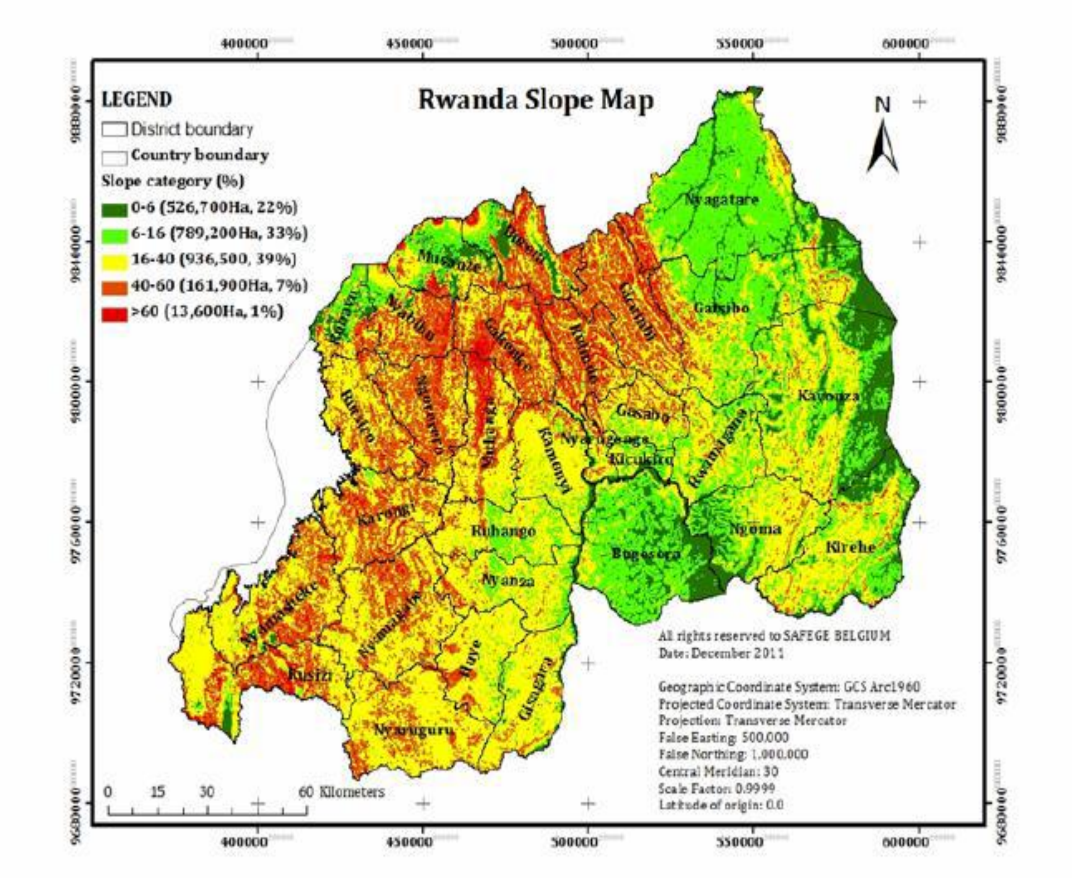
18. Do you think that, Is there proper management of your bench terraces?

- ✓ If not how? And propose the way forward

19. Suppose that you have other farm can you wish it to be treated like this?

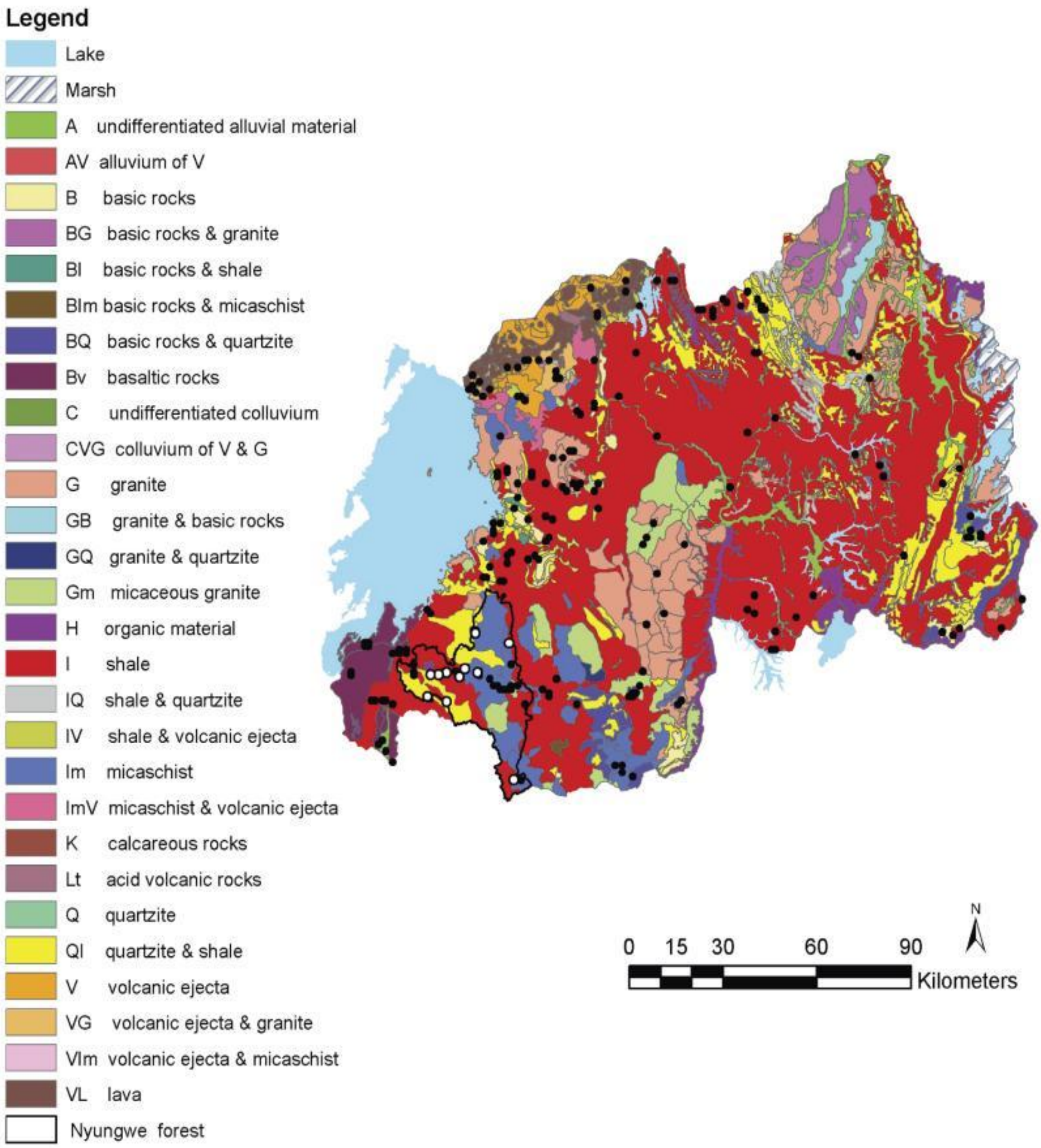
- ✓ If yes, why?
- ✓ If not, what should be done by government and other stakeholders so as to improve on your land resource and bench terraces at this site?

Appendix VI: Rwanda Slope Map



Source: EDF, 2011

Appendix VII: Rwanda Geological Map



Source: Grigoriev S 1981

Appendix VIII: Letter for Data Collection

THE OPEN UNIVERSITY OF TANZANIA

DIRECTORATE OF RESEARCH, PUBLICATIONS, AND POSTGRADUATE STUDIES

P.O. Box 23409 Fax: 255-22-2668759Dar es Salaam, Tanzania,
http://www.out.ac.tz

Tel: 255-22-2666752/2668445 ext.2101
Fax: 255-22-2668759,
E-mail: drpc@out.ac.tz

PROVINCE DE L'EST
Date de Réception 26 AUG 2016
N° enregistrement 857
A traiter
Classement

17/8/2016

Governor-Eastern Province,

Po Box 30,

Rwamagana-Rwanda

Approved. We support that research as requested.
Governor
14/09/

RE: RESEARCH CLEARANCE

The Open University of Tanzania was established by an act of Parliament no. 17 of 1992. The act became operational on the 1st March 1993 by public notes No. 55 in the official Gazette. Act number 7 of 1992 has now been replaced by the Open University of Tanzania charter which is in line the university act of 2005. The charter became operational on 1st January 2007. One of the mission objectives of the university is to generate and apply knowledge through research. For this reason staff and students undertake research activities from time to time.

To facilitate the research function, the vice chancellor of the Open University of Tanzania was empowered to issue a research clearance to both staff and students of the university on behalf of the government of Tanzania and the Tanzania Commission of Science and Technology.

The purpose of this letter is to introduce to you **Mr Bugenimana Eric Derrick ; Reg #, PG PG201507662** who is a PhD student at the Open University of Tanzania. By this letter, **Mr Bugenimana Eric Derrick** has been granted clearance to conduct research in Rwanda. The title of his research is **"Assessment of Technical efficacy of bench terraces for soil erosion control and their economic impact in Eastern Rwanda".** The research will beconducted in Rwamagana, Ngoma,Kirehe and Kayonza Districts located in Eastern Province. The period which this permission has been granted is from 17/08/ 2016 to 17/10/2016.

In case you need any further information, please contact:
The Deputy Vice Chancellor (Academic); The Open University of Tanzania; P.O. Box 23409; Dar Es Salaam. Tel: 022-2-2668820

We thank you in advance for your cooperation and facilitation of this research activity.
Yours sincerely,

Prof Hossea Rwegoshora

For: VICE CHANCELLOR

THE OPEN UNIVERSITY OF TANZANIA