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**“ANALYSIS OF THE EFFECT OF TERRACING ON SOIL EROSION CONTROL.
A CASE STUDY OF MUTETE SECTOR, GICUMBI DISTRICT, RWANDA .”**

A PROJECT REPORT

Submitted in partial fulfilment of the requirements for the award of

**MASTERS OF SCIENCE (HONS) IN WATER RESOURCES AND ENVIRONMENTAL
MANAGEMENT (WREM)**

Submitted by

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Under the Guidance of

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CERTIFICATE

This is to certify that the Project Work entitled "Analysis of the effect of terracing on soil erosion control, A case study of Mutete Sector, Gicumbi District, Rwanda. Is a record of the original bonafide work done by NDAYISHIMIYE VIRGINIE (REG.No: 215002045) in partial fulfilment of the requirement for the award of Masters of Science (hons) in Water Resources and Environmental Management in College of Science and Technology, University of Rwanda during the Academic Year 2023-2024

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*Submitted for the final Project Examination/Evaluation held at College of Science and Technology,
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DECLARATION

I, **Virginie Ndayishimiye** do hereby declare that this research project Entitled “**Analysis of the effect of terracing on soil erosion control, a case study of Mutete Sector, Gicumbi District, Rwanda.** Being submitted to the University of Rwanda for the degree of MASTER’S OF SCIENCE IN WATER RESSOURCES AND ENVIRONMENTAL MANAGEMENT is my original work and has not previously been presented or submitted elsewhere for any academic research award. In addition to this a complete list of references have provided indicating all the sources of information quoted or cited.

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Date August 2024

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DEDICATION

This work is dedicated to my darling IYAKAREMYE EPAPHRODITE and my beloved son IYAKAREMYE HIRWA MIKHAIL JASPER who sacrificed everything and helps me in different way to reach to the program's completion. They endured the demands of this work with patience, love, support and prayer.

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ABSTRACT

Land degradation poses a significant threat to agricultural and environmental development in the twenty-first century. Soil erosion, one of the major concerns, adversely affects agriculture, wildlife, and water bodies. It can be mitigated by maintaining protective soil cover or altering landscapes to manage runoff. In Gicumbi district's Mutete zone, northern Rwanda, terraces have been implemented as a key strategy for combating soil erosion, conserving water, and enhancing agricultural productivity—an approach that has been in practice for thousands of years. Despite its long history, the full range of terracing's effects and underlying mechanisms remains poorly understood due to challenges such as large-scale implementation, spatial variability, and difficulties in measuring its impact on soil erosion control. This study aims to examine the availability of land for agricultural practices on terraced versus non-terraced land, assess the impact of terracing on agricultural land use, and understand farmers' perceptions of its benefits and challenges. The study also evaluates soil erosion rates on both terraced and non-terraced lands through field observations. Using a combination of literature review, site visits, questionnaires, and interviews, the effects of terracing on soil erosion control were analyzed in terms of performance, suitability, cost-effectiveness, labor intensity, and long-term sustainability. The study found that terraced lands experience significantly lower soil erosion compared to non-terraced areas, but around 20% of arable land is lost to terrace structures. Farmers view this land loss and the labor-intensive nature of terracing as barriers to adoption. However, government subsidies, particularly in land consolidation programs, have made terracing more accessible. Despite the initial costs and labor demands, the long-term benefits, such as improved soil retention and higher crop yields, make terracing a worthwhile trade-off for farmers. Challenges related to labor and maintenance exist, but are outweighed by improved agricultural output. Farmers also called for more training, technical support, and expanded fertilizer programs to maximize terracing's benefits. While terracing has clear advantages, its negative impacts are often overlooked, and current studies have gaps in understanding its full effects. In conclusion, the adoption of terracing technology is influenced by a variety of factors, both promoting and hindering its effectiveness. Policymakers and planners should address these constraints when designing, implementing, and maintaining terracing as a critical soil erosion control measure.

LIST OF ABBREVIATIONS AND ACRONYMS

CST: College of Science and Technology

MINAGRI: Ministry of Agriculture and Animal Resources

REMA: Rwanda environment management authority

RWB: Rwanda water resource board

SWMF: Storm Water Management Facilities

GPS: Global Position System

FAO: Food and Agriculture Organization

LWH: Land husbandry Water Harvesting, and Hillside irrigation

NGO: Non-Government Organization

CPWS: Classic Public Works

VUP: Vision Umurenge Program

LS: Slope length

NISR: National institutes of statistics of Rwanda

NGOs: Non-Government organizations

SEC: Soil erosion control

SECM: Soil erosion control measures

DEM: Digital elevation model

DEM: Digital elevation model

Ha: Hectare

CIP: Crop Intensification Program

GIS: Geographical Information System

ICA: Increase Cultivable Area

USAID: United States Agency for International Development.

SOM: Soil organic matter

MPS: Mean Percentage Score

TVD: Total Variation Distance

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I. INTRODUCTION

1.1. Background of the study

Soil erosion is a deterioration of land due to the removal of its particles; it consists of about three stages that are dislodgement, transportation as well as sedimentation and its speed depends on soil type, aggregation, infiltration and ground cover. The causes of soil erosion are mainly classified as natural and anthropogenic factors and others are artificial that are human activities, poor farm management including monocropping, monoculture, conventional tillage, unsuitable irrigation models, overgrazing that all result to soil erosion and soil degradation. (EOS DATA, 2022)

Because soil erosion results in the loss of essential nutrients that lower soil fertility, it has a cascading effect on soil deterioration and has been a major obstacle to food safety as well as water quality. In addition to disrupting aquatic habitats and preventing light from penetrating water bodies, eroded soil containing contaminants like fertilizer and pesticides can contaminate water supplies, endangering human health as well as aquatic systems.

Furthermore, soil erosion affects water temperature, changes PH levels, and destroys ecosystems and lower biodiversity. Unfortunately, these interrelated factors degrade drinking water quality and call for action to reduce the risk that soil poses to the environment and public health.

The world's agricultural land is seriously degraded on about 40% due to soil erosion and this is the major threat on the earth to feed itself. Different soil conservation practice has been applied to fight against that soil loss and degradation, terracing could be one way of minimizing the degrading effect of the soil erosion and it is among the oldest method of saving soil and water. (Dorren & Rey, n.d.)

Moreover, it is the most widely used soil conservation practice throughout the world, nowadays terracing is still in many cases promoted as being a best management practice for effective soil and water conservation. (*Terraces • Integrated Water Resource Management - from Traditional Knowledge to Modern Techniques • Department of Earth Sciences, n.d.*) Terracing refers to building a mechanical structure of a channel and a bank or a single terrace wall, such as an earthen ridge or a stone wall.

Terracing reduces slope steepness and divides the slope into short gently sloping sections (*Terraces*, 2016) Terraces are created to intercept surface runoff, encourage it to infiltrate, evaporate or be diverted towards a predetermined and protected safe outlet at a controlled velocity to avoid soil erosion(Lail, 2023)

Rwanda is a thousand hill's country and according to its topography the major action of erosion has been identified as runoff and in different conservation systems terracing is included.(Alfred R. bizoza, 2014)

1.2. Problem statement

Rwanda is among African countries most highly vulnerable to water erosion, land use coupled with the growing of population with limited economic and agricultural input on a fragile soil, steep slopes and intensive rainfall result on land degradation and this had been a great hindrance on food safety. (Rwanda Water Portal et al, 2022)

This susceptibility is particularly evident in rural areas where the consequences impact the standard of living and income of rural populace as well as lower yields and unsafe settlements. Several studies, the most of which are conducted in Rwanda, indicate that the north province has a land slope gradient of more than 45degree.(EOS DATA, 2022)

Terraces are a kind of soil management technique that uses methodical site planning to prevent runoff. Although the main goal of terracing is usually to decrease runoff and soil loss, it also improves infiltration and lowers river peak discharge rates which in turn promotes rock weathering and ultimately boosts crop growth.(Dorren & Rey, n.d.)

The proposed project is a study which will analyze the effects of terracing on soil erosion control on terraced and non-terraced land in Rwanda-Gicumbi district especially Mutete sector.

1.3. Objectives of the research

1.3.1. General objective

The general objective was to quantitatively assess and analyze the effect of terracing on soil erosion control in agricultural landscapes by conducting a study comparing terraced and non-terraced areas and to understand the socio-economic impact of terracing on local farmers.

1.3.2. Specific objectives

1. To visually assess the rate of soil erosion on terrace and non-terrace agricultural lands
2. To understand farmer's perception regarding the benefits and challenges of terracing for soil erosion control.
3. To compare land availability for agricultural practice on a terraced land and non-terraced land.

1.4. Research Questions

1. How does the rate of soil erosion differ between terraced and non-terraced agricultural land as observed through visual assessment?
2. What are perceived benefits and challenges of terracing for soil erosion control among farmers in the study area?
3. How does land availability for agricultural practices differ between terraced and non-terraced agricultural lands?

1.5. Significance and justification of the study

The findings of this research would add to the understanding of soil conservation, because soil conservation in Rwanda is very sensitive due to its topography.

Rwanda is known as a thousand hills and leading to the landslides and floods on main hills of the country. In Rwanda especially in Mutete sector of Gicumbi district, there is no research done on the rate of soil erosion as observed visually on terraced and non-terraced agricultural land, posits that terraced agricultural lands will exhibit significantly lower rates of visible soil erosion

compared to non- terraced lands and This reduction in erosion is expected due to the physical barriers created by terraces which are designed to slow down water runoff, promoting water infiltration, minimizing soil particles displacement. Consequently, it is hypothesized that visual observations will reveal less evidence of soil erosion such as reduced gully formation and sediment accumulation, on terraced plots relative to non-terraced ones as well as farmers' perception regarding benefits and challenges of terracing for soil erosion control. There is a 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 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 terraces. This project is good fit between the government policy of soil and land conservation and fits also with my research interest and water 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.

The significant of this study lies on its potential to contribute valuable insights to both scientific community and agricultural practitioners, some key aspects of significance include:

1. Sustainable Agriculture practices: This study will provide evidence- based recommendations for the adoption of terracing as a sustainable agricultural practice offering erosion control benefits that can contribute to long-term soil conservation.

2. Land management strategies: Understanding the impact of terracing on soil erosion and quality can inform land management strategies aiding farmers and policy makers in implementing effective measures for sustainable land use.

3. Environmental conservation: By quantifying benefits of terracing in reducing soil erosion, this study will contribute to environmental conservation efforts emphasizing the importance of responsible agricultural practices in preserving natural resources.

4. Policy implication: Findings from this research will influence agricultural policies, encouraging the implementation of incentives or regulations to promote terracing as a soil conservation method.

5. Climate resilience: Given the potential links between soil health, erosion control and climate resilience, this study can contribute to broader discussions on building resilient agricultural systems in the face of changing climate conditions

6. Community engagement: This research can serve as a basis for community engagement and education programs, empowering farmers with knowledge about sustainable practices and encouraging the adoption of terracing for improved agricultural outcomes.

7. Economic impacts: Assessing the socioeconomic factors related to terracing adoption can provide insight into the economic implications of sustainable farming practices, potentially influencing investment decisions and financial support mechanisms

8. Scientific advancements: The longitudinal nature of this study and its comparative analysis can contribute to scientific understanding of soil dynamics, erosion patterns and the efficacy of terracing as a soil conservation technique.

1.6. Scope of the study

Delimitations, according to Eftekhari (2001) are limits established by researcher to regulate the scope of the study. They are developed before to conducting any research in order to cut down on time spent in specific areas that might be to be superfluous while still gathering information required and pertinent to the study as a whole. Accordingly, the study was conducted in Gicumbi district, Mutete Sector of Northern Rwanda to visually assess the rate of soil erosion on terrace and non-terrace agricultural lands, understand farmer's perception regarding the benefits and challenges of terracing for soil erosion control, and compare land availability for agricultural practice on a terraced land and non-terraced land.

1.7. Organization of thesis

This thesis is organized in five chapters; the first chapter contains the introduction, the problem statement, objectives, hypothesis, signification and justification of the study and the work organization. The second chapter presents the review of literature and definition of concept, theoretical and empirical literature review, and research gap. The third chapter is the research methodology while the fourth chapter presents the findings and its discussions. The last chapter focuses on conclusion and recommendations of the study.

II. LITERATURE REVIEW

2.1. Introduction

This chapter gives a brief and precise definition of key concepts, assessment of land availability and rate of soil erosion on terraced and non-terraced, farmers' perception regarding the benefits and challenges of terracing for soil erosion control. 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.

Soil erosion poses a significant threat to the productivity of agriculture and environmental sustainability. This literature review focuses on longitudinal study comparing terraced and non-terraced agricultural land to better understand and analyze their respective impacts on soil erosion overtime.

While there is a wealth of literature on various aspects of agricultural terraces, there is less information available regarding the process involved in hydrology and morphology. In this instance, I examined a variety of additional publications that covered hydrology and erosion in terraces and were published in international journals and conferences between 1980 and 2024.

2.2. Definition of concepts

2.2.1. Terrace

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.(EOS DATA, 2022) Bench terraces are a series of level or virtually level strips running across the slope at vertical intervals, supported by steep banks or risers, Bench terraces are also defined as level or nearly level steps constructed on the contour and separated by embankments known as risers.(Rwanda Water Portal et al, 2022)

They are finally libeled as horizontal flat bands formed, with variable width according to the slope, disposed like steps on watershed.

Terracing is a soil conservation practice applied to prevent rainfall runoff on sloping land from accumulating and causing serious erosion. Terraces consist of ridges and channels constructed across-the-slope.

Indiana farmers have long recognized the importance of controlling soil erosion and the benefits of applying conservation measures. For years, the basic motivation behind their conservation efforts was "to maintain the soils resource in a highly productive state."

Although that's reason enough to use sound land management practices, today farmers have an additional `motive'--compliance with the national Clean Water Act, which seeks to eliminate the pollution of streams, rivers and lakes by any source, including runoff from agricultural land.

The law specifies that control of nonpoint-source pollution is to be accomplished primarily by application of `best management practices.' BMPs are those conservation measures and/or land management techniques deemed most effective in preventing pollution by runoff or seepage from a given field or land area into watercourses.

One BMP applicable to some of the cropland of Indiana is *terracing*. This publication seeks to answer the commonly-asked questions about terraces, including: what are the different types? how do they work? where are they most effective (or ineffective)? what does it take to construct and

maintain them? and where does one get help with design, installation and financing? From the information presented, hopefully farmers can better assess the potential value of this BMP to their particular situations.(*AE-114*, n.d.)

2.2.2. Terracing as a soil conservation practice

Terracing is a soil conservation technique used to stop rainfall runoff from building up and causing significant erosion on sloping terrain. It suggests reorganizing farmlands or building unique ridged platforms to convert hills into farmlands.

Its primary functions involve removing topsoil and rearranging it to create ridges and agricultural areas. This allows water to flow to lower platforms when the upper ones are full, preventing slope erosion by distributing water more or less evenly across the hill rather than allowing it to reach the root.(Dorren & Rey, n.d.; EOS DATA, 2022)

Typically, terraces are used on slope to decrease water flows and prevent soil erosion. By creating a series of steps or platforms on landscape, terracing aims to reduce water runoff or promote water infiltration and minimize soil erosion.(Bezack et al., 2021; Lail, 2023; relief web, 2008)

2.2.3 Common types of terraces.

Most common known types of terraces are **broad-base, narrow-base, and grassed back – slope**.(EOS DATA, 2022)

1. Broad-Base terrace farming: This farming technique is suitable for gentlest hills and terrace cultivation embraces all the slopes. For this reason, they should suit machinery needs and the terrace spacing is typically equal to the number of machinery swaths. This type is applicable on slopes up to 8%

2. Grassed back- slope Terrace Farming: In these farming techniques the back slope is not cultivated unlike the main part, this main part includes the soil taken from downhill upwards with further leveling for farming.

e.g. perennial terracing.

3. Narrow- Base Terrace Farming: This is the steepest terracing type, it require less amount of earth for platforms than others.



Figure 2.2.3 1: terrace cultivation types from greener.land

2.2.4. Benefit of terrace farming

The major benefit of course, is the conservation of soil and water. Terraces reduce both the amount and velocity of water moving across the soil surface, which greatly reduces soil erosion. Terracing thus permits more intensive cropping than would otherwise be impossible.

According to [15] the following are different benefit of terracing in conservation of soil, water as well as environment.

1. BIODIVERSITY

The increased amount of nutrient and rainfall absorption in agricultural terraces benefits the plant growth. This leads to a higher biodiversity in these agricultural landscapes, compared to the harsh slopes of the mountainous regions.

The diverse landscapes with water management and crops allow for growing conditions for different species that increases the amount of biodiversity. Several studies have shown that there is an increase of 30 to 70% of biomass on terraced fields compared to non-terraced fields in similar environmental conditions.

The abandonment of agricultural terraces usually leads towards a decline in the biodiversity, with lower herbaceous flora being present. In the long run, there could be an increase in biodiversity of the abandoned agricultural terraces, with a complete transformation of the vegetation leading towards a recovery of the natural landscape.

2. CLIMATE CHANGE

By modifying the Relief Mountains and hilly regions, agricultural terraces provide several environmental benefits that could mitigate the risk of climate change such as improving rainfall absorbency, controlling soil erosion, reducing runoff, Biomass accumulation, smooth extreme summer temperatures.

Not only that but also, Mitigate the risks from floods and forest fires, Protection against mass movements or landslides, Habitat and biodiversity protection The same benefits also become negative consequences when the terraces are abandoned and no longer cared for, especially at a regional level.

3. CULTURAL

Dating back to the earliest civilization, but most intensively constructed during the later ` Middle Ages (c. AD 1100- 1600), agricultural terraces are one of the most noticeable landscapes in the Mediterranean region

They are strongly interlinked with historical and traditional heritage of the local farmers, and promotion is needed towards recognition of their function and value. The ancient knowledge on the diverse types of terrace constructions and the associated practices of water catchment, harvesting and distribution structures of the local communities are increasingly under threat of

being lost forever, mainly by the labor-intensive work and lack of interest for the practice among the younger.

4. SOCIO-ECONOMICAL

No matter the type of agricultural terrace, they all provide an increase of arable land and agricultural productivity per unit of plan metric land area. Several studies have found increases in crop yields ranging from near zero to more than 60%, with an extreme case in Tanzania of 270% (Deng et al., 2021; relief web, 2008) .These productive agricultural systems allowed for and required a higher population density Besides the incomes from tourism, this might provide a resource that could help maintain this cultural heritage practice.

2.2.5. Possible disadvantages of terraces

Besides the incomes from tourism, this might provide a resource that could help maintain this cultural heritage practice and according to (Deng et al., 2021)

Except above benefits, a number of studies have recorded the negative effects associated with terraces. These bad impacts, usually caused by inadequate design, mismanagement, and agricultural abandonment, challenge the man-land relationship and threaten ecosystem stability.

Disruption of water circulation Terracing plays a clear role in the conservation of water and soil sources, and quantitative research prove the effects of terracing on the interception of runoff. However, effects of terracing on hydrological processes should be noted, especially in areas with water resources strain. Precipitation that falls to the ground enters into both a small and large regional water cycle.

The smaller cycle includes soil infiltration and storage, rainwater collection, supplementary irrigation, and eventually evapotranspiration. The remainder of precipitation flows into watershed stream in the form of surface and underground runoff. Transforming slope lands into terraced fields may affect the small and large regional water cycle, thereby causing potential threats in the amount of available water for human activities.

Large area terracing increases water volume in the terraced field itself consequently reduces the outflow volume by intercepting runoff, altering the path of runoff and decreasing the hydrological connectivity so as to encourage it to infiltrate.

Erosion and mass movement due to poorly designed terraces although terraces are considered advisable and effective measure for soil and water conservation. Nevertheless, negative effects of poorly designed terrace are always concerned.

Deterioration of soil quality where degradation of soil quality on newly built terraced fields can be explained by the fertile topsoil is removed; soil structure is destroyed and nutrient loss due to soil and water loss. When constructing terraces, slopes must be reshaped, which has significant impact on soil and vegetation? Firstly, soil structure is primarily affected by disturbance from the reshaping of slope topography. The creation of terraces can lead to the removal of fertile topsoil and the upturning of subsoil. Those removed topsoil is then buried at terrace tips to enlarge flat area. And upturned subsoil with poor soil structure and nutrient condition

Furthermore, local vegetation will be destroyed completely in the process of terracing, thereby exposing the ground and large amount of loose materials.

In short, the author claims that terrace farming has a number of disadvantages summarized as following:

- Specific machinery to push and level the soil which are not available in most cases.
- It is a very labor-intensive and time-consuming process.
- Water circulation interference.
- If improperly constructed they can hold excess water leading to rainwater saturation.
- Deterioration of soil quality.
- Land disturbance that often requires additional treatment

2.3. Terracing technique

To some people, the word 'terrace' brings to mind *bench terraces* that are used in various mountainous regions of the world. More often, one pictures *contour terraces*, with their point rows and grassed waterway outlets that follow the lay-of-the-land.

1. Bench terracing

A bench terrace is an artificial land terrace with flat top and often nearly vertical side and used especially in series to convert mountainous slopes to arable land.

They have about three classes that are:

- Hill type bench terraces,
- Irrigated type bench terraces
- Orchard type bench terraces

Bench terraces are used to increase infiltration as well as reduce soil loss on these sloping crop fields. Due to the large volumes of infiltrated water in them during rainy seasons, the soil at the terrace bunds becomes highly saturated.

According to (*Terrace Farming*, 2021) Bench terraces are commonly used for growing rice since bench terraces allow retaining water and for this reason they are not suitable in the cases like:

- ✓ Crops are sensitive to waterlogging, e, g., potatoes
- ✓ Lands are prone to sliding;
- ✓ Frequent rains characterize weather patterns in the area.



Figure 2.3 1: Bench terraces from master class

2. Contour terracing

This type of terraces consist of points rows and grassed waterways, like in contour strip farming they follow relief contour and they require less input to arrange them and they are so difficult for farming activities due to space irregularities. (*Contour Ploughing and Terrace Farming*, n.d.; *Terrace Farming*, 2021; EOS DATA, 2022)



Figure 2.3 2: Contour terrace farming from masterclass

The construction of terraces and trenches on slope contours to detain water and sediment transported by water or gravity downslope. Such measures are known as contour terraces or contour furrowing, lined with geotextiles and filled with rock, stacked or placed to form an erosion resistant structure.

3. Parallel Terracing

Today, however, the type most common on agricultural land in the U.S. are *parallel terraces*, so named because they are constructed parallel to each other and, where possible, to the direction of field operations (Figure 2). Parallel terraces eliminate the production losses associated with point rows and minimize interference to farming operations when spaced at multiple widths of planting and harvesting equipment. (AE-114, n.d.)



Figure 2.3 3:A parallel terrace system from master class

Those terracing forms are the easiest for farming activities so they could be kept as parallel as possible. If the slope does not allow that they are built through land leveling operations. (EOS DATA, 2022)

2.4. Adaptability of terraces

Fields with long, fairly-uniform slopes that are not too steep (generally less than 8 percent) are best adapted to broad-based terraces. If the slopes are very irregular or if the soil is shallow (less than 6 inches), alternative BMPs should probably be used.

The overall slope of a field being terraced can be improved by taking fill material from the 'right' locations in that field. Topsoil should be removed from both the cut and the fill areas and stockpiled, especially with shallow soil. It can later be spread back over the terrace and borrow areas.

In some cases, on land where a total terrace system is not practical, terraces are sometimes placed across minor watercourses. This type of terrace uses subsurface outlets similar to PTO terraces. It controls sediment discharge but does not check soil erosion as effectively, since steep slopes are likely to exist above the terrace.

Generally, very effective! They intercept rainfall runoff as it starts down a slope, thus preventing a large accumulation of flow on the surface. This reduces the potential for sheet and rill erosion.(Lail, 2023)

In effect, terraces break up one long slope into a number of short ones. As already mentioned, PTO terraces also give soil particles that do erode a chance to settle out in the basin behind the terrace ridge, while the excess water is slowly discharged through a subsurface drain.

Any permanently-installed practice will, to some degree, obstruct field operations and/or take some land out of production. However, these obstructions are greatly minimized under present methods of design. For instance, with a PTO terrace system, elimination of the grassed waterways more than offsets the interference caused by cross-slope ridges and channels.

Since terraces are constructed across the slope, tillage will also be done in that direction. Cross-slope tillage may be the only additional change needed. However, use of conservation tillage practices also might permit greater distances between terraces.(Fukamachi, 2017)

2.5. Empirical literature review

The empirical literature review of technical evaluation of bench terraces has been guided by FAO and LWH technical standards of terrace construction.

2.5.1 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.

(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 ranges from 2.5 to 5 m; for machine built and tractor-cultivated terraces, the range is from 3.5 to 8 m.

In this research, I 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%.

(iv) Slope limit:

If soil depths are adequate, hand-made terraces should be employed on 7-to-25-degree (12%-47%) slopes [17].

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 $(100/20) \times 1.5 = 7.5$ meters while the spacing for 39% slope would be $(100/39) \times 1.5 = 3.85$ 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 Handmade 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 gives the height of the terrace; provides basic data for calculating the cross-section and volume of soil to be cut

(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).

The terrace must be built when the soil is neither too dry nor too wet. Start building the terrace from the top of a hill and precede downslope. It will not be washed away in the case of heavy rain. However, when topsoil treatment or preservation is carried out, it is necessary to start building from the bottom of the hill upwards. In this case, temporary protection measures should be undertaken.

Tie cord or rope around the stakes to mark each constructed terrace in sequence. The initial cut must be made immediately below the top stakes while the fill work should be started against the bottom stakes. This is done in order to ensure that the correct grade is attained without overcutting. Sometimes, rocks or clods of earth can be placed along the bottom line of the stakes to serve as a foundation before filling. During the filling operation, the soil should be compacted firmly by a beater every 15 cm. If the layer of soil fill is thick, the compacting process becomes difficult. Terraces which go across existing depression areas should be built particularly strong. The edge of a terrace should be built a little higher than planned because of settling. The rate of settling may be as high as 10% of the depth of the fill.

Both the reverse and horizontal grades should be checked by a level during construction work and corrections must be made promptly wherever necessary. The slope of the riser should be shaped to 0.75:1. Waterway shaping should be commenced only after the terraces are cut. Make sure all the terrace outlets are higher than the waterway bottom. (*M30E09.HTM*, n.d.)

2.5.2. 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:

(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. 20

(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 2.5.2.1, 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: $T.V.D. = S.L.(0.94S+0.006)$.

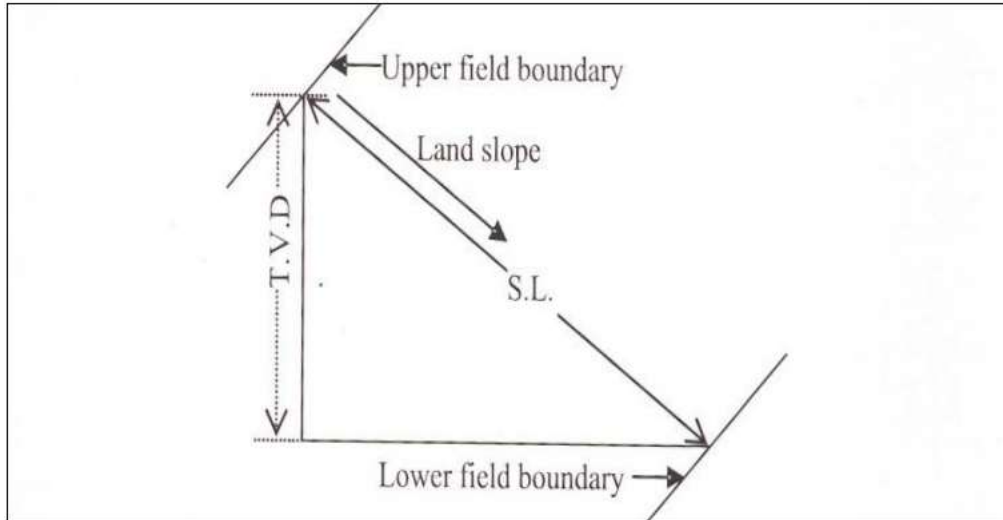


Figure 2.5.2. 1: Computation of Total Vertical Distance Source: Central Soil & Water Conservation Research & Training Institute, 2011

Figure 2.5.2.1.

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 21 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.

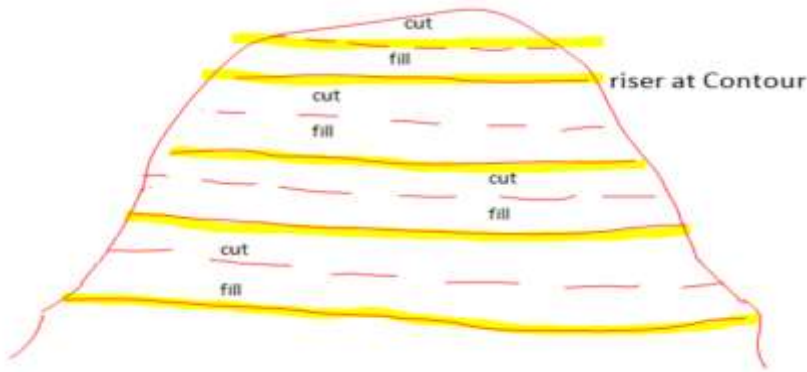


Figure 2.5.2. 2: Marking Terrace Lines in the Field Source: Central Soil & Water Conservation Research & Training Institute (2010)

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. Proceed again from this point in the same fashion to cover the entire length. In Fig. 2.5.2.3 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.

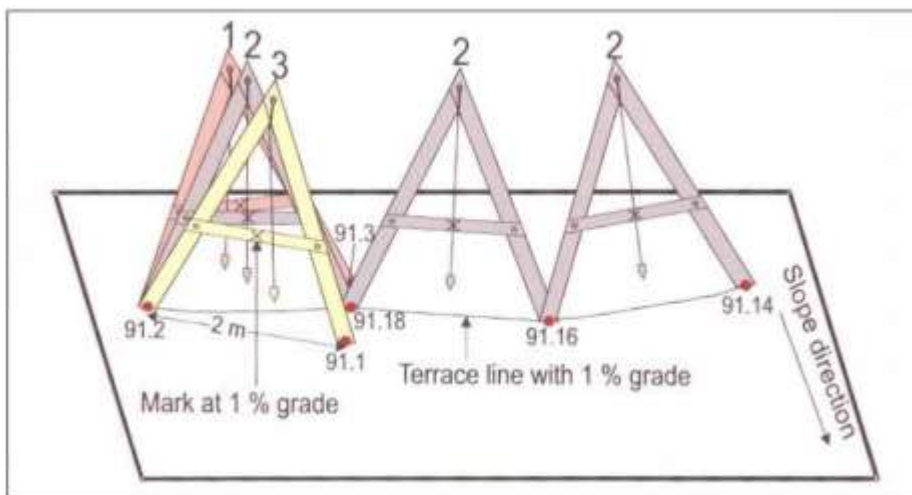


Figure 2.5.2. 3:: Use of A-frame for Marking Contours, Source: Central Soil & Water Conservation Research & Training Institute (2010)

(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.

2.5.3. 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.

The riser/ terrace wall needs 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 as the figure 2.5.3.1. below illustrates clearly the construction steps.

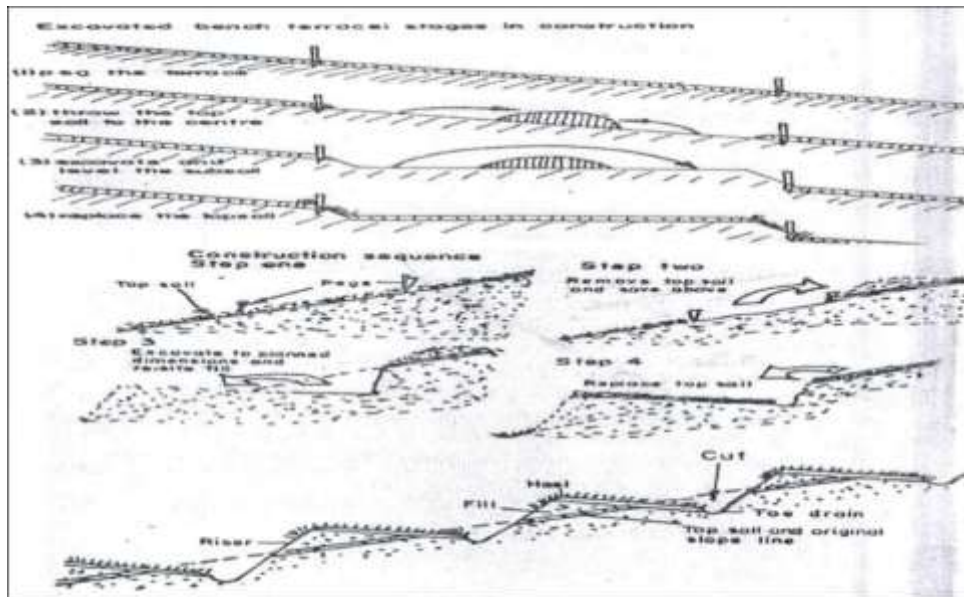


Figure 2.5.3 1: Construction Procedure of Bench Terraces Sources: Mesfin, 2016

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.

2.6. Perception of Farmers on terracing

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 severe 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)

2.7. 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 characterized 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).

2.8. Research gap

Before a problem can be addressed, it must be perceived. Addressing soil erosion with the adoption of conservation practices is no exception. farmer's perception of terracing as a soil erosion control in Rwanda has given little attention to perception variables especially in Northern province. Considering the findings reported in the literature reviewed above it is still not comprehensible whether rate of soil erosion and how farmers perceive benefits and labor requirement in terracing as well as land availability for agricultural practices. There is a dearth of studies specifically focused on local context, particularly with regard to its district topography, soil types and agricultural activities which presents research gaps in the analysis of the effects of terracing as a soil erosion control in Mutete Sector, Gicumbi District. Furthermore, not much research has been done on terracing's long-term efficacy, particularly in Rwanda's highland areas. There are few studies comparing this strategy to other soil conservation techniques or investigating its socioeconomic effects nearby farmers, taking labor and cost-benefit as well as land availability for agricultural practice and reduction of soil erosion into account.

Furthermore, not enough research has been done on how terracing can reduce effects of climate change on soil erosion especially in Mutete sector of Gicumbi District.

III. MATERIALS AND METHODS

3.1. Introduction

This chapter present the study areas where the research was conducted, indicating its geological location in relation to activities and 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 a visual analysis, a controlled investigation of the theoretical and applied aspects of measurements, and ways of obtaining and analyzing data to quantify effect of terracing as a soil erosion control in Mutete sector, Gicumbi district, Northern Rwanda.

3.2. Materials and methodologies

3.2.1. Study area description

Gicumbi district is spread across 21 sectors, 109 cells and 630 villages in the province of East North Rwanda with Byumba serving as the provincial capital. The District is 829 square kilometers in size, with 57% of that land being extremely vulnerable to erosion.

Erosion control practices in Gicumbi District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. About 18,700 hectares (which is 40% of the total land at risk) are suitable for contour bank terraces or progressive terraces, 5661 hectares are storm water management facilities or water harvesting infrastructures (SWMF) and 1190 hectares are Afforestation & Reforestation. Others are Bench terraces (2905 hectares).

My study was based on terracing as an erosion control practices especially in Mutete sectors of Gicumbi district, though I will quantify the effect of terracing as a soil erosion control.

Mutete sector total land is 5654 ha of which 3152 ha is on erosion risk where 8 ha is on extremely high erosion risk, 311ha is on a very high erosion risk, 606 ha is on high erosion risk and 2207 ha on moderate erosion risk. According to the sector topography, Terracing was among different erosion control practice applied in that region.

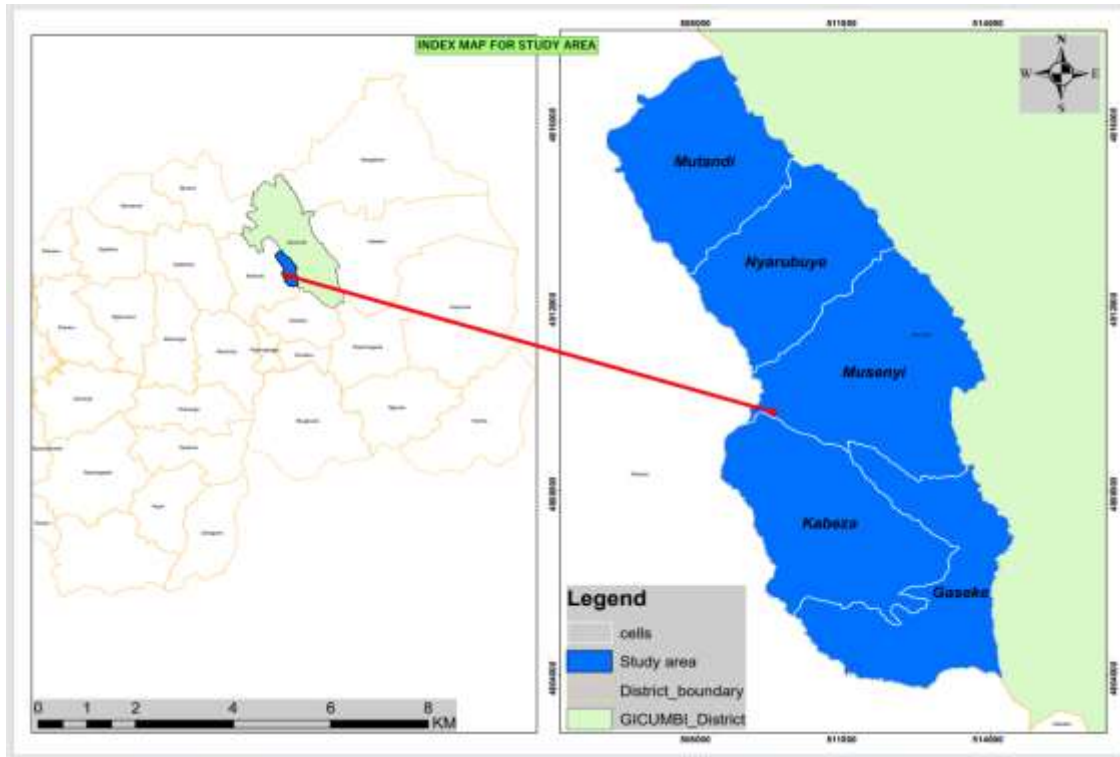


Figure 3.2.1 1 study area description

3.2.2. Terrace information

Terracing is a soil erosion control technique that involves creating step like structures on slopes to slow down water runoff, reducing soil erosion. In the context of climate change, terraces can play a significant role as they help to mitigate the impacts of extreme weather events such as heavy rainfall or storms which are becoming more frequent and intense due to climate change.(ips news, 2023)

By preventing rapid water runoff, terraces promote water infiltration allowing soil to absorb moisture and reducing the risk of erosion. This helps maintain soil fertility and prevents sedimentation in water bodies. Additionally they contribute to carbon sequestration as stable soil store more organic matter.(Anna & Pierzgalski, 2008)

In summary, Terracing is practical measure for soil erosion control that aligns with climate change adaptation by enhancing soil resilience to extreme weather events and supporting sustainable management practices.(Lail, 2023)

3.2.3. Field instrument

- GPS device for accurate site mapping
- Soil moisture sensors for both terraced and non-terraced areas
- A measuring tape and meter, calculator, pens, recording sheets, computer, questionnaire.

3.2.4. 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. Together with qualitative data gathered for comparison of terraced and non-terraced agricultural land a large amount of descriptive data was also engaged and incorporated.

Correlations between the FAO and LWH terrace standards and the field collected qualitative and quantitative data were made. Techniques for selective and random sampling were used.

3.2.5. Sampling procedures

This study was carried out in Northern Rwanda, Gicumbi district, Mutete sector. The selection of sites for sampling and study was guided by topography, availability of terraces in the mountain slopes, accessibility of population density. The materials and methods used during data collection in quantification of effect of terracing as a soil erosion control in the areas was visual assessment, questionnaire, land measurement and a lot of literature review to assess the rate of soil erosion on terraced and non- terraced agricultural land visually, to understand farmer's perception regarding the benefits and challenges of terracing as a soil erosion control and to compare land availability for agricultural practice on terraced and non-terrace land.

After selection of province, district and sectors as the case study of my research the specific sites were also selected based on terraces availability, peer person for interview for research

The researcher contacted the districts officially and sought permission in order to visit the sites and have access to needed data.

3.2.6. Data Collection and methodologies held to test the specific objectives of the study

To carry out this research, methodology which was used consisted in field visiting, Observation and technical evaluation of implemented terraces with reference to FAO standards and LWH standards and focus group for farmers' perception about terracing as a soil erosion control.

Data was collected on site and measurement of slope, terraces widths, vertical interval, heights of risers, riser slope was made to understand and compare land availability for agriculture on terraced and non- terraced land. In data collection one part of land was taken to be studied and the slope of land was measured by measuring the horizontal distance of land and the vertical distance.

After this measurement, the calculation of the slope was mad. For the slope risers, slope of bed, vertical interval and width of bed were measured on about 5 plots of different places.

Secondly, Observation and farmer's interviews was used to compare the rate of soil erosion on terraced and non- terraced agricultural land as well as farmer's perception about benefit of understand farmer's perception regarding the benefits and challenges of terracing as a soil erosion control where a random sampling of farmers for interview in the areas was used purposefully.

3.2.6.1. Visual assessment of the rate of soil erosion on terrace and non-terrace agricultural lands.

In order to achieve the first objective of this study, to assess the rate of soil erosion on terraced land versus non-terraced land.

Through different field visit on the selected site, with the help of photos, I considered the following:

1. Presence of erosion Features:

- On terraced land, I examined and look for signs of erosion such as small rills or minor gully formation.
- On non-terraced land, I examined and check for larger, more frequent erosion features like deep gullies and extensive rill network.

2. Vegetation health and coverage:

- On terraced land, I look if vegetation are healthy and dense than non- terraced agricultural land which is an indication of its effectiveness on erosion control.

3. Soil surface condition:

- On terraced land soil may appear more stable and less compacted
- On non-terraced agricultural land soil may look more compacted and crusted which is the signs of erosion.

4. Exposed roots and rocks:

- On terraced land fewer exposed roots and rocks indicate better soil retention.
- On non- terraced land more frequent exposed roots and rocks suggest higher erosion rates.

Through different field visit held on the selected sites by comparing these indicators between terraced and non-terraced agricultural lands, it helps me to visually assess the relative rates of soil erosion.

3.2.6.2. Farmers' perception regarding the benefits and challenges of terracing for soil erosion control.

The study used a combination of quantitative as well as qualitative research methodologies in order to meet the study's objectives.

There are five cells in mutete sector but three of them that have been selected for study areas are Kabeza cell, Musenyi cell, Nyarubuye cell and terracing have done by cpws(classic public works).

I contacted District as well as sector officially in order to have access to farmers who are cultivating on these terraces for surveying (focus group discussions with the key informants and the following criteria that are divided in five sections.

The first section was Demographic information and contain information including Age, gender, education background, size of the farm, types of crops she or He grows and period spend in the areas to know if the respondent is aware of history of erosion issues in the area.

Section two was Awareness and knowledge about erosion and erosion control measurement, the third section was Perception on land terracing as a soil erosion control, the fourth section was perception on non-terraced land on soil erosion control, and the fifth section which is the last was comparative perception and general opinions.

The participatory rural appraisal approach and pairwise ranking techniques were used in order to exhaust all information needed from 100 respondents in my research. 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 farmers' preferences on 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.

3.2.6.3. To compare land availability for agricultural practice on a terraced land and non-terraced land.

After identifying and selecting terraced plot for data collection, measurements of dimensions by using a measuring tape on terraced land was followed by calculations to calculate the slope or the estimated original land before terrace making to test if terrace making will reduce land for agriculture or if it will be increased.

As the figure below shows, the estimated original land is presented as dotted line, and to calculate it measurement of field surface, terrace wall or terrace riser as well as each terrace elevation which is called H on the figure is required.

For terraced land I measured the effective agricultural area by counting the total surface area of terraces excluding the non-usable parts such as the embankments and use formulas to calculate the area of each terrace (length *width) and sum these to get the total available area for agriculture.

To make the findings more reliable I used some literature to test this hypothesis of land availability for agricultural practices to see if terracing minimizes land or if it increases the land availability for agriculture.

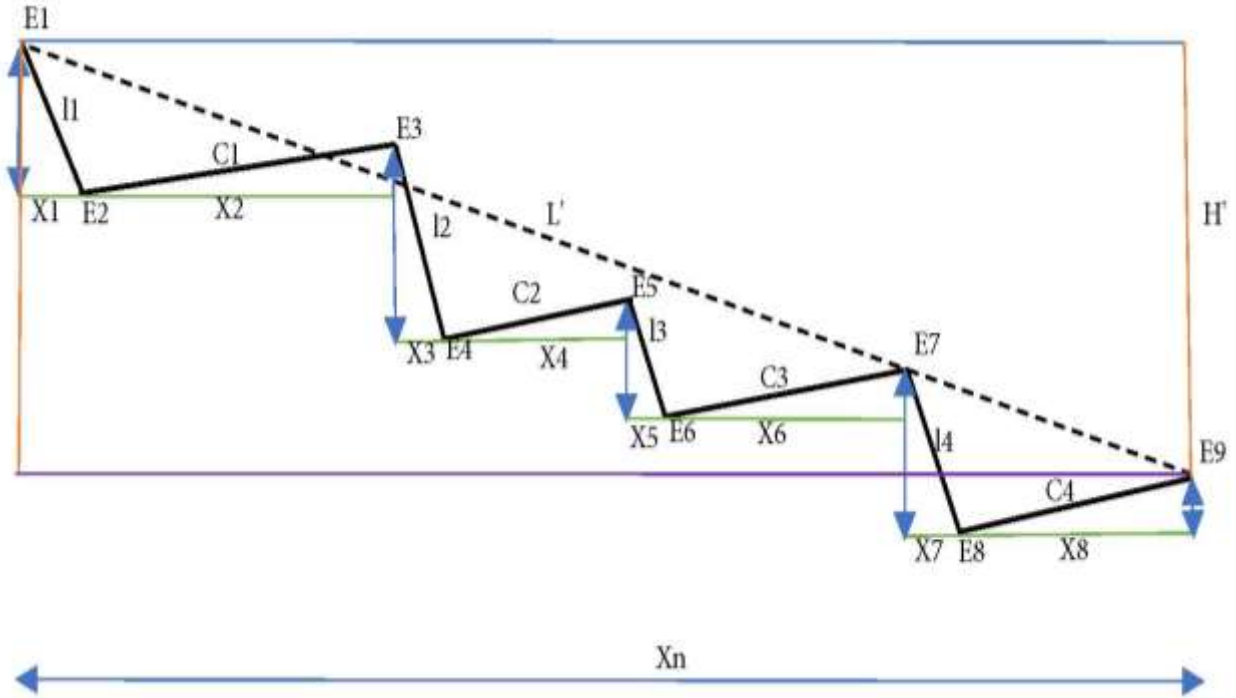


Figure 3.2.6.3 1: The measurement of land availability, Source: authors hand writing

To compare land availability for agricultural practice before and after terracing, I measured and calculated the following:

According to the figure above, I measured:

- Cultivable land length from the first plot to the fourth one: ($C_1 \rightarrow C_4$)
- Elevation for each point ($E_1 \rightarrow E_9$) which is used to compute height (H) from ($H_1 \rightarrow H_8$)
- Slope length for each terrace (l) from ($l_1 \rightarrow l_2$)

I computed also the following:

- $X_n = \sum x_i$
- $H' = E_1 - E_9$
- Original land before terracing $L' = \sqrt{(H'^2 + X_n^2)}$
- Total cultivated land after terracing ($C_n = \sum C_i$)

After calculating the original land named as L' and compare it with Cultivable land after terracing named as C_n , I can be able to conclude.

If $L' > C_n \rightarrow$ loss of land

If $L' < C_n \rightarrow$ gain of land

If $L' = C_n \rightarrow$ no gain and no loss of land, to mean before and after terracing the land remain the same.

This approach provided a comprehensive comparison of land availability on terraced versus non-terraced agricultural lands highlighting the effects of terracing as a soil erosion control measure.

3.2.7. Data Analysis, Interpretation and Presentation.

To complete this study properly, it was necessary to analyze the data collected in order to test the hypothesis and answer of respective research questions. These parts comprise the analysis, presentation and interpretation of the findings. The analysis and interpretation of data carried out in two phases.

The first part was based on the results of land availability for agricultural practices on terraced and non-terraced land coupled with visual assessment to analyze the rate of soil erosion on terraced compared to non-terraced agricultural land through field visit, observation and measurements.

The second part was based on the results of interviewer is the qualitative interpretation and to accomplish this analysis for better understanding excel calculation was used and the findings of the study was presented in tables, figures and charts.

3.2.8. Validity and Reliability of research instruments

The validity of my research is described as the degree to which a research study measures what it intends to do and its reliability is a measure of how well the study actually measures what it is supposed to measure.

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.

3.2.9. Ethical Consideration of the Study

My research had the authorization for data collection from University of Rwanda (A TO WHOM IT MAY CONCERN) to be addressed everywhere to find required data, this has been presented to Gicumbi district through their email and the district has been received it and allowed me to do my study as well.

When I reached to the sectors for the first visit, I find sector agronomist aware and happy for the great work I am doing in that region, and it is shown by being with me many times during the site visits so as to be trusted by the farmers on their field. The main purpose is to avoid going into unanticipated ethical circumstances in the respective sites. This became useful in assessing all specific objectives of my research study especially the third one which is comparing land availability for agricultural practice before and after terracing as it involves measurements as well as in assessing farmers' perception on benefits and challenges of terracing as a soil erosion control.

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. The study also maintained confidentiality of the 100 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 RESULT AND DISCUSSION

4.0. Introduction

This fourth chapter presents the photos to be used in visual assessment of rate of soil erosion on terraced and non- terraced land; it also presents tables showing farmers' perception or answers for the questionnaire regarding the benefits and challenges of terracing for soil erosion control by using excel calculation as well as detailed findings on land availability for agricultural practice on terraced land for erosion control and non- terraced land and discussion for each and every result found.

4.1. Visual assessment of the rate of soil erosion on terraced and non-terraced land

4.1.1. Terraced land

The findings provided by visual assessment on rate of soil erosion on terraced land through different field visit were presented in different criteria that are following. After examining the signs of erosion such as small rills, or minor gully formation the finding was presented in the following photos;



Figure 4.1.1 1: A terraced land showing that land appears more stable and less compacted which allow maximum water infiltration, Source: field data 2024

Terraced land is designed to reduce the velocity of water flow and enhance water infiltration which helps in combating soil erosion. The following are key point used to explain and discuss how stable and less compacted soil contributes to maximum infiltration a sign erosion control.

- **Decreased runoff velocity:** By reducing the rate at which water moves across a slope, terraces allow water to seep in more slowly and prevent erosion from rapid runoff.
- **Increasing water absorption:** Terracing reduces surface runoff and increases moisture retention by creating flat areas where water can pool and gradually absorb into soil.
- **Less soil compaction:** Because the terracing process includes releasing the soil, terraced fields typically have less compacted soil and larger holes in less compacted soil allow more water infiltration.
- **Better soil structure:** adding organic matter and preserving soil structure are common aspects of terracing which enhances water-holding capacity and infiltration rates even more.

By promoting these conditions with terrace making, terraced lands not only reduces soil erosion but also improves water management and agricultural productivity.



Figure 4.1.1 2: A terraced land showing healthy and dense vegetation a result of a well-protected area against erosion, Source: field data 2024

Growth of vegetation: Terraces frequently encourages better vegetation cover which helps to further stabilize the soil. With their roots, plants bind the soil together and can improve the soil's capacity to hold water

In conclusion, terracing contributes to increased infiltration rates and soil stability both of which lower soil erosion and increase land productivity.

4.1.2. Non- terraced land

The findings provided by visual assessment of the rate of soil erosion on a non-terraced land were presented and examined with the help of photo as follows:



*Figure 4.1.2 1:: A non-terraced more compacted and crusted soil which is the sign of erosion,
Source: field data 2024*

In non-terraced ground, exposed roots and compacted, crusted soil are obvious signs of erosion.

- **Compacted soil:** the removal of topsoil diminishes the soil capacity to absorb water which frequently leads to erosion. Rain water runs more quickly as a result which compact the soil and because compacted soil has less pore space, it can't contain as much as air which stunts plants growth.
- **Crusted earth:** rain drop impact breaks down the earth's surface scattering soil particles that eventually settle back down to form a thick coating. Erosion is made worse by this cracking which decrease water infiltration and increase runoff. Additionally, it hinders the germination of seeds and establishment of young plants.
- **Exposed roots:** soil erosion is the direct cause of roots that are visible at the surface. The roots that were previously buried become when wind or water removes the top layer of the soil. In addition to signaling soil loss, this weakens plants increasing their susceptibility to stress and decreasing their stability in the ground.

4.1.3. Comparison of rate of soil erosion on terraced and non-terraced agricultural land by visual assessment.

According to the result presented and described with the help of photos above here is the finding's discussion:

1. Effectiveness

Terracing is generally more effective at controlling soil erosion especially on steep slopes of Gicumbi district, Mutete sector due to its physical barriers.

Non terracing methods can be effective also but it might require a combination of techniques to match the efficacy of terracing.

2. Cost and labor

Non- terracing methods usually have lower initial costs and are less labor- intensive compared to the construction and maintenance of terraces. Disputing terracing's more labor intensive and high initial cost as well as maintenance cost, it offers significantly long-term benefits that make it a worthy while investment for sustainable agriculture in the following way:

Control of soil erosion: by reducing the slope into smaller, easier to manage segments, terracing is a very effective way to reduce erosion. This lessens the amount of top soil lost by enabling more water to permeate the soil and slowing down water runoff. Better crop yields, healthier soil and decreased need soil replenishment over time result from this which can more than balance the initial financial and labor outlays.

Water conservation: by forming level platforms that catch and hold rainfall terraces aid in the conservation of water, this is especially helpful in places where rain fall patterns are erratic. Increased water retention guarantees a steadier supply of water for crops lowering the need for further irrigation and supporting farming during dry spells.

Increased agricultural productivity: Terracing improves soil fertility and structure by reducing soil erosion and streamlining water management, Crop yields become more stable and agricultural production rises as the result. Terrace building labor and early expenses may be offset over time by improved economic returns brought about by increased productivity.

In summary, terracing is a highly important strategy for sustainable agriculture despite its high upfront costs and labor need over time, it can save water, preserve soil and boost output.

3. Suitability

Terracing is more suitable for steep and highly erodible lands while non-terracing methods can be applied to a broader range of landscapes including gently sloping areas.

Decrease in runoff velocity: Terracing lowers the energy available to erode soil by slowing down the velocity of water runoff on slopes. Terracing reduces surface runoff by increasing the amount of water that can permeate the soil through smaller, more controllable pieces of the slope.

Enhanced soil water retention: by forming level patches where water can collect and percolate into the earth, terracing enhances soil water retention which improves the soil's moisture content and lessens erosion, both of which are beneficial to crop growth.

In conclusion the specific condition of the area, the severity of erosion, available resources and long-term sustainable goals in controlling soil erosion in Mutete sector, terracing is a best soil erosion control measure applied and the visual assessment of soil erosion rates clearly indicates that terraced lands have lower erosion rates compared to non-terraced lands. This is consistent with the principles of terracing which aim to slow down water runoff and increase water infiltration thereby reducing soil displacement.

4.2. Farmers' perception regarding the benefits and challenges of terracing for soil erosion control

The tables below contain information from 100 respondents of my study.

They are grouped into 5 sections which are Demographic information, awareness and knowledge, perception on terracing as a soil erosion control, perception on non-terracing as a soil erosion control and comparative perception of both and general opinions. Each section has its own table and its meaningful explanations.

Table 4.2 1: Demographic information

1.Age	Under 20	0	0
	20-30	17	17%
	31-40	28	28%
	41-50	30	30%
	51-60	12	12%
	Over 60	13	13%
2.Gender	Female	63	63%
	Male	37	37%
3.Educational level	University	7	7%
	Secondary	12	12%
	Primary	51	51%
	No formal education	30	30%
4.Season living in the location	>one season	1	1%
	1 season	1	1%
	2 seasons	6	6%
	<2 season	92	92%
5.Size of the farm	>1acre	41	41%
	1-5 acres	21	21%
	6-10 acres	15	14%
	11-20 acres	13	13%
	<20acres	10	10%
6.Years of farming	>1year	8	8%
	1-5 years	33	33%
	6-10 years	9	9%

	11-20 years	29	29%
	<20 years	21	21%
7. Primarily crops grown in the areas	Grains	20	20%
	Vegetables	1	1%
	Fruits	0	0
	Mixed farming	77	77%
	Other	2	2%

According to the result presented in the table above, in 100 respondent of my survey the key variables of this section named as demographic information was the range of age of the respondent, gender, education level, season he or she is living in the location, size of his or her farm, years of farming, as well as the primary crops grown in the areas.

As the result illustrated the range of age which occupy high percentage was (42-50) this means that in that range of age people are mostly engaged in agricultural practices. it is also found that mostly male occupy the high ration than female in doing agricultural practices.

About the education level, the portion that occupy high percentage was primary education which means that even though there some elements that exceed this education level and others that do not have any formal education most people in the area that practice agriculture have primary level education.

About the season he or she held in the areas was also asked to know if the respondent is truly aware of the history of erosion and erosion control measures at all. In 100 respondents of my study about 92% of respondent has been living in the area more than two seasons which means that they are aware of all information regarding the issue of erosion and erosion control measures.

About the years of farming and size of the farm as well as the primary crops grown in the areas it is found that most respondent has less that on acre size of the farm as this is presented with a large number of percentages regarding other variables, also most of respondent have about 5 years of farming and the primary crop grown in the location has been found as mixed farming cropping type.

Table 4.2 2: Awareness and knowledge

8. Being aware of soil erosion	Yes	93	93%
	No	7	7%
9. Rate of knowledge on soil erosion	Very knowledgeable	8	8%
	Somewhat	32	32%
	Neutral	27	27%
	Not very knowledgeable	32	32%
	Not knowledgeable at all	1	1%
10. Do you receive Trainings on erosion control methods	Yes	9	9%
	No	91	91%
11. Learning methods	Formal training	7	7%
	Information sources (friends, family)	92	92%
	Government programs	0	0
	Online services	1	1%
	Other	0	0
12. Access to resources (manuals, workshop) on erosion	Yes	10	10%
	No	90	90%

According to the result presented in the table 4.2.2. which is awareness and knowledge of the respondent, it is found that 93% of respondent are aware of soil erosion, the rate of knowledge on soil erosion is not good to mean they are not knowledgeable on 32% and 92% of learning methods was from sources of information (friends, family).

91% of respondent present that there is no training received on soil erosion control methods to mean the sources of information is friends and family 92% which is informal to mean there are also no trainings provided for farmers and no access to resources like workshops or manual.

Table 4.2 3: Perception on terracing as a soil erosion control

13.Do you use terrace on your farm?	Yes	61	61%
	No	39	39%
14. Terracing effectiveness on erosion control	Very effective	39	39%
	Somewhat effective	47	47%
	Neutral	14	14%
	Not very effective	0	0
	Not effective at all	0	0
15.Cost effectiveness of terracing	Very cost effective	29	29%
	Somewhatcost-effective	43	43%
	Neutral	23	23%
	Not very cost effective	5	5%
	Not very cost effective at all	0	0
16.Terracing labor intensive comparing to other methods	Much more labor intensive	15	15%
	Somewhat labor intensive	57	57%
	About the same	15	15%
	Less labor intensive	13	13%
	Much less labor intensive.	15	15%
17.Terracing improves crop yield	Strongly agree	33	33%
	Agree	39	39%
	Neutral	27	27%
	Disagree	1	1%
	Strongly disagree	0	0
18.Sources of funds implement effective terraces	Government	82	82%
	Non-government	18	18%
	Others	0	0
	None	0	0
19.Sustainability of terraces for long term.	Very sustainable	18	18%
	Somewhat sustainable	37	37%

	Neutral	30	30%
	Not very sustainable	15	15%
	Not sustainable at all	0	0
20. Main challenges of terraces adaptation	High initial cost	25	25%
	Maintenance	57	57%
	Lack of knowledge	18	18%
	Labor requirements	0	0
	Others (specify)	0	0
21. Terracing side effect observation	Yes	92	92%
	No	8	8
22. Will you recommend terracing to other farmers	Yes	98	98%
	No	2	2%
23. Terracing impacts on biodiversity	Positively	12	12%
	Negatively	14	14%
	No impact	23	23%
	Unsure	51	51%

According to the result presented 4.2.4. which is named as perception on terracing as a soil erosion control, 61% of 100 respondent use terracing as a soil erosion control measure on their farm, including those that do not use terracing but who are aware of terracing as a soil erosion control the survey results presented above indicates that terracing is widely adopted by 61% of respondent as a soil erosion control measure, reflecting its perceived value in agricultural practices. The high percentage of respondents who recognize its effectiveness in controlling erosion that are 47% (somewhat effective) suggest that terracing is considered as a reliable method for soil conservation even though many farmers are not effectively aware of this long-term benefit.

However, respondent also highlight some challenges associated with terracing that are cost effectiveness and labor intensive as represented above by their corresponding percentage which may influence broader adoption and sustainability of this practice.

While some respondent found terracing to be cost effective 47% somewhat effective others may have encountered barriers related to the initial investment or ongoing maintenance costs which could be a limiting factor for wide implementation especially for small hold farmers.

Additionally, the positive impacts of terracing on crop yield are a crucial factor that encourages its adoption. The perception that terracing improves crop yield Suggest that despite all challenges the long-term benefits of increased agricultural productivity and reduce soil erosion outweigh the initial cost and the labor intensive.

The overwhelming majority of farmers 82% believe that the government is primarily the source of funding for terracing which indicates a strong reliance on governmental support for such initiatives which might also suggest limited access to other funding sources. Farmers are uncertain about terracing impact on biodiversity due to lack of information, experience or visible evidence linking terracing directly to biodiversity outcomes and despite all negative impacts of terracing but recognizing its long-term benefits they would recommend terracing to others even though they need more studies on ecological effects of terracing and how to face it.

Table 4.2 4: perception on non-terracing as a soil erosion control

24.Using non-terracing methods	Yes	39	39%
	No	61	61%
25. Effectiveness in using non-terracing methods in erosion control	Very effective	1	1%
	Somewhat effective	51	51%
	Neutral	0	0
	Not very effective	51	51%
	Not effective at all	7	7%
26. Cost-effectiveness in using non-terracing methods compared to terracing	Very cost effective	0	0
	Somewhat cost effective	23	23%
	Neutral	14	14%
	Not very cost effective	48	48%
	Not cost effective at all	15	15%
	Much more labor intensive	0	0

27. Labor intensive in adoption of non-terracing compared to terracing	Somewhat more labor intensive	9	9%
	About the same	19	19%
	Less labor intensive	49	49%
	Much less labor intensive	23	23%
28. non-terracing improve crop yield	Strongly agree	0	0
	Agree	16	16%
	Neutral	26	26%
	Disagree	50	50%
	Strongly disagree	8	8%
29.Sustainability in using non-terracing methods for long-term.	Very sustainable	1	1%
	Somewhat sustainable	14	14%
	Neutral	0	0
	Not very sustainable	71	71%
	Not sustainable at all	14	14%
30.Main challenges you face in adoption of non-terracing.	High initial cost	7	7%
	Maintenance	50	50%
	Lack of knowledge	29	29%
	Labor requirements	13	13%
	Others(specify)	1	1%
31.Any side effects observed while using non-terracing	Yes	34	34%
	No	66	66%
32. Will you recommend non-terracing to other farmers	Yes	17	17%
	No	83	83%
33.non-terracingimpacts on biodiversity.	Positively	0	0
	Negatively	1	1%
	No impact	45	45%
	Unsure	54	54%

The survey reveals a mixed perception of non -terracing methods for soil erosion control among farmers while 39% have adopted this method. Its adoption is hindered by different concerns that are maintenance, cost effectiveness, labor intensity, impacts on biodiversity even though

percentages are different as presented in the table 4.2.4. Moreover, the lack of awareness regarding its impacts on biodiversity points to a need for greater education and extension services to promote practices that balance productivity with environmental stewardship. Addressing these challenges could lead to more informed decision making by farmers potentially increasing the methods adoption and enhancing its long-term sustainability.

Table 4.2 5: Comparative perception and general opinions.

34.Method found more effective in erosion control	Terracing	100	100%
	Non-terracing	0	0
	Both equally	0	0
	Neither	0	0
35.Method found more cost effective	Terracing	100	100%
	Non-terracing	0	0
	Both equally	0	0
	Neither	0	0
36.More labor intensive	Terracing	91	91%
	Non-terracing	9	9%
	Both equally	0	0
	Neither	0	0
37.Greater positive impact in crop yield	Terracing	100	100%
	Non-terracing	0	0
	Both equally	0	0
	Neither	0	0
38.More sustainable in long term	Terracing	99	99%
	Non-terracing	1	1%
	Both equally	0	0
	Neither	0	0
39.More practical for your farm size and type	Terracing	64	64%
	Non-terracing	19	19%
	Both equally	17	17%

	Neither	0	0
40.Any issue faced in shifting from one method to other	Yes	3	3%
	No	97	97%
41.Do you receive any government support for erosion control methods	Yes	56	56%
	No	44	44%
42.Would you like to receive more information or training on erosion control methods	Yes	51	51%
	No	49	49%
43.Do you collaborate with farmers to implement erosion control measures	Yes	83	83%
	No	17	17%
44.How important is soil erosion control to the overall success of your farm	Very important	32	32%
	Somewhat important	22	22%
	Neutral	30	30%
	Not very important	16	16%
	Not important at all	0	0
45.How do you stay updated on new erosion control methods	Training programs	0	0
	Online services	3	3%
	Agricultural extension services	83	83%
	Farmer networks	14	14%
	Other (please specify)	0	0
46.How satisfied are you with your current erosion control	Very satisfied	10	10%
	Satisfied	35	35%
	Neutral	19	19%
	Dissatisfied	36	36%
	very dissatisfied	0	0
47.What are main sources of information on erosion control	Government programs	42	42%
	Non-government	1	1%
	Fellow farmers	55	55%
	Internet	2	2%
	Strongly agree	25	25%

48.Do you think more research is needed on erosion control methods	Agree	33	33%
	Neutral	15	15%
	Disagree	27	27%
	Strongly disagree	0	0
49.You participate in community program focused on erosion control	Yes	57	57%
	No	43	43%
50.Any challenges noticed in soil quality since implementing erosion control measures	Improved	22	22%
	No change	9	9%
	Worsened	61	61%
	Unsure	8	8%
51.Do you think erosion control measures have a significant impact on the environment	Strongly agree	10	10%
	Agree	31	31%
	Neutral	10	10%
	Disagree	41	41%
	Strongly disagree	8	8%
52.What do you think is the most critical factor for successful erosion control	Cost	9	9%
	Knowledge	37	37%
	Labor availability	40	40%
	Environmental conditions	14	14%
	Others(specify)	0	0

Farmers' perception reflects a recognition of the benefits of terracing such as increased soil moisture retention improving soil structure and high crop yields compared to non-terracing methods as it is illustrated in the tables above.

However, challenges such as the high initial cost labor and financial investments required for terrace construction and ongoing maintenance that are significant barriers to widespread adoption and these challenges highlight the need for targeted support and resources to encourage more farmers to implement terracing.

Terracing and non-terracing methods of soil erosion control offer distinct advantages and challenges when compared across various variables as illustrated in the table 4.2.5.

Terracing which involve the construction of stepped platforms on slope land is widely recognized for its effectiveness in reducing soil erosion. This method physically slows down water runoff which helps in reducing soil loss and improving water infiltration.

As a result, terracing can lead to a significant increase in crop yield particularly in hilly areas like Mutete sector, Gicumbi district where soil erosion is a major issue.

The higher crop yield is attributed to improved soil fertility and moisture retention. However, terracing is labor intensive requiring considerable workforce for the initial construction and ongoing maintenance but in many cases including in the study area government subsidize these costs as part of broader agricultural or environmental programs making it more accessible to farmers in land consolidation programs. And over time this cost issue is outweighed by increased crop yield.

In contrast, non-terracing methods such as contour plowing, strip cropping and cover cropping are generally less labor intensive and have low initial costs. Referring to this this method can be flexibly adopted to different terrain and crops. However their effectiveness in controlling soil erosion is often lower compared to terracing particularly in the areas with steep slopes. While non-terracing methods can improve crop yield to some extent they may not provide the same level of increase as terracing.

Moreover, the environmental impacts of non-terracing methods can vary, some practices like cover cropping can improve soil health and biodiversity while others can have less pronounced environmental benefits.

In addition, improper design or maintenance can lead to terrace failure which can cause severe erosion.

The last question in the survey (53) was an open question regarding to any comments, suggestion regarding erosion control methods.

Most of respondent return to the same issues which includes the following points:

- Diversification of different erosion control measure to the community.
- To find how farmers can be helped in food security at initial stage of adoption of terracing as on this stage people get farming due to low crop yield.
- Making them aware of the time of terracing before because sometimes government plans to remove existing crops from people's fields to prepare the land for building terraces likely as part of a soil erosion control or agricultural improvement project.
- Make sure that there will be conflict between farmers that are adopting that form of land consolidation method.
- Most farmers are not aware of ecological impact of using terracing and they recommend to get this part of information.

4.3. Comparing land availability for agricultural practice on a terraced and non-terraced land.

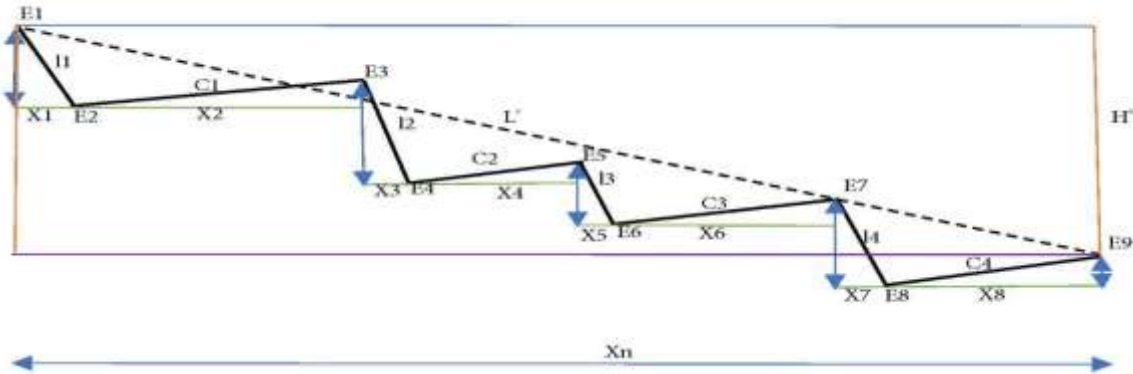
This objective was tested to see if terracing increase or decrease land availability for agricultural practice on terraced and non-terraced land and it involves several steps.

4.3.1. Physical measurements



Figure 4.3.1 1: showing measurement of slope and cultivated land of a terrace, Source: field data 2024

By using a measuring tape, I have measured the plot dimensions including slope, and cultivated land.



According to the sketch above, I calculated X_n and H' so as to calculate the value of L'

C_n (cultivated land) also is calculated so as to be compared to L' (original land).

E is the Elevation; each point has its own elevation.

$E_1=6601\text{ft}$

$E_2=6595\text{ft}$

$E_3=6597\text{ft}$

$E_4=6588\text{ft}$

$E_5=6590\text{ft}$

$E_6=6584\text{ft}$

$E_7=6586\text{ft}$

$E_8=6580\text{ft}$

$E_9=6582\text{ft}$

C is the cultivable land of terraces from the first to the fourth plot of the sample.

$$C1=5.1m$$

$$C2=3.8m$$

$$C3=4.31m$$

$$C4=4.86m$$

l is representing slope of terraces

$$l1=2.10m$$

$$l2=2.90m$$

$$l3=1.90m$$

$$l4=2.5m$$

$$H_1 = E1 - E2 \rightarrow H_1 = 6601ft - 6595ft = 6ft$$

$$1foot = 0.3048m$$

$$\text{Then } H_1 = 6 \times 0.3048 = 1.8288m$$

Having H_1 it is possible to calculate X_1

$$\text{Then } X_1 = \sqrt{(l1^2 - H_1^2)} \rightarrow \sqrt{(2.1^2 - 1.8288^2)} = 5.063m$$

$$H_2 = E3 - E2 \rightarrow H_2 = 6597ft - 6595ft = 2ft$$

$$H_2 = 2 \times 0.3048m = 0.6096m$$

$$\text{Then } X_2 = \sqrt{(C1^2 - H_2^2)} \rightarrow \sqrt{(5.1^2 - 0.6096^2)} = 5.063m$$

$$H_3 = E3 - E4 \rightarrow 6597ft - 6588ft = 9ft$$

$$H3 = 9 \times 0.3048\text{m} = 2.7432\text{m}$$

$$\text{Then } X3 = \sqrt{(12^2 - H3^2)} \rightarrow \sqrt{(2.9^2 - 2.7432^2)} = 0.941\text{m}$$

$$H4 = E5 - E4 \rightarrow 6590\text{ft} - 6588\text{ft} = 2\text{ft}$$

$$H4 = 2 \times 0.3048\text{m} = 0.6096\text{m}$$

$$\text{Then } X4 = \sqrt{(C2^2 - H4^2)} \rightarrow \sqrt{(3.80^2 - 0.6096^2)} = 3.75\text{m}$$

$$H5 = E5 - E6 \rightarrow 6590\text{ft} - 6584\text{ft} = 6\text{ft}$$

$$H5 = 6 \times 0.3048\text{m} = 1.8288\text{m}$$

$$\text{Then } X5 = \sqrt{(13^2 - H5^2)} \rightarrow \sqrt{(1.9^2 - 1.8288^2)} = 0.515\text{m}$$

$$H6 = E7 - E6 \rightarrow 6586\text{ft} - 6584\text{ft} = 2\text{ft}$$

$$H6 = 2 \times 0.3048\text{m} = 0.6096\text{m}$$

$$\text{Then } X6 = \sqrt{(C3^2 - H6^2)} \rightarrow \sqrt{(4.31^2 - 0.6096^2)} = 4.26\text{m}$$

$$H7 = E7 - E8 \rightarrow 6586\text{ft} - 6580\text{ft} = 6\text{ft}$$

$$H7 = 6 \times 0.3048\text{m} = 1.8288\text{m}$$

$$\text{Then } X7 = \sqrt{(14^2 - H7^2)} \rightarrow \sqrt{(2.5^2 - 1.8288^2)} = 1.70\text{m}$$

$$H8 = E9 - E8 \rightarrow 6582\text{ft} - 6580\text{ft} = 2\text{ft}$$

$$H8 = 2 \times 0.3048\text{m} = 0.6096\text{m}$$

$$\text{Then } X8 = \sqrt{(C4^2 - H8^2)} \rightarrow \sqrt{(4.86^2 - 0.6096^2)} = 4.82\text{m}$$

$$Xn = X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8$$

$$Xn = 1.033\text{m} + 5.063\text{m} + 0.941\text{m} + 3.75\text{m} + 0.515\text{m} + 4.26\text{m} + 1.70\text{m} + 4.82\text{m}$$

$$\mathbf{X_n=22.082m}$$

L'(Original land)

$$L'=\sqrt{(H'^2+X_n^2)}$$

$$H'=E1-E9$$

$$H'=6601\text{ft}-6582\text{ft}=19\text{ft}$$

$$H'=19\times 0.3048\text{m}= 5.7912\text{m}$$

$$L'=\sqrt{(H'^2+X_n^2)}$$

$$L'=\sqrt{5.7912^2+22.082^2}$$

L' = 22.83m (Original land before terracing)

$$C_n=C1+C2+C3+C4$$

$$C_n=5.10\text{m}+3.80\text{m}+4.31\text{m}+4.86\text{m}$$

$$\mathbf{C_n=18.07m}$$

Comparing C_n and L'

L' is equal 22.83m and C_n is 18.07m

So, L'>C_n we have loss of land

Having the original land length and the cultivated land length after terracing I was able to calculate percentage of lost land;

$$\text{Percentage of lost land}=\frac{22.84-18.07}{22.84}\times 100$$

$$\text{Percentage of lost land}=\frac{4.77}{22.84}\times 100 \approx 20.88\%$$

The result indicates that approximately 20.88% of the original land length was lost due to terracing, in assessment of land availability for agricultural practices shows that while terracing can initially reduce usable land area due to space taken up by terraces, the long –term benefits include improved soil retention and crop yields.

This trade- off is generally acceptable to farmers who prioritize sustainable land use and long-term productivity.

Over all, the study’s results validate the positive impact of terracing on soil erosion and agricultural productivity. The challenges identified by farmers particularly the costs and labor, associated with terracing suggest that additional support measures are necessary to enhance adoption rates which includes financial incentives, technical assistance and educational programs to equip farmers with knowledge and resources needed to implement and maintain terraces effectively. Farmers also mention the Losses of land for agricultural practices as a hindrance of less adoption of terraces; after testing this hypothesis the result confirm it.

The findings emphasize the critical role of terracing in sustainable land management and the importance of integrated approaches that address both the benefits and challenges of this practice by promoting terracing and providing the necessary support systems, policymakers and agricultural stakeholders can contribute to the broader goals of soil conservation, sustainable agriculture and food security.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study analyzed the effects of terracing on soil erosion control in Gicumbi district's Mutete sector, Rwanda. The objectives were to assess soil erosion rates on terraced and non-terraced agricultural lands, understand farmers' perceptions of terracing's benefits and challenges, and compare land availability for agriculture between terraced and non-terraced lands.

The findings clearly indicate that terracing significantly reduces soil erosion. Field observations and photographic evidence show that terraced lands are far more effective in controlling erosion compared to non-terraced areas. Farmers acknowledge that terracing, when correctly implemented and maintained, is a powerful tool for soil conservation, particularly when aligned with local socio-cultural practices. The survey data gathered from farmers revealed the observable benefits of terracing both on-site (reduced soil loss) and off-site (improved water quality due to less sediment runoff).

However, the study also highlights some drawbacks. About 20% of agricultural land is lost during the terracing process, primarily due to the physical space terraces occupy. This leads to an initial decrease in crop yields, compounded by reduced soil fertility and depth immediately after terrace construction. Despite these short-term losses, terracing encourages long-term benefits by stabilizing soil fertility and preventing further erosion, which, in turn, reduces downstream water pollution from sediment transport.

Farmers' ability to invest in terracing was limited by a lack of social, human, and financial capital. Terracing is labor-intensive, costly, and technically complex, requiring significant training for effective implementation. Additionally, the maintenance of terraces poses challenges. Common issues such as livestock damaging terrace structures, unchecked weed growth, unnoticed structural breaks, and poor crop management reduce the effectiveness of soil conservation efforts. These challenges hinder the ability to maintain terraces and sustain permanent agriculture on steep slopes, as well as land consolidation and intensive land use.

The study confirms that terracing is an effective soil erosion control method, significantly reducing soil loss compared to non-terraced agricultural lands. Moreover, terraced lands demonstrate increased agricultural sustainability over time. While farmers recognize the long-term benefits of terracing, such as soil preservation and higher crop yields, they also face considerable challenges, especially with the high initial labor and financial investments required for terrace construction and maintenance. Addressing these challenges through enhanced training, support, and resource mobilization will be critical to improving the adoption and effectiveness of terracing as a sustainable land management practice.

The following recommendations could be put forward to ensure that the different technical requirements are properly applied through implementation:

5.2.1. Recommendation to the government of Rwanda

- **Develop Comprehensive Farmer Training Programs:** The government should implement training programs focused on the benefits and proper techniques of terracing. These could include workshops, demonstration plots, and extension services aimed at ensuring effective and widespread adoption. In addition, the government should provide incentives, such as financial subsidies, access to credit, and necessary materials and equipment, to encourage farmers to adopt terracing. These programs should also raise awareness of the impacts of terracing on biodiversity.
- **Integrate Terracing into Climate Resilience Strategies:** Terracing should be highlighted as a critical tool in enhancing climate resilience, particularly in mitigating the impacts of extreme weather events on agriculture. The government should integrate terracing into national climate adaptation strategies and conduct comprehensive socio-economic assessments to understand how terracing affects livelihoods, food security, and community well-being. These insights can be used to refine and improve existing terracing programs.
- **Establish Robust Monitoring and Evaluation Frameworks:** The government should develop a robust monitoring and evaluation framework to assess the effectiveness of terracing initiatives. This framework should include regular soil erosion assessments, soil fertility tests, and crop yield monitoring to gather essential data. Such evaluations will help adjust strategies as needed. Furthermore, the government should support continued

research into innovative, cost-effective terracing techniques and materials, fostering collaboration with universities and research institutions to drive these innovations.

- **Raise Public Awareness on the Benefits of Terracing:** Public awareness campaigns should be initiated to educate farmers and communities about the benefits of terracing for soil erosion control and environmental health. Media campaigns, community meetings, and school programs can be effective platforms for disseminating information. The government should also form partnerships with international organizations, NGOs, and the private sector to support terracing projects. These partnerships can provide additional funding, technical expertise, and resources to expand terracing efforts.
- **Enhance Technical Supervision for Terracing Projects:** Given the complexity of terracing, it is crucial to increase supervision of technicians during the implementation of terracing activities. Close oversight is essential to ensure the proper use of recommended criteria, such as vertical interval, which directly impacts the width of terraces. Ensuring accurate construction is vital for maximizing crop production, as terraces provide the planting areas for crops. Supervised implementation will help prevent errors that may reduce the effectiveness of the terraces in both soil erosion control and agricultural productivity.

5.2.2. Recommendation to future researchers

Future researchers can contribute to the fields of soil conservation, sustainable agriculture, and water resource management by addressing current gaps and expanding upon existing knowledge through the following recommendations:

- **Conduct Detailed Cost-Benefit Analyses:** Future studies should focus on conducting comprehensive cost-benefit analyses to evaluate the economic feasibility of terracing projects. This includes assessing the initial investment, maintenance costs, and economic returns from reduced soil erosion and increased crop yields, providing a clearer picture of terracing's financial viability.
- **Utilize Advanced Modeling and Simulation Techniques:** Employ advanced modeling tools and simulation techniques to predict soil erosion patterns and the long-term benefits of terracing. Incorporating climate models can help assess the impacts of terracing under

various future climatic scenarios, offering insights into how terracing might perform under changing environmental conditions.

- **Adopt a Multidisciplinary Approach:** Future research should integrate agronomy, soil science, hydrology, and socio-economic analysis to provide a comprehensive understanding of the diverse impacts of terracing. This multidisciplinary approach will offer a more holistic view of terracing's benefits and challenges across different sectors.
- **Emphasize Long-Term Studies:** Long-term studies are essential to capturing the sustained effects of terracing on soil erosion and agricultural productivity over several seasons or years. Researchers should also encourage comparative studies between terraced and non-terraced lands across various agroecological zones to better understand how terracing affects different environmental conditions.
- **Explore Technological Advancements:** Future research should explore the potential of technological advancements in terrace design, construction, and maintenance. Investigating how technology can optimize terracing practices could expand its application and make it more cost-effective and efficient for broader use in different regions.
- **Promote Educational Programs and Financial Support Mechanisms:** Based on existing findings, researchers should advocate for terracing as a key soil conservation practice. Educational programs and financial support mechanisms are critical to alleviating the initial costs for farmers. Future studies should examine the most effective ways to implement these initiatives and monitor their impact on terracing adoption.
- **Focus on Policy and Extension Services:** Researchers should recommend that policymakers and agricultural extension services focus on providing technical assistance and training to ensure the effective implementation and maintenance of terraces. Addressing technical challenges and enhancing support systems will help contribute to sustainable agriculture and improved food security in erosion-prone regions.

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Appendix

Appendix 1:

Master's student: NDAYISHIMIYE VIRGINIE

ANALYSIS OF THE EFFECT OF TERRACING. A CASE STUDY OF MUTETE SECTOR, GICUMBI DISTRICT, RWANDA

Questionnaire on assessment of effectiveness of terracing on erosion control

52. questions are designed to assess farmers' perceptions on the effectiveness of terrace (terracing) and non-terrace (non-terracing) methods on erosion control. Each question is accompanied by possible responses.

DEMOGRAPHIC INFORMATION

1. What is your age?
 - a. Under 20
 - b. 20-30
 - c. 31-40
 - d. 41-50
 - e. 51-60
 - f. Over 60
2. What is your gender?
 - a. Male
 - b. Female
 - c. Prefer not to say
3. What is your level of education
 - a. University
 - b. Secondary education
 - c. Primary education

- d. No formal education
- 4. How long have you been living in this area
 - a. less than one season
 - b. 1 season
 - c. 2 seasons
 - d. More than 3 seasons
- 5. What is the size of your farm?
 - a. Less than 1 acre
 - b. 1-5 acres
 - c. 6-10 acres
 - d. 11-20 acres
 - e. More than 20 acres
- 6. How long have you been farming?
 - a. Less than 1 year
 - b. 1-5 years
 - c. 6-10 years
 - d. 11-20 years
 - e. More than 20 years
- 7. What type of crops do you primarily grow?
 - a. Grains
 - b. Vegetables
 - c. Fruits
 - d. Mixed farming
 - e. Other (please specify)

AWARENESS AND KNOWLEDGE

8. Are you aware of soil erosion issues on your farm?
 - a. Yes
 - b. No
9. How would you rate your knowledge of erosion control methods?
 - a. Very knowledgeable
 - b. Somewhat knowledgeable
 - c. Neutral
 - d. Not very knowledgeable
 - e. Not knowledgeable at all
10. Have you received any training on erosion control methods?
 - a. Yes
 - b. No
11. How did you learn about erosion control methods?
 - a. Formal training
 - b. Informal sources (friends, family)
 - c. Government programs
 - d. Online resources
 - e. Other (please specify)
12. Do you have access to resources (manuals, workshops) on erosion control?
 - a. Yes
 - b. No

PERCEPTION ON TERRACING AS A SOIL EROSION CONTROL

13. Do you use terracing (terrace) methods on your farm?
 - a. Yes
 - b. No
14. How effective do you find terracing in controlling erosion?
 - a. Very effective
 - b. Somewhat effective

- c. Neutral
 - d. Not very effective
 - e. Not effective at all
15. How cost-effective is terracing for erosion control?
- a. Very cost-effective
 - b. Somewhat cost-effective
 - c. Neutral
 - d. Not very cost-effective
 - e. Not cost-effective at all
16. How labor-intensive is terracing compared to other methods?
- a. Much more labor-intensive
 - b. Somewhat more labor-intensive
 - c. About the same
 - d. Less labor-intensive
 - e. Much less labor-intensive
17. Do you believe terracing improves crop yield?
- a. Strongly agree
 - b. Agree
 - c. Neutral
 - d. Disagree
 - e. Strongly disagree
18. Do farmers get resources or support to implement effective terracing
- a. government
 - b. non-government
 - c. others
 - d. none
19. How sustainable do you find terracing for long-term use?
- a. Very sustainable
 - b. Somewhat sustainable
 - c. Neutral

- d. Not very sustainable
 - e. Not sustainable at all
20. What are the main challenges you face with terracing?
- a. High initial cost
 - b. Maintenance
 - c. Lack of knowledge
 - d. Labor requirements
 - e. Other (please specify)
21. Have you observed any side effects of using terracing?
- a. Yes (please specify)
 - b. No
22. Would you recommend terracing to other farmers?
- a. Yes
 - b. No
23. Do you think terracing impacts the biodiversity of your farm?
- a. Positively
 - b. Negatively
 - c. No impact
 - d. Unsure

PERCEPTION ON NON-TERRACING AS A SOIL EROSION CONTROL

24. Do you use non-terracing methods (e.g., cover crops, mulching) on your farm?
- a. Yes
 - b. No
25. How effective do you find non-terracing methods in controlling erosion?
- a. Very effective
 - b. Somewhat effective
 - c. Neutral
 - d. Not very effective
 - e. Not effective at all

26. How cost-effective are non-terracing methods for erosion control?
 - a. Very cost-effective
 - b. Somewhat cost-effective
 - c. Neutral
 - d. Not very cost-effective
 - e. Not cost-effective at all
27. How labor-intensive are non-terracing methods compared to terracing?
 - a. Much more labor-intensive
 - b. Somewhat more labor-intensive
 - c. About the same
 - d. Less labor-intensive
 - e. Much less labor-intensive
28. Do you believe non-terracing methods improve crop yield?
 - a. Strongly agree
 - b. Agree
 - c. Neutral
 - d. Disagree
 - e. Strongly disagree
29. How sustainable do you find non-terracing methods for long-term use?
 - a. Very sustainable
 - b. Somewhat sustainable
 - c. Neutral
 - d. Not very sustainable
 - e. Not sustainable at all
30. What are the main challenges you face with non-terracing methods?
 - a. High initial cost
 - b. Maintenance
 - c. Lack of knowledge
 - d. Labor requirements
 - e. Other (please specify)
31. Have you observed any side effects of using non-terracing methods?

- a. Yes (please specify)
 - b. No
32. Would you recommend non-terracing methods to other farmers?
- a. Yes
 - b. No
33. Do you think non-terracing methods impact the biodiversity of your farm?
- a. Positively
 - b. Negatively
 - c. No impact
 - d. Unsure

COMPARATIVE PERCEPTION AND GENERAL OPINIONS

34. Which method do you find more effective in controlling erosion?
- a. Terracing
 - b. Non-terracing
 - c. Both equally
 - d. Neither
35. Which method do you find more cost-effective?
- a. Terracing
 - b. Non-terracing
 - c. Both equally
 - d. Neither
36. Which method do you find more labor-intensive?
- a. Terracing
 - b. Non-terracing
 - c. Both equally
 - d. Neither
37. Which method do you believe has a greater positive impact on crop yield?
- a. Terracing
 - b. Non-terracing

- c. Both equally
 - d. Neither
38. Which method do you believe is more sustainable in the long term?
- a. Terracing
 - b. Non-terracing
 - c. Both equally
 - d. Neither
39. Which method do you think is more practical for your farm size and type?
- a. Terracing
 - b. Non-terracing
 - c. Both equally
 - d. Neither
40. Have you faced any issues when switching from one method to another?
- a. Yes (please specify)
 - b. No
41. Do you receive any governmental support for erosion control methods?
- a. Yes
 - b. No
42. Would you like to receive more information or training on erosion control methods?
- a. Yes
 - b. No
43. Do you collaborate with other farmers to implement erosion control measures?
- a. Yes
 - b. No
44. How important is soil erosion control to the overall success of your farm?
- a. Very important
 - b. Somewhat important
 - c. Neutral
 - d. Not very important
 - e. Not important at all
45. How do you stay updated on new erosion control methods?

- a. Workshops/training programs
 - b. Online resources
 - c. Agricultural extension services
 - d. Farmer networks
 - e. Other (please specify)
46. How satisfied are you with your current erosion control methods?
- a. Very satisfied
 - b. Satisfied
 - c. Neutral
 - d. Dissatisfied
 - e. Very dissatisfied
47. What are your main sources of information on erosion control?
- a. Government programs
 - b. Non-governmental organizations
 - c. Fellow farmers
 - d. Internet
 - e. Other (please specify)
48. Do you think more research is needed on erosion control methods?
- a. Strongly agree
 - b. Agree
 - c. Neutral
 - d. Disagree
 - e. Strongly disagree
49. Would you participate in a community program focused on erosion control?
- a. Yes
 - b. No
50. Have you noticed any changes in soil quality since implementing erosion control measures?
- a. Improved
 - b. No change
 - c. Worsened

- d. Unsure
51. Do you think erosion control measures have a significant impact on the environment?
- a. Strongly agree
 - b. Agree
 - c. Neutral
 - d. Disagree
 - e. Strongly disagree
52. What do you think is the most critical factor for successful erosion control?
- a. Cost
 - b. Knowledge/training
 - c. Labor availability
 - d. Environmental conditions
 - e. Other (please specify)
53. Do you have any additional comments or suggestions regarding erosion control methods?
