



COLLEGE OF SCIENCE AND TECHNOLOGY

SCHOOL OF ENGINEERING

DEPARTMENT OF CIVIL, ENVIRONMENTAL AND GEOMATIC ENGINEERING

P.O. Box: 3900 Kigali, Rwanda.

“IMPACT OF CLIMATE CHANGE ON IRRIGATION PROJECTS. CASE STUDY OF CYARUHOGO RICE PERIMETER”

A PROJECT REPORT

Submitted in partial fulfilment of the requirements for the award of

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

Submitted by

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UNIVERSITY of
RWANDA

**COLLEGE OF SCIENCE AND TECHNOLOGY
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DEPARTMENT OF CIVIL, ENVIRONMENTAL AND GEOMATIC ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that the Master's thesis entitled "Impacts of Climate Change on Irrigation Projects. Case Study of Cyaruhogo Rice Perimeter" is a record of original bonafide work done by Marie Claire USANASE (Reg. No. 220019825) in partial fulfillment of the requirement for the award of MSc Degree in Water Resources and Environmental Management at the University of Rwanda, College of Science and Technology during the Academic Year 2023-2024.

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This MSc Thesis was successfully defended and evaluated at the College of Science and Technology, on 29 August 2024

DECLARATION

I, **USANASE Marie Claire**, do hereby declare that this research project, being submitted to the University of Rwanda for the degree of **MASTER'S OF SCIENCE in Water Resources and Environmental Management**, is our original work and has not previously been submitted elsewhere. In addition, we do declare that a complete list of references have provided indicating all the sources of information quoted or cited.

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Signature:

DEDICATION

I dedicate this thesis to Almighty God, My husband, My Supervisors and classmates

ACKNOWLEDGEMENT

First and foremost, I would like to give thanks to Almighty God who always walked with me from the starting up to the end of this journey and before. Without the mercy, guidance, and protection of the Lord, this research would barely be a dream.

Special thanks to my supervisor **Associate Professor Felicien MAJORO** who has always been patient and encouraged me through the hardest time in my research. He helped me to do the best work kindly in each stage of my thesis with clear guidance.

ABSTRACT

Irrigation projects are important for food security; however, water requirements for sustainable irrigation may be affected by climate change. Climate change is projected to have significant impacts on agricultural production. Therefore, understanding the regional impacts of climate change on irrigation demand for crop production is important for watershed managers and agricultural producers to understand for effective water resources management. For irrigation project, the climate change affects it through the erosion, sedimentation in reservoir, flood, drought, etc. These impacts was be assessed in this research and measures were be taken for maintaining the irrigation system in Cyaruhogo wetland. The specific objectives like identifying the source of water for irrigation at Cyaruhogo wetland, assessing the cause of sedimentation in irrigation reservoir and Results analysis and discussion according to the laboratory tests were be used for achieving on the goal. To reach on objectives, interview were be conducted according to the prepared question for sample population in beneficiary area. The PH of water was be tested in laboratory to know if the irrigated water has acceptable PH for supporting crops. The PH of water in chemical analysis is 6.91 which is in acceptable limit, electrical conductivity is 374.4 μ s/cm and it is in range. The sediment has measured in laboratory and then the total sediment per year each dam is 13440tons, 11600tons and 13440 tons to Cyimpima, Bugugu and Gashara respectively. So the erosion control structure is needed to reduce the sediment enters in dam for maintain the capacity of water storage and keeping the product rises from Cyaruhogo wetland.

Key word: climate, climate change, irrigation system and effect of climate change on rice yield

List of Abbreviation

GDP: gross domestic product

IWU: irrigation water use

JICA: Japan International Cooperation Agency

PH: Potential of Hydrogen

REMA: Rwanda Environmental Management Authority

SSA: Sub-Saharan Africa

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1. INTRODUCTION

1.1. BACKGROUND

A difficult reality that affects many facets of life, including agriculture, which is highly reliant on the environment and natural resources, is climate change. Rice is the primary staple crop after wheat and is the source of 50% calories for the almost 50% population of the world, and its demand will increase by 28% in 2050 [1]. The primary sustainable food supply, agriculture, is greatly impacted by weather extremes and climate change, including temperature variations, erratic rainfall patterns, and a rise in the frequency of floods and droughts[2]. If global temperatures increase, the spatial and temporal variabilities of climate are also expected to increase. Globally, rainfall is projected to increase, but the locations and extent of desert areas are expected to change. Weather is expected to become more extreme and variable. Water requirements in arid areas are projected to increase. Planning is needed to mitigate through improved management strategies the likely adverse effects of climatic change on water supplies and on crop production.

Studies on the effects of climate change are essential since the amount of water needed for irrigation is heavily reliant on precipitation and possible evapotranspiration. One of the biggest environmental and economic issues the international community is currently experiencing is climate change, which has had a significant negative influence on the sustainability of irrigated agricultural expansion in recent decades[3].

The understanding of the effects of climate change as a result of human activities and influences is becoming accelerated from time to time. Climate change and its instability have many impacts on the hydrological cycle and, hence, on the world's water supply systems. This reality has been confirmed by the Intergovernmental Panel on Climate Change, and greenhouse gases have played a major role in global and regional climate change[4]. However, Reduced crop yields, increased water scarcity, an increase in the quantity and variety of pests (weeds, rodents, and insects), new plant diseases, a shift in the growing season, and a rise in the cost of agricultural production are some of the detrimental effects of climate change on the productivity of farming businesses [3].

Climate change, which will increase crop evapotranspiration, change the quantity of rainfall and rainfall patterns, and lead to greater variations in river runoff and groundwater recharge, will affect both rainfed and irrigated agriculture, but the integration of climate change into the planning and design of investments can considerably reduce the risks to the water infrastructure used for

agriculture [5]. Because a large portion of the population in Sub-Saharan Africa (SSA) depends on agriculture for a living, the region's agriculture sector is the most powerful economic sector in the world. Agricultural development is still the primary means of eradicating poverty in the region. However, because to its very nature, agriculture is heavily impacted by climatic variations, including changes in temperature, rainfall, sunshine, and drought[6].

Since agriculture is Rwanda's main industry, contributing 30% of the country's GDP in 2019 and employing 70% of the workforce, it is essential to the country's economic growth and efforts to reduce poverty. However, given the country's history of low rainfall, high temperatures in the east, and the effects of global climate change on rainfall distribution, water scarcity continues to be a major obstacle to agricultural productivity, particularly crop production[7].

Rwanda has a temperate tropical climate and two main rainy seasons (February–May; September–December) that determine planting and harvesting cycles. Rainfall varies geographically, with the East and Southeast receiving less precipitation (700–1100 mm annually) than the west and northwest (1300–1600 mm annually)[8]. Rwanda is challenged by climate variability, from changes in rainfall patterns to more extreme weather events.

In addition, there is an increase pressure on natural resources (such as water and land) due to population growth, intensification of agriculture, rapid urbanization and industrialization, leading to intensified competition between water users and reduction in water quality. These challenges need to be addressed by Rwanda's water governance institutions to ensure an equitable, sustainable and climate proof system of water allocation.

Irrigation in Rwanda began during the Belgian colonial rule in 1945 at Karongi (Kibuye), after the famine known as Ruzagayura (1943–44). An 8-km water channel was dug from Ntaruka towards Rubengera with its tributaries irrigating local people's farms. However, most farmers have not been able to take full advantage of the swamps in their natural state, since most swamps are frequently completely flooded and establishing drainage systems is too expensive. It is vitally important that Rwandan irrigation infrastructure be renovated and built [9]. In other hand, agriculture is directly affected by climatic conditions and changes, and it is essential to understand the impact of climate change on agricultural water resources for sustainable agriculture and to minimize the negative effects caused by such changes [10].

1.2. PROBLEM STATEMENT

Rwandan agriculture presents a strong dependence on rainfalls and vulnerability to climate shocks. The low-level use of water resources for irrigation makes agricultural production unpredictable from one season to another. The dry season which is characterized by high temperatures, low humidity, which causes watering holes and rivers to dry up, and low and unpredictable precipitation, resulting in little to no rainfall. Droughts and floods are common in tropical regions, including Rwanda in Cyaruhogo wetland, and are likely to be aggravated by climate change. Irrigation water came from groundwater, through springs or wells, surface water, through rivers, lakes, or reservoirs, or even other sources such as treated wastewater or desalinated water. As a result, climate changes will affect all resources of water for irrigation projects by declining the quantity of water needed and change the quality of water needed for irrigation. Consequently, assessing the effects of climate change on hydrological systems has become critical, this will affect the irrigation projects. In Rwanda, most studies conducted in irrigation sector focus on agricultural water distribution and performance of irrigation infrastructure, but they don't look on the impact climate change on irrigation projects used in irrigation to increase crop yield.

The PH of water and soil is the problem to the crops in the wetland. As the rainy changes seasonally, already it value changes too. The water in irrigation dams is from the rainfall flows through the canals to the reservoir. In this process the level of sediment increases, the storage capacity of dam reduces according to the debris from soil erosion. So the impact of climate is big issue to the irrigation project in agriculture field.

1.3. OBJECTIVE

1.3.1. General objective

The general objective of this MSc thesis is to investigate the impacts of climate change on rice irrigation project in Cyaruhogo marshland located in Rwamagana District.

1.3.2. Specific objectives

The study will be guided by the following specific objectives

1. To identify the key climate change factors that are affecting rice yield in the Cyaruhogo Rice Perimeter.
2. To assess the impact of climate change on rice yield in the Cyaruhogo Rice Perimeter.

3. To develop adaptation strategies to mitigate the impact of climate change on rice yield in the Cyaruhogo Rice Perimeter.
4. To investigate on Challenges and Barriers to Adaptation in mitigating the impact of climate change on rice yield in the Cyaruhogo Rice Perimeter

1.4. RESEARCH HYPOTHESIS

The changing climate conditions significantly affect the efficiency and sustainability of irrigation projects, leading to alterations in water availability, crop yields, and economic outcomes for agricultural communities. The effect of climate change will be identified by testing soil and water in dry and rainy season, the results will provide the clear how the change in climate cause impact on irrigation system.

1.5. RESEARCH QUESTIONS

At the end of this project we will be able to answer the following questions:

- Where the water use in irrigation system at Cyaruhogo marshland comes from?
- What is the cause of sediment in irrigation dam?
- How the PH of water and sediment in reservoir be obtained and analyzed?

1.6. RESEARCH SIGNIFICANCE

This thesis proposal will provide the different impacts of climate change on irrigation system. Irrigation process is very importance in agriculture and land conservation. During the dry season, the water is needed to the crops and it is possible when the irrigation system is adopted. During the rainy season, the crops no need for irrigating but the irrigation dam stores the water from the catchment areas. However, debris from the heavy rain water enters in the reservoir and at the end, storage capacity diminishes and then production capacity reduces during the long dry season. For protecting this irrigation dams, the erosion control strategies will be taken for preventing the irrigation system effect from climate change.

2. LITERATURE REVIEW

2.1. DEFINITIONS

2.1.1. Weather

Weather is a behavior of atmosphere at any given moment. Weather is expressed in terms of temperature, humidity, precipitation, cloudiness, visibility and wind [11]. It represents the day-to-day or moment-to-moment variations in these elements in the Earth's atmosphere. Weather conditions can change rapidly due to factors like air pressure systems, solar radiation, and the movement of air masses, among others

2.1.2. Climate

Climate represents aggregate weather conditions over longer time periods, such as decades or centuries. It is the slowly varying aspect of the atmosphere-hydrosphere-land surface system. It is typically characterized in terms of averages of specific states of the atmosphere, ocean, and land, including variables such as temperature (land, ocean, and atmosphere), salinity (oceans), soil moisture (land), wind speed and direction (atmosphere), and current strength and direction (oceans) [12]

2.1.3. Climate change

Climate change is also the change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time period. The state of the climate that is characterized by long-term variations in the mean and/or variability of its attributes, whether brought on by human action or natural processes, is known as climate change. Examples of natural variables that add to the climate system's inherent variability are variations in solar radiation and volcanism [4]

Climate change and its impact on agriculture and water resources have become a global concern. Globally, the effects of extreme weather events on food production and the availability of water resources are beginning to have social and economic ramifications. It also brought about variations in wind speed, sea level rise, frequency and severity of droughts, and rainfall intensity[10].

2.1.4. Irrigation system

An irrigation system is a method or system used to artificially supply water to land or crops to assist with agricultural production, landscaping, or other purposes where water is needed. The primary goal of irrigation systems is to provide the necessary amount of water in a controlled manner to optimize plant growth and ensure crop health [13]

Irrigation is the artificial application of water to the soil through various systems of tubes, pumps, and sprays. Irrigation is usually used in areas where rainfall is irregular or dry times or drought is expected. Irrigation requirements are determined by climate and by crop and soil characteristics. Differences in crop evapotranspiration (ET) rates have caused by differences in canopy resistance and percent of green ground cover. Since irrigation provides for more efficient water application scheduling and higher production, it has been used for at least 4,000 years. In spite of population growth, irrigated agriculture, together with better crop types and chemical inputs, produced 24% more food per person between 1961 and 1997 [14].

Irrigation water demand in the command area is affected by rainfall and climate conditions in the river basin. In climate change conditions, rainfall and temperature are predicted to increase and projected to impact irrigation water requirements significantly[15]. Thus far, certain research has validated how climate change affects the need for irrigation water in rice-producing nations. However, as streamflow is the main source of irrigation systems, climate change also affects it. The irrigation (including construction of dams) also changes the river flow for up and downstream users. A dam can create waterlogging problems upstream of the dam. The drainage of wetlands has to be planned carefully and requires special wetland irrigation management to reduce and mitigate the degradation and problems with other water users in the catchment. Large wetland irrigation schemes can influence the water balance of the entire catchment.

Rwanda, a country known for its hilly terrain and relatively small land area, faces unique challenges when it comes to agricultural practices, including irrigation. Here's a detailed description of the irrigation systems commonly used in Rwanda:

Gravity Flow Irrigation: Due to its hilly landscape, gravity flow irrigation is a widely used method in Rwanda. This system utilizes the natural slope of the land to distribute water from higher to lower elevations. Canals, ditches, and terraces are constructed to channel water from rivers,

streams, or reservoirs to fields. Farmers carefully manage these channels to ensure proper water distribution to crops.



Figure 2.1: Gravity flow irrigation system

The figure 2.1 presents the gravity flow irrigation system but the some challenges are produced in this method such as Water is at high turbidity level, it is not advisable to the farmers or other investors to make direct connection to the existing system and the time to clean is need water before applying to drip irrigation system

Surface Irrigation: Surface irrigation methods, such as furrow and basin irrigation, are also employed in Rwanda. In furrow irrigation, small channels or furrows are created between crop rows, and water is allowed to flow through them, saturating the soil and reaching plant roots. Basin irrigation involves creating small, leveled depressions in the field and flooding them with water. Both methods are relatively simple and can be effective for crops like rice and vegetables. It is thought that surface irrigation systems have low efficiency, with an average of roughly 60%. This indicates that only 60% of the water given is retained by crop roots in the top layer of the soil, where it can be used for their benefit. The remaining 40% leaves the field either surface runoff at

the end of the field or deep percolation beneath the root zone. The figure 2.2 shows the surface irrigation system which is commonly used in Rwanda especially in the rice field.

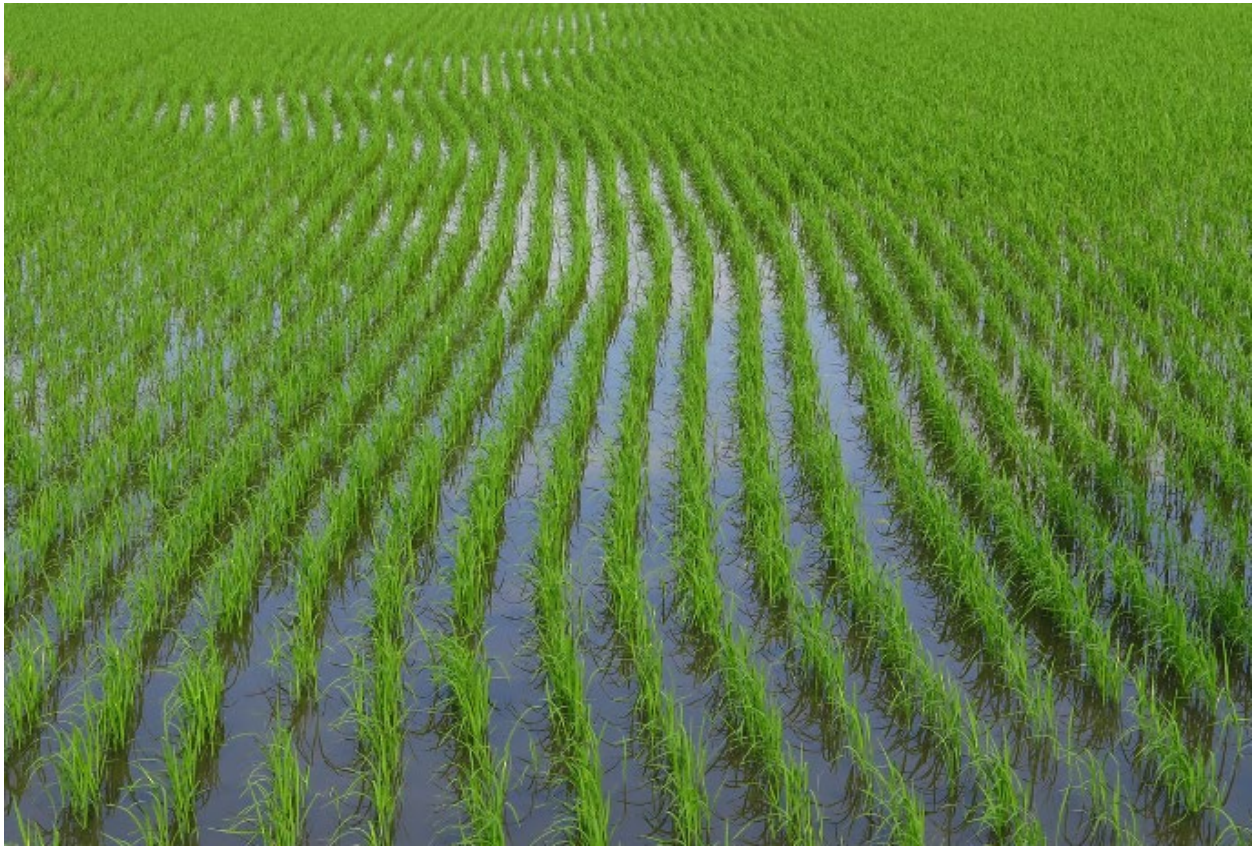


Figure 2.2: surface irrigation system

Sprinkler Irrigation: In areas where water resources are more abundant or where terrain makes gravity flow irrigation difficult, sprinkler irrigation systems are utilized. Sprinklers distribute water over the crops in a controlled manner, simulating natural rainfall. This method is particularly suitable for crops like maize, potatoes, and beans. It requires infrastructure such as pumps, pipes, and sprinkler heads, and can be more costly to implement and maintain compared to gravity-based systems. The figure 2.3 illustrates the sprinkler irrigation which acts as the rain in Ngoma district.



Figure 2.3: sprinkler irrigation system in Ngoma district

Drip Irrigation: Drip irrigation is gaining popularity in Rwanda, especially for high-value crops like fruits and vegetables. This system delivers water directly to the roots of plants through a network of pipes and emitters. It is highly efficient in water usage as it minimizes evaporation and runoff. Drip irrigation also allows for precise control over water delivery, which can improve crop yields and quality. While initial setup costs may be higher, drip irrigation can lead to significant water savings and increased productivity over time [16].

Figure 2. 4 provides information about the generation of water directly to the roots of vegetable and it's also easy to control the flow of water



Figure 2.4: drip irrigation system

Rainwater Harvesting: In addition to conventional irrigation methods, rainwater-harvesting techniques have employed to capture and store rainwater for agricultural use during dry periods. Farmers construct reservoirs, ponds, or tanks to collect runoff from rooftops or other impermeable surfaces. This stored water can then be used for irrigation when needed, reducing reliance on seasonal rainfall and surface water sources. The figure 2.5 demonstrates the water from rain collected, harvested and used in irrigation process.



Figure 2.5: Rainwater harvested to form reservoir

Small-Scale and Community-Based Systems: Many irrigation systems in Rwanda are small-scale or community-based, managed by local farmers or cooperatives. These systems often involve collaboration among farmers to share water resources, maintain infrastructure, and collectively manage water usage. Community involvement is crucial for the success and sustainability of these irrigation schemes. The figure 2.6 presents the local or community irrigation system at small scale of their field manually.



Figure 2.6: small scale and community based system

Overall, the irrigation landscape in Rwanda is diverse, with various methods and approaches tailored to the country's topography, climate, and agricultural practices. Sustainable water management and efficient irrigation techniques are increasingly emphasized to enhance agricultural productivity, ensure food security, and mitigate the impacts of climate change.

2.2. CLAUSES OF CLIMATE CHANGE

2.2.1. Deforestation and Land Use Changes

Deforestation is the loss of tree cover, usually as a result of forests being cleared for other land uses such as farming or ranching. Some limit the definition of deforestation to the permanent conversion of forests to another habitat. Climate change is one of the greatest concerns to mankind in recent times [17]. Clearing forests and converting land for agriculture, urbanization, and other purposes reduces the Earth's capacity to absorb CO₂ through photosynthesis. Additionally, these activities release stored carbon into the atmosphere and reduce carbon sinks, exacerbating greenhouse gas concentrations.



Figure 2.7: Deforestation

The figure 2.7 presents deforestation image where the trees are cleared either for farming or infrastructure purposes. Deforestation often involves burning trees and vegetation, which releases large amounts of carbon stored in biomass into the atmosphere as CO₂. Additionally, when forests are cleared for agriculture, urbanization, or infrastructure development, the disturbance of soils and vegetation can lead to the release of other greenhouse gases such as methane (CH₄) and nitrous oxide (N₂O).

The charcoal preparation process is also big issue for cutting trees. Traditional source of energy for cooking is firewood and charcoals. This method effects the forest where it is destroyed every

moment. The figure 2.8 indicates the coal at the end stage with the CO₂ generated during the process.



Figure 2.8: charcoal preparation

2.2.2. Agriculture practices

Agricultural activities, including livestock farming and rice cultivation, produce methane and nitrous oxide emissions. Livestock, particularly cattle, release methane during digestion (enteric fermentation), while rice paddies emit methane as a byproduct of flooded soil conditions. Agricultural activities, especially the use of synthetic fertilizers and animal manure, contribute to nitrous oxide emissions, a potent greenhouse gas. Carbon Dioxide (CO₂), Land clearing for agriculture releases carbon dioxide stored in vegetation and soils. Food security and production depend heavily on study into how climate change is influencing agriculture technology because the crop requires a lot of water and occupies a lot of space worldwide [2]. Most countries in Sub-Saharan Africa depend on rain-fed agriculture for food security and employment to keep their economies growing and viable while in Rwanda, agriculture represents more than 43% of the Gross Domestic Product and crop production constitutes the major part of agricultural production for the majority of the Rwandese households.

2.2.3. Industrial processes

Certain industrial activities, such as cement production, steelmaking, and chemical manufacturing, release greenhouse gases like CO₂ and methane (CH₄) into the atmosphere. This process can also cause the climate change due to high amount of gases emitted in atmosphere. Many industrial processes rely on fossil fuels like coal, oil, and natural gas for energy. Burning these fuels releases CO₂ directly into the atmosphere, adding to the greenhouse gas concentration. For air pollution; Alongside GHGs, industries emit pollutants such as sulfur dioxide (SO₂), nitrogen oxides (NO_x), and particulate matter. These can have indirect climate effects by altering atmospheric chemistry, affecting cloud formation, and contributing to local climate patterns.



Figure 2.9: production of CO₂ from industry (CO₂ PAPER)

Figure 2.9 indicates the much gases emit to the atmosphere from industry process. Global carbon dioxide emissions from fossil fuels and industry totaled 37.15 billion metric tons (GtCO₂) in 2022. Emissions are projected to have risen 1.1 percent in 2023 to reach a record high of 37.55 GtCO₂

2.3. IMPACT OF CLIMATE CHANGE

2.3.1. Water scarcity

When there is a temporary shortage of water or when poor quality makes it difficult to use, it is referred to as a water scarcity. It is a state that develops when a nation's or region's water supplies

are insufficient to meet the needs of its ecosystems and population [18]. Climate change exacerbates water scarcity through various mechanisms:

- **Changes in Precipitation Patterns:** Climate change alters precipitation patterns, leading to increased variability in rainfall. Some regions experience more intense rainfall and flooding, while others face prolonged droughts. This variability can strain water management systems and reduce reliable access to water resources.
- **Melting of Glaciers and Snowpack:** Rising temperatures cause glaciers and snowpack in mountainous regions to melt faster and earlier in the year. This can initially increase water availability, but over time, reduced snow and ice cover diminishes the natural storage capacity for water, exacerbating water scarcity during dry seasons.
- **Sea Level Rise:** Sea level rise can lead to saltwater intrusion into freshwater sources in coastal areas, contaminating groundwater reservoirs and reducing their usability for agriculture and drinking water.
- **Changes in River Flows:** Altered precipitation patterns and increased evaporation rates due to higher temperatures affect river flows. This can reduce water availability for agriculture, industry, and community dependent on river water.
- **Increased Frequency of Extreme Events:** Climate change is associated with more frequent and intense extreme weather events, such as hurricanes, cyclones, and storms. These events can damage water infrastructure, disrupt supply systems, and contaminate water sources, exacerbating water scarcity in affected regions.
- **Impacts on Groundwater Resources:** Changes in precipitation and temperature patterns affect groundwater recharge rates. Over-extraction of groundwater combined with reduced recharge due to climate change can lead to declining groundwater levels, exacerbating water scarcity in regions reliant on groundwater.
- **Ecosystem Impacts:** Changes in water availability and quality due to climate change can harm freshwater ecosystems and the services they provide, such as water purification and habitat for aquatic species. This further impacts human access to clean water resources.
- **Social and Economic Consequences:** Water scarcity intensified by climate change can lead to conflicts over water resources, displacement of populations, migration, and economic losses in sectors reliant on water, such as agriculture and tourism.

2.3.2. Drought

Drought is a prolonged period of abnormally low rainfall or precipitation, typically lasting weeks to years, that results in a water shortage. It is characterized by a deficiency of water supply that adversely affects agriculture, water resources, ecosystems, and human activities. Drought reduces surface water availability in rivers, lakes, and reservoirs, which are crucial for agriculture, industry, and urban water supply [19]. Climate change is associated with more frequent and intense heatwaves, which can exacerbate drought conditions by accelerating evaporation rates and drying out soils.

Groundwater resources may also become depleted as prolonged drought reduces recharge rates. Rising temperatures cause glaciers and snowpack to melt faster, altering the timing and amount of water runoff. This can initially increase water availability but reduces water storage capacity over time, contributing to drought conditions during dry seasons.

2.3.3. Flooding

Flooding is when water covers land that is usually dry. It happens when rivers overflow, heavy rain causes streets to fill with water, or when coastal areas are flooded by ocean water during storms. Floods can damage homes, roads, and crops, and they can be dangerous for people and animals. Climate change influences flooding in several significant ways:

- **Increased Intensity of Rainfall:** Warmer temperatures can lead to increased evaporation, which in turn increases the capacity of the atmosphere to hold moisture. This results in more intense rainfall events, increasing the likelihood of flash floods and urban flooding.

- **Changes in Precipitation Patterns:** Climate change alters global and regional precipitation patterns. Some areas may experience more frequent heavy rainfall events, while others may experience longer dry spells, which can lead to more severe droughts followed by intense floods when rain finally falls.

- **Melting Glaciers and Snow packs:** Rising temperatures accelerate the melting of glaciers and snowpack. This can initially increase water availability, but the sudden release of large amounts of water can lead to riverine flooding downstream.

□ **Sea Level Rise:** Climate change causes sea levels to rise due to melting ice caps and thermal expansion of seawater. Higher sea levels increase the risk of coastal flooding during storms and high tides, especially in low-lying coastal areas.

□ **Changes in Storm Patterns:** Climate change can alter storm tracks and intensities, potentially leading to more frequent and severe hurricanes, typhoons, and cyclones. These storms can bring heavy rainfall and storm surges that lead to coastal and inland flooding. Flooding caused by climate change can lead to displacement of communities, loss of livelihoods, disruption of businesses, and increased costs for disaster response and recovery.

2.4. MEASUREMENT OF CLIMATE CHANGE

Measurement of climate change involves assessing changes in various climate variables over time to understand trends, impacts, and potential future scenarios.

2.4.1. Climate variables monitoring

Monitoring climate variables is crucial for understanding climate patterns, assessing climate change impacts, and informing decision-making in various sectors. Some variables in climate monitoring are temperature, precipitation, humidity, wind speed and direction, solar radiation, sea level; glacier and ice shut mass balance. Climate variables monitoring involves the systematic collection, analysis, and tracking of various factors that characterize the Earth's climate system. These variables include but are not limited to:

1. **Temperature:** Measured globally using surface stations, satellites, and buoys to monitor changes in average temperatures over time.
2. **Precipitation:** Recording rainfall and snowfall patterns to understand regional water availability and climate patterns.
3. **Humidity:** Monitoring atmospheric moisture content, which affects cloud formation and precipitation.
4. **Wind:** Measuring wind speed and direction to assess weather patterns and climate impacts such as storm development.
5. **Atmospheric Pressure:** Tracking changes in air pressure to understand weather systems and circulation patterns.

6. **Solar Radiation:** Measuring incoming solar energy, which influences Earth's climate and weather systems.
7. **Greenhouse Gases:** Monitoring concentrations of gases like carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), which affect the Earth's energy balance and climate.
8. **Ocean Variables:** Monitoring sea surface temperatures, ocean currents, and ocean acidification to understand their role in climate regulation and impacts.
9. **Glacier and Ice Sheet Monitoring:** Tracking changes in ice extent, thickness, and volume to assess contributions to sea-level rise.
10. **Biological Variables:** Monitoring changes in vegetation cover, biodiversity, and ecological indicators to understand climate impacts on ecosystems.

2.4.2. Crop Yield and Production Analysis

Yield is influenced by climate and temperature, plant and water management, and soil nutrient management factors. The government of Rwanda has recognized the importance of irrigation development for better water management and crop production as well [6]. Rice production is considered as one of the profitable enterprises for smallholder farmers as regards the utilization of the hydro-agricultural investments laid out. In Rwanda, rice has been designated as one of the "priority food crops" due to its ability to maximize the use of existing marshland area and lessen the strain on hillside land.

Rwanda has made an effort to increase the benefits by deliberately increasing the area of marshlands used for rice production. However, imports of rice are still required because the local supply of rice cannot keep up with the local demand. Depending on water abstraction, Rwanda's 501,509 hectares of irrigation potential are split into six (6) domains, with 123,164 ha (24.6%) having potential for marshlands [20]

Soil moisture constants

The soil moisture constant represents definite soil moisture relationship and retention of soil moisture in the field. The soil moisture constant represents definite soil moisture relationship and retention of soil moisture in the field [21].

Soil water has previously classified as gravitational, capillary, or hygroscopic water. Under the circumstances, the hygroscopic and capillary fluids are in balance with the soil. When the soil has the highest concentration of capillary and hygroscopic waters, respectively, the two equilibrium points are the maximum capillary capacity and the hygroscopic coefficient. Soil moisture constant is the quantity of water that a soil contains at each of these equilibrium points.

Though the maximum capillary capacity represents the maximum amount of capillary water that a soil holds, the whole of capillary water is not available for the use of the plants. The plants cannot utilize a part of it, at its lower limit approaching the hygroscopic coefficient. Similarly, a part of the capillary water at its upper limit is also not available for the use of plants. Hence, two more soil constants; viz., field capacity and wilting coefficient have been introduced to express the soil-plant-water relationships as found to exist under field conditions.

1. Field capacity: It is the capacity of the soil to retain water against the downward pull of the force of gravity. At this stage, only micropores or capillary pores are filled with water and plants absorb water for their use. At field capacity, water is held with a force of $1/3$ atmosphere. Water at field capacity is readily available to plants and microorganisms.

2. Wilting coefficient: The stage at which plants start wilting for want of water is termed the Wilting Point and the percentage amount of water held by the soil at this stage is known as the Wilting Coefficient. It represents the point at which the soil is unable to supply water to the plant. Water at wilting coefficient is held with a force of 15 atmospheres.

3. Hygroscopic coefficient: The hygroscopic coefficient is the maximum amount of hygroscopic water absorbed by 100 g of dry soil under standard conditions of humidity (50% relative humidity) and temperature (15°C). This tension is equal to a force of 31 atmospheres. Water at this tension is not available to plant but may be available to microorganisms.

4. Available water capacity: The amount of water required to apply to a soil at the wilting point to reach the field capacity is called the "available" water. The water supplying power of soils is related to the amount of available water a soil can hold. The available water is the difference in the amount of water at Field Capacity (0.3 bar) and the amount of water at the Permanent Wilting Point (15 bars).

5. Maximum water holding capacity: It is also known as maximum retentive capacity. It is the amount of moisture in a soil when its pore spaces, both micro and macro-capillary, are completely filled with water. It is a rough measure of total pore space of soil. Soil moisture tension is very low between 1/100th to 1/1000th of an atmosphere or pF 1 to 0.

The soil moisture constants, type of water and force, which it has held, has summarized in the table 2.1.

Table 2.1: moisture Soil moisture constants and range of tension and pF

S.No.	Moisture class	Tension (atm/bar)	pF
1	Chemically combined	Very high	---
2	Water vapour	Held at saturation point in the soil air	---
3	Hygroscopic	31 to 10,000	4.50 to 7.00
4	Hygroscopic coefficient	31	4.50
5	Wilting point	15	4.20
6	Capillary or available water	1/3 to -31	2.54 to 4.50
	Moisture equivalent	1/3 to 1	2.70 to 3.00
	Field capacity	1/3	2.54
	Sticky point	1/3 (more or less)	2.54
	Gravitational	Zero or less than -1/3	<2.54
	Maximum water holding capacity	Almost zero	---

PF is the value of decimal logarithm water column in cm.

2.4.3. Estimation of potential evapotranspiration

Potential evapotranspiration (PET) plays a significant role in climate change studies and assessments, particularly in understanding its impacts on water resources, agriculture, ecosystems, and overall climate dynamics. It can cause some agriculture impacts. The first one is Crop Water Requirements. PET can use to estimate the water needs of crops, influencing irrigation scheduling and agricultural planning. The secondary is Productivity. Changes in PET due to climate change affect crop yields and agricultural productivity, influencing food security and rural livelihoods.

To calculate the irrigation water requirements for Cyaruhogo Wetland, we need specific data such as the area of land to be irrigated, the crop types being grown, soil characteristics, and climate conditions. Without this detailed information, it's challenging to provide an accurate calculation. However, I can outline a general approach to estimate irrigation water requirements

To Determine Crop Water Requirements, Different crops have varying water needs depending on factors such as growth stage, climate, and soil conditions. Crop water requirements can be estimated using reference evapotranspiration (ET₀) data and crop coefficients (K_c) specific to the crop types being grown. Account for Soil and Climate Conditions is importance for the Soil characteristics (e.g., texture, infiltration rate) and climate conditions (e.g., temperature, humidity, and rainfall) influence water availability and irrigation scheduling. Local meteorological data and soil information can be used to adjust crop water requirements accordingly. To Calculate Effective Rainfall, Effective rainfall refers to the portion of precipitation that contributes to soil moisture and can offset irrigation water requirements. By subtracting effective rainfall from total precipitation, you can estimate the additional water needed for irrigation. Estimate Irrigation Application Efficiency: Irrigation application efficiency accounts for losses during water application, including evaporation, runoff, and deep percolation. Common irrigation methods have different application efficiencies, which should be considered when calculating irrigation water requirements.

Determine Irrigation Frequency and Duration Based on crop water requirements, soil moisture levels, and irrigation system characteristics, determine the frequency and duration of irrigation applications needed to meet crop demand while avoiding water stress or waterlogging. To Calculate Total Irrigation Water Requirement, once you have estimated the crop water requirements, effective rainfall, and irrigation application efficiency, you can calculate the total irrigation water requirement for Cyaruhogo Wetland by summing the water needed for each irrigation event over the growing season.

The determination of the gross irrigation water requirements must assume an irrigation efficiency (IE) which is the ratio of the amount of water consumed by the crop to the amount of water supplied through irrigation[22]. This is the scheme efficiency including conveyance (ec) and field application (ea),

$$IE\% = ea\% \times ec\% \dots\dots\dots Eq (1)$$

as defined by Food Agriculture Organization [8].

The system efficiencies for the different systems considered are given below:

- Marshland surface with lined primary canals and earthen (clay) secondary/tertiary canals:

$$IE = 90\% \times 60\% = 54\% \dots\dots\dots Eq (2)$$

The program calculates the net irrigation demand for each 10-day period for a particular cropping pattern and set of monthly climate data and soil type. Crop factors (K_c) specific to crop type and stage of growth are used to calculate the crop's evapo-transpiration (ET_{crop}) requirement under prevailing evapo-transpiration (ET_o)

Conditions:

$$ET_{crop} = K_c \times ET_o \dots\dots\dots Eq (3)$$

The irrigation requirement, is the difference between the crop's evapo-transpiration (ET_{crop}) and the effective rainfall ($Reff$), calculated for each 10-day interval throughout the growing season:

$$CWR = ET_{crop} - Reff$$

Because vegetables are grown continuously throughout the year, without predictable planting and harvest dates, a weighted mean crop factor has been used to estimate water demand. The calculated K_c for continuous vegetable production is 0.88, based on published crop factors for a range of common vegetables grown in Rwanda, namely tomato, onion and cabbage.

2.5. IMPACTS OF CLIMATE CHANGE ON CROP PRODUCTION

Climate change is already having an impact on agriculture and this situation is leading to reductions in crop production and lower incomes in affected places around the world. Rwanda has experienced the effects of climate change and variability through a growing number of disasters in recent decades especially droughts, floods, landslides[23]. The rainfall seasons have already been unexpectedly starting late and farmers were increasingly wary of establishing new optimal times for planting their crops that has negatively impacted their livelihoods and increased vulnerability to food insecurity [24]. Therefore, the irrigation system will be the solution for the Rwandan farmers. Through a variety of methods, climate change has a substantial global impact on crop production, affecting agricultural yields in terms of both quantity and quality. Although

rice is an important staple food crop, climate change is having an impact on its productivity and growth. Climate change is to blame for both the poor supply and the rising demand, which has an impact on global food security and the economy. Among the effects of climate change are droughts, floods, tropical storms, degraded soil, and saltwater intrusion onto agricultural land owing to sea level rise. High temperatures also affect rainfall distribution and produce these events. There some key impacts of reduction on crop production.

2.5.1. Changes in temperature and precipitation patterns

✓ Variations in Temperature

Heat Stress: As temperatures rise, crops may experience heat stress, which can diminish yields, interfere with flowering, and hinder crop development.

Changes in Growing Seasons: Crop calendars and management techniques may be impacted by temperature trends that upset customary planting and harvesting schedules.

Optimal Temperature Range: Each crop has an optimal temperature range for growth and development. Changes in temperature, especially extremes (heatwaves), can push crops outside this range, leading to reduced yields or crop failure.

✓ Changes in Precipitation Patterns

Droughts: More frequent and severe droughts can cause water stress in crops, which lowers yields and growth Heavy rains and flooding can harm crops, change the composition of the soil, and make them more susceptible to pests and illnesses.

✓ Pest and Disease Outbreaks

Higher temperatures have the potential to increase the geographic range of pests and illnesses, bringing additional risks to crops. Variations in temperature and precipitation can make environments more conducive to the growth of illnesses and pests, which can result in greater infestation rates.

✓ Access to Water

Water Scarcity can be source of water shortage. A reduction for water available for irrigation due to altered precipitation patterns and increased evapotranspiration can have an impact on agricultural production.

Demand for Irrigation: Increasing temperatures and shifting precipitation patterns may lead to a rise in irrigation demand, further taxing water supplies.

✓ Levels of Carbon Dioxide

CO₂ Fertilization Effect: Depending on the crop and environmental factors, increased atmospheric CO₂ levels can initially improve photosynthetic and water usage efficiency in various crops.

Changes in Nutrient Content: Crops' nutritional quality may be impacted by changes in nutrient content brought on by elevated CO₂ levels.

✓ Adaptation Challenges

Variability: Farmers may find it more difficult to forecast and adjust to shifting conditions because of increased climate variability, which may have an impact on crop management choices.

Infrastructure: Farmers' capacity to address climate-related issues may be hampered by a lack of adaptable infrastructure, such as irrigation systems and storage facilities.

✓ Regional variation

Regional Sensitivities: Depending on their geographic position, the local climate, and the agricultural techniques now in place, different regions will be affected by climate change in different ways.

2.5.2. Effects on crop yields and quality

Global food security and agricultural economies can be impacted by the direct and indirect effects of climate change on crop output and quality. This is an in-depth analysis of how crop productivity and quality can be impacted by climate change:

By impairing photosynthesis, respiration, and nutrient uptake, higher temperatures, particularly heatwaves during crucial growth stages, can lower agricultural yields. Heat stress can cause a grain's protein level, oil composition, and overall nutritional value to decrease [25]. More frequent and severe droughts lower soil moisture, which stresses crops' ability to absorb water. Crop

damage from heavy rains and flooding can result in waterlogging, nitrogen leaching, and increased susceptibility to diseases, all of which lower crop quality and output. Increasing temperatures and changing precipitation patterns can help diseases and pests expand to new areas and change the course of their life cycles. Changes in temperature and precipitation can affect soil nutrient availability and composition, influencing crop growth and quality.

Some mitigations have needed for improving the crop yield and quality through the following:

Crop breeding: It is critical to create crop types that are tolerant of heat, drought, pests, and diseases.

Water Management: One way to lessen the effects of shifting precipitation patterns is to enhance irrigation methods and adopt water-saving measures.

Policy and Planning: Long-term resilience may enhanced by putting policies into place that support sustainable agriculture methods and lower greenhouse gas emissions.

2.5.3. Shifts in pest and disease dynamics

Changes in temperature and precipitation patterns can alter the distribution, prevalence, and severity of pests and diseases, affecting crop yields and quality. For example, warmer temperatures can lead to increased pest populations and faster reproduction rates, while changes in precipitation patterns can affect the transmission of diseases by pests and vectors. Temperature-related alterations in pest and disease behavior result in altered assault capabilities. The influence of rising temperatures and atmospheric CO₂ levels on crops' capacity to combat insect pests and diseases have covered in this review [26].

Anything that people perceive as a threat to themselves, their property, cattle, or crops have considered a pest. Nematodes, insects, weeds, mollusks, bacteria, fungi, phytoplasmas, viruses, and viroids should all be included in the definition of a pest. Climate change has a notable influence on pest and disease dynamics, affecting both the range and intensity of various pests and pathogens that affect crops, forests, and natural ecosystems. Climate change can shift pest and disease dynamics in many ways.

Higher Temperatures: A lot of illnesses and pests have a range of temperatures in which they can survive. These ranges can spread when temperatures rise enabling viruses and pests to spread into previously unsuitable geographic areas for their survival.

Altitudinal Shifts: In a similar vein, diseases and pests may relocate to higher elevations in response to rising temperatures, affecting mountainous areas that were previously comparatively pest-free.

Host Susceptibility: Plants' ability to withstand pests and illnesses may affect by climate change. Plants that are under stress due to heat, drought, or changes in nutrient supply are more susceptible to assaults.

Mutualistic Relationships: The natural equilibrium between pests, diseases, and their natural enemies, predators, parasites, and pathogens can upset by climate change, which may encourage pest outbreaks of a particular kind.

Direct Damage: Diseases and pests can cause direct agricultural damage, resulting in lower yields and financial losses for farmers.

Indirect Effects: By modifying nutrient cycling, soil health, and ecosystem functioning, changes in pest and disease dynamics can also have an indirect impact on crop health.

2.6. IMPACTS OF CLIMATE CHANGE ON LIVESTOCK AND ANIMAL HUSBANDRY
Climate affects livestock growth rates, milk and egg production, reproductive performance, morbidity, and mortality, along with feed supply[27]. The impact of climate change has anticipated increasing the susceptibility of livestock systems and amplifying current elements that influence livestock production systems, such as quickening economic and population expansion, growing consumer demand for food (including cattle). Climate change observes in all concerns of daily life

2.6.1. Heat stress and animal productivity

Heat stress significantly affects animal production across various species, including cattle, poultry, pigs, and others. Livestock farming is often a crucial source of income and livelihood for many rural communities. Climate change impacts on livestock productivity can therefore have significant economic and social consequences. Livestock products (meat, milk, eggs) are essential sources of protein and nutrition. Disruptions in livestock productivity can affect food security, particularly in vulnerable populations.

Reduced Feed Intake and Digestibility

Decreased Appetite: Animals suffering from heat stress frequently consume less food. Animals may feel uncomfortable in high temperatures, which may lead to them eating less.

Decreased Digestibility: Excessive heat can hinder an animal's ability to break down food into energy and nutrients by impairing the digestive system.

Changes in Metabolism and Nutrient Utilization

Energy Expenditure: Animals under heat stress divert energy towards cooling themselves (e.g., through panting), reducing the energy available for growth, reproduction, and milk/meat production.

Nutrient Imbalances: Heat stress alters mineral metabolism and utilization, potentially leading to imbalances in calcium, phosphorus, and electrolytes.

Impaired Growth and Production

Firstly, Reduced Growth. Heat stress can cause young animals to grow more slowly, which lowers their overall production. Secondly, Diminished Milk Yield. During times of heat stress, dairy cows may produce less milk, which can affect the amount and quality of milk that has produced. Additionally, Poor Reproductive Performance. In breeding animals, heat stress can cause decreased rates of conception, lower fertility, and greater rates of embryo mortality.

Health Problems Caused by Heat

Animals suffering from severe heat stress may get heat exhaustion or heat stroke, which can be fatal if left untreated. Panting more to stay cool can lead to respiratory issues, especially in animals whose respiratory systems have already damaged. Disease Susceptibility increases due to possible immune system weakness, animals under heat stress are more prone to infections and illnesses.

2.6.2. Changes in forage availability and quality

Reduced precipitation and increased temperatures associated with climate change can lead to drought conditions, diminishing the growth of pasture grasses and forage crops. This reduction in forage quantity can directly limit the amount of feed available for livestock; potentially leading to shortages and increased costs for supplementary feed. The geographical distribution of forage plants can also impacted by climate change. Variations in temperature and precipitation patterns

have the potential to modify the plant species that flourish in specific areas, hence changing the pasturelands' composition and appropriateness for cattle grazing.

Nutritional Content: Variations in temperature and moisture, in particular, can have an impact on the nutritional makeup of forage plants. This may influence the amounts of minerals, fiber, and protein that are essential to the health and functionality of animals.

Digestibility: Modifications in the quality of fodder may have an impact on digestibility, which may have an impact on how well cattle are able to absorb nutrients from their diet. Reduced growth rates, milk output, and general animal performance can result from poor digestibility.

2.6.3. Increased disease risks and vector-borne diseases

When an infected arthropod, also known as a vector, bites a human or an animal, it can spread pathogens (bacteria, viruses, protozoa, or parasites) that cause vector-borne diseases. The most prevalent carriers are fleas, sandflies, ticks, and mosquito's [28]. Some of the source of vector-borne diseases have explained as follow:

Climate and Weather: Variations in temperature, humidity, and precipitation can have an impact on vector distribution, abundance, and activity. These variables can vary due to climate change, which will affect the seasonality and geographic range of vector-borne illnesses.

Habitat and Land Use: Urbanization, deforestation, and changes in land use can alter the habitats and breeding grounds for vectors, which can have an impact on vector populations and the dynamics of disease transmission.

2.6.4. Higher crop, grass and forestry yields due to CO₂ fertilization

CO₂ fertilization can potentially increase crop, grassland, and forestry yields by enhancing photosynthesis and water use efficiency. The concept of CO₂ fertilization refers to the potential beneficial effect of increased carbon dioxide (CO₂) levels in the atmosphere on plant growth and productivity [29].

During photosynthesis, in which plants transform CO₂ and sunlight into sugars and oxygen, CO₂ is a vital component. In many plant species, higher CO₂ concentrations can promote photosynthesis, which raises growth rates and biomass production. Enhanced Water Use Efficiency to the Plants by exposing to higher CO₂ levels tend to open their stomata, or tiny pores

on their leaves, less frequently. This phenomenon lowers the amount of water lost through transpiration. Environments with limited water resources may benefit most from this increased water use efficiency.

For C3 and C4 Plants; Different types of plants respond differently to elevated CO₂ levels. C3 plants (like wheat, rice, and soybeans) generally show increased photosynthetic rates and yields under elevated CO₂ conditions. C4 plants (like maize and sugarcane) may also benefit, though typically to a lesser extent than C3 plants. Elevated CO₂ can enhance the efficiency with which plants use nitrogen and other nutrients, potentially leading to increased yields under optimal nutrient availability. Grasslands, which include both natural and managed pastures, can experience increased biomass production and forage quality under elevated CO₂ levels. This can benefit livestock productivity by providing feed that is more nutritious.

Tree Growth requires the CO₂. Faster tree growth rates can result in higher timber production in managed forests when CO₂ levels have raised. By removing CO₂ from the atmosphere and storing it in soils and wood, trees and forests play a critical role in reducing the effects of climate change.

2.7. IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES AND IRRIGATION

The distribution of water resources both spatially and temporally have anticipated, impacted by changes in temperature and precipitation patterns brought on by climate change [30]

2.7.1. Changing water availability and rainfall patterns

Global water supplies and rainfall patterns are being significantly impacted by climate change. Elevated temperatures exacerbate the hydrological cycle, resulting in increased frequency and intensity of precipitation events in certain areas and worsening drought conditions in other locations. The stability of ecosystems, agricultural output, and freshwater supplies have all influenced by this unpredictability. Water scarcity has exacerbated in regions that rely on seasonal rainfall or glacial meltwater, as changes in precipitation timing and distribution can do. The situation is made more complicated by sea level rise, which raises the possibility of saltwater seeping. The potential of saltwater intrusion into freshwater sources has increased by sea level rise, which further complicates the situation.

2.7.2. Water Stress and irrigation challenges

Climate change poses significant challenges to irrigation projects, necessitating adaptive strategies, investment in resilient infrastructure, and sustainable water management practices to ensure food security and agricultural livelihoods in a changing climate. Climate change alters precipitation patterns, leading to changes in water availability for irrigation [18]. In some regions, there may be increased rainfall intensity, causing flooding and soil erosion, while in others; there may be more frequent and prolonged droughts, reducing water availability for irrigation. Some effects of climate change on water stress and irrigation challenges have explained as follow:

Reduced Water Availability: Modifications in precipitation patterns, such as longer droughts and heavier rainfall events, lower the total amount of water available. This has an immediate effect on crop yields and agricultural output in irrigation systems that depend on steady and reliable water sources.

Demand Increased: In order to sustain agricultural output, crop water requirements have altered by rising temperatures and variations in precipitation, which raises the need for irrigation. This increases the strain on already scarce water supplies and may cause disputes over the distribution of water among residential, commercial, and agricultural applications.

Increased Evapotranspiration: Rising temperatures increase evapotranspiration rates, leading to greater water loss from both soil and plants. This necessitates more frequent irrigation or higher volumes of water to maintain crop productivity, placing additional demands on irrigation systems.

Saltwater Intrusion: Sea-level rise associated with climate change can lead to saltwater intrusion into coastal aquifers and estuaries, compromising the quality of irrigation water and rendering it unsuitable for agriculture. This requires additional investment in desalination or alternative water sources for irrigation.

Extreme Weather Events: Climate change is associated with an increase in the frequency and intensity of extreme weather events such as hurricanes, cyclones, and heavy rainfall events. These events can damage irrigation infrastructure, disrupt water supply systems, and cause soil erosion, impacting agricultural productivity and necessitating costly repairs.

Changes in Crop Suitability: Climate change can alter the suitability of certain crops for specific regions due to shifts in temperature and precipitation patterns. Irrigation projects may need to adapt

to accommodate changes in crop selection and agronomic practices to maintain agricultural productivity.

Increased Energy Costs: Irrigation systems reliant on pumping water from wells or surface water sources may experience increased energy costs due to higher temperatures and greater water demand. This can strain the financial viability of irrigation projects, particularly for smallholder farmers with limited resources. In response to climate change, governments may implement regulations and policies aimed at mitigating its impacts, such as water use restrictions or requirements for more water-efficient irrigation technologies. Irrigation projects may need to comply with these regulations, requiring investment in new infrastructure or management practices.

3. MATERIALS AND METHODS

This chapter discusses the methodology used in the study, describes the study areas, the population and sample size, sample selection techniques, research instruments, methods of data collection, data management and analysis.

3.1. SITE DESCRIPTION

Rwamagana is a district in Eastern Province, Rwanda. Its capital is Rwamagana city, which is also the provincial capital and it has 14 sectors. The District of Rwamagana has a mild tropical climate with four distinct seasons: two are cold and the remaining two are dry. It is located between 1°57'2, 7" south latitude and 30°26'8" longitude (EDPRS self-assessment district report). It receives a fair amount of rain each year, particularly in the months of April through May and October through December. The year-round average temperature is consistent, ranging from 19° to 30°[16]. Located at an elevation of none meters (0 feet) above sea level, Rwamagana has a Tropical wet and dry or savanna climate (Classification: Aw). The district's yearly temperature is 23.42°C (74.16°F) and it is 2.98% higher than Rwanda's averages. Rwamagana typically receives about 228.75 millimeters (9.01 inches) of precipitation and has 281.94 rainy days (77.24% of the time) annually.

Historically, Rwamagana, where Kigabiro, Rubona, and Mwulire are located, experiences a tropical savanna climate. This typically means a wet season from around October to May and a

dry season from June to September. However, for specific details on the average annual rainfall in these sectors, you would need to consult a recent weather database or a meteorological service for up-to-date information. The average rainfall for Rwanda the average rainfall is 1250 mm per annum: The average temperature in the Eastern parts of the district is more than 21 degrees Celsius (MINAGRI, 2012a) while the national average of 19 degrees Celsius (MINAGRI, 2012a). The agriculture in the district has potential due to the availability of water resources like rivers but farmers are suffering from drought due to the weather conditions. However, in 2024 Rwamagana receives the rain in ranging between 500 - 600 millimeters. .

The three dams as the figure 14 presents, has the different height and water storage capacity where Cyimpima, Bugugu and Gashara have the storage capacity of 640000 m³, 580000 m³ and 640000m³ respectively. The deep is 11m for Cyimpima, 12m for Bugugu and 13m for Gashara. The storage capacity of all three dams and their heights. Each dam has the irrigation area to supply water. Cyimpima dam irrigates 56ha, Gashara supplies 66ha and Bugugu irrigates 48ha to cover all wetland of 170ha. Before reaching to the dam there are constructed canal 8.8km for Cyimpima, 7.1km for Gashara and 7.8 km for Bugugu dam.

3.1.1. Site localization map

Cyaruwego marshland is located at Rwamagana, where Kigabiro, Rubona, and Mwulire are located, experiences is also with mwulire and sibagira and Nyagasenyi cells. Figure 3.1 indication the location of Cyaruwego wetland.

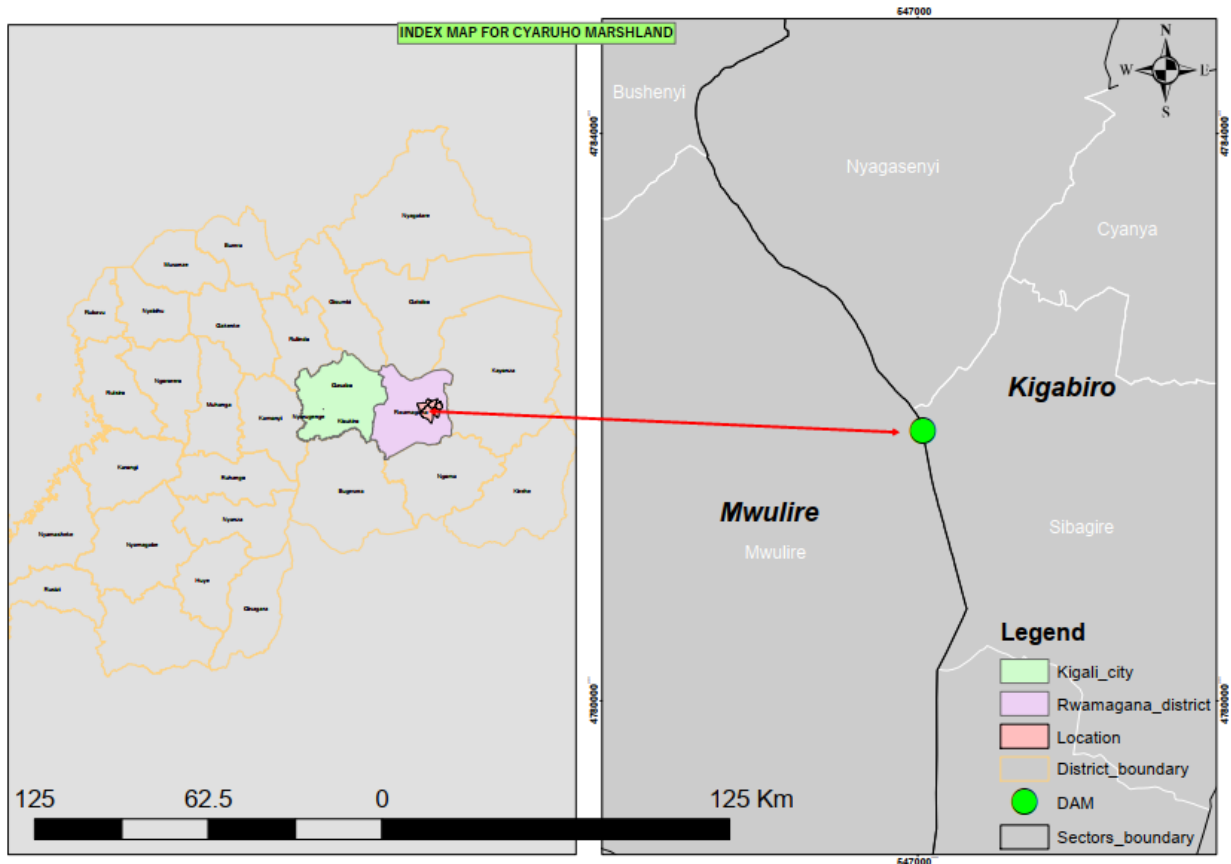


Figure 3.1: site location

3.1.2. Irrigation infrastructures in Cyaruhogo marshland

Cyaruhogo wetland irrigation project has been three years since the Government of Rwanda through Japan International Cooperation Agency (JICA) of rehabilitation for production enhancement. This wetland covers three sectors of Kigabiro, Rubona and Mwulire in Rwamagana district. Before the rehabilitation, farmers used to grow rice on 260 hectares. With irrigation infrastructures put in place, they extended agricultural activities on 340 hectares which helped them to increase the produce from 3.5 tons to 6 tons with optimism to reach 7 tons in the near future (February,2022).

On 170 hectares of land, three rice farmers' cooperatives with 600 members cultivate rice in Cyaruhogo Wetland. Two dams and a 23.5-kilometer water pipe has constructed as part of the project to irrigate the wetland's rice fields. In the summer season, the crops in the Cyaruhogo wetland were like the grass in desert as the figure 3.2 presents.



Figure 3.2: Cyaruhogo wetland in dry season with rice crop

Jean Claude Musabyimana, Permanent Secretary at the Ministry of Agriculture, Advised the locals to protect the irrigation systems and make use of the jobs that had been generated while they had built. The people who live close to the marsh should benefit greatly from the irrigation project's planned job growth. You ought to seize this chance to advance your financial development. We implore you to protect the dams so they can be constructed for the good of all of us in the future," stated Musabyimana.

Musabyimana went on to say that, the Rwandan government intends to increase agricultural production by increasing the area under irrigation, as shown in the 7-year Government Program. This had been accomplished in collaboration with various partners, including the Japan International Cooperation Agency (JICA), which is funding the project.



Figure 3.3: Rehabilitation of CYARUHOGO Marshland for doubling the farmer yield

The figure 3.3 presents the site visit of JACA and GoR team at Cyaruhogo marshland in order to increase the farmer yield for rehabilitate the existing wetland. This improvement of modern irrigation system plays the role to the beneficiaries especially the farmers of this wetland. The figure 10 illustrates the strong technology applied in this irrigation project.

This USD 20 million Project included rehabilitation of two storage dams, Cyimpima and Gashara, construction of one new storage dam (Bugugu), construction of a 23.7 km long concrete main canals along the three irrigation schemes, construction of secondary canals, as well as capacity building of farmers in irrigation water management. This handover ceremony was attended by the Governor of Eastern Province, the Ambassador Extraordinary and Plenipotentiary of Japan to Rwanda, the Permanent Secretary in the Ministry of Agriculture and Animal Resources, the Chief Representative of JICA, the Director General of Rwanda Agriculture and Animal Resources Development Board (RAB), Senior officials from RAB, farmers, and houses of media.



Figure 3.4: the new dam for irrigating crops at Cyaruhogo wetland (Bugugu dam)

The figure 3.4 presents the source of water for doubling the yield as the Dr. Charles Bucagu, Deputy Director General in charge of Agricultural Research and Technology Transfer at Rwanda Agricultural Board (RAB) said that the production has doubled from 3 tons to 6 tons of rice per hectare and this means increasing profitability in agriculture. One of the important factors is farmers continuing to grow crops whether it is rainy or drought season. In the dams of Cyimpima and Gashara, the basins in poor condition have been repaired. Pipelines were also laid to supply 1,174 rice, maize and soybean farmers, irrigating 170 hectares in three Rwamagana marshes. With this project, the irrigated swamps in Rwanda are increasing by 30 hectares. The country has a total of 589,000 hectares of marshland with only 48% irrigated.



Figure 3.5: modern in the irrigation infrastructure of Cyaruhogo wetland

The figure 3.5 illustrates the irrigation system at Cyaruhogo Wetland that has designed to support the sustainable management and utilization of water resources within the wetland area. This system has implemented to support agricultural activities in the vicinity, ensuring efficient water distribution to crops while minimizing the impact on the wetland ecosystem.

As the backbone of the economy, agriculture in Rwanda is essential for both economic growth and the reduction of poverty. It generates 30% of the GDP in 2019 and employ 70% of the population; in light of the historical and contemporary climate problems such as low rainfall, high temperatures in Eastern. Rwanda, and the global effects of climate change that are having a negative impact on rainfall distribution water scarcity continues to be a major issue that has an impact on agricultural production, particularly crop production[4]. As of the last update in January 2022, approximately 32% of Rwanda's GDP comes from agriculture, and the sector employs about 70% of the country's labor force. However, the specific percentage of agricultural output dependent on irrigation systems may vary depending on several factors, including climatic conditions, the availability of water resources, and the types of crops grown.

In Rwanda, irrigation plays a significant role in enhancing agricultural productivity, particularly in areas where rainfall is insufficient or unreliable. While a substantial portion of agriculture in Rwanda still relies on rain fed farming, the adoption of irrigation technologies and practices has been increasing steadily, especially for high-value crops such as vegetables, fruits, and export-oriented crops like coffee and tea. The Rwandan government has been investing in irrigation infrastructure and promoting the adoption of modern irrigation techniques to improve crop yields, increase food security, and reduce vulnerability to climate variability. This includes the construction of small-scale irrigation schemes, the promotion of drip irrigation and sprinkler systems, and the rehabilitation of existing irrigation infrastructure.

3.1.3. Irrigation water management in Cyaruhogo rice irrigation scheme

Since 2019, irrigation Project had target to generate a synergistic effect with the Project for Water Management and Capacity Building (WAMCAB), under the support by the Japan International Cooperation Agency (JICA). Effective irrigation water management in rice irrigation schemes is crucial for optimizing water use, enhancing crop productivity, and ensuring sustainability.

Some area in irrigated zone can fail due to improper maintenance of marshland. Before 2019, Cyaruhogo was not irrigated because the canals were damaged by cows and goats (no control of

grazing) in the swamps and water does not reach the tail farmers as provided by distribution convention. At the head reach, there was no water crisis because the reservoirs were located near the head reach, so that the average increase in cultivated area per farmer was good.

The term Participatory Irrigation Management (PIM) refers to the participation of users (the farmers) in all aspects of irrigation management and at all levels. All aspects include planning, design, construction, operation and maintenance, financing, decision rules, Monitoring and Evaluation of the irrigation system. PIM processes build two forms of capital: productive capital (better maintained irrigation infrastructure) and social capital (new institutions such as skills, leadership and community action).

Normally, water management could be under the great cooperatives authority at the distribution canal. For secondary and tertiary levels farmers could be in charge of water management team where each farmer must supply water to its field according a defined convention given by the team water management. If not they will have a severe punishment.

Enhance Water Delivery Systems. Maintain and upgrade irrigation infrastructure such as canals, ditches, and field channels to reduce water loss due to leaks and inefficiencies. Implementing lined or piped delivery systems can improve water distribution and reduce wastage.

Before farmers drill or broadcast rice seed, they saturate the soil with water. Farmers irrigate the first time when the rice stands a few inches tall because the emerging rice plants will drown if the farmers submerge the land prior to this stage.

Foster Farmer Education and Training: Precision land leveling is critical to achieving uniform stands. Provide training and resources to farmers on modern irrigation techniques, water management practices, and the benefits of sustainable irrigation methods. Increased awareness and knowledge support better adoption of effective practices.

3.1.4. Site topography

Rwamagana is located in the lowlands of the East. The lowlands are dominated by a depression of the relief, generally undulating between 1500-1100 m of altitude. Land use and land covers patterns are important in environmental impact assessment study from the point of view that land use describes the present use such as agriculture, settlement, etc. and land cover, describes the material on it such as forest, vegetation and rocks or building.

The District of Rwamagana is characterized, in general, by lowly undulating hills separated by valleys some of which are swampy and boggy. It has average elevation of 1594m, Longitude: 30.3896651. The figure 3.6 identify how the topography of Rwamagana looks like.

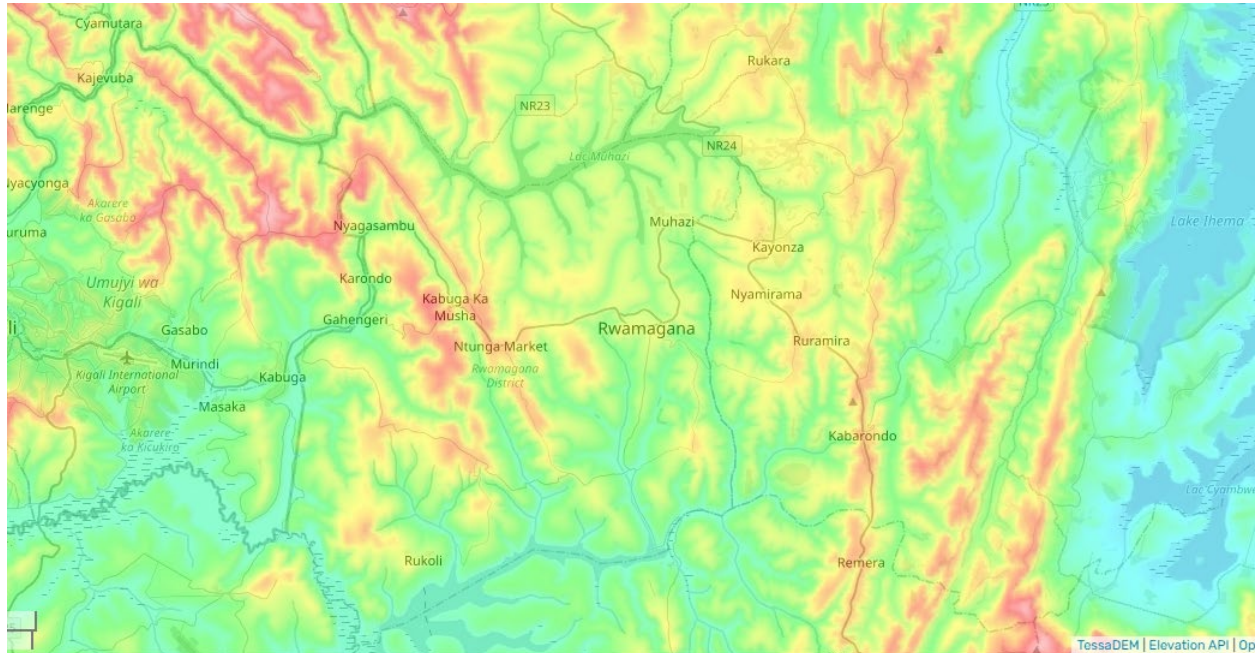


Figure 3.6: Rwamagana topographic map, elevation, terrain.

3.1.5. Rainfall pattern of the site

The historical rainfall data for 42 years from the nearest meteorological station, Mwulire station, were collected through the Rwanda Meteorology Agency, and the related IDF curves were established accordingly. The Gumbel distribution method statistically analyzed those data, establishing their corresponding IDF curves. We used the established IDF curves to determine the rainfall intensity, which corresponds to the calculated time of concentration within the considered return period.

Extreme events like severe storms, floods, and droughts can sometimes impact hydrologic systems. The magnitude of an extreme event is inversely related to its frequency of occurrence; very severe events occur less frequently than more moderate events. The goal of frequency analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence using probability distributions.

The return period T of the event $X \geq x_T$ is the expected value of t , $E(t)$, its average value measured over a very large number of occurrences. Thus, the return period of an event of a given magnitude may be defined as the average recurrence interval between events equaling or exceeding a specified magnitude.

The probability $p = P(X \geq x_T)$ of occurrence of the event $X \geq x_T$ in any observation may be related to the return period in the following way. For each observation, there are two possible outcomes: either "success" $X \geq x_T$ (probability p) or "failure" $X < x_T$ (probability $1-p$). Since the observations are independent, the probability of a recurrence interval of duration T is the product of the probabilities of $t-1$ failures followed by one success, that is, $(1-p)^{t-1}p$.

Assuming that the series of data is infinite, the $E(T)$ can be expressed as:

$$E(t) = \sum_{t=1}^{\infty} (1-p)^{t-1} \times p$$

Developing this expression in terms and after some algebra:

$$E(t) = T = \frac{1}{p}$$

So, the probability of occurrence of an event in any observation is the inverse of its return period.

$$P(X \geq x_T) = \frac{1}{T}$$

a) Gumbel Extreme Values Distribution

A large amount of process events in hydrology are right skewed, leading to differences between the mode, median and mean of their distributions. The objective of this distribution is to build the relation between the probability of the occurrence of a certain event, its return period and its magnitude.

Data preparation for Gumbel method

For this project, the daily rainfall data for a period from 1981 to 2022 were used.

- 1- Rank the yearly maximum flood values from low to high. So assign lowest rank 1 to the lowest data value and assign the highest rank N to the highest data value:

- 2- Calculate for each observation the left sided probabilities (failure probabilities) by the Empirical frequency formula from Hazen:

$$P_L = \frac{R - 0.5}{N}$$

Where P_L = left sided probability

R = Rank

N = number of observations

- 3- Determine the return period for each observation

$$T = \frac{1}{P_R} = \frac{1}{1 - P_L}$$

- 4- Determine the plotting position for each observation

$$Y = -\ln(-\ln(P_L))$$

- 5- Finally, since the 'y' axis is directly related to the probability or the return period, the values are exchangeable. The next step is to replace the values in the 'y' axis by the corresponding of P and T. To do that the following equations are determined:

$$P_L = e^{-e^{-y}}$$

$$T = \frac{1}{P_R} = \frac{1}{1 - P_L}$$

The statistical methods discussed are applied to extend the available data and hence predict the likely frequency of occurrence of natural events. Given adequate records, statistical methods will show that floods of certain magnitudes may, on average, be expected annually, every 10 years, every 25 years, every 50 years, every 100 years and so on.

The collected data were the daily rainfall data for a period of 42 years, from 1981 to 2022. We conducted a hydrological analysis by categorizing these data. The hydrological study focused on the annual maximum daily rainfall data, a crucial factor in determining the peak discharge for road construction and flood control projects.

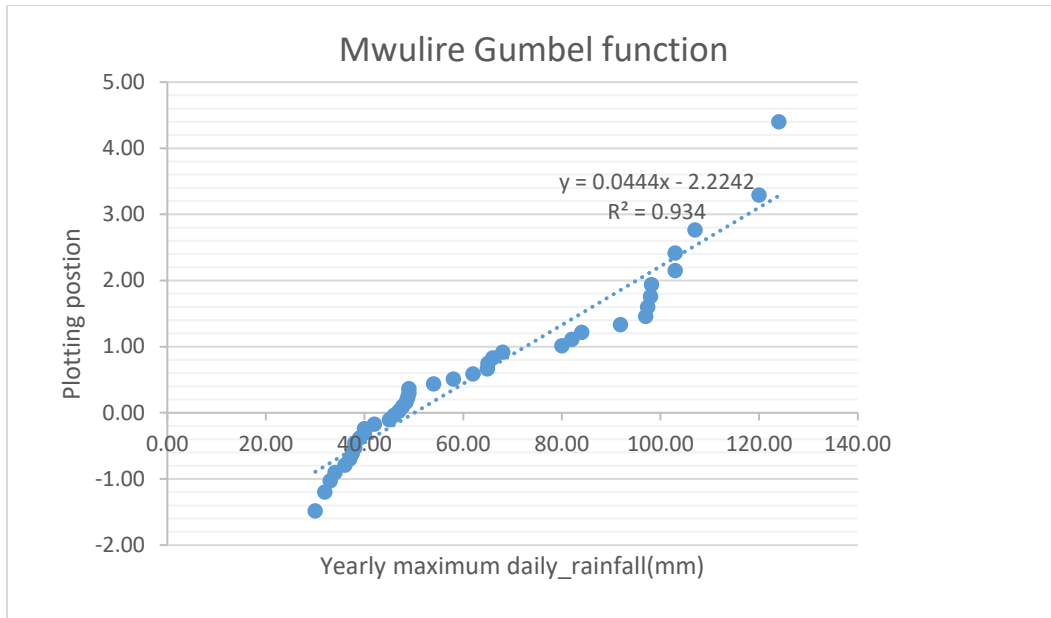


Figure 3.7: Gumbel function for mwulire station

Table 3.1: maximum and minimum temperature and rain data per year in Rwamagana

Month	Day	Night	Rain Days
January	26°c	16°c	12
February	27°c	16°c	14
March	26°c	16°c	17
April	24°c	15°c	19
May	24°c	15°c	11
June	25°c	15°c	2
July	27°c	16°c	1
August	27°c	17°c	4
September	27°c	17°c	12
October	26°c	16°c	18
November	25°c	15°c	22
December	25°c	15°c	17

The weather averages for the month of July, temperature averages around 27°C and at night, it feels like 16°C. In July, Rwamagana gets on an average 5.51mm of rain and approximately 1 rainy days in the month. Humidity is close to 56%.

Maximum rainfall occurred in 1999 which is 124mm and minimum occurred in 1992 which is 30mm.

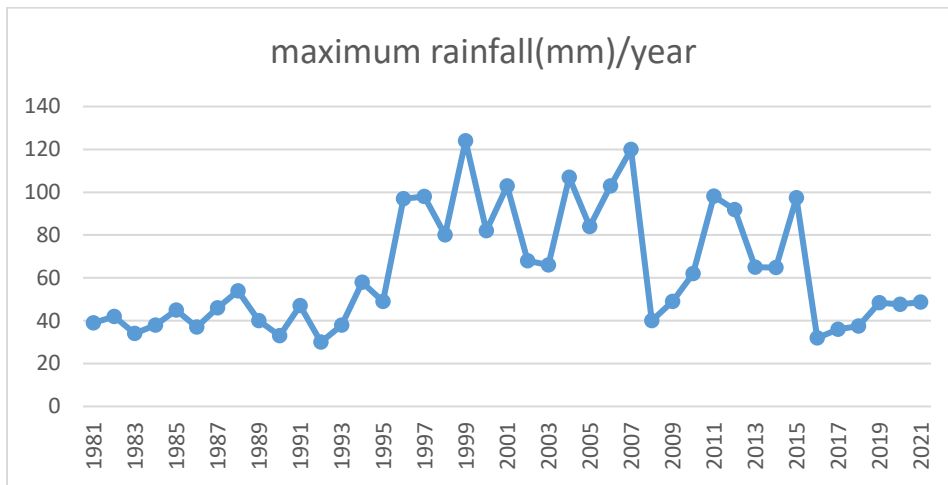


Figure 3.8: maximum rainfall data (1981-2022) at mwulire station

3.1.6. Catchment Area and their parameters

The catchments for this project were delineated based on the digital elevation model (DEM) of 10 m of resolution by using the Arc Hydro and HEC-GeoHMS tools integrated into Arc GIS and HEC-HMS softwares. The delineated catchments area is 256km², covering the all irrigation scheme.

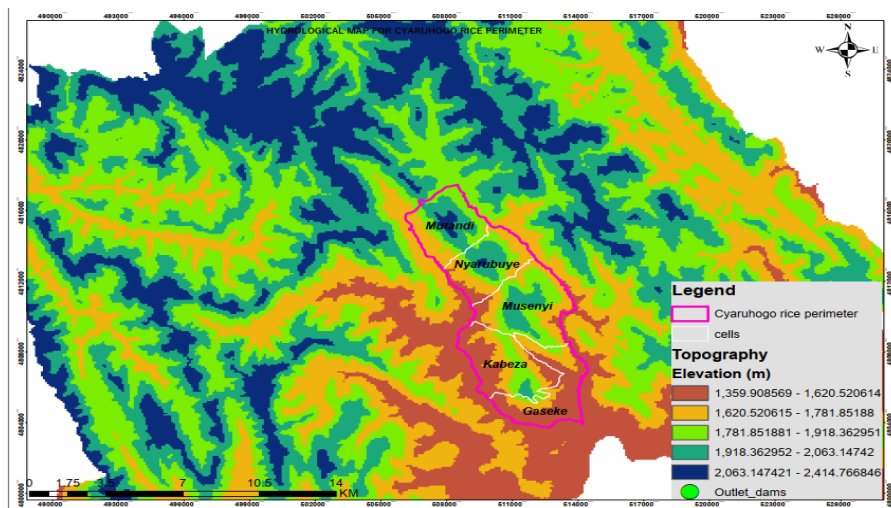


Figure 3.9: hydrological map

3.1.7. Hydrograph of the site

The figure 3.8 presents the flow of water in the study scheme. All dams supply the marshland of Cyaruhogo.



Figure 3.10: dams use in irrigation system at Cyaruhogo marshland

3.1.8. Socio economic environment

The household economic condition with reference to poverty and extreme poverty are set at 118,000 and 83,000 RWF, Rwamagana district is ranked sixth bottom position countrywide by percentage of extreme-poor and poor1 population categories. About 70% of the population in Rwamagana district is identified as non-poor, 18% as poor (excluding extreme-poor) and 12% as extreme-poor. Compared with other districts of Eastern Province, Rwamagana district comes first for proportion of non-poor. Rwamagana district is among the five districts within the 25–40% interval for the proportion identified as poor [31]

3.2. RESEARCH MATERIALS

Materials for research are those that will aid in understanding a subject and constructing a convincing case or justification. In this research, several materials are required such as questionnaire design, participants, laboratories experiments for measuring different parameters and excel software has used to analyze the results.

3.3. RESEARCH METHODS

3.3.1. Site visits

Cyaruwego wetland is where around 1300 farmers are used to yield production according to availability of water from three dams. Table 3.2 presents the catchment areas and dam storage capacity.

Table 3.2: Dams' capacity and their catchment area

Dam	Unit	Cyimpima	Gashara	Bugugu
Catchment area designed	Km ²	15.3	26.5	13.9
Dam Capacity	M ³	640,000	640,000	380,000

3.3.2. Questionnaire design and interviews

In this dissertation, questionnaires and interviews are essential tools used to collect data from participants. Here's a breakdown of how they are typically approached in the research process. There is no limited in terms of age, gender, options and other case. The respondents had equal chance in questionnaire.

Population of the Study

The research population or target groups included the rice farmers 1300 in the Cyaruwego wetland in all three schemes of Cyimpima, Bugugu and Gashara and 20 cooperative representatives and 3 local government agronomists. The farmer presented the benefits of irrigation system to their yield and to the society in general.

Sample size

When it is not possible to study an entire population but the population is known, a smaller sample is taken from strata by purposive sampling technique. When it is not possible to study an entire population but the population is known, a smaller sample is taken from strata by purposive sampling technique. Yamane's formula allows a researcher to sample the population with a desired degree of accuracy. Yamane's formula is used to calculate the sample size.

With regard to the level of accuracy, we used a confidence level of 90%, this means that there are 90 chances in 100 (or 0.9 in 1) that the sample results represent the true condition of the

population within a specified precision range against 10 chances in 100 (or .10 in 1) that it does not. The Yamane’s formula was applied to calculate the number of householders’ respondents, and calculated as follows:

$$n = \frac{N}{1+N(e)^2} \dots\dots\dots (Eq2)$$

Whereas: n= Number of samples or sample size

N= Total population

e= Error of tolerance (10% =0.1)

The total number of population in all schemes are 1324 population. Then the sample size to participate in this study is calculated as follows:

$$n = \frac{N}{1+N(e)^2} = \frac{1324}{1+1324(0.1)^2} = \frac{1324}{1+13.24} = 93 \text{ users as irrigation beneficiaries}$$

Table 3.3: sample size from population target

Sample size	farmers	Cooperative presidents	agronomist	Irrigation engineer	Totals
Cyaruhogo wetland	81	9	2	1	93

The table 3.3 indicates the number of participants during the research to be interviewed. The farmers is 81, cooperative presidents is 9, 2 agronomists and 1 irrigation engineer.

3.3.3. Soil sampling and laboratory tests

The perimeter was subdivided into two blocks for which 10 plots were randomly sampled. Using a marker pen, we marked you on an auger successively, 0-20, 20-40 and 40-60 cm depth. The auger was driven into the ground to collect soil samples each time, at the depth determined by the auger graduation. Soil test: The textural classification is based on the particle-size distribution of the percent of gravel, sand, silt, and clay size fractions present in a given soil. Such as Massachusetts Institute of Technology (M.I.T) classification or sieve analysis, liquid and plastic limit system (M.I.T classification)

3.3.4. Water sampling and laboratory tests

Testing water quality before using it for irrigation is crucial to ensure that it meets the requirements for healthy plant growth and soil preservation. Water from three different dams namely Cyimpima, Bugugu and Gashara has taken for measuring several parameters

It includes PH, Electrical Conductivity (EC), Total Dissolved Solids(TDS, Dissolved Oxygen (DO),Sodium Adsorption Ratio (SAR), Calcium (Ca), Magnesium (Mg), Sodium (Na), and Potassium (K): These are essential nutrients for plant growth, and their levels in water can affect soil fertility and plant nutrition, Boron (B), Chloride (Cl), Heavy Metals and Microbiological Contaminants.

Water sampling consisted of taking a sample at the intake, two samples throughout the perimeter and a sample at the outlet of the irrigated perimeter. This was carried out using plastic bottles emptied after consumption of the contents

3.3.5. Sediment from laboratory process

The quantity of sediment in one litre of water was measured by heating water and then measure the quantity of sediment from water by using balance.

3.3.6. Secondary data collection

Documentary sources were used as secondary data obtained from Journals, Textbooks, Water user's association records, MINAGRI reports, NISR reports, and other written materials about irrigated agriculture. Such documents allowed the researcher to acquire relevant information to support the research findings. However, it is important to note that these research instruments are not equally limited; rather, they serve to complement each other.

3.3.7. Data analysis

Data analysis is the most crucial part of any research and it summarizes collected data. Collected data from the site will be analyzed by using excel to interpret the participation of respondents in this research.

4. RESULTS AND DISCUSSION

4.1. TOPO MAP AND MAIN FEATURES OF THE SITE

The District of Rwamagana characterized by lowly undulating hills separated by valleys some of which are swampy and boggy. This kind of topographical layout constitutes an important potentiality for modern irrigation system and mechanized agriculture. Agriculture and live stock is the principal economic activity that employees over 80% of the population in rural areas of whom, at least 85% use traditional agriculture practices. The major crops of the district include bananas, rice, maize, pineapple and coffee. The District is rich in Minerals (Cassitérite, Colombo tantalite and Wolfram) especially in parts of the sectors of Musha, Mwulire and Gahengeri which is exploited by mining companies.



Figure 4.1: Cyaruhogo marshland's location

4.2. INTERVIEW'S RESULTS

4.2.1. Identification of the respondents

The table 4.1 presents the age of respondents during the questionnaire and interview.

Table 4.1: Age of respondents

Years of respondents	Number	Percentage
18-30	27	29.03226
31-45	36	38.70968
46-60	25	26.88172
60-above	5	5.376344
total	93	100

It shows that 27 of irrigation beneficiary representing 29% are 18-30 years, 36 of irrigation beneficiary representing 38.7% are 31-45 years old and 125 of project beneficiary representing 26.883percentage are 46-60 years old and 5 of irrigation beneficiary presenting 5.4% are over 60 years old.

Respondents based on gender are also included in this research. The number of female are more than double of male in the wetland as the table 4.2 illustrates

Table 4.2: Gender of respondents

Respondents	Quantity	Percentage
male	27	29.03226
female	66	70.96774
total	93	100

The table 4.2 shows that 66 respondents representing 71% are female, while 27 respondents representing 29% are male.

The several categories are used in the interview such as farmers, cooperative presidents, agronomists and irrigation engineers.

Table 4.3: Occupation respondents

Respondents	number	percentage
Famers	81	87.09677
cooperative	9	9.677419
Engineer	1	1.075269
agronomists	2	2.150538
total	93	100

The table 4.3 **reveals** that 81 of respondents of farmers level was too high at 87.09%, 9 respondents of cooperative presidents were 9.67%, 2 agronomists at 2.15% and, 1 respondent of irrigation engineers were at be 1.07%.

The respondent's status of Cyaruhogo wetland farmers are described in the table 4.4. Some are married, single and widowers

Table 4.4: Civil status of respondents

Respondents	number	percentage
married	62	66.66667

single	14	15.05376
widower	17	18.27957
total	93	100

The table 4.4 presents how the status of respondents looks like. Married people are 62 (67%), widowers are 17 (18%) and single are 14 with rate of 15%.

In wetland the farmers and staffs have different qualification as the table 4.5 shows

Table 4.5: participant's qualification

Respondents	number	percentage
unschooled	27	29.03226
primary	26	27.95699
secondary	30	32.25806
diploma	7	7.526882
bachelors	3	3.225806
total	93	100

The table 4.5 presents the number of same qualified in the Cyaruhogo wetland. Unschooled people are 29%, primary is 28%, secondary is 32%, diploma is 7.53% and bachelors is 3.22%.

Raising awareness of the development of the Cyaruhogo marsh

The majority of farmers in the Cyaruhogo wetland believe that the irrigation system is the source of their products. Awareness themes have presented in table 4.6.

Table 4.6: raising awareness of the development wetland

theme	effective	percentage
Increase in agricultural production	28	30.11%
increase in rice production	39	41.94%
Technical innovation in agriculture.	18	19.35%

fight against poverty	8	8.60%
total	93	100%

The table 4.6 indicates that the development of zones depends on some target of beneficiaries such as increase in agriculture, the respondents are 28 (30.11%), increase in rice production is 39(41.94%), technical innovation in agriculture is 18 (19.35%) and fight against poverty is 8(9.86%)

4.2.2. People’s knowledge about soil erosion climate change

Table 4.7 presents the number of respondents according to the knowledge about soil erosion due to climate change. The 80.64% has knowledge about soil erosion, 17.2% presents the some with knowledge but not enough and 2.15% has no idea about it.

Table 4.7: People’s knowledge about soil erosion due to climate change

Respondents	number	percentage
yes	75	80.64516
no	2	2.150538
not enough	16	17.2043
total	93	100

4.2.3. Causes of climate change in the area of Cyaruhogo marshland

Some causes of climate change in the Cyaruhogo marshland are temperature, precipitation and human activities. The table 4.8 illustrates the results from participants

Table 4.8: Cause of climate change ay Cyaruhogo marshland

Respondents	number	percentage
temperature	43	46.23656
precipitation	23	24.73118
human activities	27	29.03226
total	93	100

From table 4.8, 46.23% agreed that temperature can cause the change in climate in Cyaruhogo wetland, 24.74% mentioned precipitation while 29.03% agreed the human activities as cause of climate change in this study area.

4.3. EFFECTS OF CLIMATE CHANGE ON CYARUHOGO RICE YIELD PERIMETER

4.3.1. Factors of climate change that affect the yield production of rice

Several climate factors can significantly influence rice yield production at Cyaruhogo wetland such as change in temperature, precipitation, humidity, carbon dioxide, and sunlight and season variation.

- ❖ Temperature variation: Rice is temperature-sensitive at all growth stages. While ideal temperatures vary from variety to variety, in general, growth is best served by temps between 20°C and 35°C. While low temperatures can delay maturity and diminish grain filling, high temperatures during the flowering and grain-filling stages can reduce output. Warmer temperatures and altered precipitation patterns can create favorable conditions for pests and diseases that affect rice plants. This can lead to higher crop losses if not managed properly.
- ❖ Precipitation: Rainfall or irrigation that is both sufficient and evenly distributed is essential for rice farming. While too much water can produce flooding, which also hinders growth and development, too little water can induce drought stress and lower output.
- ❖ Humidity: Rice requires high humidity levels, especially during the flowering and grain-filling stages. Low humidity levels can affect pollen viability and reduce grain formation
- ❖ Carbon Dioxide (CO₂) Levels: Higher CO₂ levels and heat stress can reduce the nutritional quality of rice. For example, elevated CO₂ levels may decrease protein and micronutrient content in rice grains. Under some circumstances, higher atmospheric CO₂ concentrations may encourage photosynthesis in rice plants, increasing biomass and production. However, nutrient availability and other environmental conditions may have an impact on how much of this advantage is realized.
- ❖ Wind: Particularly while the plant is in the blooming and grain-filling stages, strong winds can physically harm rice plants. Pollen distribution can also be impacted by wind, which may result in reduced grain set and yield.

- ❖ Sunlight: Rice is a C3 plant and requires sufficient sunlight for photosynthesis and proper growth. Light intensity and duration influence the photosynthetic rate, which in turn affects biomass production and grain yield. The level of sun can cause the drought as effect of sun prolongation. In this case irrigation is needed otherwise loss for rice farmers.

From the respondent’s options, the table 4.9 presents that the farmers gain or loss according to the climate change.

Table 4.9: Effect of climate change on rice parameter

Respondents	quantity	percentage
loss	61	65.5914
gain	32	34.4086
total	93	100

From table 4.9, 65.59% of respondents agreed that the climate change can cause loss in the rice yield while 34.4% disagreed

4.4. CYARUHOGO CATCHMENT SOIL CLASSIFICATION

4.4.1. MIT soil classification or sieve analysis

The textural classification is based on the particle-size distribution of the percent of gravel, sand, silt, and clay size fractions present in a given soil. Such as Massachusetts Institute of Technology classification system (M.I.T classification) and the U.S. Department of Agriculture.

Sieve analysis consists of shaking the soil sample through a set of sieves that have progressively smaller openings. U.S. standard sieve numbers and the sizes of openings are given in Table 4.10. The smallest-sized sieve that should be used for this type of test is the U.S. No. 200 sieve

For gravel soil, the current size designation for U.S sieve is:

Table 4.10: U.S. standard sieve

100.0 mm	37.5 mm	12.5 mm
75.0 mm	31.5 mm	9.5 mm
63.0 mm	25.0 mm	8.0 mm
50.0 mm	19.0 mm	6.3 mm
45.0 mm	16.0 mm	

For sandy soils, the designation used number as shown in Table 4.10

Table 4.11: US standard sieve sizes

Sieve no.	Opening (mm)	Sieve no.	Opening (mm)
4	4.75	35	0.500
5	4.00	40	0.425
6	3.35	50	0.355
7	2.80	60	0.250
8	2.36	70	0.212
10	2.00	80	0.180
12	1.70	100	0.150
14	1.40	120	0.125
16	1.18	140	0.106
18	1.00	170	0.090
20	0.850	200	0.075
25	0.710	270	0.053
30	0.600		

Other contraries may use a different size. In addition, some use sieve No. 270

(0.053 mm), No. 325 (0.045 mm), and No. 400 (0.038 mm). Once the percent finer for each sieve is calculated, then are plotted on semilogarithmic graph paper with percent finer as ordinary scale, and sieve opening size as the abscissa (logarithmic scale).

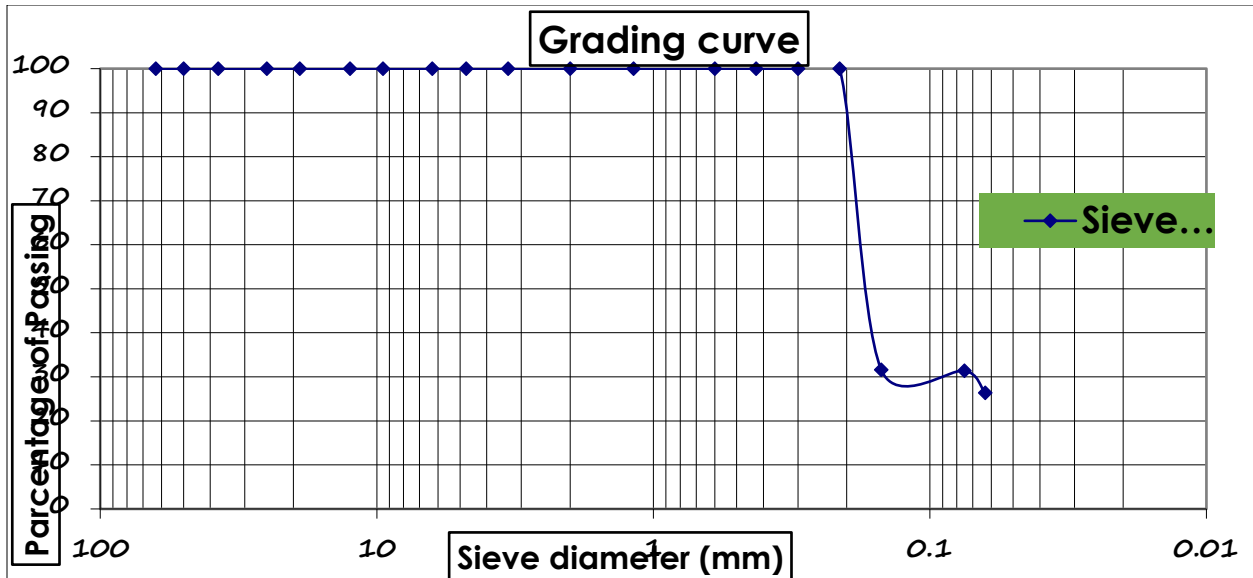
This plot is referred to as the particle-size distribution curve.

Table 4.12: Sieve analysis with hydrometer for point 1

SIEVE ANALYSIS WITH HYDROMETER						
Sieze of Washed and Oven Dried Soil Samples		Sieve (mm)	Partial Retained (gr)	Cumulative Retained (gr)	% Retained	% Passing
Initial Mass (gr):	644.8	63	0	0	0.0	100.0
Final Mass (gr):	440.8	50	0	0	0.0	100.0
		37.5	0	0	0.0	100.0
Soil Coefficients		25	0	0	0.0	100.0
Coefficient of Curvature (CC)	<i>N/A</i>	19	0	0	0.0	100.0

Coefficient of Uniformity (CU)	<i>N/A</i>	12.5	0	0	0.0	100.0
Soil Characteristic Diameters		9.5	0	0	0.0	100.0
D60	<i>0.17</i>	6.30	0	0	0.0	100.0
D30	<i>0.07</i>	4.75	0	0	0.0	100.0
D10	<i>N/A</i>	3.35	0	0	0.0	100.0
		2	0	0	0.0	100.0
Soil Matrix Composition by Mass		1.18	0.0	0.0	0.0	100.0
GRAVEL(%)	<i>0.0</i>	0.6	0.0	0	0.0	100.0
Coarse Sand(%)	<i>0.00</i>	0.425	0.0	0.0	0.0	100.0
Medium Sand(%)	<i>0.00</i>	0.3	0.0	0.0	0.00	100.0
Fine Sand(%)	<i>68.58</i>	0.212	0.0	0.0	0.0	100.0
SAND	<i>68.58</i>	0.15	440.8	440.8	68.4	31.6
SILT AND CLAY(%)	<i>31.4</i>	0.075	1	442.2	68.6	31.4
		0.063	33	474.9	73.7	26.3

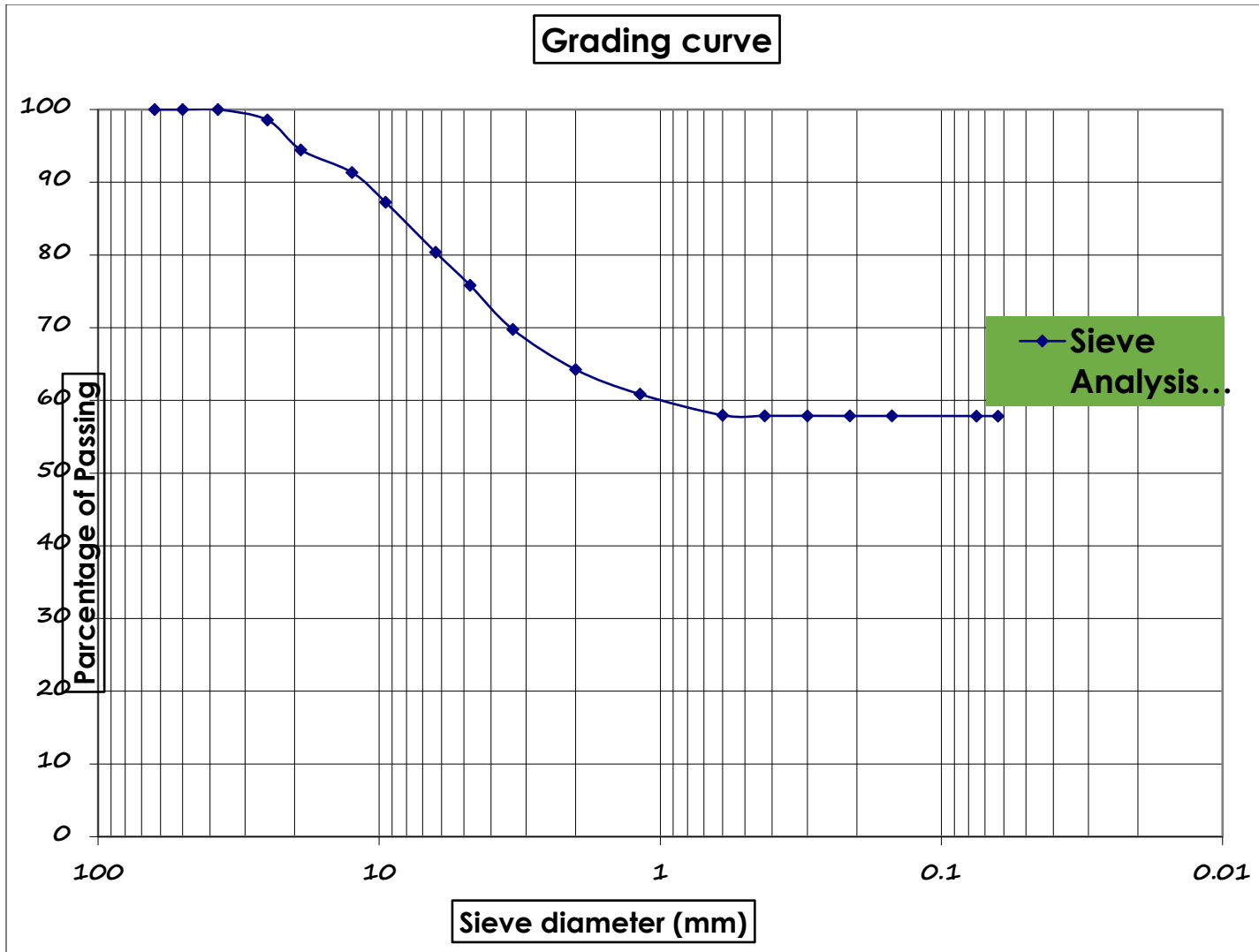
Table 4.13: Sieve analysis with hydrometer for point 1



Initial Mass (gr):	<i>644.8</i>
Final Mass (gr):	<i>380.0</i>
Soil Coefficients	
Coefficient of Curvature (CC)	<i>N/A</i>
Coefficient of Uniformity (CU)	<i>N/A</i>
Soil Characteristic Diameters	
D60	<i>0.08</i>
D30	<i>0.06</i>
D10	<i>N/A</i>
Soil Matrix Composition by Mass	
GRAVEL(%)	<i>0.0</i>
Coarse Sand(%)	<i>0.00</i>
Medium Sand(%)	<i>0.00</i>
Fine Sand(%)	<i>41.87</i>
SAND	<i>41.87</i>
SILT AND CLAY(%)	<i>58.1</i>

63	0	0	0.0	100.0
50	0	0	0.0	100.0
37.5	0	0	0.0	100.0
25	0	0	0.0	100.0
19	0	0	0.0	100.0
12.5	0	0	0.0	100.0
9.5	0	0	0.0	100.0
6.30	0	0	0.0	100.0
4.75	0	0	0.0	100.0
3.35	0	0	0.0	100.0
2	0	0	0.0	100.0
1.18	0.0	0.0	0.0	100.0
0.6	0.0	0	0.0	100.0
0.425	0.0	0.0	0.0	100.0
0.3	0.0	0.0	0.00	100.0
0.212	0.0	0.0	0.0	100.0
0.15	0.0	0.0	0.0	100.0
0.075	270	270.0	41.9	58.1
0.063	205	474.9	73.7	26.3

Table 4.15: Sieve analysis with hydrometer for point 2



4.4.2. Liquid Limit (LL) and plastic limit

Table 4.16: Liquid Limit (LL) and plastic limit for point1

Date of Test:	24/5/2024	Point1	1
Sample N°:	0	Depth (m):	0.30

		Liquid limit					5 (<35)	Plastic limit		Liquid limit
		1	2	3	4					
Number of blows		15	20	24	30	35				28.31%
Pan Nr ^o		1	2	3	4	5	1	2		
Wet weight + pan	[g]	25.0	28.0	32.0	33.0	20.0	14.3	14.5		
Dry weight + pan	[g]	21.3	22.8	21.1	23.7	19.6	17.0	12.4		Plastic limit
weight of pan	[g]	1.5	1.5	1.5	1.5	1.5	1.5	1.5		
weight of water	[g]	3.7	5.2	10.9	9.3	0.4	-2.7	2.1		0.92%
Dry weight	[g]	19.84	21.3	19.6	22.2	18.1	15.5	10.9		
Moisture content	[%]	18.4%	24.4%	55.6%	41.9%	2.2%	-	17.4%	19.3%	
Estimation for 25 blows	[%]	17.34%	23.7%	55.3%	42.8%	2.30%				Plasticity Index
Average	[%]	28.31%						0.92%		27.39%

Table 4.17 Liquid Limit (LL) and plastic limit for point 1

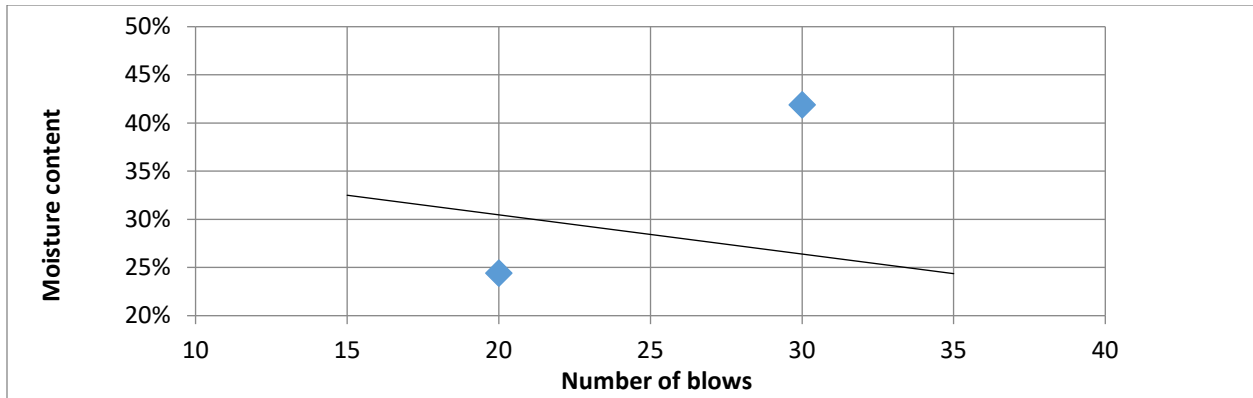
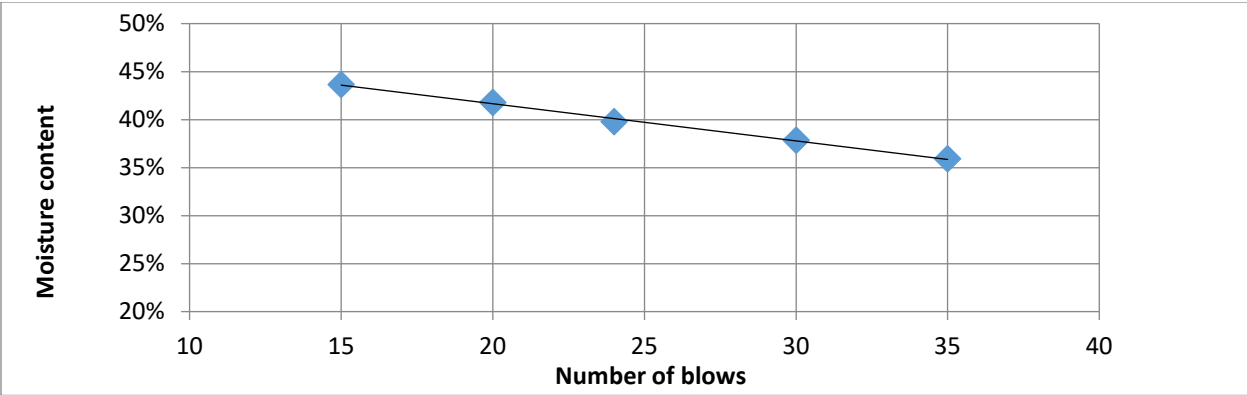


Table 4.18: Liquid Limit (LL) and plastic limit for point2

Date of Test:	24/5	Point4	1						
Sample N°:	1	Depth (m):	0.30						
		Liquid limit					Plastic limit		Liquid limit
		1	2	3	4	5 (<35)			
Number of blows		15	20	24	30	35			39.48%
Pan Nr°		1	2	3	4	5	1	2	
Wet weight + pan	[g]	30.0	31.7	28.9	32.1	26.1	14.3	14.5	
Dry weight + pan	[g]	21.3	22.8	21.1	23.7	19.6	12.2	12.4	Plastic limit
weight of pan	[g]	1.5	1.5	1.5	1.5	1.5	1.5	1.5	
weight of water	[g]	8.7	8.9	7.8	8.4	6.5	2.1	2.1	19.45%
Dry weight	[g]	19.84	21.3	19.6	22.2	18.1	10.7	10.9	
Moisture content	[%]	43.6%	41.8%	39.8%	37.8%	35.9%	19.6%	19.3%	

Estimation for			40.6	39.6	38.6	37.4		Plasticity
25 blows	[%]	41.03%	7%	0%	8%	0%		Index
Average	[%]	39.48%					19.45%	20.03%

Table 4.19: Liquid Limit (LL) and plastic limit for point2



4.5. IMPACTS OF CLIMATE CHANGE ON IRRIGATION WATER AT CYARUHOGO WETLAND

The findings indicate that variations in temperature and precipitation patterns have affected the availability of water resources. The availability of irrigation water in wetlands is impacted by climate change in multiple ways which including in main categories of temperature and rainfall. The study area has no weather station which is operational, one meteorological station (Kigali Airport) closer to the study area was selected to know the variations in rainfall and temperature patterns. This station was selected simply because it is the closest functioning station and the climatic conditions are similar to those of Rwamagana District

Modifications to Precipitation Patterns: As a result of climate change, rainfall is becoming more erratic and intense. This may lead to dry spells that are followed by heavy downpours, which could reduce the amount of water in wetlands that are utilized for irrigation.

Variations in climate can cause disturbances in the natural cycles of water, which can impact the availability of surface water in wetlands and the rates at which groundwater recharges. This

unpredictability may make irrigation water management. Rwamagana experiences extreme seasonal variation in monthly rainfall. Rain falls throughout the year in Rwamagana. The figure 4.2 presents the average rainy in Rwamagana. This data is from the meteorological station (Kigali Airport) 2016-2024. Where 1 inch is equal to 0.0254m

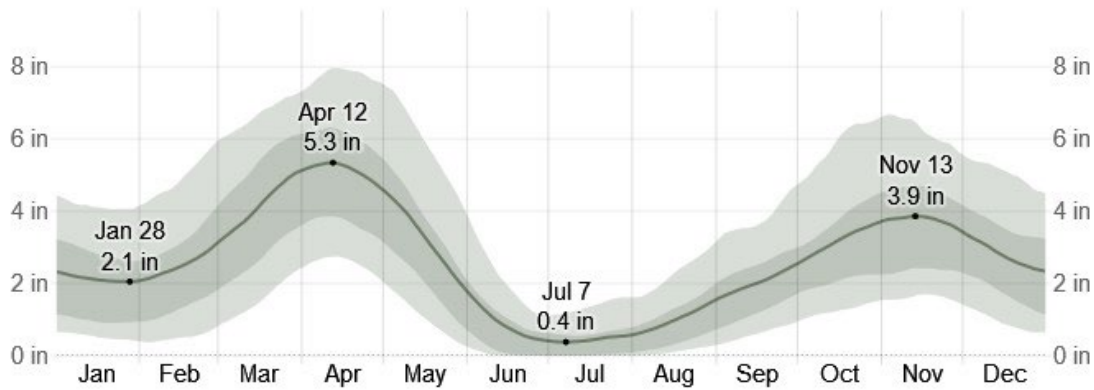


Figure 4.2: average rainy of Rwamagana from 2016-2024

In April, the rainy is heavy where the erosion case occurs and then the sedimentation created in the dam. Sediment in the reservoir decreases the dam capacity and then crop yield reduces during the dry season. Since July, the long dry season occurs where the irrigation activities are needed in the wetland. And also in November the rainy also falls in the wetland.

Temperature analysis

Elevated Evapotranspiration: The rising temperatures linked to global warming have the potential to augment the rates of evaporation from marshes and transpiration from plants. This may result in less water being available overall for irrigation. In dry season, the temperature rises and water for irrigation reduces. The figure 4.3 presents the variation of temperature in Rwanda.

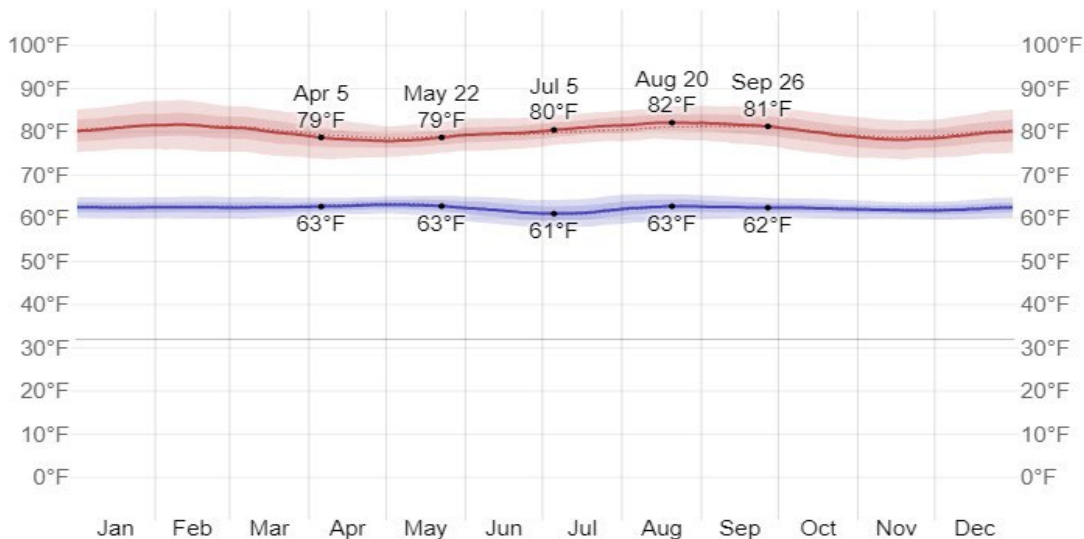


Figure 4.3: average temperature at MWulire station

Source: Kigali metrological station

Sea Level Rise: In coastal wetlands, an increase in sea level cause freshwater supplies utilized for irrigation to become contaminated by saltwater. Crop productivity may be impacted by this incursion since it may lower irrigation appropriateness and deteriorate water quality.

Extreme Weather Events: Storms, hurricanes, and cyclones are examples of the extreme weather events that are becoming more often and intense due to climate change. These occurrences have the potential to destabilize irrigation infrastructure and reduce water supply by causing flooding or erosion in wetlands.

Ecological Impacts: Wetland ecosystems and biodiversity may be impacted by changes in water availability and quality brought on by climate change. The availability of ecosystem services that support sustainable irrigation methods may be impacted by changes in habitat conditions.

Adaptive techniques, such as better water management techniques, water-efficient irrigation technologies, sustainable wetland management, and climate-resilient agricultural methods, are crucial to reducing these effects. In addition, community involvement and policy actions can help to guarantee sustainable irrigation water usage in the face of changing climate conditions and strengthen the resilience of wetland ecosystems.

4.5.1. Effect of climate change on raw water quality of Cyaruhogo wetland

Water quality has tested in laboratory from three dams such as Cyimpima, Gashara and Bugugu. Rainfall patterns, frequency variations, flood fluctuations, and other extreme occurrences all lead to changes in the flows regimes that are brought about by modifications in the hydromorphology, chemical reactions, and ecological environment of the water bodies.

Increased air temperature, Excess evaporation, increase in nutrient loading. Then, Reduced stream flow and fluctuations of basic water quality parameters and also Increase in total Nitrogen, phosphorous occurs. Increased water temperature, runoff, sediment, increased greenhouse gases(GHG) emissions and drought-flood fluctuations are found to impact water quality parameter like river discharge, suspended solids and nutrient causing impacts on increasing phytoplankton and disturbances. All these factors influence the Green House Gases (GHG) concentrations, which lead to global temperature increase and climate extreme events like heavy rainfall, extreme heat, drought, wildfires, cyclone, hurricane and any super storms

They have high risks on water quality in the form of increased water turbidity, total suspended solids (TSS), total solids (TS) and pathogens in water, thereby, changing the water quality of rivers/water bodies. So the change of climate cause negative effects on Cyaruhogo wetland.

4.5.2. Effect of the irrigation system on the biological environment

There are three animal species listed: insects, amphibians, and birds. Mammals and reptiles were not seen in the field survey. Nonetheless, the data showcased here was gathered through interviews with community members. Additionally, a few plant species were noted. Rice and other food crops including beans and soya were the most prevalent in all of the sites surveyed.

Amphibians: The species were observed at several locations in Cyaruhogo Mash. It is difficult to say that those are the only species found in this area since the sampling was done in mornings and afternoons only. Some amphibian species are known to be nocturnal. However, given that the ecosystem is mostly disturbed, it is difficult to find other species. The figure 4.2 presents flog in Cyaruhogo marshland.



Figure 4.4: frog in marshland

Birds: during the site visit, around 9 species of birds were identified in presented in figure 4.3.



Figure 4.5: birds in marshland

Not only the above animals, *Canis adustus*, *Genetta servalina*, *Galerella* and *sanguinea* were founded in that area before the project.

Apart from the animals, the different vegetable spaces was found in the wetland which was affected in the construction project of irrigation. The respondents said that flora species were in Gashara area

After interviewing the beneficiaries from Cyaruhogo wetland, the major respondents agree that irrigation system is the source of products doubly as the table 4.20 illustrates.

Table 4.20: respondents for effect of irrigation system in wetland

option	number	percentage
profit increases	85	91.40%
loss	8	8.60%
total	93	100.00%

According to the respondents, the irrigation system helps the farmers to rise the products even if it is dry season but the little number of respondents around 8(8.6%) disagreed

4.6. LABORATORY TEST RESULTS

4.6.1. At Cyimpima dam

Rainy season:

Date: 14 may 2024, a litre of water was taken from Cyimpima dam for measuring the PH of water, Total Suspended Solids (TSS), total Dissolved Solids (TDS), electrical conductivity and turbidity of soil.

Laboratory Glassware

Glassware: Various types of glassware are used in conjunction with pH meters or test strips for accurate measurements.

Components:

Beakers, Flasks, and Test Tubes: Used to hold and mix samples.

Burettes: Used in titrations to determine pH.

Table 4.21: PH of water and electrical conductivity in the soil in rainy season at Cyimpima dam

Position for sampling	PH at water	EC ($\mu\text{s/cm}$)	TSS (mg/l)	TDS (mg/l)	Turbidity (NTU)
At streamflow entering the dam	6.95	107.2	364	122.1	67.8
At the irrigation water coming from the dam	7.01	108.74	334	69.2	53.1
Water in selected plot	6.78	104.7	307	63.9	31.5

The table 4.21 shows the PH of water entering in the dam in rainy season, electrical conductivity, Total Suspended Solids (TSS), total Dissolved Solids (TDS) and turbidity of soil, in the dam and the water irrigated to the scheme. PH of water entering to the dam is higher than the water going to be used in irrigation. TSS before entering to the dam is 364 mg/l while the water from the reservoir to the scheme is 307mg/l. turbidity for water flowing to the dam is 67.8 NTU and outlet from the dam to the scheme is 31.5NTU.

Dry season: 27 June 2024

The bottle of one litre was taken from Cyimpima dam and it's around.

Table 4.22: PH of water and electrical conductivity in the soil in dry season at Cyimpima dam

Position for sampling	PH at water	EC ($\mu\text{s/cm}$)	TSS (mg/l)	TDS (mg/l)	Turbidity (NTU)
At streamflow entering the dam	6.99	107.5	323	95.3	49.56
At the irrigation water coming from the dam	7.06	108.8	312	45.7	37.92
Water in selected plot	6.81	105.3	272	49.2	29.5

Table 4.22 indicates that the PH at streamflow entering the dam is 6.99, 6.81 for outlet water from the dam to the plot. TSS changes from the incoming water to the dam reduces to the water from the dam 323mg/l to 272mg/l respectively.

4.6.2. At Bugugu dam

Rainy season: 14 may 2024

The table 4.23 illustrates the PH of water and electrical conductivity of water, TSS, TDS and turbidity.

Table 4.23: PH of water and electrical conductivity in rainy season at Bugugu dam

Position for sampling	PH at water	EC ($\mu\text{s}/\text{cm}$)	TSS (mg/l)	TDS (mg/l)	Turbidity (NTU)
At streamflow entering the dam	6.82	106.4	357	112.9	75.2
At the irrigation water coming from the dam	7.1	107	327	78.9	65.28
Water in selected plot	6.8	105.9	309	68.79	42.5

Dry season: on 14 June 2024,

The bottle of one litre was taken from Bugugu dam for measuring the PH of water and calcium chloride in order to see if there is no effect of irrigation water to the crops. PH was determined through laboratory test

Table 4.24: laboratory test parameters at Bugugu dam

Position for sampling	PH at water	EC ($\mu\text{s}/\text{cm}$)	TSS (mg/l)	TDS (mg/l)	Turbidity (NTU)
At streamflow entering the dam	7.03	108.4	298	101.2	57.2
At the irrigation water coming from the dam	7.21	107.56	302	87.6	54.2

Water in selected plot	6.84	106.4	279	74.12	38.5
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The table 4.24 indicates the PH at water, electrical conductivity, TSS, TDS and turbidity of water entering Bugugu dam, outlet and in dam before irrigation

4.6.3. At Gashara dam

Rainy season: on 14 may 2024, the bottle of one litre was taken from Gashara dam for measuring the PH of water electrical conductivity, TSS, TDS and turbidity as the table 4.25 presents

Table 4.25: PH of water and electrical conductivity in the soil in rainy season at Gashara dam

Position for sampling	PH at water	EC (µs/cm)	TSS (mg/l)	TDS (mg/l)	Turbidity (NTU)
At streamflow entering the dam	6.62	106.9	307	109.2	67.8
At the irrigation water coming from the dam	6.91	107.2	298	96.2	55.2
Water in selected plot	6.77	104.9	277	81.6	39.8

The table 4.25 Hence, PH influences the solubility of essential nutrients in the soil. PH of Gashara dam at the inlet of the dam is 6.62, 6.91 and 6.77 at the water flow from reservoir. Electrical conductivity decreases from the inlet to outlet of reservoir. The sediment is low at the outgoing water because it remains in the reservoir.

Dry season: on 14 June 2024, the bottle of one litre was taken from Gashara dam for measuring the PH of water and calcium chloride in order to see if here is no effect of irrigation water to the crops. PH was determined through laboratory test

Table 4.26: PH of water and electrical conductivity in the soil in dry season at Gashara dam

Position for sampling	PH at water	EC ($\mu\text{s}/\text{cm}$)	TSS (mg/l)	TDS (mg/l)	Turbidity (NTU)
At streamflow entering the dam	6.67	107.02	279	231.7	53.2
At the irrigation water coming from the dam	7.02	107.2	243	279.2	49.8
Water in selected plot	6.74	104.99	207	178.3	37.2

4.7. CHEMICAL AND PHYSICAL CHARACTERISTICS OF SOIL

Physio-chemical characteristics of the soil in the project area, heavy metals were also assessed. The objective of this study was to investigate the heavy metal concentrations present such as (Cu, Cr and Zn) in three site. Nine samples were gathered and examined in the lab. The concentrations of Cu, Cr, and Zn in the extractants were measured using atomic absorption spectrophotometry, and the heavy metal ions in the soil samples were extracted using an acid mixture (IN HCL/1NH₂SO₄) in accordance with Perkins (1970).

Table 27: heavy metal in rainy season

site	layer	heavy metal results (ppm)			
		Pb	Cr	Cu	Zn
Cyimpima	up layer	10.1	30.3	0.41	6.33
	middle layer	4.4	30.3	0.34	4.43
	lower layer	3.64	51.52	0.34	5.19
Bugugu	up layer	11.2	46.97	0.37	5.95
	middle layer	6.4	66.67	0.41	4.94
	lower layer	5.2	39.39	0.41	7.09
Gashara	up layer	9.6	30.8	0,03.	18.85
	middle layer	5.7	36.36	0.14	9.61
	lower layer	4.1	37.88	0.31	8.35

Testing for heavy metals such as lead, cadmium, chromium, arsenic, and mercury is essential to ensure water safety and prevent contamination of soil and crops

In the soil solution, anions and cation or metal are existing in their compound. The table 4.29 presents existing ions at different streams in unit of parts per million (ppm).

Table 4.28: Existing Ions in soil solution in dry season

sample	SO ₄ ²⁻ (ppm)	NO ₃ ⁻ (ppm)	Pb (ppm)	Cd(ppm)	Cr(ppm)
upstream	16.1	1.09	10.1	0.61	0.5
middle stream	16.4	1.42	4.4	0.21	0.11
down stream	12.4	1.31	3.64	0.21	0.11
average	14.96667	1.273333	6.046666667	0.343333	0.24

The table 4.29 indicates the ions that found in the soil concentration. Sulfate and nitrate are the cations in this solution and heavy metal such as lead (Pb), cadmium (Cd) and chromium (Cr). The concentration in Pb, Cd, Cr is high at the intake level and at the exit of the irrigated perimeter. This would mean that these elements are already present in the irrigation water and that part of it is used at the irrigated perimeter. From the founded results, the lead is in range of acceptable lime with average of 6ppm where the standard value is from 5 to 1000ppm, for cadmium the average ppm found is 0.34 which as in range of acceptable standard from 0.01 to 0.7 ppm. However, chromium does not concern because of its value is out of range at 0.24ppm.

Table 4.29: Existing Ions in soil solution in rainy season

sample	SO ₄ ²⁻ (ppm)	NO ₃ ⁻ (ppm)	Pb (ppm)	Cd(ppm)	Cr(ppm)
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upstream	16.02	1.07	10.05	0.6	0.45
middle stream	16.1	1.37	4.3	0.19	0.1
down stream	12.39	1.28	3.61	0.2	0.1
average	14.83667	1.243333	5.98666667	0.343333	0.2166

4.8. EFFECT OF SEDIMENT IN IRRIGATION SYSTEM

Table 4.31 presents level of irrigation dam has affected by sediment from erosion.

Table 4.30: level of how sediment affect the dam capacity

respondents	number	percentage
yes	79	84.95%
no	14	15.05%
total	93	100.00%

The capacity of dam presents the level of water to be used in irrigation. At Cyaruhogo wetland, the respondents 79(84.95%) agreed that the sediment can reduce the water storage in dam but 14(15.05%) disagreed as the table 10 indicates.

4.8.1. Sediment level at Cyaruhogo wetland's dam

In wetland, sediments can come from the erosion debris. Most often it is caused by soil erosion or sediment spill. Sediment entry into irrigation channels can occur both from natural causes such as heavy runoff and human behavior such as overgrazing or deforestation.

4.8.2. Sediment determination though the laboratory

Determining sediment in a laboratory by heating one liter of water typically involves a process known as gravimetric analysis, where sediment is separated and quantified based on its weight after drying.

Materials Needed:

- Water sample containing sediment (1 liter)

- Glass beaker (large enough to hold the entire sample)
- Hot plate or heating mantle
- Stirring rod
- Filter paper or filter membrane (appropriate pore size)
- Vacuum filtration setup or gravity filtration setup
- Weighing balance
- Drying oven
- Wash bottle with distilled water (optional, for rinsing)
- Gloves and safety goggles

Procedure:

1. **Sample Preparation:** Ensure the water sample is well-mixed to distribute sediment evenly, if sediment tends to settle.
2. **Heating the Water:**
 - Transfer the water into a clean glass beaker.
 - Place the beaker on a hot plate or heating mantle.
 - Gradually heat the water to near boiling, but do not allow it to boil vigorously, as this can lead to loss of sediment.
 - Use a stirring rod to gently stir the water during heating to prevent localized overheating.
3. **Boiling and Settling:**
 - Once the water reaches near boiling, maintain this temperature for about 15-20 minutes to facilitate settling of sediment particles.
 - Avoid disturbing the sediment settled at the bottom of the beaker during this process.
4. **Decantation (Optional):**
 - After heating, allow the beaker to cool slightly. If the sediment has settled well, carefully decant (pour off) the clear water above the sediment layer into another container, leaving the sediment behind.
5. **Drying the Sediment:**

- Transfer the sediment from the beaker onto a pre-weighed filter paper or filter membrane.
- Spread the sediment evenly on the filter paper or membrane.
- Place the filter paper or membrane with the sediment into a drying oven.
- Dry the sediment at a suitable temperature (commonly around 105°C to 110°C) until a constant weight is achieved (typically overnight).

6. Weighing the Sediment:

- After drying, allow the filter paper or membrane to cool in a desiccator to avoid moisture absorption.
- Weigh the filter paper or membrane with the dried sediment using a precise weighing balance.
- Record the weight of the filter paper or membrane and the dried sediment.

7. Calculations:

- Calculate the weight of the sediment by subtracting the weight of the filter paper or membrane (and any residue if pre-weighed) from the combined weight of the filter paper or membrane with dried sediment.

The water sampled in rainy season because much sediments is following through the canal due to the soil erosion. After boiling water of one litre of water, 21 gram/year has obtained in laboratory for Cyimpima and Gashara dams while for Bugugu dam, the 20grams/year has founded. The table below presents the total sediment per year for each dam. In my research, the sediment quantity was calculated in period of 25years.

Table 4.31: Sediments in dams after 25years

Dams	Sediment from 1litre (g)/year	Storage capacity of dam(m ³)	Total sediment per year (ton)	Total sediment in 25 years (ton)
Cyimpima	21	640000	13440	336000
Bugugu	20	580000	11600	290000
Gashara	21	640000	13440	336000

From table 4.32, the sediment from laboratory is 21g from 1litre of water at Cyimpima and Gashara, and 20g for Bugugu. The total sediment in Cyimpima dam occupies 13440m³ in year as Gashara dam and 11600 m³ for Bugugu as well.

In one litre of water from the dam, there is 21g of sediment for Cyimpima and Gashara dams, but 20g for Bugugu dam. To calculate the total sediment in the dam, take gram of sediment in 1litre of water times total capacity of dam.

For Cyimpima, total sediment per year= (0.021kg*640000 000kg)/1 litre=13440000 kg or 13440 tons

For Bugugu, total sediment per year= (0.02kg*580000000kg)/1litre=11600 tons of sediment per year.

After 25years, the sediment will occupy a half of dam storage capacity where Cyimpima sediment will be at 336000 tons same as the Gashara, and Bugugu will be occupied by sediment at 290000 tons of sediments

4.9. ADAPTATION STRATEGIES TO MITIGATE THE IMPACT OF CLIMATE CHANGE ON RICE YIELD IN THE CYARUHOGO RICE PERIMETER.

Mitigating the effects of climate change on rice productivity in wetlands necessitates a multimodal strategy that incorporates different approaches [32]. These are some adaption techniques that has designed especially for the cultivation of wetland rice:

4.9.1. Water Management Techniques

Alternate Wetting and Drying (AWD): Use AWD methods to apply irrigation water sporadically and let it drain instead of flooding the area nonstop. This can preserve or increase production while using less water.

System of Rice Intensification (SRI): Use younger seedlings, adjust plant spacing, and provide intermittent irrigation to preserve soil moisture when implementing the System of Rice Intensification (SRI). Higher yields can result from improved water and nutrient efficiency brought about by SRI.

Investing in water storage infrastructure such as reservoirs and rainwater harvesting systems to capture and store water during wet periods for use during dry spells. Farmers have adopted a novel

method to preserve soil moisture and structure in order to lessen soil deterioration and breakdown brought on by rising temperatures and unpredictable rainfall (Nguyen & Sahin, 2021).

4.9.2. Improved Irrigation Infrastructure

Modernize irrigation systems to cut down on water loss and increase efficiency. To guarantee uniform water distribution and reduce evaporation losses, this can involve the use of drip irrigation, sprinkler systems, or laser leveling. During dry spells, invest in water storage structures like ponds or reservoirs to collect and hold runoff or rainfall for use in irrigation.



Figure 4.6: dam with water canals for dam protection

4.9.3. Crop and Variety Selection

Choose rice types that are more resilient to salinity, flooding, or drought based on the climate and local conditions. In order to mitigate risk and maintain a certain level of productivity in the face of climate change, diversify your crop varieties.

4.9.4. Conservation and Management of Soils

To strengthen soil structure, lower erosion, and increase water infiltration and retention, use conservation tillage techniques. Increase the fertility and moisture-holding capacity of your soil by adding organic matter through cover crops or composting. Implementing conservation

agricultural techniques to enhance soil structure, water retention, and nutrient cycling, such as limited tillage and cover crops. Improving soil fertility and resistance to climatic stresses by incorporating organic amendments and soil conditioning practices.

4.9.5. Early Warning Systems and Climate Information

Provide farmers with timely weather forecasts and advisories related to climate change by establishing or improving climate information systems. Provide early warning systems for severe weather conditions, such as storms or floods, so that farmers can take precautionary action to save their infrastructure and crops.

4.9.6. Building Capabilities and Engaging the Community

Through workshops, farmer field schools, and demonstrations, educate farmers on climate-smart agricultural practices and adaptation options.

Encourage the development of community networks and knowledge-sharing platforms to help farmers who are facing comparable climate difficulties learn from and adapt to one another.

4.9.7. Crop Breeding and genetic improvements

The art and science of enhancing valuable agricultural plants for the benefit of humanity is known as crop breeding. The ability of a crop or plant breeder to identify plant variations such as yield and the quantity of pods per plant, to name a couple that may have economic worth is the foundation of the art of breeding.

The goal of crop breeding adaptation tactics and genetic advancements in response to climate change is to create cultivars that are more resilient to temperature rises, unpredictable rainfall patterns, and increased pest and disease challenges. In order to incorporate features like heat and drought tolerance, pest resistance, and increased nutrient uptake efficiency, genetic diversity from gene banks and wild relatives is used. The production of climate-resilient cultivars is accelerated by precision breeding techniques including as genome editing and marker-assisted selection, which allow for the focused increase of desirable features. In order to validate and field test these new cultivars across a variety of climatic circumstances and ensure that they fulfill local agricultural demands while also supporting global food security and sustainability efforts, cooperation between researchers, breeders, and farmers is crucial.

4.9.8. Pest control

In pest control, integrated pest management (IPM) techniques that reduce dependency on chemical pesticides and increase ecosystem resilience are the focus of adaptation strategies for climate change. In order to control pest populations, this involves supporting biological control techniques such as the use of parasitoids and natural predators. Pest life cycles can be disrupted and pest pressures can be decreased by implementing cultural techniques such as crop rotation, intercropping, and planting pest-resistant crop cultivars. Early warning systems and crop monitoring technology facilitate prompt pest discovery and control. Furthermore, encouraging farmer extension services and education on integrated pest management (IPM) techniques guarantees successful execution and adaptation to shifting pest dynamics brought on by climatic variability. Agricultural systems can promote sustainable farming practices and be more resilient to insect outbreaks caused by climate change by incorporating these measures.

4.9.9. Institutional Support and Policy:

Promote laws that encourage the use of sustainable farming methods, such as those that provide financial incentives for doing so and allocate funds for agricultural extension and research.

To enable efficient water management, land use planning, and disaster preparedness in response to the consequences of climate change, strengthen local institutions and governance structures.

Encourage the study and creation of novel techniques, crop types, and technology that will make wetland rice farming more resilient to climate change. Promote creativity and experimentation with adaptable farming methods that are suited to regional conditions and farmer requirements. Giving farmers access to insurance policies, subsidies, and climate finance channels will encourage them to invest in climate-resilient technology and infrastructure. Creating risk management plans and backup plans to deal with market volatility and climate-related calamities mitigating and adaptation strategies such as alternate wetting and drying, inter cropping with short term vegetation, limiting chemical fertilizers by precise farming, usage of rice cultivars with low methane emission, improved tillage, recycling of farm waste into organic fertilizers, and by developing integrated rice farming system

4.10. CHALLENGES AND BARRIERS TO ADAPTATION IN MITIGATING THE IMPACT OF CLIMATE CHANGE ON RICE YIELD IN THE CYARUHOGO RICE PERIMETER.

The challenges and barriers to adaptation in mitigating the impact of climate change on rice yields, specifically in the Cyaruhogo Rice Perimeter.

4.10.1. Socio-economics challenges and barriers

1. Financial Constraints

High Costs of Adaptation: The costs associated with adopting new technologies, improving irrigation systems, or switching to more resilient rice varieties can be prohibitive for many farmers, especially smallholders.

Access to Credit: Limited access to financial services and credit can prevent farmers from investing in necessary adaptation measures or recovering from climate-induced losses.

Farmers frequently do not have access to enough resources to purchase climate-resilient practices and technology, such as sustainable soil management methods, better seeds, or irrigation systems. Because of the perceived risks related to agriculture and climate unpredictability, financial institutions could be reluctant to grant loans.

Socio-cultural norms and traditional farming practices may hinder the adoption of new technologies and practices, particularly among marginalized or remote communities. Resistance to change and lack of community support can further impede adaptation efforts.

Smallholder and low-income farmers, who are often the most vulnerable to climate change, may struggle to access credit or insurance products needed to manage higher production costs and mitigate risks. Limited financial resources hinder their ability to invest in climate-resilient technologies and practices

Socio-economic challenges, such as poverty, limited access to credit, and inadequate infrastructure, can impede farmers' ability to adapt to climate change. Smallholder farmers, in particular, face significant challenges in accessing resources, including finance, technology, and inputs, needed to implement adaptation measures. Limited resources and financial constraints can hinder the adoption of climate-resilient practices, such as purchasing drought-resistant seeds or investing in irrigation infrastructure (Bryan et al., 2018; Thornton et al., 2018).

2. Market Access and Economic Viability

Price Volatility: Fluctuations in rice prices can affect farmers' income stability, making it harder for them to invest in adaptation technologies.

Market Access: Poor infrastructure and lack of access to markets can limit farmers' ability to sell their produce at fair prices, affecting their economic resilience. Farmers may face difficulties in accessing credit or insurance to manage higher costs or invest in climate-resilient practices. Financial institutions might perceive agricultural investments as high-risk due to climate uncertainties, limiting farmers' ability to secure necessary funding.

3. Poverty and Income Inequality

Limited Resources: Farmers in poverty may lack the resources to implement adaptation strategies, such as purchasing improved seeds or investing in irrigation.

Income Disparities: Economic inequality can exacerbate the difficulties faced by disadvantaged groups in adapting to climate change, as they may have less access to information, technology, and support services.

Climate change often leads to higher costs for essential resources such as water and energy. More frequent and severe droughts increase the need for irrigation, raising water and energy expenses. Additionally, managing heat stress and extreme weather conditions often requires more energy for cooling and ventilation in agriculture.

In terms of Infrastructure, Extreme weather events like floods, storms, and heatwaves can damage agricultural infrastructure such as irrigation systems, storage facilities, and transportation networks. Repairing or replacing this infrastructure incurs additional costs and disrupts food production and supply chains.

Changes in crop yields brought on by the climate may result in increased costs for inputs like herbicides, fertilizers, and seeds. Farmers may need to make larger investments in more costly inputs in order to control risks and maintain production, as climatic conditions grow more uncertain.

Adjustments in farming operations are typically necessary to adapt to climate change, and these adjustments might raise labor costs. For instance, it could be necessary to monitor and manage

crops, soil, and pests more frequently. Operating costs have also increased by providing farmers with the training and skill development they need to implement new technology or practices.

Increased crop yield unpredictability due to climate change may affect market pricing and perhaps lower farmers' income. Farmers find it difficult to properly plan and budget due to unpredictable yields, which raises risk and financial uncertainty [33]

With more costs to the farmer, some will no longer find it financially feasible to farm. Agriculture employs the majority of the population in most low-income countries and increased costs can result in worker layoffs or pay cuts. Other farmers will respond by raising their food prices; a cost which is directly passed on to the consumer and affects the affordability of food. Some farms do not sell their produce but instead feed a family or community; without that food, people will not have enough to eat. This results in decreased production, increased food prices, and potential starvation in parts of the world.

4. Knowledge and Information Gaps

Many farmers may not be aware of the available adaptation options or the benefits of adopting new technologies and practices. Limited agricultural extension services can mean that farmers do not receive the necessary training or information to implement effective adaptation measures.

In several publications, it has discovered that farmers' ability to adjust has limited by a lack of knowledge. Farmers' poor understanding has made it difficult for them to adapt to climatic anomalies. Studies carried out by farmers reveal this ignorance of adaption strategies. Many farmers are unable to implement any kind of adaptation strategy because of this obstacle. Furthermore, farmers are unable to improve their farming practices by implementing modern adaptation techniques due to a lack of technical understanding. In order to properly adapts, female farmers in particular must rely on their male colleagues, who are knowledgeable about farming techniques[34]. Consequently, in order to forecast weather patterns and changes, farmers must rely on their own experience as well as traditional wisdom.

Farmers' adaptation has hampered by their limited access to agricultural extension agents since they are unable to acquire modern farming techniques.

A large number of farmers do not have access to current data, technical expertise, or training on climate-smart methods and tools. This inhibits agricultural systems' ability to innovate and restricts their capacity to apply adaptive strategies successfully. Knowledge gaps and limited awareness about the impacts of climate change and available adaptation options can pose barriers to adaptation in agriculture. Farmers need access to up-to-date climate information, as well as training and extension services, to understand the changing climate risks and make informed decisions. Bridging knowledge gaps and enhancing awareness through farmer education programs, capacity-building initiatives, and knowledge-sharing platforms are crucial for facilitating effective adaptation (Reidsma et al., 2019; Sova et al., 2020).

5. Education and Skill Levels

Low Literacy and Education: Lower levels of education and technical skills can limit farmers' ability to understand and adopt new farming techniques and technologies.

Training Availability: Limited access to training programs and agricultural education can hinder the adoption of innovative practices and technologies.

6. Institutional and Policy Challenges

Weak Institutional Support: Inadequate support from governmental and non-governmental institutions can limit the effectiveness of adaptation strategies. This includes insufficient policy frameworks, lack of research, and poor infrastructure. **Policy and Institutional Support:** Farmers frequently lack the incentives, financial assistance, or regulatory support they need to implement climate adaptation techniques because of inconsistent or insufficient policies and institutional frameworks. This includes a lack of funding for climate resilience-focused agriculture research and extension services. Inadequate infrastructure, such as roads and storage facilities, restricts farmers' ability to transport and store their produce effectively. Limited market access and price volatility further discourage investments in resilient agricultural practices.

Inadequate policy frameworks and support systems can exacerbate the challenges. Lack of subsidies, incentives, or financial assistance for climate adaptation can prevent farmers from accessing necessary resources and technologies.

7. Social and Cultural Barriers

Resistance to Change: Traditional farming practices and cultural norms can sometimes resist new methods or technologies, even when they are beneficial for adaptation.

Community Engagement: Lack of community involvement in decision-making processes can lead to less effective adaptation strategies, as solutions may not align with local needs and practices.

8. Health and Labor Issues

Health Impacts: Climate change can exacerbate health issues, which may reduce the labor force available for farming. Poor health can also limit the ability of farmers to work effectively.

Labor Availability: Migration to urban areas or other regions in search of better opportunities can lead to a shortage of labor for rice cultivation, affecting productivity [35]. Labor shortages and increasing cost pressures highlight the need for greater support for farm mechanization, although mechanization poses a new set of challenges. Higher food prices can strain household budgets, particularly for low-income families. As food becomes more expensive, these households may struggle to access sufficient and nutritious food, leading to increased food insecurity and malnutrition.

4.10.2. Environmental challenges and barriers to adaptation in mitigating the impact of climate change

1. Climate Change Effects

Temperature Increases: Higher temperatures can affect rice growth stages, reduce yields, and increase the prevalence of pests and diseases.

Altered Rainfall Patterns: Changes in rainfall, including irregular or insufficient precipitation, can disrupt the water supply needed for rice cultivation.

2. Water Availability and Management

Water Scarcity: Climate change can exacerbate water scarcity, affecting irrigation systems and water availability for rice paddies.

Flooding: Increased frequency and intensity of heavy rainfall can lead to flooding, which can damage crops, erode soil, and lead to nutrient loss.

3. Soil Health and Degradation

Soil Erosion: Extreme weather events such as heavy rains and storms can cause soil erosion, reducing soil fertility and productivity.

Soil Salinization: Rising sea levels and increased evaporation can lead to soil salinization, making the soil less suitable for rice cultivation.

4. Pests and Diseases

Increased Pest Infestations: Warmer temperatures and altered weather patterns can expand the range and increase the number of pests and diseases affecting rice.

Disease Outbreaks: Changing climatic conditions can favor the development and spread of rice diseases, affecting crop yields.

5. Biodiversity Loss

Ecosystem Disruption: Climate change can disrupt ecosystems and reduce biodiversity, which can affect natural pest control and soil health.

Loss of Pollinators: Changes in climate can influence the availability of natural pollinators and beneficial organisms that are crucial for healthy rice ecosystems.

6. Soil Moisture and Temperature

Inconsistent Soil Moisture: Variability in soil moisture due to changing precipitation patterns can influence rice growth and yield.

Soil Temperature: Rising soil temperatures can affect rice seed germination and growth, potentially reducing yields.

7. Extreme Weather Events

Heatwaves: Prolonged heatwaves can stress rice plants, affect flowering, and reduce yields.

Storms and Hurricanes: Severe storms can cause physical damage to crops and infrastructure, leading to significant yield losses.

8. Erosion and Land Degradation

Land Degradation: Continuous cultivation without proper land management can lead to degradation, affecting soil fertility and productivity.

Erosion Control: Inadequate erosion control measures can exacerbate soil loss and negatively affect rice yields.

5. CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

The Cyaruhogo wetland is located in eastern province where the long dry season is higher than other provinces in Rwanda. The irrigation project was implemented in this wetland for improving agriculture product doubly. To increase water in this zone, the three dams was constricted by JICA program. This dams now supply enough water whenever is needed. Due to the heavy rain, the sediment enters in the dams from the erosion issue. This project has measured the quantity of sediments which enter in the dams during the dry and rainy seasons but in dry season is not considered due to zero water from the rain. After laboratory test, the PH of water and its electrical conductivity are suitable for rice crop.

The total sediment founded from lab shows that in 2045, the storage capacity of dams will be store a half of its original volume.

5.2. RECOMMENDATION

The heavy rain is the source of sedimentation is the storage reservoir. The prevention of water flow from the surrounding area is required through the mitigation for erosion in catchment area. Preventing sediment flows into a dam is crucial for maintaining its functionality and longevity. Sediment accumulation can reduce water storage capacity, impact water quality, and interfere with dam operations. Install erosion control structures such as check dams, silt fences, and sediment basins in critical areas where runoff concentrates is needed. Collaborative efforts among governments, researchers, and local communities are essential to develop and implement effective adaptation strategies for maintaining rice yields in the face of climate change. These structures help to slow down water flow, trap sediment, and promote settling before water reaches the dam.

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APPENDIX

APPENDIX 1: SITE PICTURES



APPENDIX 2: QUESTIONNAIRES

Questionnaire: Effects of Heavy Rainfall in Irrigated Schemes

Section 1: Demographic Information

1. Age:
 - Under 18
 - 18-30
 - 31-45
 - 46-60
 - Over 60
2. Gender:
 - Male
 - Female
 - Other
3. Occupation:
 - Farmer
 - Irrigation Engineer
 - Project Manager
 - Government Official
 - Other (please specify)
4. Years of experience in irrigation/agriculture:

Section 2: Rainfall Patterns

5. How frequently does heavy rainfall occur in your region?
 - Rarely
 - Occasionally
 - Frequently
 - Very frequently
6. Have you noticed any changes in rainfall patterns over the past few years? If yes, please describe.

Section 3: Impact on Irrigated Schemes

7. How does heavy rainfall affect the infrastructure of the irrigated scheme? (Check all that apply)
 - Erosion of canals
 - Flooding of fields
 - Damage to irrigation pumps
 - Blockage of drainage systems
 - Other (please specify)
8. In your opinion, what is the most significant impact of heavy rainfall on crop production in the irrigated scheme?
9. Have you observed any changes in crop yields or quality due to heavy rainfall? If yes, please elaborate.

Section 4: Mitigation Measures

10. What measures are currently in place to mitigate the effects of heavy rainfall in the irrigated scheme?
11. How effective do you find these measures in minimizing the impact of heavy rainfall?
12. Are there any additional measures you believe could be implemented to better manage heavy rainfall in the irrigated scheme? If yes, please suggest.

Section 5: Future Considerations

13. How do you anticipate heavy rainfall patterns to change in the future?
14. What steps do you think should be taken to adapt to these potential changes?

Section 6: Additional Comments

15. Is there anything else you would like to share regarding the effects of heavy rainfall in irrigated schemes?