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Assessment of Physical Status of The Irrigation Structures in Nyarubogo Irrigation Scheme, Rwanda

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ABSTRACT

The physical status of irrigation structures holds immense importance in ensuring the efficient and sustainable management of water resources for agricultural purposes. This study aimed to assess the physical status of the Nyarubogo irrigation scheme structures, which has implications for the level of performance of this irrigation scheme. Specifically, the study assessed the effectiveness of the irrigation infrastructures in terms of intake efficiency, canal physical condition, and command area development. Cross sectional study design was employed, and units for the study were randomly selected to be included in this study. Observation method were used to characterize the physical condition of the Nyarubogo irrigation scheme while questionnaire survey were used to collect data on the implication of socioeconomic characteristics on the performance, and effectiveness of irrigation system. The collected data were fitted to the irrigation structures assessment approaches suggested by Bos, Zende and Nagarajan. Analysis of farmer's responses was through Statistical Package for the Social Sciences (Version 27). This study evaluated the physical status of about 130 irrigation structures in Nyarubogo irrigation scheme. The structures included 7 division boxes, 73 water drops, 2 aqueducts, 42 turnouts, 4 bridges, and 2 Culverts. Overall, the scheme had an effectiveness of 63.8%, with culverts, bridges, and water drops presenting more than the average functional condition of 64.38%, 75.00%, and 100.00%, respectively. The intake efficiency during this study was found to be 67% accumulated from efficiencies of sediment level (20%), embankment (35%), and sluice gate (12%) based on their weightage percentage and rank scores. The overall canal condition was good and was quantified to 70%. The command area development was exhibiting subpar performance, registering a mere 32% effectiveness. Moreover, the study evaluated how farmers' socio-economic status influenced the inadequate maintenance of the Nyarubogo irrigation systems. It uncovered numerous elements contributing to this dilemma: there was limited engagement of women and youth in agricultural pursuits, low educational attainment, challenges surrounding land ownership (specifically, land tenure), the small size of land holdings per household and a notable absence of government incentives for maintenance efforts. These factors, however, when coupled with inadequate funds derived from water fees, significantly obstruct the proper care of these irrigation infrastructures. On the other hand, high runoff due to heavy rainfall was mentioned by the majority of farmers (20.7%) among the primary causes of poor maintenance of irrigation structures. Generally, the evaluation of the Nyarubogo irrigation system structures emphasizes the uneven levels of efficacy and challenges, highlighting the necessity of focused maintenance efforts and enhanced water management techniques.

Keywords: Irrigation Infrastructures, Nyarubogo, Performance Assessment, Physical Status, Rwanda

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I. INTRODUCTION

In many nations, agriculture is the main driver of food security, economic growth, and the alleviation of poverty. Generally speaking, agriculture uses between 70 and 90 percent of the water used globally (Molden, 2013). Since irrigation greatly contributes to food security, the majority of agricultural water use is for this purpose (Rosegrant, 2019). Although only 20% of the world's agricultural land is irrigated, irrigation produces 40% of the world's food supply according to Caldera & Breyer (2023). Additionally, improved seeds, fertilizers and agrichemicals are among the production inputs whose efficiency is increased by irrigation (Khaloui et al., 2014). Nonetheless, there are typically significant water losses in agriculture, particularly with irrigation systems (Çakmak, 2003).

According to Food and Agriculture Organization (FAO, 2009), countries in sub-Saharan Africa (SSA) continue to face low scheme productivity despite investments in irrigation projects, with many of these projects producing below potential. Consequently, food insecurity continues to affect nearly 30% of the people living in sub-Saharan Africa on a regular basis (Bjornlund et al., 2020). Factors such as poor management, inadequate or nonexistent rural financing mechanisms, high input prices, particularly for fertilizer, poor operation and maintenance of irrigation infrastructures, uncertainty surrounding land tenure, and a lack of farmer organizations, contribute to low crop productivity due to inefficient irrigation schemes (Balana & Oyeyemi, 2022; Bjornlund et al., 2017; Fanadzo & Ncube, 2018; Gashayie & Singh, 2015; Mwamakamba et al., 2017).

The development of irrigation structures plays a role in the irrigation scheme's dependability, improving irrigation effectiveness and preserving the sustainability of water resources. More efficient irrigation results in lower losses, which improves the application of water on farms as well as increased scheme productivity (Playán & Mateos, 2006). Many irrigation systems in Africa, even those owned by the government, experience poor operation due to a lack of repair and maintenance despite large investments in the development of new infrastructure (Lebdi, 2016; Nakawuka et al., 2018; Shayamano, 2016). Low productivity notwithstanding, irrigation schemes have greatly benefited society economically by creating jobs and business centers. Effectively managed and sustainably maintained irrigation systems have positive effects on the community and should raise food production (FAO, 2014). Reasons behind the deterioration or abandonment of numerous irrigation schemes in Africa revolve around factors such as the socio-economic status of farmers, inadequate crop management, poor irrigation infrastructure management (Dejen, 2015), poor management and inadequate funding (Mukoto, 2008). Although accurate resource assessment and sound engineering are essential to the success of small-scale irrigation schemes, an efficient operation and maintenance (O and M) system is a major factor determining the long-term performance and sustainability of these schemes (Hedayat, 2011). Frequent irrigation scheme maintenance lowers costs for maintenance and repair, extends system life, and maintains project irrigation efficiency at targeted level (Hill, 2008). Studies have shown that the poor performance of irrigation schemes is stimulated by both high maintenance costs and inadequate irrigation scheme maintenance (Hedayat, 2011; M. Fanadzo, 2012; Mnkeni et al., 2010).

In Rwanda, agriculture is considered as the economic engine for growth (EDPRS-II, 2013; GoR, 2007) and aims to reduce poverty and achieve food security through commercialized and professional agriculture. Meanwhile, population growth and increasing urbanization are expected to push water demand further, putting the country at risk of severe water stress and decreased water quality due to increasing pollution. The Government of Rwanda has recognized the fundamental importance of irrigation for the future economic and social development of the country and that increasing agricultural productivity is one of the main strategies for poverty reduction. In line with Rwanda's development agenda and the milestones set within the Economic Development and Poverty Reduction Strategies ('EDPRS' I,II) which were implemented from 2008 to 2018, and the Irrigation Policy and Action Plan (MINAGRI, 2013), the Government continuously invests in the development of small, medium and large-scale irrigation schemes on both hillside and marshland areas (MINAGRI, 2020).

At present, Rwanda has established approximately 148 irrigation schemes that are found on hillsides and marshlands. Many of these well-established irrigation schemes have been plagued by poor performance, with low water use efficiency and low production levels that translate into low farmer incomes and productivity. Dams and field networks are among the constructed irrigation infrastructures that are not well-operated and maintained, unusable, or underutilized (MINAGRI, 2020).

1.1 Statement of the Problem

The Nyarubogo irrigation scheme is one of the schemes found in Nyanza District, Rwanda which was developed in 2010 with an irrigation water storage Dam to increase paddy production in Nyarubogo Marshland. This scheme, with 229.5 ha of command area, worked properly for a few years after putting the dam in place. However, the scheme has started to experience decreasing paddy production and low performance compared to what was intended per year as farmers decided to cultivate around half of the command area in the dry season (season A) every year due to poor maintenance and operation of irrigation structures. There are limited studies that have been conducted on the status of irrigation structures in some of Rwandan irrigation schemes such as (Nzeyimana, 2021; Hakuzimana and Masasi, 2020), however no such study is available to Nyarubogo irrigation scheme. Therefore, this study aimed to assess the physical status of the Nyarubogo irrigation scheme structures, which has implications for the level of performance of this irrigation scheme.

1.2 Research Objectives

i. To assess the effectiveness of the irrigation infrastructures in terms of intake efficiency, canal physical condition, and command area development
ii. To assess the implications of farmers' socio-economic status to irrigation structures' maintenance and operation

II. LITERATURE REVIEW

2.1 Theoretical Review

The theories of resource allocation, social capital, and sustainable infrastructure management altogether provide a useful lens to evaluate the effectiveness and maintenance of irrigation infrastructure in this study. The Sustainable Infrastructure Management Theory highlights the need of long-term infrastructure use and functioning so as to minimize infrastructure deterioration, proactive maintenance and flexibility (Chester & Allenby, 2018). When applied to irrigation projects, this theory emphasizes how crucial it is to routinely evaluate conditions, such sedimentation and sluice gate performance, in order to avoid major failures and guarantee steady water supply.

In agricultural situations, where expenditures for water and maintenance are often few, Resource Allocation Theory's emphasis on fair and effective resource allocation is pertinent (Ostrom, 1990). According to this theory, by limiting abuse and minimizing wear on vital components, efficient resource allocation guarantees optimum system performance. By highlighting the importance of cooperative behaviors, trust, and community engagement in maintenance tasks, social capital theory further supports these viewpoints (Putnam, 1993). When taken as a whole, these theories provide a coherent view of the variables affecting the sustainability of irrigation infrastructure and emphasize the need of an integrated strategy that incorporates resource management, community involvement, and technical upkeep.

2.2 Empirical Review

Irrigation infrastructure is essential for increasing agricultural output and food security, according to recent research. Well-maintained irrigation systems greatly raise agricultural yields and farmers' incomes in dry areas. According to the study conducted in India by Dawit et al., (2020), farmers who had access to effective irrigation systems experienced increase in yield by 56 to 120% compared to those without irrigation. However, Ray & Majumder, (2024) pointed out that while irrigation may act as a critical buffer against climatic unpredictability, there is a need of investing in irrigation infrastructure, especially in regions that are vulnerable to water shortages. In order to preserve these systems and guarantee long-term productivity improvements, routine maintenance and community engagement may be required.

In Morogoro Tanzania, Makaka (2020) examined a number of irrigation systems and found that poor irrigation infrastructures was prevalent and is the leading causes of low agricultural productivity. According to their research, these shortcomings led to less effective water delivery, which in turn decreased agricultural yields and made people more susceptible to food insecurity. In order to encourage sustainable agricultural practices, literature emphasize the need of a methodical approach to irrigation infrastructure development, concentrating not only on building but also on continuing maintenance and farmer education (Velasco-Muñoz et al., 2024).

Furthermore, a number of empirical research have investigated the socioeconomic aspects impacting irrigation infrastructure upkeep. For instance, a research by Idahe and Solomon (2024) showed that farmers' socioeconomic status—which includes their income and educational attainment—had a substantial impact on their motivation and ability to do maintenance tasks. Higher educated farmers were more inclined to take part in infrastructure maintenance because they understood how important it was to their livelihoods (Alavaisha & Lindborg, 2022). The study by Mwadzingeni et al., (2022) emphasizes the relationship between socioeconomic circumstances and the durability of irrigation infrastructures, indicating that raising farmers' incomes and levels of education may result in better maintenance techniques and, ultimately, more efficient irrigation systems.

III. METHODOLOGY

3.1 Description of the Study Area: Location

Nyarubogo irrigation scheme is located in Nyanza District, Rwanda between two latitudes of 2º 15’S and 2º25’S and two longitudes of 29º50’’ E and 29º55’’ E with a mean altitude of 1,376 m. Water used in the scheme for irrigation comes from the Nyarubogo River which is ephemeral. The scheme is for paddy production, implemented on 174 ha. It receives water from Nyarubogo dam with a capacity of 500 000 m^3 constructed across the Nyarubogo River. Water flows by gravity to the Nyarubogo irrigation scheme from the dam.

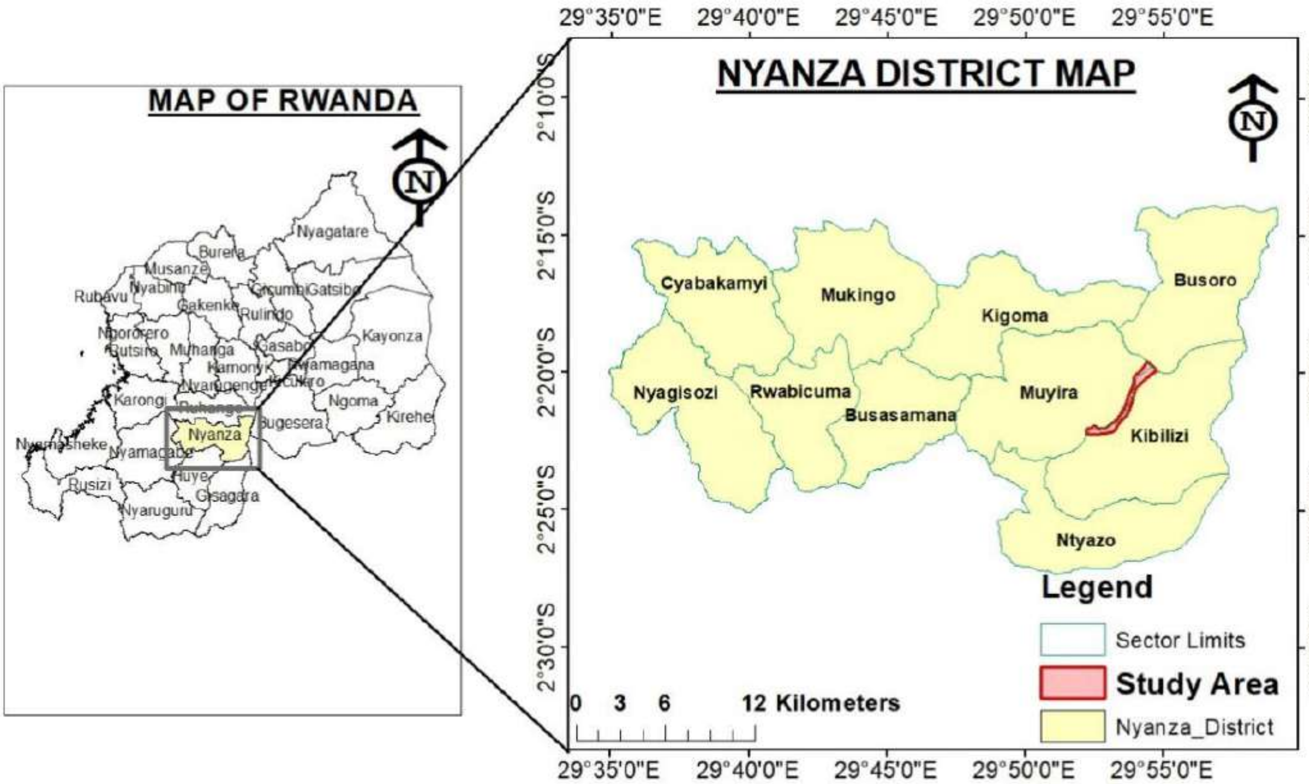

Figure 1
Map Showing the Location of the Study Area

Climate

Nyanza District is characterized by a tropical climate with two main seasons, the rainy season (November to April) alternating with a dry season (May to October). The average annual rainfall ranges between 1001-1050 mm and the average annual temperature of about 25°C according to Rwanda Meteorological Agency (RMA, 2024).

Agricultural Activities

Farming and raising livestock are the two main agricultural pursuits in the research region. Paddy, beans, bananas, maize, sorghum and vegetables are the main income and food crops farmed. Small ruminants, poultry and dairy cattle are examples of livestock that support the local population's way of life. Farmers frequently employ zero grazing as a strategy to increase milk yield and decrease epidemics (Nyanza-District, 2013).

Scheme Layout

Water from main canal is discharged into the right and left secondary earth canals (SC). Water is released into tertiary canals (TC) from each secondary canal. Water is supplied to the farms of the scheme by gravity through the tertiary canals. The plan also includes a main drain and field drains (Figures 1 and 2) and the steering basin in (Figure 2) stands for chute or drop structure.

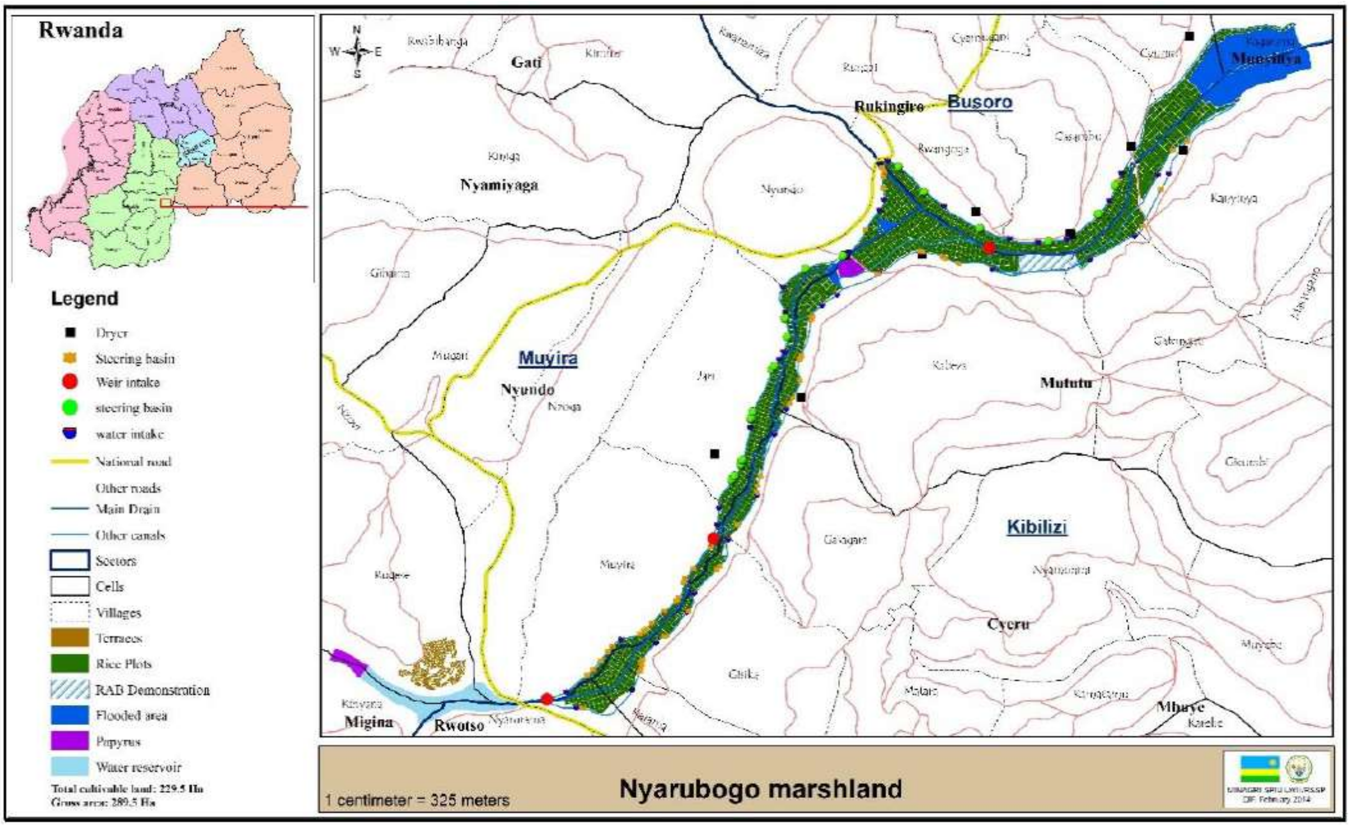

Figure 2
Nyarubogo Irrigation Scheme Layout (Source: *Rwanda Agriculture Board)*

3.2 Assessment of the Effectiveness of Infrastructure

Effectiveness of Infrastructure was computed as the proportion of structures that function normally to all structures (Bos et al., 1993).

$$Effectiveness\ of\ Infrastructure = \frac{Number\ of\ Functioning\ Structures}{Total\ Number\ of\ Structures} \quad (1)$$

A structure is considered functional if it can be used or operated to carry out its intended purpose while maintaining an acceptable standard of accuracy. To ensure the effectiveness of the analysis, the structures were categorized according to their hierarchical significance (primary, secondary, or tertiary level) and each level was subjected to analysis.

3.3 Intake Efficiency

For this indicator, field physical observation was conducted to examine the following parameters: Condition of its Embankments (CE), intake Sedimentation Level (SL), and Sluice Gate Operation (SG). They were separated into five groups (classes) and every class was assigned a rank number from one to five (Table 1). The collected data were used in the following formula:

IE= {(CE Rank*weightage) + (SG Rank*weightage) + (SL Rank*weightage)} (2)

The sedimentation level (SL) which gives an insight into the amount of sediments accumulated in the reservoir was determined by introducing a long wooden stick in water until it was stopped by a layer of sediments, which left a mark on that stick and using a tape measure to determine how high the water column is now in relation to how high the intake was initially (this measuring process took place when the dam was passing water in the spillway to ensure it was at its full supply level). The condition of the intake's embankments (CE), which indicates a possible water leakage, was identified after assessing the intake's physical characteristics, such as erosion, land sliding and seepage. Sluice Gate operation (SG), which represents the intake water release capacity, was established through an assessment of the structure's condition, including maintenance and operation, anti-corrosion treatment and gate lubrication.

Once each parameter's value (percentage) was established, the weightage of the parameter was multiplied by the rank that corresponded to the value and the products summed up to yield the intake efficiency. (Zende & Nagarajan, 2013) recommended the relative weightage of each parameter (Table 1).

Table 1
Evaluation of Irrigation Structures' Physical State

Parameter	Class (%)	Rank	Weightage
Sedimentation level (with reference to total capacity) (SL)	<10	5	50
	11-30	4	
	31-50	3	
	51-70	2	
	>70	1	
Embankment (damage in % of total length (EL)	<10	5	35
	11-20	4	
	21-30	3	
	31-50	2	
	>50	1	
Sluice gate operation: Level of sedimentation with reference to gate opening (SGL)	Below	5	15
	Close to gate	4	
	Same level	3	
	Above the gate level	2	

Source: *Zende and Nagarajan* (2013)

3.4 Canal Condition

Bank collapse (BC), water pools (WP) (primarily due to sediment deposition), seepage through the embankment, weed growth (WG) inside the canal, and conveyance losses (CL) were used to evaluate the canal condition (CC). The data gathered was utilized to weight and rank each independent parameter. according to (Zende & Nagarajan, 2013) (Table 2).

CC= {(BC Rank*weightage) + (WG Rank*weightage) + (WP Rank*weightage) + (CL Rank*weightage)} (3)

Evaluation of canal bank condition was done by physical observation of the damaged area of earth, stones and masonry works along the canal, and collapse of canal banks all categorized as bank collapse (BC). Water pools parameter was evaluated by observation of state of water movement and water stagnation caused by sediment deposition and canal bed erosion creating depressions which impede canal water flow. Weed growth (WG) was evaluated by measuring the length of the canal infested with weeds from upstream to downstream which was divided by the whole length of the canal under consideration to determine the percentage of canal length with weed growth. A water inflow-outflow method of direct measurement was employed to determine the extent of water losses in the secondary canals. To find the canal condition, the weightage of each parameter was multiplied by the rank that corresponded to its value (percentage), and the products summed up to yield CC (Eq. 3).

Table 2
Assessment of Physical Condition of Canals

Parameter	Class (%)	Rank	Weightage
Conveyance loss (CL) (Evaporation and Seepage)	<10	5	40
	11-30	4	
	31-50	3	
	51-70	2	
	>70	1	
Bank collapse (in % of total Canal length (EL)	<10	5	30
	11-20	4	
	21-30	3	
	31-50	2	
	>50	1	
Water pooling in Canal (WP)	<10	5	20
	11-30	4	
	31-50	3	
	51-70	2	
	>70	1	
Weed growth (WG)	<10	5	10
	11-30	4	
	31-50	3	
	51-70	2	
	>70	1	

Source: *Zende and Nagarajan* (2013)

Command Area Development

The cropped area (CA), regulatory constraints (RC) and water sharing issues (WSI) assessed the command area development (CAD) of the water infrastructure project. Classifications, rankings, and weights were applied to the identified status of the corresponding parameter (Zende & Nagarajan, 2013) (Table 3).

CAD= {(CA Rank*weightage) + (RC Rank*weightage) + (WSI Rank*weightage)} (4)

Cropped area (CA) is the ratio that results from dividing the land area that is currently under cultivation by the total area of the scheme that is cultivable. Regulatory constraints (RC) were ascertained by determining the primary limitations, which comprised insufficient agricultural inputs and scarcity of water. Water sharing issues (WSI) were clearly established by evaluating the degree to which water is distributed among head-tail farmers in times of water scarcity through the use of a questionnaire survey, focus group discussions, and information from key informants. The command area development was then obtained by multiplying the rank by the weight of each parameter, which matched each parameter's value (percentage). The results were then added up. (Eq. 4).

Table 3

Evaluation of Command Area Development

Parameters	Class (%)	Rank	Weightage
Cropped Area (CA) (Reference to proposed)	<10	1	60
	11-30	2	
	31-50	3	
	51-70	4	
	>70	5	
Water flow Regulatory Constraints (RC)	<10	5	20
	11-20	4	
	21-30	3	
	31-50	2	
	>50	1	
Water sharing issues (WSI)	<10	5	20
	11-30	4	
	31-50	3	
	51-70	2	
	>70	1	

Source: Zende and Nagarajan (2013)

Socio Economic Status of Farmers

To determine socio-economic status of farmers a questionnaire was administrated to 120 farmers and the data collected were used to understand farmers' family composition, ages, land size, land ownership, and perception of farmers of causes of poor performance of irrigation structures.

3.5 Sampling Methodology and Data Collection

During the study period, the number of working and non-working structures was determined via fieldwork and structures physical observation. To determine the state (condition), cleanliness, operation, and maintenance of the main, secondary, and tertiary canals structures as well as the dam, an inspection and evaluation were conducted. Various data sets, including Intake Efficiency (IE), Canal Condition (CC), and Command Area Development (CAD), were determined to assess the services delivered by water infrastructures. Besides that, a household survey, focus group discussion, and key informant interviews were carried out to determine the underlying causes and consequences of irrigation structures' performance. Three strata were created by stratifying the sampling frame in order to produce a representative sample (head, middle, and tail) (Bailey, 1994). A basic random sample approach was used to choose 40 farmers from each stratum, for a total of 120 respondents. The key informants comprised three irrigators from water users organization leaders, two scheme agronomists, one farmer's cooperative officer, two experienced paddy farmers with at least seven years in this scheme and two primary school teachers from the surrounding population. In total, twelve participants, of which six were men and six were women, were part of the focus group discussion, making a total of 142 respondents.

3.6 Data Analysis

Excel software for data entry and Statistical Package for the Social Sciences (SPSS) computer software package (version 27) to extract data from respondents, as well as descriptive statistics principles, were used to obtain the degree of performance for different infrastructures based on the aforementioned indicators. To obtain the effectiveness of infrastructure, equation 1 was used for each type of structure and for the overall structures, considering the number of non-functioning structures and the total number of functioning structures. Intake efficiency was analyzed using data from the field to estimate the performance class in terms of operation for every parameter (sediment level, embankment level and sluice gate), as shown in Table 1, while Table 2 and Table 3 were used to analyze the performance of canals condition and command area development respectively.

IV. FINDINGS &DISCUSSION

4.1. Effectiveness of Infrastructure

The effectiveness of the irrigation infrastructures in Nyarubogo irrigation scheme is summarized in Table 4. A total of 130 structures were assessed in the scheme, including 7 division boxes, 73 water drop structures, 2 aqueducts, 42 turnouts, 4 bridges and 2 culverts. The results illustrate that 4 out of 7 division boxes are in good condition giving effectiveness of infrastructure of 57.14 %. Likewise, the effectiveness of infrastructure for water drop structures, aqueducts, turnouts, bridges, and culverts is 64.4%, 50.0%, 61.9%, 75.0%, and 100.0% respectively.

While the overall average effectiveness of irrigation infrastructures stands at 63.8%, only culverts, bridges, and water drops presented a better functional condition than the average of the scheme. These structures play a critical role in regulating water flow, managing drainage, and ensuring efficient irrigation practices. Other structures, such as division boxes, aqueducts, and turnouts, are functioning below the overall scheme average, implying deficiencies in their functionality. The findings from this study are in agreement with those reported by (Checkol & Alamirew, 2008) from a study conducted in the Geray Irrigation Scheme, Ethiopia, where the effectiveness of infrastructure was equal to 67% with the implication that nearly one-third of the structures were not functioning as it was intended.

The poor structural condition of the structures which on average stands at 36.2% could be due to a number of reasons. Firstly, the scheme is surrounded by mountains, which in turn convey high rainfall runoff to the scheme with high sediment loads, causing floods that destroy irrigation structures during the rainy season (Enkhbold, 2020). Secondly, it was observed that activities from the construction of the Busoro bridge on the public road Bugesera-Nyanza, which passes close to the scheme, are destroying some structures. For instance, a division box which is close to the bridge was damaged as a result of those activities. Thirdly, the irrigation fees collected per area are unsatisfactory similar to the findings by (Mchelle, 2011), which in turn fail to cover the reconstruction costs of structures such as division boxes and aqueducts. The situation is further excarbated due to the fact that farmers do not contribute effectively in maintenance activities (Sithirith, 2017) believing that the irrigation fees paid are enough for such activities. Lastly, cattle coming for grazing in this area especially in the dry season when pastures in the mountains have been depleted, also destroy the infrastructures.

Table 4

Effectiveness of Infrastructures in Nyarubogo Irrigation Scheme

Structure name	Total Number of structures	Number of functioning structures	Number of non-functioning (Poor) structures	Effectiveness of infrastructures (%)
Division boxes	7	4	3	57.1
Drop structures	73	47	26	64.4
Aqueducts	2	1	1	50.0
Turnouts	42	26	16	61.9
Bridges	4	3	1	75.0
Culverts	2	2	0	100.0
Total	**130**	**83**	**47**	**63.8**

4.2 Intake Efficiency

4.2.1 Sediment Level

The results from this study reveal a significant reduction in the dam reservoir depth and open water area from its design of 9m deep to 5.2m, and 26.3ha to 17.8ha, respectively (Table 5). Sediment deposition is the main reason toward reduced dam reservoir depth and open water area in the scheme. Since the construction of the dam, it has never been flashed out or dredged. This dam was constructed to store mainly runoff water from its catchment as Nyarubogo doesn’t have a permanent flow throughout the year. The dam catchment accommodates different farming activities with no conservation measures to prevent soil erosion by water. This influences the rate of sedimentation in runoff towards the dam. Lack of maintenance of sluice gates is another factor contributing to the poor condition of structures, which, in the case of sluice gates, made them inoperable, requiring extra manpower to maneuver them due to the level of sediment and the lack of greasing regularly.

4.2.2 Embankment Level

This is calculated by considering the damaged length of the embankment to the total length of it. During this study 15 m of the showed presence of sheet erosion by rainfall and the total length of the embankment is 180 m, hence the damaged length was quantified to 8.33 % (Table 5). The embankment was still in good condition, showing only slight erosion of the embankment length. According to (Vermillion et al., 1999), flow control structures would require maintenance or rehabilitation if there was a deviation of more than 5% in terms of structural defectiveness, which is the case with Nyarubogo.

To keep the Nyarubogo irrigation scheme going, more maintenance operations need to be done to increase the scheme's intake efficiency. These results are consistent with the findings of (Zende and Nagarajan, 2013) in a study where the intake efficiencies were 69% for the Hinganga on Talav reservoir and 66% for the Alsund Talav reservoir and the poor performance of these two reservoirs was highly attributed to sedimentation as both were only able to store water at a rate less than 50% of their capacity.

4.2.3 Sluice Gate

The results show that the irrigation scheme has serious problems with sedimentation and intake efficiency, which have an immediate effect on the system's use and performance. An increase in maintenance needs is reflected in the size of the sediment accumulation, especially near the sluice gate, which necessitates the use of extra personnel to operate. At first, a single person could operate the sluice gate; however, due to rising silt levels, at least two people are now needed to manually open and shut the gate. This suggests a decrease in operational effectiveness as well as a rise in the amount of manpower needed to maintain the infrastructure. Better sediment management techniques are required, since the sediment accumulation is probably the consequence of upstream erosion and insufficient desilting methods as pointed out by Obialor et al., (2019).

Additionally, the scheme's intake efficiency was assessed at 67%, with the total performance being influenced by the sluice gate condition, sediment level, and embankment stability. According to the results in Table 5, the sluice gate was responsible for 12% of the inefficiency, the embankment level for 35%, and the sediment level for 20%. These numbers show that the main causes of decreased intake efficiency, which affects the scheme's ability to efficiently provide water to the irrigation region, are sedimentation and embankment stability problems. Browder et al., (2019) highlighted that the sluice gate and embankment may experience increased wear and tear due to the high sedimentation levels, which would shorten the structure's lifetime and need more frequent repairs.

Given that 33% of the intake system's physical condition is considered unsatisfactory, the irrigation scheme is confronted with a major operational difficulty that might possibly reduce crop yields by limiting the amount of water delivered to fields. This inefficiency implies that about one-third of the system is susceptible to malfunctions, which might affect the water supply's dependability, particularly during crucial growth season times. Targeted interventions, such silt removal, embankment strengthening, and maybe the installation of automated gate mechanisms to lessen the labor intensity of gate operations, will probably be necessary to address these problems.

Table 5
Physical Assessment of Intake in Nyarubogo Irrigation Scheme

Parameter	Class (%)	Rank	Weightage (%)	Weightage per unit Rank	IE (%)
Sediment level	51-70	2	50	10	20
Embankment level	< 10	5	35	7	35
Sluice gate	Close to gate	4	15	3	12
Total			**100**	**20**	**67**

4.3 Canals Condition

Canals condition was calculated by referring to Table 2. The total length of the canal is 23 km, and the length of canal bank collapse, water pooling and weed growth were found to be 3.2 Km out of 23 km, 2.7 km and 8.5 km, respectively. The length for every parameter is divided by total length of the canal gives the percentage that determine the operation class and automatically the rank for each parameter. The overall canal condition was found to be good at 70% rating (Table 6).

It is clear from the results that conveyance losses contribute most to the inefficiency of the system, which is not surprising as more than 95% of its length is not lined, along with canal bank collapse, which is caused by high runoff from the mountains located in this region during the rainy season. The flush floods erode the canal banks and deposit sediments along the canal bed, giving rise to water stagnation in some parts of the canal and impairs water flow. Apart from this, there are also farmers in the buffer zone of the scheme who cultivate close to the canal without any consideration for the safety of the canal, leading to its collapse. Weed growth can be attributed to poor maintenance resulting from the unwillingness of farmers to participate in community outreach to supplement the tiny budget for canal maintenance accruing from contributions of the farmers as irrigation water fees.

Table 6
Physical Condition Assessment of Canals in Nyarubogo Irrigation Scheme

Parameter	Class (%)	Rank	Weightage (%)	Weightage per unit Rank	Canal condition (%)
Bank Collapse	11-20	4	30	6	24
Water pooling/Ponding	11-30	4	20	4	16
Weed Growth	31-50	3	10	2	6
Conveyance loss	31-50	3	40	8	24
Total			**100**	**20**	**70**

4.4 Command Area

Command area development was obtained based on three components: cropped area, water flow regulatory constraints, and water sharing issues. Based on data collected from the farmers' cooperative office, every year for season A (Dry season) only half of the scheme is cultivated for that the cropped area is around 50 %. For instance, in 2024 season A cropped area was 110 ha which is equal to 47.93 % of the total command area (229.5 ha). For Water flow regulatory constraints three out of seven water division boxes are damaged, and the four remaining ones, their gates are not functioning well, farmers have to block water by using bananas steam, and grasses to divert water). Water sharing Issues were identified by using the responses from the questionnaire. Farmers disclosed that there are conflicts in water sharing (between farmers with consecutive farms) and WUO members do not respect the provided time to avail water in the farms in dry season.

The results from this study indicate a fair command area development of the irrigation scheme, which stands at 68% (Table 7). However, the unsatisfactory performance can be attributed to water flow constraints, water sharing issues, and cropped area factors. These constraints are more apparent during the dry season when the area experiences a remarkable water scarcity and low water storage from the dam. Around half of the command area is left uncultivated since there isn't enough water to irrigate all farms of the scheme during the dry season.

Destruction of two of the division boxes exacerbated the problem as farms that were being fed by these irrigation structures have to be cultivated only during the rainy season (season B) where there is enough rainfall to respond to paddy crop water requirement. Results from this study are consistent with those reported by (Agide Dejen, 2012) for Godino and Gohaworki subsystems of Wedecha irrigation scheme in Ethiopia with the command area development ratio ranging from 67% to 92%. However, the findings contradicts with the findings by (Awulachew et al., 2005), who reported that command area development for most schemes in Ethiopia stands at 40%. This implies that Nyarubogo scheme has been faring better than other schemes in the region in spite of the observed constraints.

Table 7
Evaluation of Command area Development in Nyarubogo Irrigation Scheme

Parameter	Class (%)	Rank	Weightage (%)	Weightage per unit Rank	Command Area Development (%)
Cropped Area	31-50	3	60	12	36
Water flow regulatory constraints	11-30	4	20	4	16
Water sharing Issues	11-30	4	20	4	16
Total			**100**	**20**	**68**

4.5 The Implication of Farmers' Socio-Economic Status in the Physical Status of Irrigation Infrastructures

Table 8, provides a summary of the survey sample's primary socioeconomic attributes. The various factors that are taken into consideration include the heads of the households' age, gender, education level, and land tenure. Table 9 shows a summary of two additional factors which are land size and householder's ages. Heads of households were, on average, 46.51 years old, and their ages ranged between 29 to 73 years old. Majority (78.33 %), this has a crucial implication for irrigation structures' poor maintenance. These findings indicate that the majority of farmers were aged male individuals. This implies that youth and women do not actively participate in agriculture activities undertaken in the Nyarubogo irrigation scheme. It should be noted that youth and women are important actors in development activities, particularly agriculture activities. While older farmers may have gathered experience and knowledge about conventional irrigation techniques, older farmers may be unable to execute the manual labor necessary for maintenance duties due to physical restrictions compared to young farmers.

The findings are similar with the study by Sharaunga and Mudhara, (2018) who pointed out that farmers' socioeconomic profiles such as age, gender, level of education, and size of the farm have a major impact on the physical state of irrigation facilities. FAO (2021) acknowledged the role of youth in improving food systems and food security and believed that youth are triggers of sustainable future food systems. Further, limited access to resources and decision making authority among female farmers within agricultural communities, may have an effect on their capacity to take part in infrastructure maintenance projects (FAO, 2011; Mehra and Rojas, 2008; World Bank, 2009)

Land size per householder is reported on an average of 0.24 ha (Table 8), implying that farmers own a small piece of land which might be because of reliance on other sources of income to feed their families than farming in Nyarubogo irrigation scheme which forces them to channel their time to other activities and not participate as required in maintenance of irrigation infrastructures from this scheme.

Further results reveal that 68.33% of farmers had completed their primary education, whereas 11.67% of respondents had not attended any formal schooling, 13.33 % attended adult education; 6.67% of respondents had finished their secondary education, and none of the farmers had completed their university education. The findings indicate that the majority of farmers in the study area have low levels of education, which has had a detrimental effect on irrigation structures' performance. This is because the farmers can't easily assimilate all technical skills that are paramount to the good maintenance of scheme water infrastructures and understand well the role played by irrigation structures maintenance in water resource management and sustainability of the scheme as well. Farmers' educational backgrounds have an impact on their ability to access cutting-edge technical solutions that could result in the best understanding, particularly when it comes to irrigation structure repair works. The degree to which technical skills necessary for system maintenance are assimilated depends on one's educational background. Furthermore, these levels can also indicate one's capacity for productive farming (Chidavaenzi et al., 2021).

On the other hand, during focus group discussion, 75% (9/12) of Farmers confirmed that they are paying water fees and rent for land (the land is totally for the government), the rates are 300 frw/are or 30,000 frw/ha (23 USD/ha) per season, and 40 frw/are or 4,000 frw/ha (3.1 USD/ha) per year for water fees and land renting respectively, with these expenses, farmers expected to have maintenance support from the government that owns the land, and the government doesn't provide such fund which leads to ineffective maintenance of irrigation structures in this study area.

Table 8

Gender, Education, Age Category, and Land Ownership of Respondents (Number of Participants is 120)

Parameter	Frequency	Percentage
Gender		
Female	26	21.67
Male	94	78.33
level of education		
Adult education	16	13.33
No formal education	14	11.67
Primary	82	68.33
Secondary	8	6.67
University	0	0.00
Category of Age		
16-30	3	2.50
31-50	71	59.17
51-70	45	37.50
70 and above	1	0.83
land ownership		
Rented from Government	120	100.00

Table 9

Age and Land (farm) size Averages of the Respondent's Sample

Parameter	Number of respondents	Range	Minimum	Maximum	Mean	Std. Error
Age (years)	120	44	29	73	46.51	0.937
Land size (ha)	120	0.95	0.5	1	0.24	1.357

4.6 Causes of Poor Maintenance of Irrigation Structures

In this study farmers have pointed out several challenges that contribute to poor maintenance of irrigation infrastructures (Table 10). Factors such as improper livestock grazing, heavy runoff during certain seasons, lack of funding from water fees, and difficulties with government support and maintenance finances confront an enormous challenge in guaranteeing the maintenance of irrigation infrastructure. Furthermore, the fact that farmers do not own the land increases the complexity by lowering their feeling of accountability and motivation to make infrastructure maintenance investments and management (McConne and Dillon, 1997; Mudd, 2021). This mismatch in responsibility for ownership and upkeep exacerbates already-existing problems and makes it more difficult to manage irrigation facilities sustainably.

Moreover, inadequate leadership and organizational deficiencies exacerbate the scheme's maintenance problems. Unfair distribution of water supplies and inefficient management systems incite farmers' discontent, which impedes group efforts to maintain infrastructure (Oremo, 2020).). It also puts irrigation system integrity at further risk because buffer zone degradation is not addressed by preventive measures. It is imperative that better governance systems, fair resource distribution, and participatory decision-making procedures that prioritize the sustainable management of irrigation facilities and empower farmers be put in place in order to address these systemic issues.

Table 10
Factors Causing Unsatisfactory Maintenance of Irrigation Structures

Factors causing unsatisfactory maintenance of irrigation structures	Frequency	Percentage
No maintenance funds or support from the government	101	17.5
high runoff occurs in season B	119	20.7
Poor leadership and poor organization of the work	48	8.3
Unfair distribution, allocation of water resources	29	5.0
Unauthorized Livestock grazing in the scheme	43	7.5
Insufficient funds collected from water fees	87	15.1
Lack of measures to prevent Erosion from the scheme's buffer zones	77	13.4
Land not owned by farmers	72	12.5
Sum	**576**	**100.0**

V. CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusion

The purpose of this study was to assess the operational efficiency as well as physical state of the irrigation structures that are part of the Nyarubogo irrigation scheme. The study assessed the development of the command area, the physical state of the canal, the effectiveness of the intake, and the infrastructure. The study found that, despite the superior performance of certain infrastructural components such as water drop structures bridges, and culverts, the overall efficiency of irrigation structures was compromised, underscoring the necessity of targeted interventions. Moreover, deficiencies in the development of the command area, canal operations, and maintenance of intake structures were observed, emphasizing the necessity of addressing these issues to ensure the sustainability of the irrigation scheme. This study offers insightful suggestions for improving the resilience and efficacy of the Nyarubogo irrigation scheme, which will ultimately lead to higher agricultural productivity and better water resource management in the area.

5.2 Recommendations

Based on the findings from this study, the Rwanda Government should allocate supplementary funds for infrastructural maintenance, especially targeting big infrastructures that cannot be improved by the water fees collected from the scheme's farmers. The accumulated sediments from the Nyarubogo dam should be flushed out to create more storage for water to increase the command area under cultivation even during the dry season. Establishment of a protective farming mechanism in the scheme's buffer zones should be prioritized to reduce the rate of soil erosion by water and the quantity of runoff generated from the surrounding mountains. The water users' organization should take the lead in sensitizing its members on their role to participate in operation and maintenance activities of their scheme. Maintenance and repair works of the scheme's infrastructures have to be done in a timely and adequate manner.

Conflict of Interest

The authors would like to state that they have no relevant conflicts of interest to report regarding this study.

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