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Performance Assessment Of Water Distribution Systems For Nyarubogo Irrigation Scheme, Rwanda

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Abstract – This study aimed to examine hydraulic performance and productivity of Nyarubogo irrigation scheme, with a particular emphasis on water delivery performance ratio (WDPR), adequacy, efficiency, dependability, equity, and productivity.The results show that the head, middle, and tail sections had average WDPR of 0.98, 0.60, and 0.52, respectively. The tail and head sections had values of delivery performance ratio (DPR) that indicated a slight under-discharge (0.55) and slight over-discharge (1.04). The temporal average adequacy from head (0.995) to tail (0.742), values showed a decrease across the irrigation scheme while spatial adequacy fluctuations ranged from 0.882 to 0.909. The dependability was classified as good (0.011) at the head and at the middle (0.096), and fair (0.14) at the tail sections of the irrigation scheme. The study further found an average equity ratio of head to tail (ERHT) of 2.06 indicating downstream disparities in the distribution of water equity. The equity was classified as good at the head and middle, and fair equity at the tail. Efficiency was good at the middle (0.983) and tail (0.969), and poor at the head (0.671). The land productivity of 4.04±0.13 tons/ha were produced on average at upstream, 3.92±0.17 tons/ha at midstream, and 3.5±0.14 tons/ha at downstream. At the head, the water productivity (WP) was 0.39 kg/m³ which was low as compared to midstream (0.62 kg/m³), and downstream (0.63 kg/m³). The economic water productivity (EWP) values were $0.17/m³, $0.27/m³, and $0.28/m³ for the head, middle, and tail end of the irrigation scheme, respectively. These findings highlighted the necessity of implementing focused interventions in water management and infrastructure, particularly in the middle and tail sections, so as to guarantee fair distribution of water and improve overall scheme productivity.

Keywords: Water distribution, systems, hydraulic performance, irrigation scheme, Rwanda.

I. INTRODUCTION

Irrigated farming accounts for 20% of the world cultivated area and contributes about 40% of the world food production (World Bank, 2022). Over years, the global intensification of agriculture production has been highly associated with increased water and energy inputs to grow (Mashnik *et al.,* 2017). Farmers benefit from irrigation development through improving food security, economic growth, and lowering poverty levels (Mhembwe *et al.,* 2019). According to the World Bank (2022) irrigated agriculture is more productive, with at least two times higher than rainfed farming per unit area, thus enabling intensive production.

The current irrigated land in Rwanda stands at 66 840.5 ha which is equivalent to 11.33% of the total potential irrigable area which is 589 711 ha with prospects to increase the irrigated area to 102 284 ha by 2024 (Mukeshimana *et al.,* 2022). However, many irrigation schemes in Rwanda like other developing countries experience poor infrastructures, inefficient irrigation practices, water allocation issues (IIIE, 2020), water losses, inconsistent system functioning, and disintegration of irrigation components (Sirimewan *et al.,* 2019). Further, challenges such as poor water quality, water scarcity and inefficient infrastructures, cost of modernized irrigation systems, market, bureaucracy in legal framework, low farmers participation and disorganization of farmers associations impede the sustainable irrigation practices (Kanda and Lutta, 2022). According to Muema *et al.*(2018) regular irrigation performance assessment is essential for sustainable irrigated agriculture production.

The irrigation schemes performance evaluation can be done through a combination of multiple variables including hydraulic performance indicators (HPI) (Kartal *et al.*, 2020), and Socio-economic performance indicators (SPI). Among the indicators, the HPI provide more insights on the efficacy of water distribution systems and pin points if water delivery is satisfactory. The HPI are such as adequacy, equity, efficiency, dependability, conveyance efficiency, and delivery performance ratio. By understanding irrigation schemes performance, water resources managers and other stakeholders are able to identify areas of inconsistency such as clogs, leaks, or uneven water delivery, and come up with counteractive measures to improve the system performance.

Several studies have been conducted to evaluate the performance of different irrigation schemes in Rwanda and found varying performances. The study by Hakuzimana and Masasi, (2020) evaluated the performance of Rugeramigozi irrigation scheme in terms of water productivity and water service delivery, and found the overall poor performance of the scheme which necessitate infrastructures improvement and intensive management practices so as to enhance sustained productivity of the scheme. Niragire *et al.* (2021)assessed funded portable and Nsengimana et al. (2023) assessed irrigation scheduling of soyabeans both studies were conducted under sprinkler irrigation systems in eastern province and found a satisfactory performance of the irrigation systems. Another study by Narayanan (2014) revealed that higher performance of irrigation scheme for Rwamagana rice project in Rwanda is associated with regular involvement of farmers in irrigation management practices. Such studies are very insightful in improving the overall irrigation scheme performances in Rwanda, however, Nyarubogo irrigation scheme lacks such kind of studies prompting to its unknown level of performance.

This study aims to (1) address information deficiencies existing regarding the efficacy of Nyarubogo irrigation scheme with respect to water delivery efficiencies, water productivity and (2) reveals farmers' perception on these irrigation scheme performance indicators. This is information is crucial to schemes managers which may help them to improve the performance of the Nyarubogo irrigation scheme.

II. Materials and Methods

2.1 Description of the Study Area

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. The scheme spans three sectors (Kibirizi, Busoro and Muyira). Water flows by gravity to the Nyarubogo irrigation scheme from the dam.

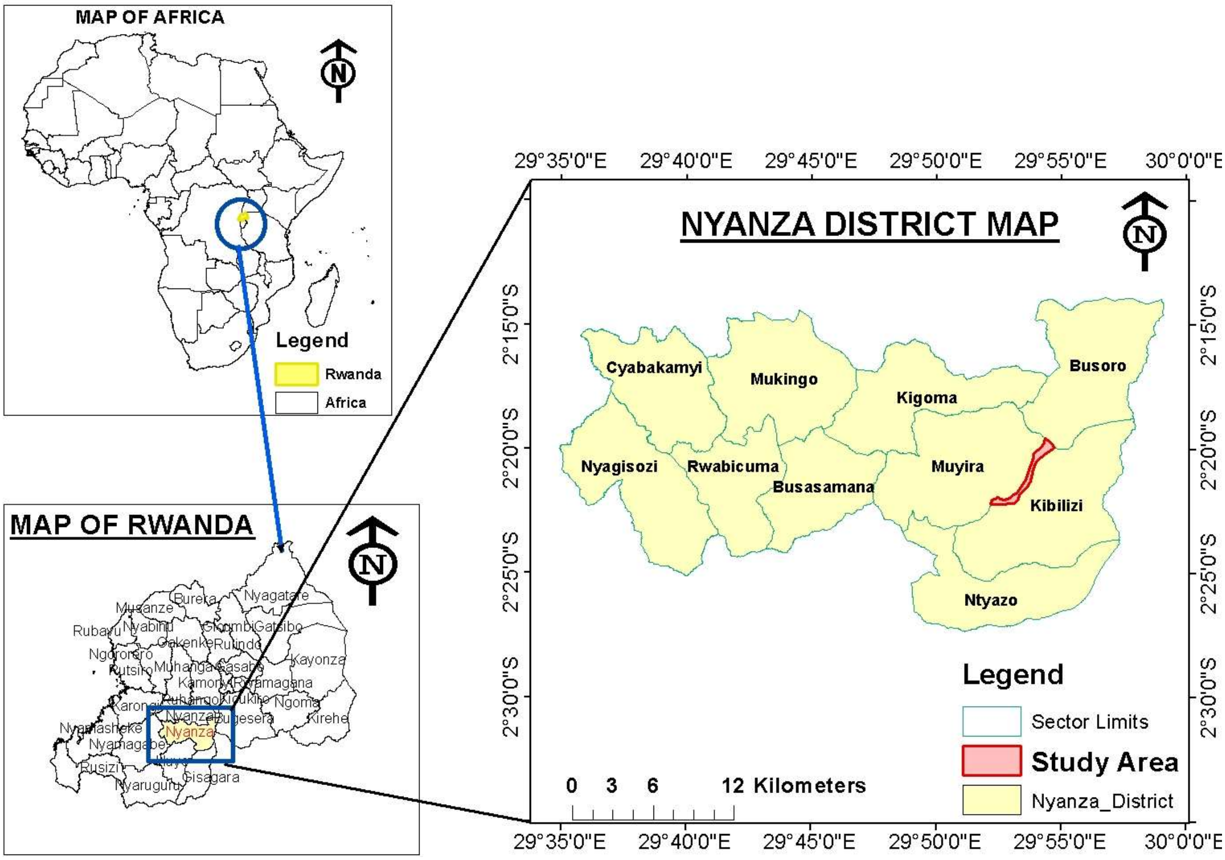

Figure 1: Study Area

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.

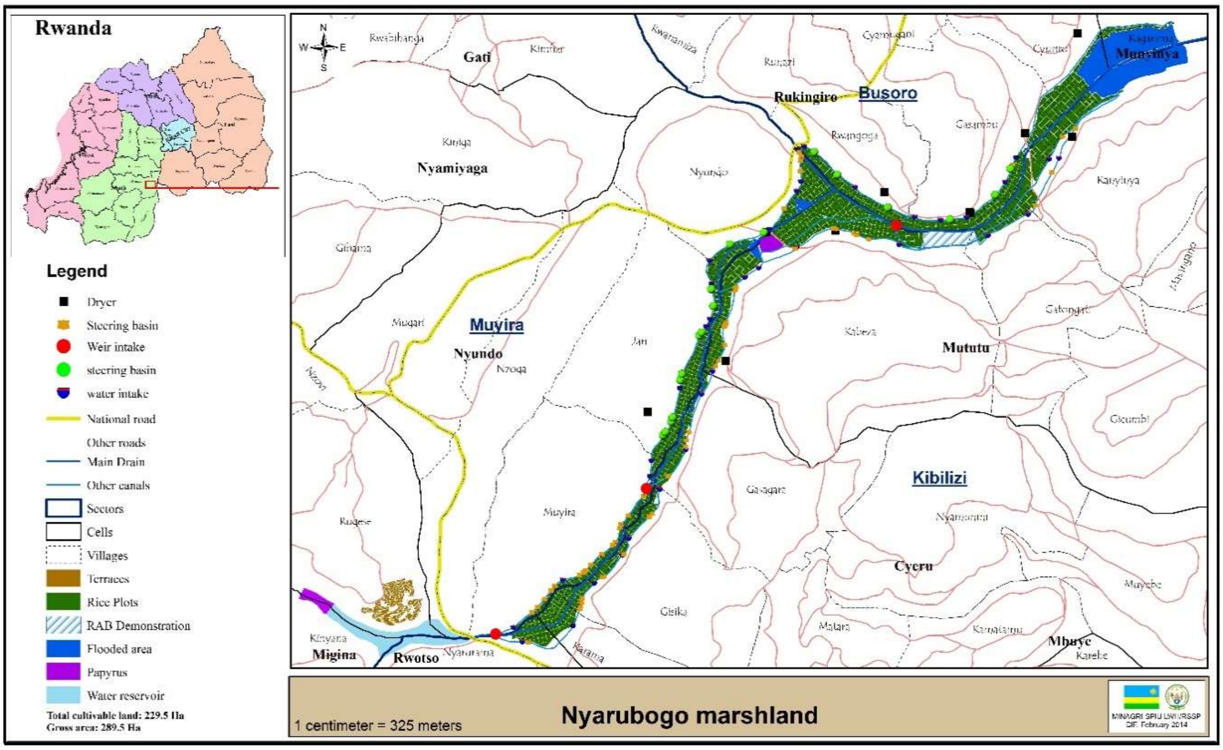

Figure 2: Nyarubogo Irrigation Scheme layout (Source: Rwanda Agriculture Board)

2.2 Data Collection

Data were collected from primary and secondary sources. The collection of primary data involved soil samples to retrieve soil texture, soil samples were taken using stratification approach, the strata were formed based on scheme zones (head, middle and tail) (McKenzie et al., 1999), soil infiltration rate, field observations to know the farming crop in the area and irrigation processes. The individual interviews, key informant interviews and focus group discussions (120, 10, and 12 participants respectively) were conducted at Nyarubogo irrigation schemes with irrigation participants to unveil the water distribution schedule at Nyarubogo irrigation scheme, data for crop yield were collected through questionnaire used in the three sections of the scheme (Head middle and tail). The secondary data, such as crop-specific irrigation areas, delivered water discharge from water users' organisation, and climatic data for thirteen years (2011 to 2023), were obtained from RMA recorded by Busasamana-Nyanza Station.

2.2.1 Secondary canals and irrigation area

The Table 1, shows the distribution of irrigated areas to their corresponding canals, during the dry season each farm zone received water on two consecutive days per week.

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Table 1: Plot zone names and irrigated area

Location	Canal name	Plot zone name	Irrigated area (ha)
Head	SC1-R	Matara	18.3
	SC2-L	Muyira	14.5
Middle	SC1-R	Gasagara	14.8
	SC2-L	Jali	18
Tail	SC1-R	Mahwa	21.3
	SC2-L	Nyundo	23

III. DATA PROCESSING AND DATA ANALYSIS

The hydraulic performance indicators were calculated using variables obtained after field data processing.

3.1 Determination of required discharge per season

CROPWAT 8.0 calculations were used to determine crop water requirements during the growing season. This involved estimating monthly water required discharge (Q_R) at various canal locations. Water discharge required was obtained by multiplying gross irrigation, irrigation interval and the area to be irrigated (Allen *et al.*, 1998b).

According to FAO guidelines for crop water requirements, the crop coefficient for cultivated crops was determined (Allen et al., 1998b). The calculation of crop evapotranspiration involved multiplying the crop coefficient (KC) by the reference evapotranspiration (Eto) formula 1.

$$ETc = Kc \times Eto \quad (1)$$

Where:

ETc = Crop Water Requirements (mm/day); Kc= Crop Coefficient; and

ETo = Reference Evapotranspiration (mm/day)

Water application process losses are not factored into the estimation of net irrigation requirement (In). It comes from the field equilibrium. Formula 2

$$In = ETc - Pe \quad (2)$$

Where:

In= Net irrigation requirement; ETc = Crop water requirements (mm/day); and Pe = effective dependable rainfall (mm); Pe = 0.8P- 25 if P> 75 mm/ month and Pe =0.6P-10 if P < 75 mm/ month (FAO, 1993).

Losses of water during application and transportation to the field are factored into the gross irrigation requirement. It is described in terms of efficiency when computed from net irrigation requirement, as Equation 3 illustrates.

$$Ig = In / E \quad (3)$$

Where:

Ig = the Gross irrigation requirement (mm); In = the Net irrigation requirement (mm);

and E = the overall project efficiency, E = 45% for surface irrigation (FAO, 2018).

Table 2: Irrigation schedule

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Rice	0	0	0	0	57	232.1	151	157.8	137.3	89.6	28.1	0
Net scheme irrigation required.												
in mm/day	0	0	0	0	1.8	7.7	4.9	5.1	4.6	2.9	0.9	0
in mm/month	0	0	0	0	57	232.1	151	157.8	137.3	89.6	28.1	0
in l/s/ha	0	0	0	0	0.21	0.9	0.56	0.59	0.53	0.33	0.11	0
Irrigated area	0	0	0	0	100	100	100	100	100	100	100	0
(% of total area)												
Gross irrigation (continuous irrigation)												
(l/s/ha)	0	0	0	0	0.467	2	1.244	1.311	1.178	0.733	0.244	0
Gross irrigation (continuous irrigation) for 7 days (l/s/ha)	0	0	0	0	3.267	14	8.711	9.178	8.244	5.133	1.711	0

Considering that the irrigation procedure in place and land area required to irrigate, we have to convert gross irrigation rate on continuous basis (l/s/h) to the required water flow in cubic meter per second (m^3/s) in two days per week for each cropping month, the formula 4 was adopted.

$$X=(0.001*Y*A)/2 \quad (4)$$

Where

X: Required Gross irrigation (Rotational irrigation) for 2 days per week ($m^3/s/ha$)

0.001: Conversion factor from litre (l) to cubic meter

Y: Required Gross irrigation (continuous irrigation) for 7 days Per week (l/s/ha)

A: Area to be irrigated

In estimating the required water discharges, the month of May was not considered as it was a period for rice nursery and land preparation, farmers planted on 15/06/2023, hence the gross monthly discharges were calculated from June to November 2023.

3.2 Soil textures and infiltration rate

Soil texture was determined by the hydrometer method, which is based on physical settlement of soil particles in water (Bouyoucos, 1962), soil samples were analyzed in soil laboratory of Rwanda Agriculture and animal resources development Board (RAB). The first stage in a soil particle size analysis is the dispersion of the soil into the individual particles. These are the sand (2.00-0.05 mm), silt (0.05-0.002mm) and clay (<0.002 mm) fraction. After obtaining the soil composition in sand, silt and

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clay in terms of percentage, the texture of soil was determined by soil textural triangle (Figure 2) and required soil parameters by soil water characteristics application (vesion 6.02.74) (Alaboz *et al.,* 2021). Eight soil samples were taken using Auger tool at 30 cm depth three from upstream, two from middle and and three downstream of the scheme. The soil infiltration rate was measured by using double rings infiltrometer (with inner ring diameter of 30 cm and outer ring 60 cm) whereby three points were sampled (upstream, middle and downstream) to get the overall soil infiltration.

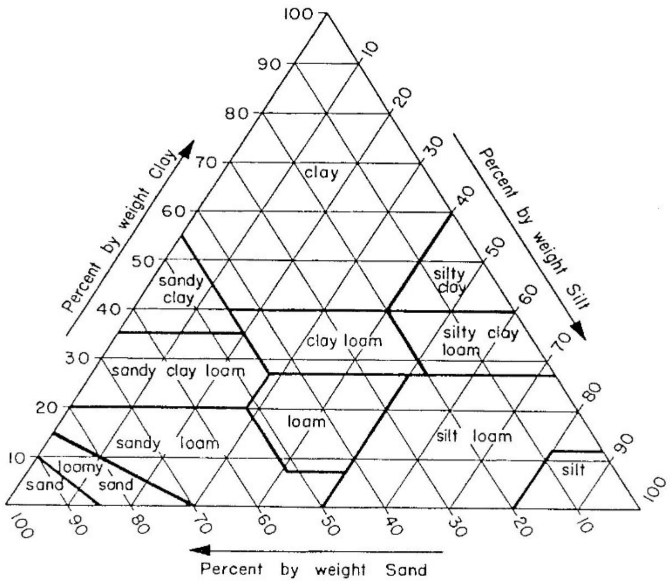

Figure 3: Soil Textural triangle, showing the percentages of clay (below 0.002 mm), silt (0.002-0.05 mm), and sand (0.05-2.0mm) in the basic soil textural classes (FAO, 2006).

After analysis, the soil testure classes in the scheme fall in three classes which are clay, clay loam and sandy clay loam (Table 3). Scheme's soil is dominated by Sandy clay loam, 62.5 % of soil in the scheme are sandy clay loam according to eight sampled soil points.

Table 3: Soil samples texture

Location	**Identifications**	**Latitude**	**Longitude**	**Elevation(m)**	**Sand (%)**	**Silt**	**Clay**	USDA textural class
	Nyarubogo p1	-2.367483	29.885238	1398.3	57	18	25	Sandy clay loam
Head	Nyarubogo p2	-2.364500	29.885594	1396.3	43	28	29	Clay loam
	Nyarubogo p3	-2.352253	29.894364	1385.5	65	12	23	Sandy clay loam
	Nyarubogo p4	-2.336774	29.898833	1375.5	51	18	31	Sandy clay loam
Middle	Nyarubogo p5	-2.336660	29.900680	1373.2	37	22	41	Clay
	Nyarubogo p6	-2.329101	29.908555	1369.6	39	28	33	Clay loam
Tail	Nyarubogo p7	-2.323328	29.927007	1354.6	51	22	27	Sandy clay loam
	Nyarubogo p8	-2.324837	29.927916	1355.5	58	19	23	Sandy clay loam
Average					50.13	20.88	29	Sandy clay loam

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3.3 Soil Infiltration rate

A Double Ring infiltrometer was used with 45 cm in height and inner ring measuring 30 cm in diameter. The inner cylinder is where the infiltration measurements are obtained. The diameter of outer ring was 60 cm which is used to create the buffer pond to reduce lateral spreading of water. The cylinders were penetrated to 10 cm below the surface of the ground to stop water losses.

The net time (Tn) for every measurement was measured in minute (min) and net water depth (Wd) decreasing in centimeter (cm), therefore soil infiltration rate (Y in mm/hr) was calculated by using equation 5.

$$Y = \frac{Wd*10*60}{Tn} \quad (5)$$

Based on the obtained data, Figure 4, Figure 5 and Figure 6, represent soil infiltration rate on different locations in Nyarubogo irrigation scheme.

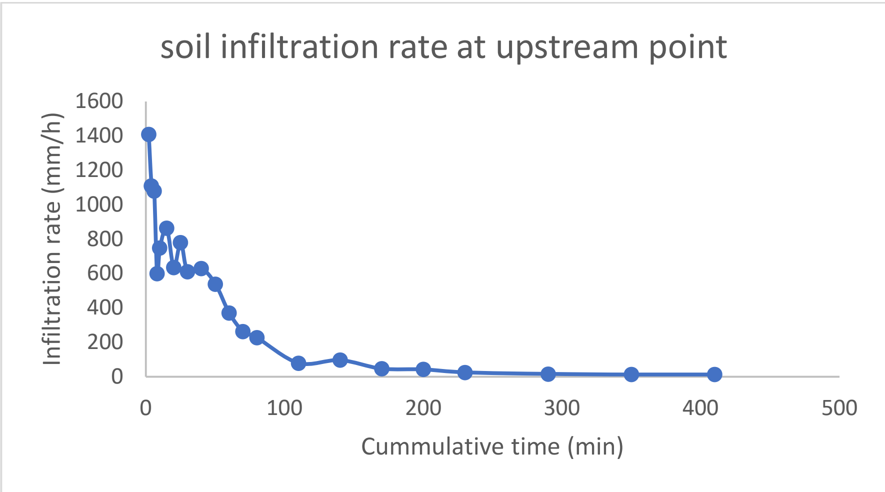

Figure 4: Soil infiltration rate for upstream point (coordinates: -2.367483 S, 29.885238 E)

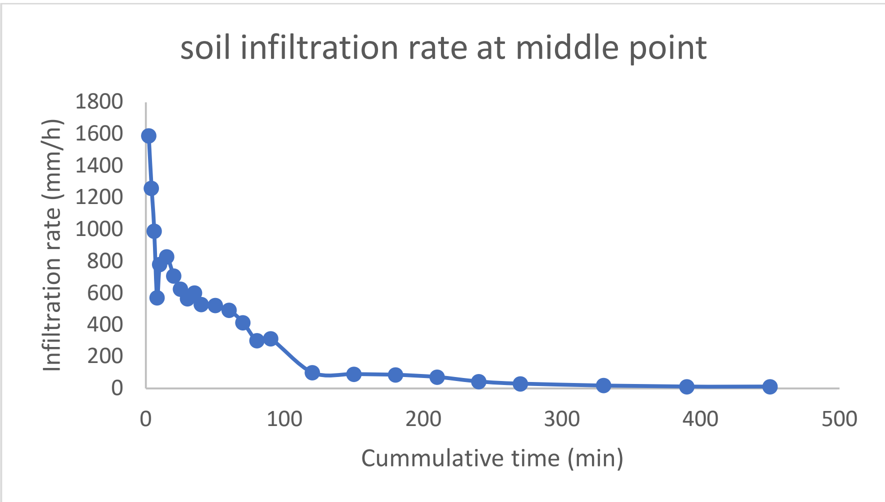

Figure 5: Soil infiltration rate for middle point (coordinates: -2.336774S, 29.898833 E)

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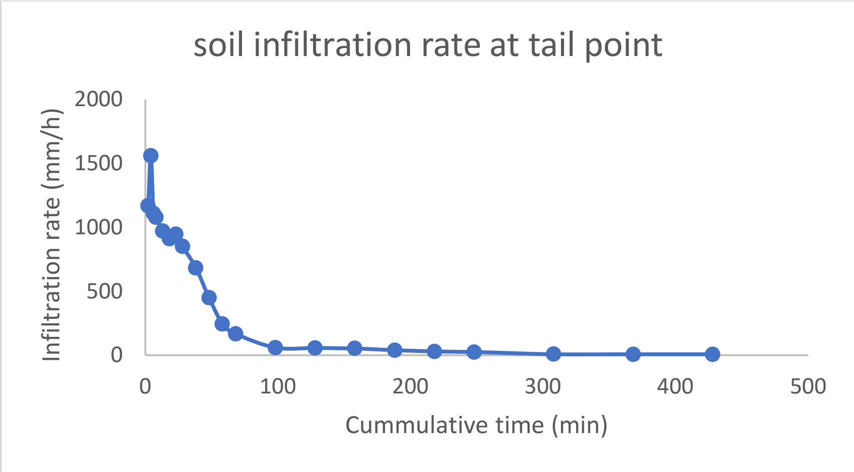

Figure 6: Soil infiltration rate for downstream point (coordinates: -2.323328 S, 29.927007 E)

The infiltration rate of the soil in this study was estimated to 11 mm/hr by taking the average of the above three points with infiltration rates of 14 mm/hr, 12 mm/hr and 8 mm/hr for upstream, middle and tails points, respectively.

3.4 Meteorological data

Meteorological data for this study area were obtained from RMA recorded from Busasamana-Nyanza Station for a period of thirteen years up to November 2023, these data were grouped into average monthly data as required in CropWAT 8.0 (Figure 7 and Figure 8)

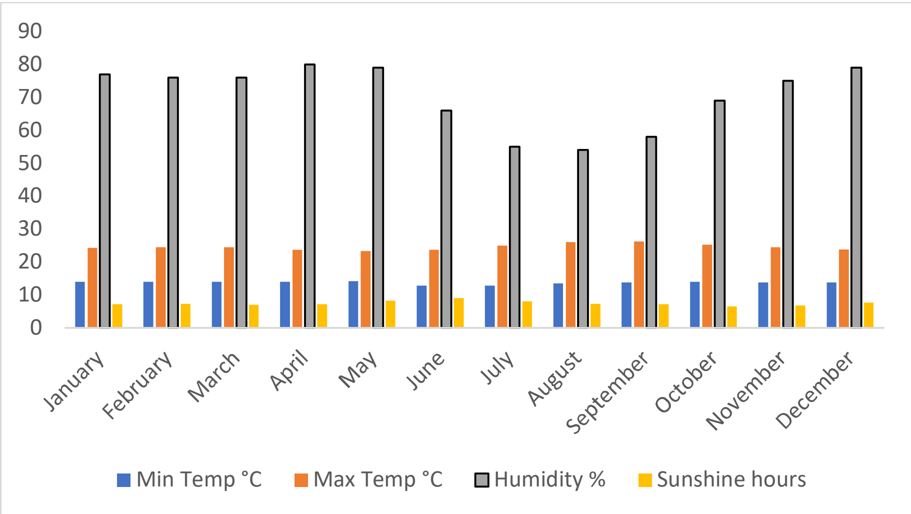

Figure 7: Climatic data (minimun and maximum temperatures, humidity and sunshine hours)

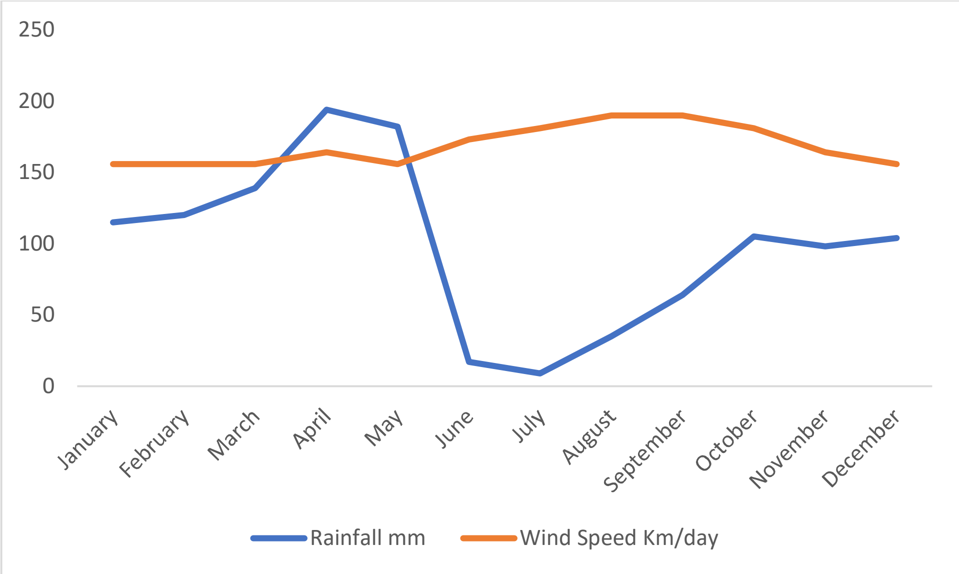

Figure 8: Rainfall and wind speed data

3.5 Type of the crop cultivated in the scheme

In the Nyarubogo irrigation scheme, the main crop cultivated there is paddy (Rice), which was cultivated on the whole area during this research. Therefore, it was taken into consideration to calculate crop water requirement and plant coefficients (Kc) are 1.05 for the initial stage, 1.2 for the midseason, and 0.9 for the late season (Allen *et al.,* 1998a).

3.6 Hydraulic Performance Indicators

In the Nyarubogo irrigation scheme, four indicators (Adequacy, Dependability, Equity and Efficiency) were used to determine the irrigation system performance. The data collected in a single irrigation season from June to November for year 2023 were used to evaluate indicators of hydraulic performance. Water delivery performance in the irrigation canals were assessed according to the delivery discharge and monthly requirements. Further indicator such as equity ratio for head to tail were used to estimate water delivery performance at the field level.

At any given point in the season, the most fundamental and short-term performance indicators compare the actual discharge to the target or expected discharge (Bos *et al.,* 1993). Delivery performance ratio (DPR) and water delivery performance are the two most significant hydraulic performance indicators (Molden and Gates, 1990). The formulas for these two parameters are 6 and 7.

Water Delivery Performance = Actual Volume / Target Volume (6)

Delivery Performance Ratio= Actual Discharge /Target Discharge (7)

3.6.1 Adequacy

Water adequacy in irrigation refers to the capacity of irrigation system to deliver the amount of water that meet the crop's water demands and can be preserved in the effective root zone (Sánchez *et al*., 2015). Water requirements by the crop, water availability and supply are the main determinants of water adequacy in irrigation (Phadnis & Kulsreshtha, 2011). Adequacy was calculated according to Molden and Gates, (1990).

$$P_A = \frac{1}{T}\sum_T \left(\frac{1}{S}\sum_S \frac{Q_D}{Q_R}\right) \quad (8)$$

Whereas

$$P_A = \begin{cases} \frac{Q_D}{Q_R}, & Q_D \leq Q_R \\ 1, & Otherwise \end{cases}$$

T =Time period (months) S = Site where the canal is serving QD = The actual amount of water delivered (m3/s) QR = Required discharge (m3/s).

3.6.2 Dependability

Dependability refers to the consistency and reliability of irrigation services (Kumar et al., 2022) such as the quality of water supplied for agriculture and it encompasses delivery timing and discharge reliability. The dependability of Nyarubogo irrigation scheme was obtained using the formular by Gorantiwar and Smout, (2005).

$$P_D = \frac{1}{S}\sum_S CV_T \frac{Q_D}{Q_R} \qquad (9)$$

CVT = Temporal coefficient of variation of the ratio QD/QR over a region S and a time T, QD = The actual amount of water delivered (m3 /s) QR = Required discharge (m3 /s).

3.6.3 Equity

Equity is the fair distribution of water to the irrigation beneficiaries throughout the system. When the ratio of water distribution at the head end and water distribution at the tail end is equal to 1, the system conforms to the equitable distribution and confronts when the ratio is less or higher than 1 (Deshmukh, 2018). According to Bwambale *et al.* (2019) when all locations or users receive required water supply, adequate water or water they entitled for, a perfect equitable water distribution would emerge. The equitable water distribution was calculated according to Molden and Gates (1990).

$$P_E = \frac{1}{T}\sum_T CV_S \left(\frac{Q_D}{Q_R}\right) \qquad (10)$$

CV_S = Spatial coefficient of variation of the ratio QD/QR over a region S and a time T QD = The actual amount of water delivered (m3 /s) QR = Required discharge (m3 /s).

3.6.4 Equity Ratio for Head and Tail (ERHT)

This is an important indicator for both water delivery and water conveyance. It refers to the fair distribution of water among users from the downstream (tail) and upstream (head) of the irrigation system. The equity ratio for head and tail was obtained as follows:

$$ERHT = \frac{\frac{1}{n}\sum_{t=1}^{t=n}\frac{Q_D}{Q_R}(Headend)}{\frac{1}{n}\sum_{t=1}^{t=n}\frac{Q_D}{Q_R}(Tailend)} \qquad (11)$$

Where: n = number of periods monitored QD = The actual amount of water delivered (m3 /s) QR = Required discharge (m3 /s)

3.6.5 Efficiency Indicator

In hydraulic performance, efficiency is referred as degree in which the irrigation system conserve water. It is a ratio of the required amount of water for a certain area to the amount of water distributed for the specified area. This is important for reducing pressure in water sources and reducing infrastructure expenditures and possibly allow irrigation of more land. The efficiency indicator was calculated as follows (Molden & Gates, 1990):

$$P_F = \frac{1}{T}\sum_T \left(\frac{1}{S}\sum_S \frac{Q_R}{Q_D}\right) \qquad (12)$$

Where: $P_F = \begin{cases} \frac{Q_R}{Q_D}, & Q_R \leq Q_D \\ 1, & Otherwise \end{cases}$

PF = is the spatial and temporal average of the ratio of QR/QD indicator over a region S and time period T QD = The actual amount of water delivered (m3 /s) QR = Required discharge (m3 /s)

3.6.6 Coefficient of variation (CV)

An indicator for figuring out the variation discharge in secondary canals is the coefficient of variation, or CV. The CV, or coefficient of variation, is a metric used to indicate discharge variability and track changes at a particular site. The standard deviation divided by the mean is known as the coefficient of variation. Equation 13 (Clemmens and Molden, 2007) was used to calculate it.

$$CV = \frac{Standard\ deviation\ of\ discharges}{Mean\ of\ discharges}. \quad (13)$$

3.6.7 Conveyance Efficiency

This shows the quantity of lost water along the main irrigation canal. For Nyarubogo irrigation scheme the conveyance efficiency was calculated as follows (equation 14):

$$E_C = \frac{V_m}{Q_0} \times 100 \quad (14)$$

Vm = volume of water delivered to the distribution system (m3 /s) Q0 = amount of water abstracted from the river (m3 /s).

Table 4: Performance indicators ranges (Molden & Gates, 1990).

	Range		
Performance Indicators	**Good**	**Fair**	**Poor**
Adequacy	0.90-1.00	0.80-0.89	<0.80
Dependability	0.00-0.10	0.11-0.20	>0.20
Equity	0.00-0.10	0.11-0.25	>0.25
Efficiency	0.85-1.00	0.70-0.84	<0.70
ERHT	0.8-0.9 &1.1-1.3	0.7-0.79 & 1.21-1.3	<0.7 or >1.3

3.6.8. Water productivity

Productivity is the ratio of output to input, which is used to quantify performance. Parts of the system or the entire system may be evaluated for productivity. It could be responsible for all or only one of the production system's inputs, leading to the development of two productivity indicators. Molden (1997).

Two measures of productivity exist in systems: partial or single factor productivity, which is the ratio of total tangible output to input of a single factor, and total productivity, which is the ratio of all tangible outputs divided by all tangible inputs. Factors in agricultural systems include labor, capital, land, water, and nutrients.

Thus, water productivity (WP) is a partial-factor productivity that gauges how systems turn water into products and services, just like land productivity (Molden et al., 2003) and the equation for it as suggested by (Molden et al., 2003) is mentioned in equation…

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Water Productivity (WP) = $\frac{Output\ Derived\ from\ water\ use}{Water\ input}$ (15)

The considered output in this study was paddy yield (Kg) and water input (m3)

IV. Results

4.1 The efficacy of Nyarubogo irrigation scheme with respect to water delivery efficiencies

4.1.1 Crop water requirement

The table 5 indicates the crop water requirements, dependable rainfall, net irrigation and gross irrigation which are 766.08 mm, 119.9 mm, 646.18 mm and 1435.96 mm respectively.

Table 5: Crop water requirement and gross irrigation

Month	Decade	Stage	Eto mm/day	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec	Ig mm/dec
Jun	2	Init	3.94	1.05	4.14	41.37	0.00	41.37	91.93
Jun	3	Init	4.05	1.05	4.25	42.53	0.00	42.53	94.50
Jul	1	Deve	4.16	1.06	4.41	44.10	0.00	44.10	97.99
Jul	2	Deve	4.27	1.11	4.74	47.40	0.00	47.40	105.33
Jul	3	Deve	4.38	1.16	5.08	50.81	0.10	50.71	112.68
Aug	1	Mid	4.45	1.20	5.34	53.40	2.30	51.10	113.56
Aug	2	Mid	4.56	1.20	5.47	54.72	3.40	51.32	114.04
Aug	3	Mid	4.60	1.20	5.52	55.20	5.40	49.80	110.67
Sep	1	Mid	4.63	1.20	5.56	55.56	7.10	48.46	107.69
Sep	2	Mid	4.67	1.20	5.60	56.04	8.80	47.24	104.98
Sep	3	Mid	4.52	1.20	5.42	54.24	12.50	41.74	92.76
Oct	1	Late	4.37	1.17	5.11	51.13	17.70	33.43	74.29
Oct	2	Late	4.18	1.10	4.60	45.98	21.80	24.18	53.73
Oct	3	Late	4.12	1.01	4.16	41.61	20.50	21.11	46.92
Nov	1	Late	4.01	0.93	3.73	37.29	18.50	18.79	41.76
Nov	2	Late	3.90	0.89	3.47	34.71	1.80	32.91	73.13
Average (mm/dec)						47.88	7.49	40.39	89.75
Total (mm/cropping season)						**766.08**	**119.90**	**646.18**	**1435.96**

4.1.2 Hydraulic Performance Indicators

Table 6 contains all discharges (delivered and required) for both secondary canals, one on the right and another on the left side of Nyarubogo Bed River, for all months since June to November 2023.

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Table 6: Delivered and Required discharges in secondary canals (M^3/s)

Location		Month	QD	QR	QD/QR
head		June	0.147	0.1281	1.000
		July	0.133	0.0797	1.000
	SC1-R (Right)	Aug	0.107	0.0840	1.000
		Sept	0.071	0.0754	0.942
		Oct	0.068	0.0470	1.000
		Nov	0.041	0.0157	1.000
head		June	0.108	0.1015	1.000
		July	0.107	0.0632	1.000
	SC2-L (Left)	Aug	0.096	0.0665	1.000
		Sept	0.093	0.0598	1.000
		Oct	0.065	0.0372	1.000
		Nov	0.043	0.0124	1.000
Middle		June	0.095	0.1036	0.917
		July	0.051	0.0645	0.791
	SC1-R (Right)	Aug	0.047	0.0679	0.692
		Sept	0.057	0.0610	0.934
		Oct	0.032	0.0380	0.842
		Nov	0.016	0.0127	1.000
Middle		June	0.113	0.1260	0.897
		July	0.065	0.0784	0.829
	SC2-L (Left)	Aug	0.06	0.0826	0.726
		Sept	0.068	0.0742	0.916
		Oct	0.041	0.0462	0.887
		Nov	0.013	0.0154	0.844
Tail		June	0.121	0.1491	0.812
		July	0.064	0.0928	0.690
	SC1-R (Right)	Aug	0.072	0.0977	0.737
		Sept	0.063	0.0878	0.718
		Oct	0.039	0.0547	0.713
		Nov	0.029	0.0182	1.000

Tail		June	0.107	0.1610	0.665
		July	0.076	0.1002	0.758
		Aug	0.071	0.1055	0.673
	SC2-L (Left)	Sept	0.076	0.0948	0.802
		Oct	0.043	0.0590	0.729
		Nov	0.012	0.0197	0.609

4.1.3 Water delivery performance

The table 7, shows the results for actual target discharges plus volume delivered and targeted for the whole cropping season; these results were calculated taking into consideration that the irrigation is made two days per seven days (week), discharges were calculated for these secondary canals as the monthly average of the ones recording from June to November, the cropping season counts 150 days (approximately 22 weeks); therefore the delivered volume was found based on this number of weeks, the Target Volume was obtained through irrigated area multiple by design discharge (0.824 l/s/ha) (ADP, MINAGRI, 2009).

Table 7: Target and delivered water volumes in Nyarubogo irrigation scheme

Reach	Irrigated area (Ha)	canal name	Actual discharge (m3/s)	Target Discharge (m3/s)	Volume delivered (m3)	Target Volume (m3)
head	18.3	SC1-R	0.095	0.097	179625.6	195426.4
	14.5	SC2-L	0.085	0.077	162201.6	154846.1
middle	14.8	SC1-R	0.050	0.078	94406.4	158049.8
	18	SC2-L	0.060	0.095	114048.0	192222.7
tail	21.3	SC1-R	0.065	0.113	122918.4	227463.6
Total	23	SC2-L	0.064	0.122	121968.0	245617.9

4.1.4 Water delivery performance and Delivery performance ratio

Water delivery performance and Delivery performance ratio have been obtained by using equation 6 and equation 7, the results for them are summarized in table 8, the average WDP are 0.98, 0.60, and 0.52 for head, middle and tail respectively which means that the actual water volume doesn't be more than the target volume in all the main three parts of the farm and DPR average values were found to be 1.04 to the head, 0.63 to the middle and 0.55 to the tail, the situation reveals that at the head the actual discharge was slightly more than the target one, while for middle and tail parts of the scheme actual discharges were below the target discharges**.**

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Table 8: Water delivery performance and Delivery performance ratio

	HEAD			Middle			Tail		
Parameter	**Right**	**Left**	**Average**	**Right**	**Left**	**Average**	**Right**	**Left**	**Average**
WDP	0.92	1.05	0.98	0.60	0.59	0.60	0.54	0.50	0.52
DPR	0.97	1.11	1.04	0.63	0.63	0.63	0.57	0.53	0.55

4.1.5 Adequacy

In the Nyarubogo irrigation scheme adequacy indicator was determined as shown in Figure 9. The scheme had the adequacy spatial values of 0.995 at the head, 0.856 at the middle, and 0.742 at the tail end of the scheme, whereas the temporal values of adequacy are 0.882, 0.845, 0.805, 0.885, 0.862 and 0.0.909 in June, July, August, September, October and November 2023 respectively in the scheme (Table 9). The adequacy results show that adequacy was good for head, fair for middle and poor for tail (Figure 9) comparing them to the standard (Table 4).

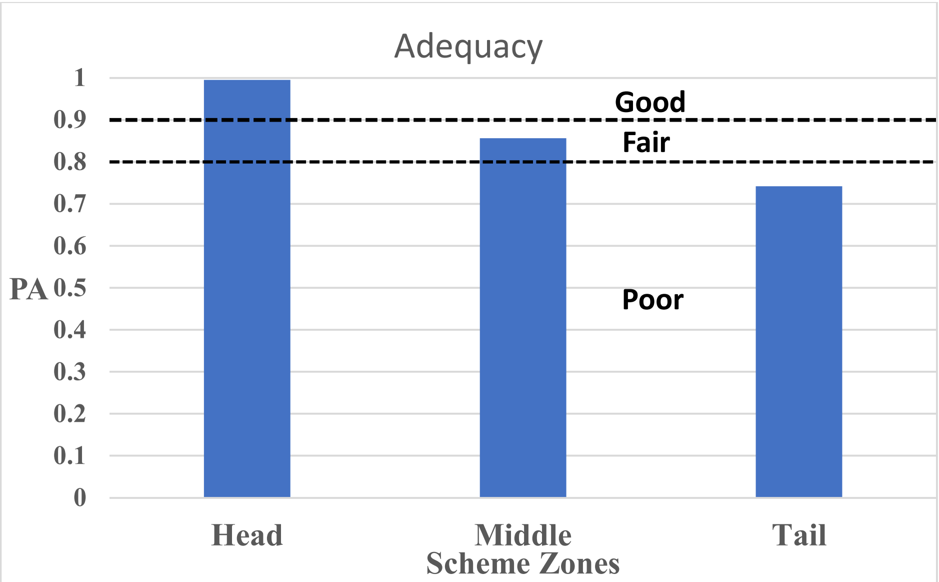

Figure 9:Average Water distribution adequacy in Nyarubogo irrigation Scheme

Table 9: Temporal and spatial Average Adequacy of Water distribution in Nyarubogo irrigation Scheme

MONTH	HEAD		Middle		Tail		temporal PA
	Right	Left	Right	Left	Right	Left	
June	1.000	1.000	0.917	0.897	0.812	0.665	0.882
July	1.000	1.000	0.791	0.829	0.690	0.758	0.845
Aug	1.000	1.000	0.692	0.726	0.737	0.673	0.805

Sept	0.942	1.000	0.934	0.916	0.718	0.802	0.885
Oct	1.000	1.000	0.842	0.887	0.713	0.729	0.862
Nov	1.000	1.000	1.000	0.844	1.000	0.609	0.909
	0.990	1.000	0.863	0.850	0.778	0.706	
Spatial Average PA	0.995		0.856		0.742		0.865

4.1.6 Dependability

Results in Figure 10 show the calculated PD which is expressed as a ratio of Q_D to Q_R for the canals over time T by using equation 9. The dependability of the Nyarubogo irrigation scheme at the head, middle and tail is 0.011, 0.096 and 0.114, respectively. This indicator was measured with reference to the equation 9. According to the standard Molden and Gates (1990), PD>0.20 dependability is classified as poor, whereas 0.00-0.10 and 0.11-0.20 are classified as good and fair dependability, respectively. Table 4 shows these results, classifying the study area as good at both the head and middle and fair dependability at the tail.

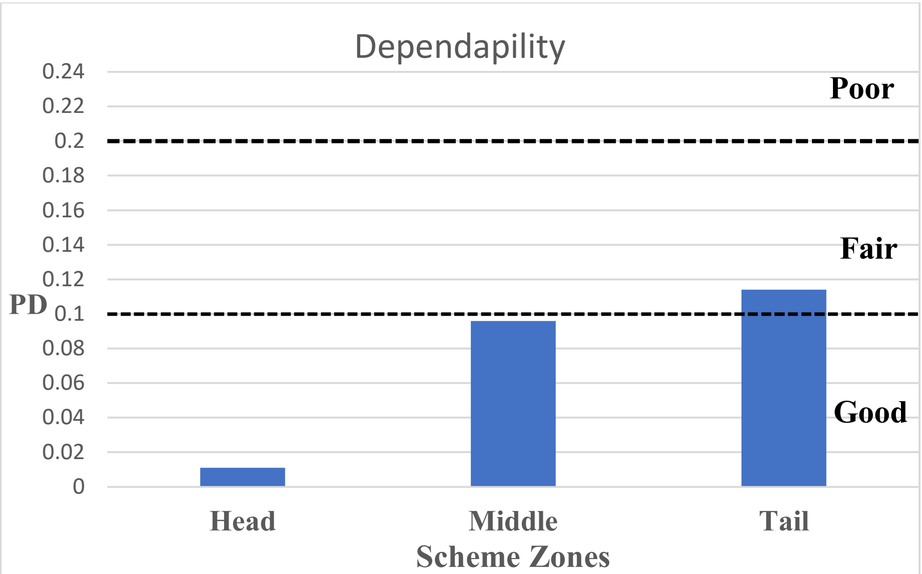

Figure 10: Dependability of water supplied in Nyarubogo irrigation Scheme

Further, farmers within Nyarubogo irrigation scheme were interviewed on whether they receive water at the right time or not. Majority (58%) of farmers did not receive water at the right time, with majority (22.5%) of respondents along the downstream experienced no water delivered at the right time (Figure 11a). For farmers who did not receive water at the right time, majority (62.9%) of 70 respondents received water after 1 hour with most of them (30.0%) along the midstream. Only few respondents received water more than 3 hours of the required time, with about 5.7% of the respondents along the downstream of the irrigation scheme (Figure 11b).

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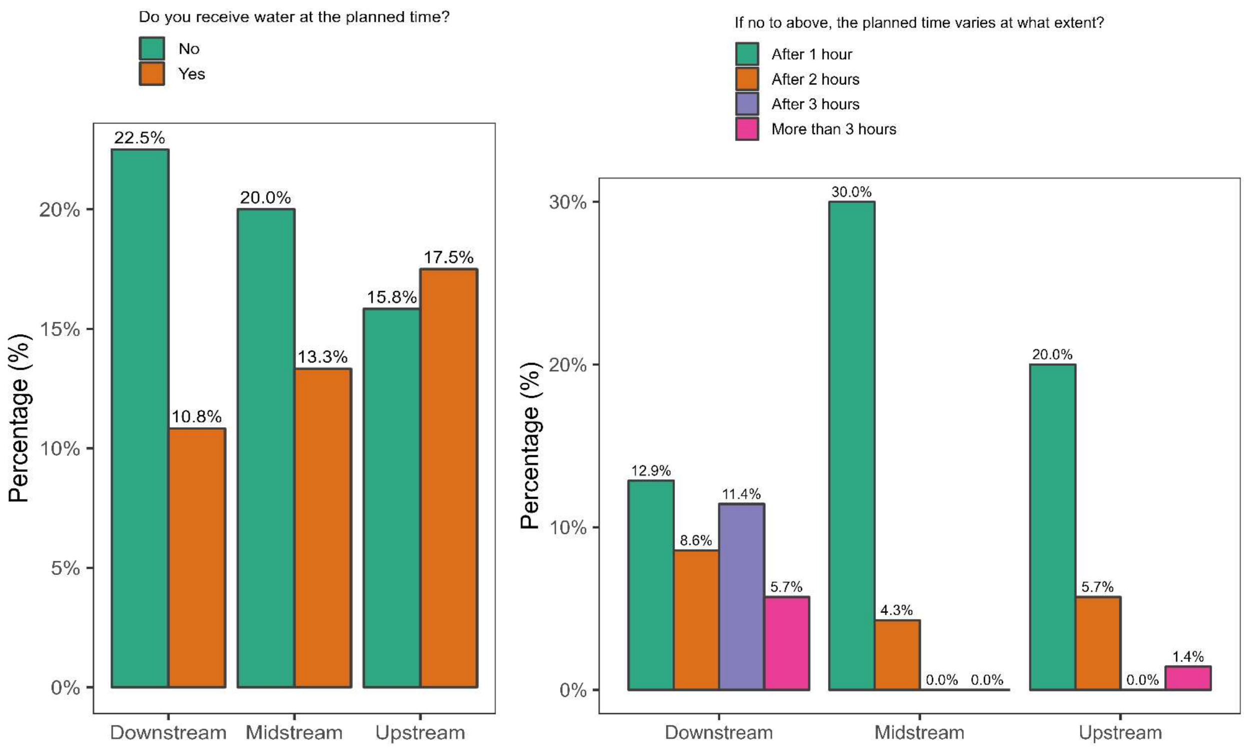

(a) (b)

Figure 11 : Farmers's perception on water supply dependability.

4.1.7 Equity

Equity plays a crucial role during the assessment of hydraulic performance with respect to a fair distribution of water, as expressed by equation 10. Results in Figure 12 summarize the equity in water distribution for the secondary canals found at the tail, middle, and head of the Nyarubogo irrigation scheme. As classified in Table 4, equity of water distribution in this scheme was found to be good in both the head and middle parts and fair for the tail part of the Nyarubogo irrigation scheme.

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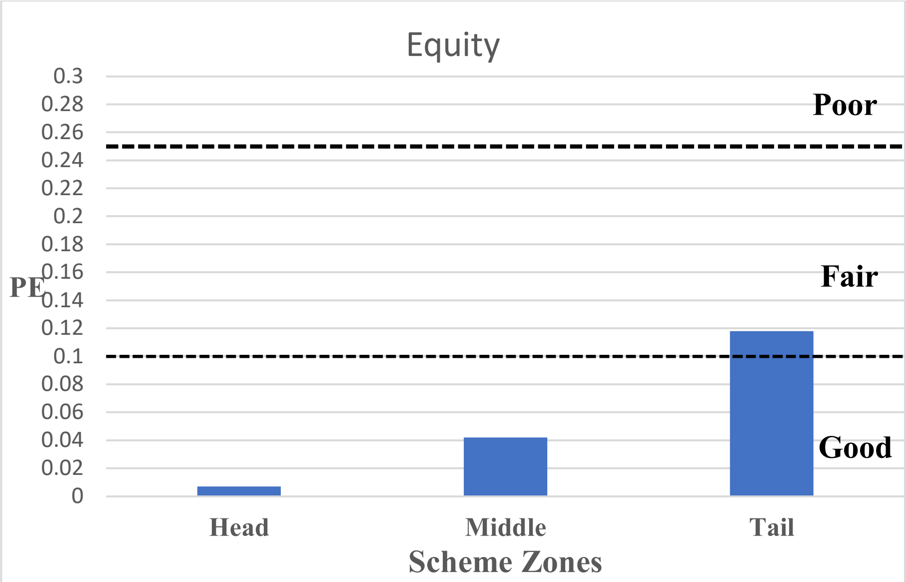

Figure 12: Equity of water supplied in Nyarubogo irrigation scheme

Farmers in the Nyarubogo irrigation scheme reported on how irrigation water is distributed among farmers in the scheme. Over 60% of the respondents mentioned that water is distributed equally, with each farmer receiving a fair share, with the majority (25.83%) of respondents coming from midstream of the scheme (Figure 13a) . Regarding water allocation decision-making, the majority (54%) of respondents reported that decisions are made through a formal committee involving representation from various stakeholders, with more responses (21.67%) from downstream of the scheme (Figure 13b).

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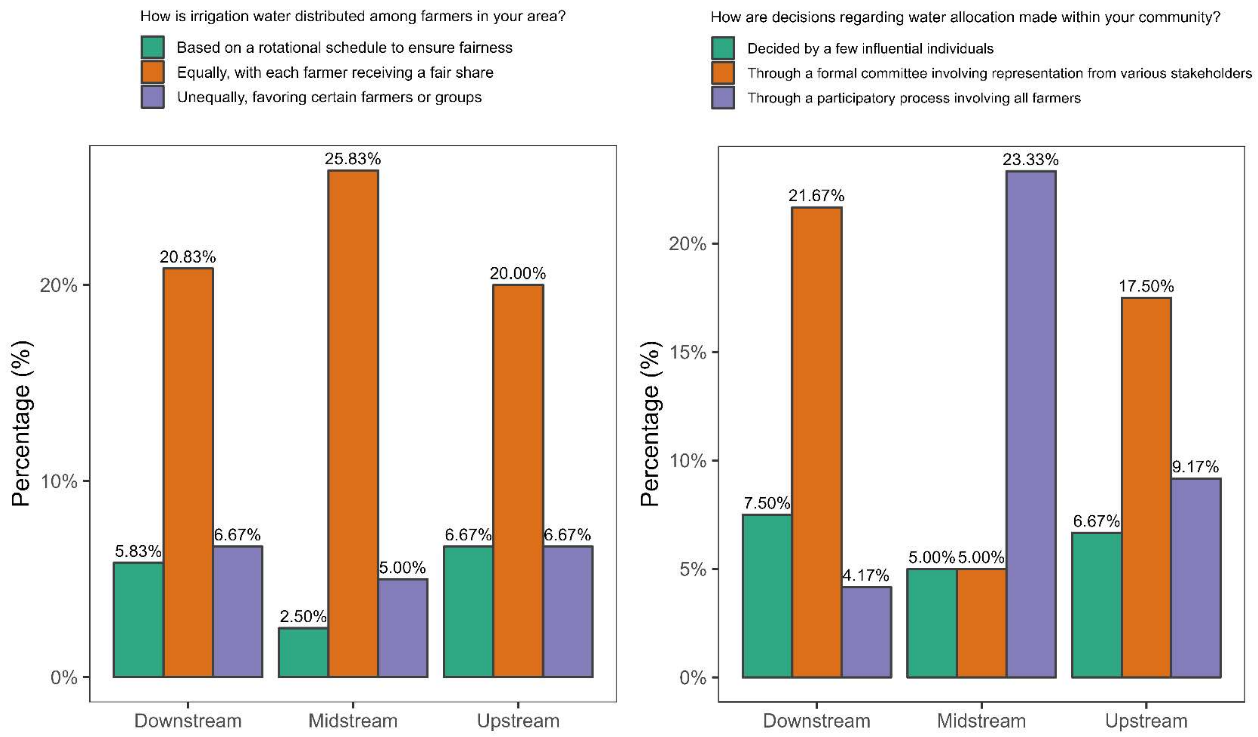

(a) (b)

Figure 13 : Farmers's perception on water distribution Equity

4.1.8 Equity Ratio for Head and Tail (ERHT)

The equity ratio of Nyarubogo irrigation scheme gave details of how water for irrigation was managed and fairly distributed in the tail end and head end of the secondary irrigation canals. The ERHT was calculated with the help of equation 11, and the results are tabulated in Table 12. The equity ratio for head and tail ranges from 1.5 to 2.76 and an average of 2.06, which represents a poor indicator referring to the standard (Table 4), given that all values are more than 1.3.

Table 12: Equity ratio for Head and Tail of the scheme

	Head		Tail		
Month	**Right**	**left**	**Right**	**left**	**ERHT**
June	1.15	1.06	0.81	0.66	1.50
July	1.67	1.69	0.69	0.76	2.32
August	1.27	1.44	0.74	0.67	1.93
September	0.94	1.56	0.72	0.80	1.64
November	1.45	1.75	0.71	0.73	2.22
	2.61	3.47	1.59	0.61	2.76
Average ERHT					2.06

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4.1.9 Efficiency Indicator

Results in Figure 14 revealed the efficiency temporal values for outlet pointed at the tail, middle, and head of the secondary canals. To get the results, equation 12 was adopted. Nyarubogo irrigation scheme has an efficiency temporal value of 0.671 at the head end, 0.983 at the middle, and 0.969 at the tail end. According to Table 4 by Molden and Gates (1990), the efficiency was classified as poor at the head and good at the middle and tail.

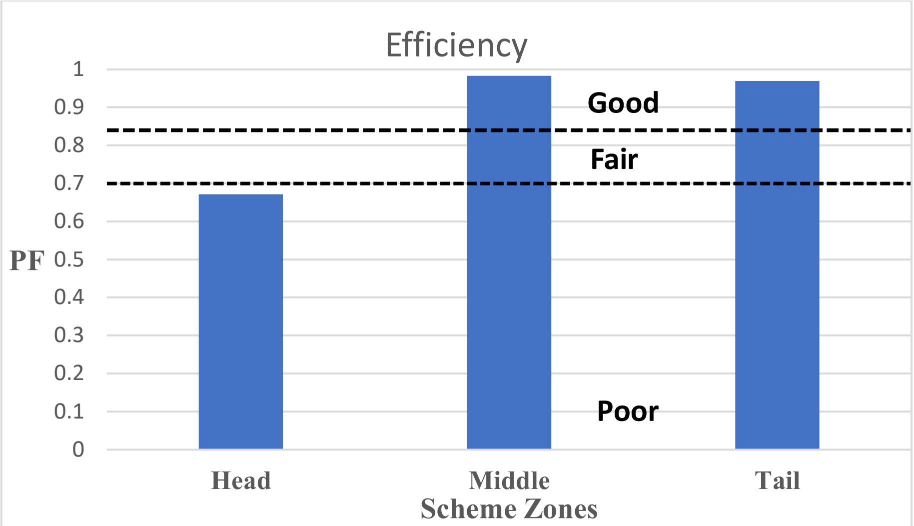


Figure 14: Efficiency Indicator in Nyarubogo irrigation scheme

4.1.10 Conveyance Efficiency

The conveyance efficiency of Nyarubogo irrigation scheme was determined by considering the recorded discharges for diverted water (water from the intake) and delivered water by secondary canals at the farm blocks, equation 14. The results in Figure 15 show that the average conveyance efficiency of the Nyarubogo irrigation scheme secondary canal was 65.2 %, 62.6 % and 57.1 % for the head, middle and tail, respectively. FAO (2008) states that the standard value of conveyance efficiency for an adequately maintained canal is 95% for lined canals and 75% for unlined canals. The conveyance efficiency results in this present research for unlined canals fall into a low class compared to the range suggested by FAO.

The low conveyance efficiency observed in the canals of Nyarubogo irrigation scheme may be attributed to the canal poor maintenance, water seepage losses, weed growth and canal bank collapse observed in different parts (Areas) of the canals.

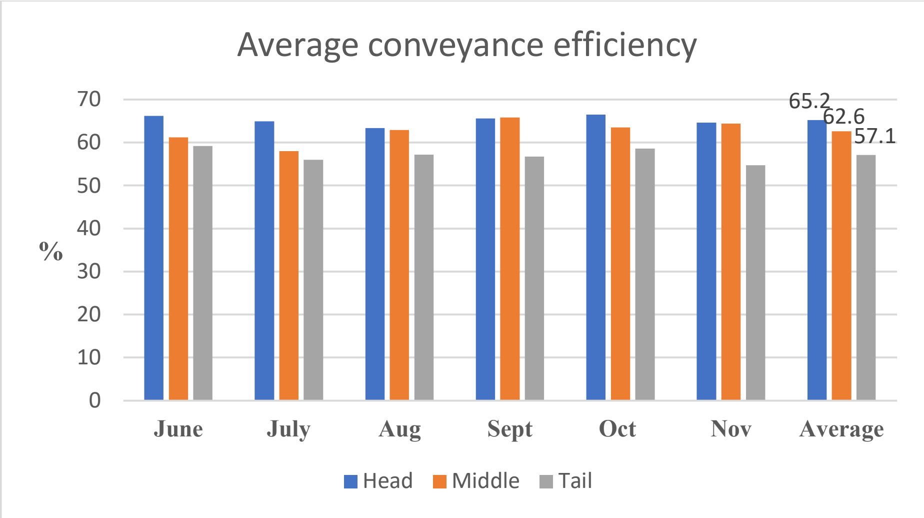
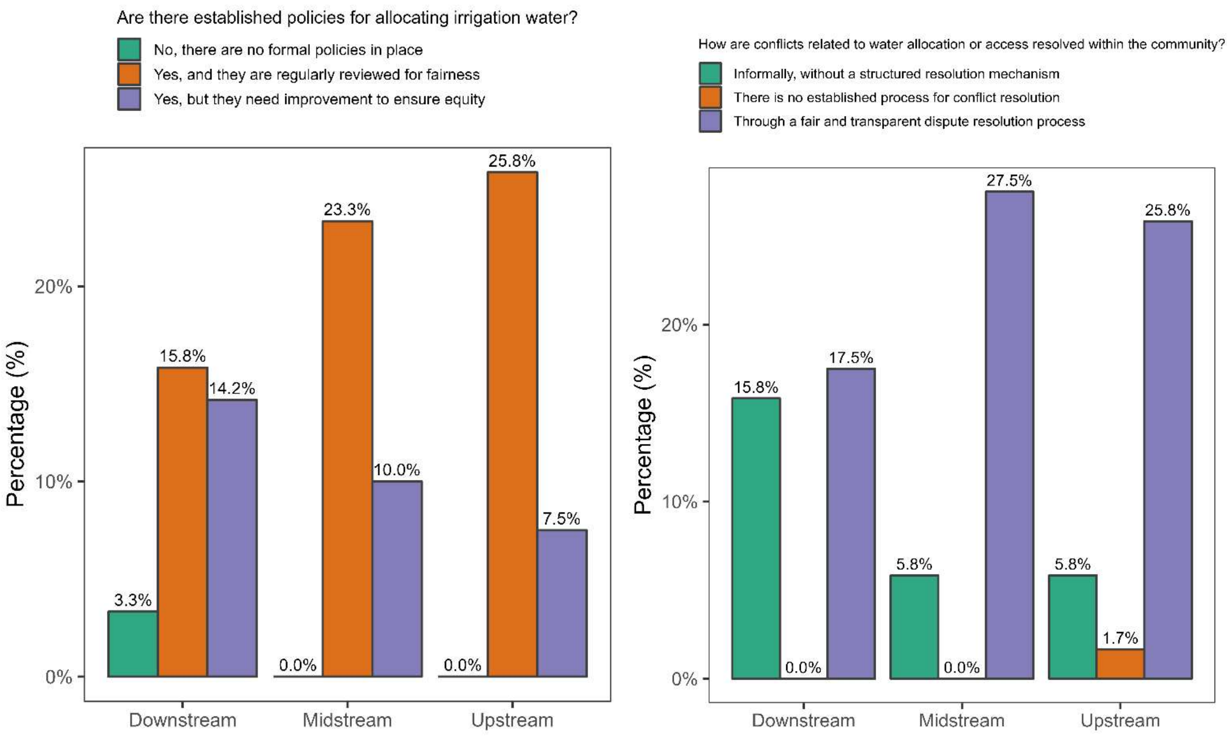


Table 15: Average conveyance efficiency (%) for Nyarubogo irrigation scheme

4.2 The farmers' perception on irrigation scheme performance indicators.

4.2.1 Water Management of the irrigation scheme

In this study, farmers were interviewed on the presence of established policies for allocating irrigation water and conflicts resolution during allocation and access to water. Majority (64.9%) of farmers reported the presence of policies which are regularly reviewed for fairness with 25.8 % from upstream (Figure 16a). Regarding conflicts resolution, majority (71.7%) reported that conflicts are resolved through a fair and transparent dispute resolution process with 27.5% of them from were from midstream (Figure 16b).



(a) (b)

Figure 16: Farmers' perception on water management of the irrigation scheme

4.2.2 Rice yield of Nyarubogo irrigation scheme

In this study, the mean yield (tons/ha) showed no significant differences between scheme portion ($p>0.05$). The average rice yield was higher for the head (4.04±0.13 tons/ha) followed by middle (3.92 ±0.17 tons/ha) and tail (3.5 ±0.14 tons/ha) of the Nyarubogo irrigation scheme (Figure 17). The low yield in tail section of the irrigation scheme can be due to inequality of water distribution between the head, middle, and tail end of the scheme because for optimum productivity, water availability is necessary.

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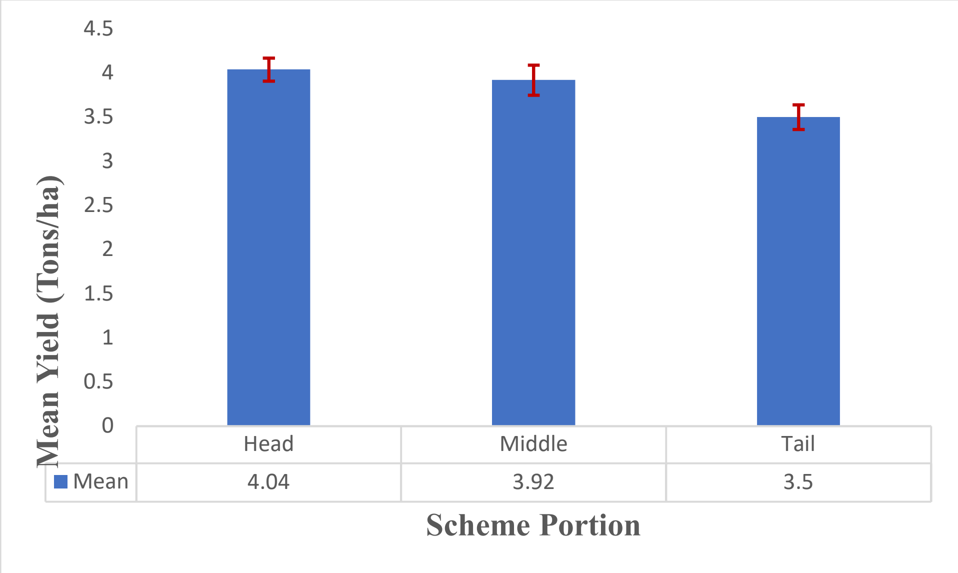

Figure 17: Average Rice Yield of the scheme (Season 2024A)

4.2.3 Physical and Economic Water Productivity

Physical and economic water productivity has been calculated using equation 15, for physical water productivity the output was paddy yield in Kg while Economic water productivity ($/m^3) was obtained by taking the product of physical water productivity and yield unit price ($/Kg). Physical and economic water productivity results of Nyarubogo irrigation Scheme are summarized in Table 14, the physical water productivity is 0.39 kg/m3 from the head, 0.62 Kg/m3 from the middle, and 0.63 from the tail of the scheme, for all parts of the scheme actual physical water productivity was greater than target physical water productivity because of not supplying quantities of water more than target water use per ha in these respective parts. The price of Rice yield was fixed at 550 Frw/Kg by Gikongo Rice factory and this is the factory that collects rice yield from this scheme, 1USD= 1235 Frw in December 2023 (BNR, 2023), therefore the actual economic water productivity was 0.17 $/m3, 0.27 $/m3, and 0.28 $/m3 for head, middle, and tail of the irrigation scheme subsequently.

Table 14: Physical and economic water productivity from Nyarubogo irrigation scheme (Season 2024A)

Parameter	Head	Middle	Tail	Average
Land size in ha	32.8	32.8	44.3	
Actual water use per ha(m3)	10421.6	6355.3	5527.9	7434.9
Target water use per ha(m3)	10679.0	10679.0	10679.0	10679.0
Total Yield per ha (kg)	4040.0	3920.0	3500.0	3820.0
Actual physical WP (kg/m3)	0.39	0.62	0.63	0.55
Target physical WP (kg/m3)	0.38	0.37	0.33	0.36
Total yield cost per ha ($)	1799.2	1745.7	1558.7	1701.2
Actual Economic WP ($/m3)	0.17	0.27	0.28	0.24
Target Economic WP ($/m3)	0.17	0.16	0.15	0.16

V. Discussion

The findings from this study reveal that there are notable spatial differences in the Nyarubogo irrigation scheme's delivery performance ratio (DPR) and water delivery performance (WDP). As water goes downstream, there is a steady reduction in the actual water volume supplied relative to the required volume. This implies that the middle and tail sections suffer significant deficits while the head region obtains nearly the exact target volume. The findings are consistent with the study by Agide *et al.* (2016) who observed inadequacy of water delivered on the tail of the irrigation scheme. DPR values support this discrepancy as well, with the head part receiving slightly over-target discharges (1.04) and the middle and tail regions receiving much less than target discharges (0.63) and 0.55, respectively. These disparities highlight structural inadequacies (Cunha *et al.,* 2019) and possible injustices in the scheme's water allocation.

The adequacy indicator, which measures how well the irrigation system meets crop water requirements, shows that the head section has very high adequacy (0.995) ranked as good, while the middle (0.856) and tail (0.742) sections lag behind classified as fair, and poor respectively. Agide *et al.* (2016) reported a contradicting observation, with poor adequacy at both head, middle, and tail sections. The monthly adequacy values, which span from 0.805 to 0.909 show spatial variations in the irrigation season's water delivery performance over different months. These findings implies that although the head part always gets enough water, the middle and tail areas are more likely to experience shortages, which could have an impact on crop development and output. A closer proximity to the water source and improved management techniques may have contributed to the observation at the head section, where the actual discharge marginally exceeds the target, indicating better control and less losses. Under-delivery occurs in the middle and tail sections, probably as a result of evaporation, seepage, and operational inefficiencies during the water's passage through the system.

The dependability assessment of the irrigation scheme portrays that different portions have varying degrees of dependability. Based on Molden and Gates' (1990)standards, the Nyarubogo irrigation scheme exhibits good dependability at the head and middle portions and fair dependability at the tail, with temporal coefficients of variation (CVT). Tebebal and Ayana, (2015)found a similar patterns of good dependability in the head section of the irrigation scheme compared to the middle and tail sections. These results suggest that water delivery is more trustworthy upstream, where variations in delivery times and amounts are more noticeable, but less reliable downstream, closer to the source.

Further, the observed difficulties are highlighted by farmer interviews, where the majority (58%) report not obtaining water at the appropriate time. This is especially felt downstream, where 22.5% of farmers report not receiving water on time. After one hour, a sizable majority (62.9%) of customers who experienced delays got water; the midstream was most negatively impacted (30.0%). These results highlight the need for upgraded infrastructure and management to increase dependability and guarantee fair water distribution (Tebebal and Ayana, 2015) across the Nyarubogo irrigation scheme.

Equity, which is important for equitable water distribution, was found to be good at the head and middle portions but only poor at the tail, which is the same as what was reported by (Agide *et al.*, 2016). This is also demonstrated by the equity ratio (ERHT) values, which range from 1.5 to 2.76 and 2.06 on average and are below the benchmark. The majority of farmers (25.8%) perceived that water distribution is fair, and formal committees oversee decision-making processes. Nevertheless, the ERHT values indicate that downstream farmers receive a disproportionately smaller share of water than the upstream (Suttles *et al.,* 2021). The observed variation in fairness and effectiveness within the irrigation scheme may be attributed to structural imbalances that impact farmer access to water. This disparity underscores the need for improvement in equity measures, especially in the tail area for farmers to receive equal water.

The scheme's efficiency exhibited variability in performance, as indicated by the temporal values of the outlet points located at the head, middle, and tail of the secondary canals. Using the criteria established by Molden and Gates (1990), the head portion had a poor efficiency score of 0.671, while the middle (0.983) and tail (0.969) sections were categorized as good. This suggests that even as water management gets better downstream, the system's total performance is affected by the early inefficiencies at the head. Moreover, conveyance efficiency data show a subpar performance in the scheme's head, middle, and tail, with respective values of 65.2%, 62.6%, and 57.1%. These values show considerable water losses from seepage, inadequate maintenance, and structural problems, including canal bank collapse and weed growth (Chaube *et al.*, 2023). The findings fall short of the FAO (2008) criteria for unlined canals.

The Nyarubogo irrigation scheme's rice yield data shows varied productivity gradients in different areas of the scheme. There is a noticeable decline in productivity as one proceeds downstream with highest values upstream compared to downstream. This pattern represents the difficulties that farmers downstream are facing, which may be brought on by irregular water supplies (Nakawuka *et al.,* 2018). In order to provide more consistent rice yields across the whole program, the observed yield gradient highlights the necessity for targeted agronomic support and infrastructure enhancements to raise production in the less productive downstream areas.

The scheme's efficient use of water is further demonstrated by the physical and economic effects of water productivity. The tail and middle sections use water more efficiently than the head section, as shown by the physical water productivity values of 0.39 kg/m³ at the head, 0.62 kg/m³ midway, and 0.63 kg/m³ downstream. Based on the exchange rate and stable rice price, the economic water productivity was determined to be \$0.17/m³ at the head, \$0.27/m³ midstream, and \$0.28/m³ downstream. This implies that downstream regions, probably as a result of improved water management techniques, achieve larger economic returns per unit of water consumed, even in the face of reduced yields. Literature has highlighted that, both the tail end and head end location in the irrigation scheme may have negative effects on farm productivity (Manero *et al.*, 2019). However, in order to optimize overall yields and financial gains, attention should be focused on improving headwater usage efficiency and raising yields downstream, possibly via better irrigation techniques, improved management of water, and agronomic practices.

VI. CONCLUSION

Generally, the study found a substantial differences in water supply performance, sufficiency, reliability, equality, and productivity in the Nyarubogo irrigation project in its various portions. The middle and tail parts struggle with fair to poor adequacy, lower yields, fair to bad equity, and fair dependability concerns whereas the head section shows high yields and outstanding reliability, however it presents a poor water efficiency. Even if the economic productivity of water in downstream locations is greater, these places have inferior adequacy and insufficient water supply. These results highlight the need for focused interventions in water management and improvements to infrastructure, especially in the middle and tail portions, in order to guarantee fair distribution of water and raise total production.

VII. RECOMMENDATIONS

In light of the study's findings, the following are recommended in order to improve the effectiveness and productivity of the Nyarubogo irrigation scheme:

i. To guarantee a steady and dependable water supply, the infrastructure for water delivery should be improved. Upgrade and maintain the irrigation infrastructure, particularly in the middle and tail parts. This includes controlling weed growth, fixing leaks, and avoiding canal bank collapses.

ii. Effective water management techniques, such as better scheduling irrigation hours and using water-loss-reducing technology, should improve water management practices to ensure equity for both parties to receive enough water.

iii. Regulations and procedures should be enhanced to promote a fair and equal distribution of water throughout the system. This would include more oversight and control over the distribution of water, particularly for farmers downstream who now get less water.

iv. Agronomic support should be offered to farmers so as to assist farmers in adopting improved agronomic techniques that may boost rice yields and enhance water usage efficiency, especially in the upstream regions.

v. To enhance water resource management, a formal committee with diverse stakeholders, including farmers, should be trained to ensure transparent decision-making and dispute resolution

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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REFERENCES

[1]. Agide, Z., Haileslassie, A., Sally, H., Erkossa, T., Schmitter, P. S., Langan, S. J., & Hoekstra, D. (2016). *Analysis of water delivery performance of smallholder irrigation schemes in Ethiopia: Diversity and lessons across schemes, typologies and reaches*. International Livestock Research Institute.

[2]. Alaboz, P., Demir, S., & Başayiğit, L. (2021). Evaluation of soilwat model for soil physical properties in the different land use. *AGBIOL 2021*, 691.

[3]. Allen, R. G., Pereira, L. S., Raes, D., Smith, M., & others. (1998a). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *Fao, Rome*, *300*(9), D05109.

[4]. Allen, R. G., Pereira, L. S., Raes, D., Smith, M., & others. (1998b). FAO Irrigation and drainage paper No. 56. *Rome: Food and Agriculture Organization of the United Nations*, *56*(97), e156.

[5]. Bos, M. G., Murray-Rust, D., Merrey, D. J., Johnson, H., & Snellen, W. (1993). Methodologies for assessing performance of irrigation and drainage management. *Irrigation and Drainage Systems*, *7*, 231–261.

[6]. Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils 1. *Agronomy Journal*, *54*(5), 464–465.

[7]. Bwambale, E., Home, P. G., Raude, J. M., & Wanyama, J. (2019). *Hydraulic performance evaluation of the water conveyance system of Doho Rice Irrigation Scheme in Uganda*.

[8]. Chaube, U. C., Pandey, A., & Singh, V. P. (2023). Maintenance of Canals and Related Structures. In *Canal Irrigation Systems in India: Operation, Maintenance, and Management* (pp. 353–387). Springer.

[9]. Clemmens, A., & Molden, D. (2007). Water uses and productivity of irrigation systems. *Irrigation Science*, *25*, 247–261.

[10]. Cunha, H., Loureiro, D., Sousa, G., Covas, D., & Alegre, H. (2019). A comprehensive water balance methodology for collective irrigation systems. *Agricultural Water Management*, *223*, 105660.

[11]. Deshmukh, S. (2018). *Equitable water distribution in canal system: A today's need*. *5*(9). https://www.jetir.org/papers/JETIRA006310.pdf

[12]. FAO. (1993). *CLIMWAT for CROPWAT: a climatic database for irrigation planning and management.*

[13]. FAO. (2006). Plant nutrition for food security. *A Guide for Integrated Nutrient Management. FAO Fertilizer and Plant Nutrition Bulletin*, *16*(368), 201–214.

[14]. Gorantiwar, S. D., & Smout, I. K. (2005). Performance assessment of irrigation water management of heterogeneous irrigation schemes: 1. A framework for evaluation. *Irrigation and Drainage Systems*, *19*, 1–36.

[15]. Hakuzimana, J., & Masasi, B. (2020). Performance evaluation of irrigation schemes in Rugeramigozi marshland, Rwanda. *Water Conserv. Manag*, *4*(1), 15–19.

[16]. Kanda, E. K., & Lutta, V. O. (2022). The status and challenges of a modern irrigation system in Kenya: A systematic review. *Irrigation and Drainage*, *71*, 27–38.

[17]. Kartal, S., Değirmenci, H., & Arslan, F. (2020). Assessment of irrigation schemes with performance indicators in southeastern irrigation district of Turkey. *Journal of Agricultural Sciences*, *26*(2), 138–146.

[18]. Kumar, A., Saini, M., Patil, R. B., Al-Dahidi, S., & Mellal, M. A. (2022). Reliability, Availability, Maintainability, and Dependability analysis of Tube-wells Integrated with Underground Pipelines in agricultural fields for irrigation. *Advances in Mechanical Engineering*, *14*(8), 16878132221115931.

[19]. Manero, A., Wheeler, S. A., Zuo, A., & Mdemu, M. (2019). Exploring the head versus tail-end dichotomy on yield and farm incomes in smallholder irrigation schemes in Tanzania. *Water Resources Research*, *55*(5), 4322–4342.

[20]. Mashnik, D., Jacobus, H., Barghouth, A., Wang, E. J., Blanchard, J., & Shelby, R. (2017). Increasing productivity through irrigation: Problems and solutions implemented in Africa and Asia. *Sustainable Energy Technologies and Assessments*, *22*, 220–227.

[21]. Molden, D. J., & Gates, T. K. (1990). Performance measures for evaluation of irrigation-water-delivery systems. *Journal of Irrigation and Drainage Engineering*, *116*(6), 804–823.

[22]. Muema, F. M., Home, P. G., & Raude, J. M. (2018). Application of benchmarking and principal component analysis in measuring performance of public irrigation schemes in Kenya. *Agriculture*, *8*(10), 162.

[23]. Mukeshimana, G., Mupenzi, C., & Ndayambaje, J. (2022). Analysis of irrigation development to crop production in the Kirehe district case of Nasho irrigation schemes. *East African Journal of Science and Technology*, *12*(12).

[24]. Nakawuka, P., Langan, S., Schmitter, P., & Barron, J. (2018). A review of trends, constraints and opportunities of smallholder irrigation in East Africa. *Global Food Security*, *17*, 196–212.

[25]. Narayanan, K. (2014). Impact of participatory irrigation management–case study: Cocurirwa Cooperative, Rwamagana Rice Project, Rwanda. *Advances in Plants & Agriculture Research*, *1*(3), 00013.

[26]. Niragire, T., Süheri, S., & Pande, S. K. (2021). Performance evaluation of hand-move sprinkler irrigation system: A case study in Rwanda. *Int. J. Innov. Approaches Agric. Res*, *5*, 37–51.

[27]. Phadnis, S. S. S., & Kulsreshtha, M. (2011). Need of benchmarking for socially and environmentally sustainable development of a major irrigation scheme. *Water and Energy International*, *68*(1), 30–36.

[28]. Sánchez, J. A., Reca, J., & Martínez, J. (2015). Irrigation water management in a Mediterranean greenhouse district: Irrigation adequacy assessment. *Irrigation and Drainage*, *64*(3), 299–313.

[29]. Sirimewan, D., Manjula, N., Samaraweera, A., & Mendis, A. (2019). *Issues in sustainable water management of irrigation systems in Sri Lanka*.

[30]. Suttles, K. M., Eagle, A. J., & McLellan, E. L. (2021). Upstream solutions to downstream problems: Investing in rural natural infrastructure for water quality improvement and flood risk mitigation. *Water*, *13*(24), 3579.

[31]. Tebebal, M., & Ayana, M. (2015). Hydraulic performance evaluation of hare community managed irrigation scheme, southern, Ethiopia. *International Research Journal of Engineering and Technology (IRJET)*, *2*.

[32]. World Bank. (2022). Water in agriculture. *World Bank*. https://www.worldbank.org/en/topic/water-in-agriculture.

[33]. McKenzie NJ,Ryan PJ, de Gruijter JJ (1999) Spatial prediction of soil properties using environmental correlation. Geoderma 89, 67-94.

[34]. Nsengimana, A., Bazimenyera, J., Niyonkuru, R., Nsengiyumva, J. N., & Karangwa, A. (2023). Crop evapotranspiration, irrigation water requirement, and irrigation scheduling of soybeans under sprinkler irrigation system at Nasho Sector, Rwanda. *International Journal of Progressive Sciences and Technologies (IJPSAT)*, *38*(1), 225-234.