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Evaluation of Irrigation Systems Using Technical Performance Indicators and Farmers' Knowledge in Burundi

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Abstract: Many irrigation schemes developed in Burundi indicate to perform below their potential. Major causes of poor performance are mainly due to the inequitable water distribution and mismanagement. This study aimed to evaluate the irrigation system using performance indicators and farmers' knowledge. In this study, a float method was used for determining flow rate, the discharge and conveyance efficiency at the main secondary and tertiary canals. The task involved the determination of irrigation water allocation and distribution at main, secondary and tertiary canals. Based on the climatic data, the crop water requirement was determined and by discharge data, the conveyance efficiency, the adequacy, the efficiency, the dependability, the equity of water supply. We have also evaluated the *productivity of agricultural water use* by comparing the quantity *of water delivery* to the field within the output. The results indicate that 82.48, 80.40 and 66.38% of water conveyed by the system in lined main canal, lined secondary canal and unlined secondary canal, respectively reach the destined farms. The results show further more that the system of water distribution was good in terms of adequacy and poor in terms of efficiency and fair to both dependability and equity. The physical and economical water productivity was 0.97 kgm^{-3} and 0.45\$m^3 at head, 1.36 kgm^{-3} and 0.63\$m^3 at the middle and 1.41 kgm^{-3} and 0.65 at the tail. The results show further that the water productivity performance was found to be 0.72, 1.16, and 1.31 at the head, middle and tail, respectively. The findings from survey have shown that the majority of farmer lack of crop water requirement. The study suggests adding more efforts for improving efficiency, temporal uniformity and equity in water allocation.

Keywords: Conveyance Efficiency, Delivery Performance, Water Productivity

1. Introduction

Irrigated agriculture has played a significant role in increasing global production and food security [1]. In Africa, agriculture is one of the most important social and economic sectors where more than two thirds of people's livelihoods depend on farming and two thirds of poor people's household budgets are used for food [2]. As consequence, improving the wellbeing of people depends for a major part on the performance of the agricultural sector in Africa. Moreover, the performance of agricultural sector is low and hunger continues to be a risk in Sub-Saharan. Agricultural transformation is needed to concentrate on these challenges and irrigation is one pillar to contribute to such transformations [3]. Nevertheless, the achievement of irrigation system in agricultural management depends on the amount of water supply, demand and rational allocation of water in meeting the demand or to reducing the gap between the demands. The achievement of an irrigation water delivery system can be assessed by how well it meets the objectives of delivering the right amount of water to the right time and place [4].

Moreover, different indicators of measuring irrigation system performance have been developed by several authors: [5-7] to make it easier to evaluate irrigation water distribution systems in terms of their sufficiency, efficiency, dependability, and equity. These indicators can be classified into two categories: (i) to evaluate the water allocation [6] such as of adequacy, efficiency, dependability and equity internally and (ii) to evaluate water allocation outcomes in the form of economic revenue, environmental effect and agricultural production externally [8, 9]. In addition, multiple indicators have been used to monitor performance, such as land and water productivity, water availability, sufficiency, and fairness in water allocation, which have largely showed inequitable water allocation and canal misuse [10, 11].

Water use in Burundi is mutually shared by three sectors such as agriculture (79.26%), domestic (15.39%), and industry (5.35%). Irrigation has become the most important factor in the agricultural sector in Burundi due to climatic change and weather variability. Irrigation, on the other hand, is limited to surface irrigation (ponds, ditches, and furrows) and is in poor condition [12]. Burundi has significant potential for irrigable land both in wetlands and plains (83000 ha) but only 2430 ha (20.6%) of agricultural area are equipped for irrigation. The expansion of area equipped for irrigation could increase crop intensification, increase yields and reduce losses caused by irregularities in rainfall [13]. Additionally, the introduction of the system of rice intensification (SRI) has shown that yields could go from 2 to 7 tons per hectare of paddy under average condition of implementation of the technique and if water control was ensured as well as quality seeds and fertilizers [14]. However, for the vast majority of farmers, irrigation control necessitates a conceptual shift and the acquisition of new technical skills [13].

Several researches [13, 14] have been done to evaluate the performance of irrigation schemes in Burundi. However, little is known about the performance of the water delivery system in the Burundian agricultural sector. Thus, there is a need to assess the irrigation water delivery and consumption patterns in order to improve the irrigation water management. The specific objective of this study was to evaluate how well water delivery indicators performed in terms of adequacy, efficiency, dependability and water productivity at Kidwebezi Irrigation Scheme.

2. Materials and Methods

2.1. Study Area

The Study was conducted at Kidwebezi Irrigation Scheme located in Mpanda District, Bubanza Province in Burundi's western region. The scheme covers an area of about 83 ha and lies at Latitude of 3° 11' 60" South and Longitude 29° 23' 59" East. Kidwebezi is situated in the Imbo plain, one of the eleven natural regions of Burundi. Imbo plain is a lowland area with an average elevation of 1000 m above the sea level. The rainfall regime in this zone is bimodal, with a short rainy season from October to January, and a long wet rainy season between March and May. The annual rainfall in this zone ranges between 700 and 1000 mm, and the temperature ranges from 24°C to 28°C and has a dry season of about five to six months. The major activities of the people of Kidwebezi include farming and livestock keeping. Major food and cash crops grown include paddy, maize, beans, watermelon, potatoes and vegetables. Livestock production includes beef and dairy cattle, small ruminants and poultry, which are kept mainly for income generation [14].

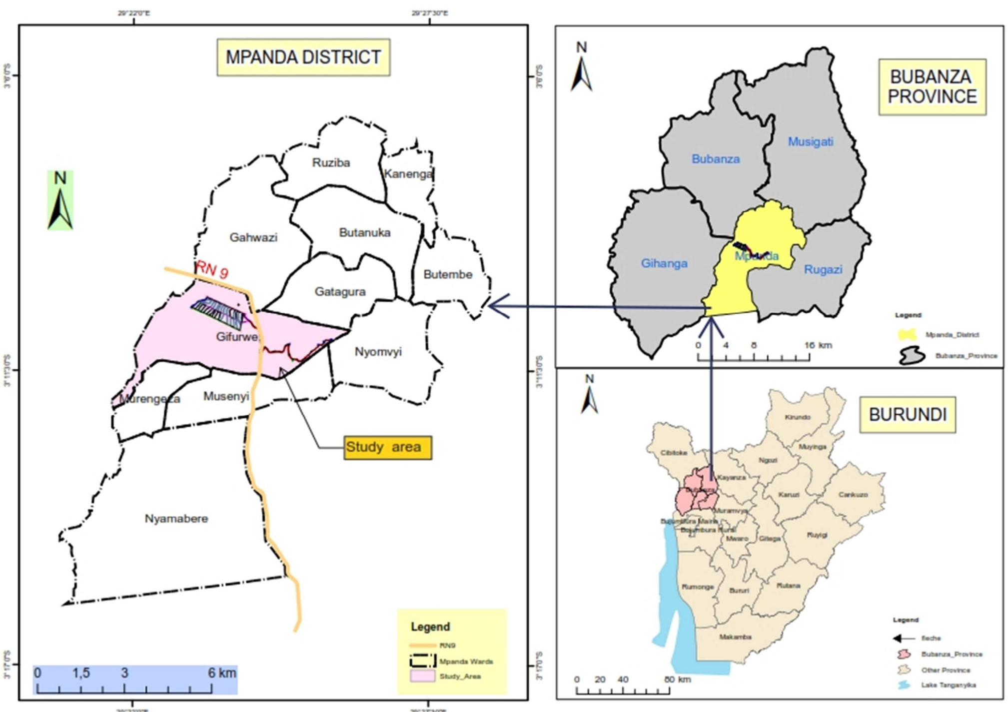

Figure 1. *Sketch Map showing location of the study area (IRRI-Burundi, 2021).*

2.2. Scheme Layout

From Gifurwe River diversion, water is conveyed by gravity to the Kidwebezi irrigation scheme by a lined main canal which runs for about 4.9km of long from the intake to secondary canals. The main canal is divided in two secondary canals just before reaching the scheme. Then, through the two secondary canals, one on the right (SC1) another on the left (SC2), divert water from the main canal and distribute it into the tertiary canals. The secondary canals are both divided into 15 tertiary canals which irrigate from plots of different size designed in way that facilitate their management and easiness of water distribution. Also, the scheme comprises field drains, two collector drains and the main drain to remove the excess water from the field.

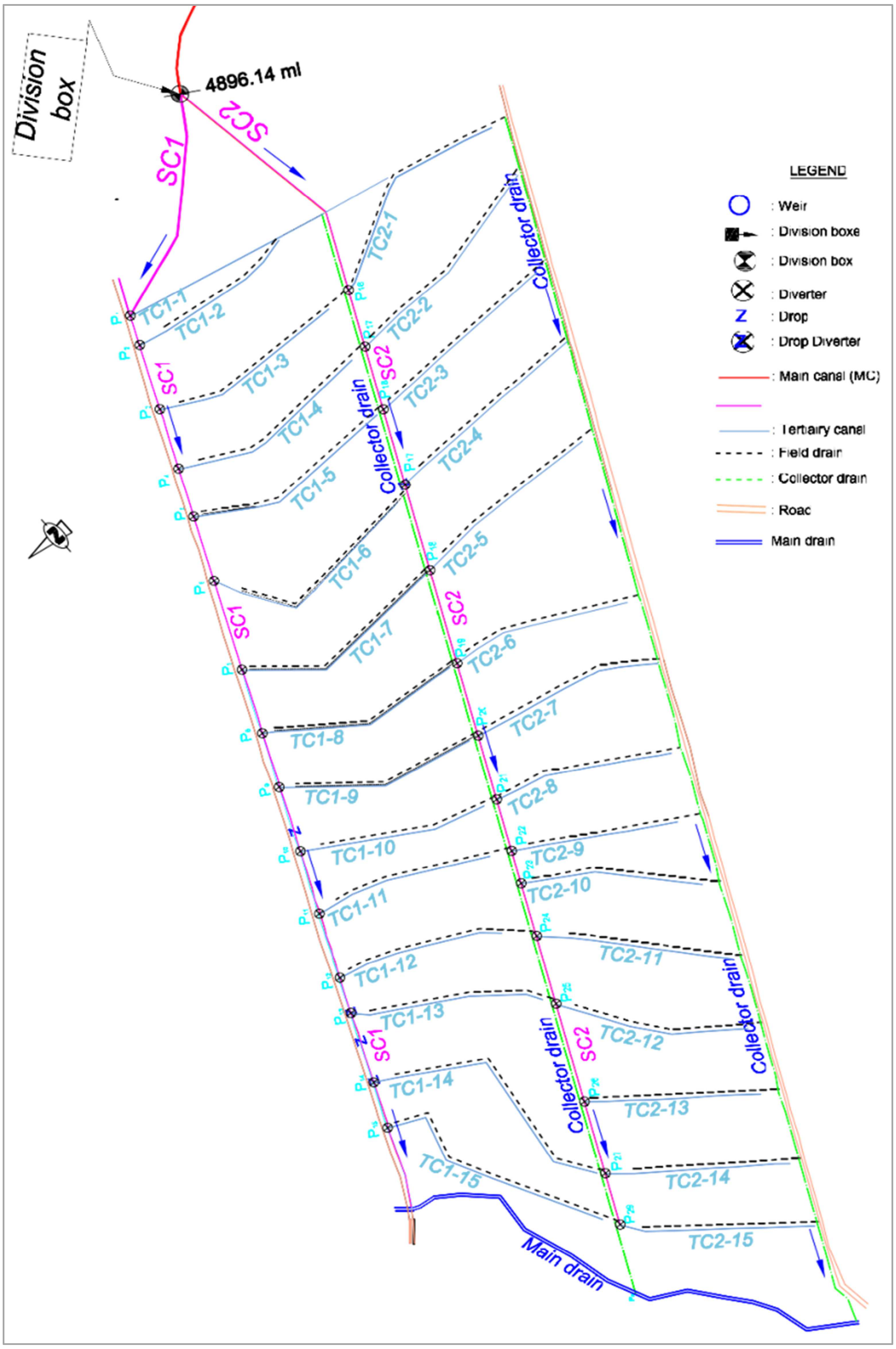

Figure 2. *Layout of Kidwebezi Irrigation Scheme (IRRI Burundi, 2021).*

2.3. Methods

2.3.1. Estimation of Crop Water Requirement

Climatic data used were collected at Gihanga meteorological station. Mean daily weather conditions data for 20 years (2001-2020) such as relative humidity, temperature (min and max), wind speed and radiation were used to determine (ET_O) using INSTANT computer program. The FAO Penman-Montheith methodology through the CROPWAT 8.0 windows program was used to determine reference evapotranspiration. Crop coefficient for cultivated crops was obtained from FAO guidelines for crop water requirements. Crop evapotranspiration is calculated as a product of crop coefficient (K_C) and reference evapotranspiration (ETo) [15], as given in Equation 1.

$$ETc = Kc \ x \quad ETc \tag{1}$$

Where ETc = Crop Water Requirements (mm/day);
Kc= Crop Coefficient; and
ETo = Reference Evapotranspiration (mm/day).

2.3.2. Technical Performance Evaluation

Technical performance indicators used in this study included the measurement of conveyance efficiency of the main canal and secondary canals, water delivery performance.

a) Conveyance efficiency

Conveyance efficiency is estimated by measuring inflowing and out flowing water along the selected canal lengths. The efficiency is affecting by different factors including canal lining, evaporation of water from the canal, technical and managerial management facilities of water control [16]. It is expressed using Equation 2.

$$Conveyance\ Efficiency = \frac{Total\ water\ Supply\ by\ the\ Conveyance\ System}{Total\ Inflow\ \text{into}\ the\ Conveyance\ System} \tag{2}$$

b) Water delivery performance

The most basic and short-term performance indicators compare the actual discharge to the expected or target discharge at any given time of the season [17]. The most important hydraulic performance indicators are delivery performance ratio (DPR) and water delivery performance [18] According to Bos *et al*. [17], the delivery performance ratio and water delivery performance are calculated using the Equations 3 and 4.

$$Delivery\ Performance\ Ratio = \frac{Actual\ Discharge}{Target\ Discharge} \tag{3}$$

$$Water\ Delivery\ Performance = \frac{Actual\ Volume}{Target\ Volume} \tag{4}$$

2.3.3. Irrigation Efficiency Indicators

Irrigation efficiency is an evaluation of hydraulic conditions in a spatial context over a specific time period. Irrigation efficiency is usually measured in terms of volume delivered over a period of time rather than instantaneous discharge. Bos and Nugteren [6] have discussed in detail the indicators of efficiency, the most important ones are efficiency, adequacy, dependability and equity.

i. Efficiency

Efficiency embodies the potential to conserve water by comparing water delivery with water requirement. The determination of water efficiency is calculated using the Equation 5 as proposed by Molden *et al*. [18].

$$P_F = \frac{1}{T}\sum_R \left(\frac{1}{R}\sum \frac{Q_R}{Q_D}\right) \tag{5}$$

Where P_F= efficiency of irrigation water supply;
Q_D = amount of water delivered;
Q_R =amount of water required;
T = one irrigation season (days); R=one region R

ii. Adequacy

The two most important aspects in irrigation planning, design, and operation are the available water supply and the water demands [19]. The ratio of supply to demand constitutes an important concept named Relative Water Supply, as firstly described by Levine [20] and Abernethy [5]. This indicator provides information about the relative abundance or scarcity of water. The determination of adequacy is calculated using the Equation 6.

$$\text{Re}lative\ water\ \text{supp}ly = \frac{Total\ water\ \text{supp}ly}{Total\ crop\ water\ requirement} \tag{6}$$

The total water supply is the summation of actual irrigation water supply by system via irrigation canals and the total rainfall; and the term crop water requirement is defined as the amount of water needed to compensate the evapotranspiration loss from the cropped field for a specific time. Crop water requirement is estimated by CROP WAT model simulation [15]. When the volume delivered exceeds the volume necessary, the amount delivered is accepted as adequate without taking into account the amount of exceeding, and the ratio is taken as one; a value of less than 0.80 is considered insufficient water supply [18].

iii. Dependability of water supply

Dependability refers to the system's ability to provide water at the desired time and in the desired location. The predictability of water deliveries is concerned with the time of water delivery compared to the planned time [17].

$$P_D = \frac{1}{R}\sum_R CV_T\left(\frac{Q_D}{Q_R}\right) \tag{7}$$

Where P_D = Dependability of irrigation water supply; CV_T = Temporal coefficient of variation; Q_D = Amount of water delivered; Q_R = Amount of water required; R = the region R; T= one irrigation season. CV_T (Q_D/Q_R) = temporal coefficient of variation of the ratio Q_D/Q_R over the region R. Dependability in water is greater when P_D approaches zero in delivery.

iv. Equity

According to Molden and Gates, [18], Equity of irrigation water supply is defined as the delivery of fair share of water to all irrigators' rights through the system. However, equity does not mean automatically equal but equity is the achieving of a fair distribution of water. It expressed the degree of variability in relation to water delivery from point to point over the irrigated area [21]. Equity is calculated using Equation 8.

$$P_E = \frac{1}{T}\sum CV_R\left(\frac{Q_D}{Q_R}\right) \quad (8)$$

Where P_E = equity of irrigation water supply; CV_R= spatial coefficient of variation over the region R; Q_D= amount of water delivered; $_{QR}$= amount of water required; and T= one irrigation season (days). CV_R (Q_D/Q_R) = Spatial coefficient of variation of the ratio Q_D/Q_R over the region R. P_E in water is shown to be greater when it approaches zero (spatial uniformity) in water delivery [18].

2.3.4. Determination of Water Productivity (WP)

Kijne and Barker [23] defined water productivity (WP) as a reliable indicator of an agricultural system's ability to turn water into food. The ratio of crop output to irrigation water applied by the irrigation system during crop growth is known as irrigation water productivity [23]. Water productivity can be expressed in physical or economic terms as factor of productivity. It is expressed in terms of weight (kg) or even in monetary terms ($) to comparison different crops [24]. The determination of water productivity is calculated using the Equations (9) and (10) [24].

$$Water\ \text{Pr}oductivity = \frac{Output\ delivered\ from\ water\ use}{Total\ water\ imput} \quad (9)$$

$$Water\ \text{Pr}oductivity\ Performance = \frac{Actual\ water\ productivity}{\text{T}arget\ water\ productivity} \quad (10)$$

2.4. Sampling Methodology, Data Collection and Analysis

2.4.1. Sampling Method

To obtain a representative sample of farmers, the sampling frame was stratified into three strata (head, middle and tail); from each stratum a simple random sampling technique was used to select 30 respondents among the farmers, making 90 respondents in total [25]. The key informants included two (2) Irrigators' Association leaders, one (1) Kidwebezi Water Officer, one (1) Cooperative Officers, two (2) experienced paddy farmers and (2) SRDI Staff Manager. Ten (10) Participants for Focus Group Discussion and 8 key informants were selected, making 108 respondents. Key informant interviews were conducted using a prepared checklist.

2.4.2. Data Collection

In this Study, different methods and activities were used to collect data such as field measurements, inspections/ observations, Survey questionnaire, Key informant interviews, Focus group discussions and review of different documents. Field measurements were conducted to evaluate the performance of irrigation system at the main, secondary and at the sampled tertiary canal. The field data were collected to evaluate performance indicators using performance indicators proposed by Molden and Gates [18]. These indicators include water delivery, water use efficiency, water productivity and environment aspect. Moreover, in order to collect important information related to irrigation water management, the degree of farmers' knowledge in crop water requirement, irrigation water use practices and their impact on paddy productivity, the interview survey, Focus Group Discussion and Key informants interviews were conducted.

a) Determination of the discharge

The amount of water flow passing in the main, secondary and tertiary canals was measured and collected using floating method. This method consists of estimating the average flow velocity (V), and measuring the area of the cross-section, called the ''wetted cross-section'' (A). The discharge (Q) is determined by multiplying the cross sectional area of water by average velocity of the water [26].

$$Q = A\ V \quad (11)$$

Where Q = stream discharge (m^3/s); A= cross-sectional area in m^2; and V = surface flow velocity in m/s.

In order, to obtain the average velocity, the surface velocity was reduced by using a correction factor k of 0.85 which is a commonly used value [27].

The flows were monitored weekly at the main and secondary canals and at 6 turnouts on tertiary canals sampled randomly (two at the head, two at the middle and two at the tail) during growing season from January to April 2021.

b) Determination of volume of water delivered, target and required per season

Based on CROPWAT calculations, irrigation water deliveries were determined during the growing season (from January to April). Hence, Q_D and Q_R values were determined monthly. Farmers using water from the downstream farmers claimed that they get less water than upstream farmers. To study this claim, Q_D and Q_R were determined for the head, middle, and tail of the secondary and sampled tertiary canals.

The amount of water delivery (Q_D in m^3) was determined using the product of actual discharge (m^3/s), the duration of irrigation per day (sec) and number of irrigation days for each stage. Total target volume (m^3) was determined by multiplying the scheme area by irrigation interval, irrigation duration (24hours divided by number of hours per day) and target discharge (m^3/day). The amount of water required was determined by multiplying the gross irrigation (mm/day), irrigation interval (day), duration of irrigation (24h per irrigation time in h) and area to be irrigated [28].

2.5. Data Analysis

The data collected from respondents using questionnaires, focus group discussion and key informants were descriptively analysed using SPSS (Statistical package for social sciences) (IBM SPSS version 21). Descriptive statistics was employed for the analysis of the data collected from field measurements. Spatial and temporal distribution of required, scheduled and delivered water was used to evaluate the water delivery performance.

3. Results and Discussion

3.1. Degree of Farmers' Awareness Crop Water Requirement

Table 1. *Farmers who keeping records of irrigation water applied throughout the season and factors to consider for deciding when to irrigate.*

Farmer recording water applied throughout the season	Percentage (%)
Yes	0.00
No	100
Total	100
Factors considering to decide when to irrigate	
Fixed number of days between irrigation	50.00
Available moisture content	3.33
Crop appearance	10.00
Others (do not know)	36.67
Total	100

The results in Table 1 show that 100 per cent of the respondents do not keep records of irrigation water applied in their farm plots throughout the growing season. Farmers do not have enough knowledge to compute the quantity of water applied. This can be attributed to the degree of weakness of the extension service and lack of training on crop water requirement. None of the farmers has the awareness of water applied throughout the season.

As for the factors influencing farmers' decisions on when to irrigate, results show that about 50 percent of the respondents reported that they decide when to irrigate by using a fixed number of days between irrigations fixed by the water committees, 10 per cent just use the available moisture content by observations, 3.33 per cent use crop appearance while 36.67 per cent do not consider any factor on deciding when to irrigate just follow the schedule (Table 1). It was further observed that, most of the farmers lack understanding of when a crop requires different amount of water at different stages. That has a consequence in using water, especially when there are shortages or abundances of water, where they tend to either over or under use water instead of using it efficiently. Thus, more training on water management and water requirement can help to improve the use of water efficiently leading to increase productivity and sustainability.

3.2. Water Physical and Chemical Properties

The result from laboratory has shown that electrical conductivity of water (EC_w) was 0.101 dS/m at the upstream and 0.157 at the downstream. According to the irrigation water quality criteria as revised by the Colorado University State in 2007 [29], the quality of water in Kidwebezi irrigation scheme was found to be excellent because it was in rank of good for irrigation purposes (Appendix Table A1). As suggested by Shahinasi and Kashuta, (2008) the normal ranking in irrigation water should be in range of between 0 and 3 dS/m for EC_w, 0-20, 0-5, 0-0.052 0-40 mg/l for Ca^{2+}, Mg^{2+}, K^+ and Na^+ respectively (Appendix Table A2). The exchangeable bases such as Ca^{2+}, Mg^{2+}, K^+ and Na^+ were found to be 1.6, 1.0, 2.72 and 11 for upstream 3.1, 1.3, 2.9 and 22.8 for downstream respectively. These results reveal that the values of EC_W and exchangeable bases at the downstream are high than upstream that can be explained by the fact that the water samples were taken after being drained from the field contained the residual of some inputs such as fertilizers or pesticides, however the values from the analysis show that both upstream and downstream ranged in acceptable water properties for growing paddy.

Table 2. *Chemical properties of irrigation water at the experimental site.*

Parameters	H_2O	ECw	Ca^{2+}	Mg^{2+}	K^+	Na^+	SO_4^{2-}	NO_3^-	NO^-_2
Units	pH	Ds/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Upstream	7.52	0.101	1.6	1.0	2.72	11.0	27	2.59	5.54
Downstream	7.1	0.157	3.1	1.3	2.9	2.8	43	4.93	3.87

3.3. Crop Water Requirement

The results in Table 3 show that for different parameters during growth stages of paddy were 20, 42, 30 and 28 days, Kc were 0.76, 1.05, 1.2 and 0.9 and daily ETc of 4.45, 6.99, 8.19 and 5.46 mm/day for the initial, development, mid- season and late season stages, respectively.

Table 3. *Determination of ETo and ETc in the Study area.*

Growth stages	Initial stage	Development stage	Mid season stage	Late stage	Total
Stage duration	1/1-20/1	21/1-3/3	4/3-2/4	3/4-30/4	
Periods (days)	20	42	30	28	120
ETo (mm/day)	5.855	6.657	6.825	4.955	
Kc	0.76	1.05	1.2	0.9	
ETc (mm/day)	4.45	6.99	8.19	5.46	
RAM (mm)	42	42	42	42	
Interval (days)	9	6	5	7	
Total ETc (mm)	89	293.58	245.7	152.88	781.534

The results in Table 4 show that the total water applied during the growing season was 342.2 mm and 760.6 mm for net and gross water requirement, respectively.

Table 4. *Determination of crop water requirement.*

Growth stage	ETc (mm/day)	ETc (mm/stage)	Pe (mm/month)	Pe (mm/stage)	In (mm)	Ig (mm)
Initial stage	4.45	89	112.7	72.7	16.3	36.2
Develo. stage	6.99	293.6	106.3	159.5	134.2	298.1
Mid- s. stage	8.19	245.7	95.7	92.6	153.1	340.2
Late s. stage	5.46	152.9	122.4	114.2	38.7	85.9
Total (mm)		781.2	437.1	439.0	342.2	760.4

3.4. Water Allocation at Kidwebezi Irrigation Scheme

Due to the shortage of water, water allocation is by rotation to canals or to blocks. The approved irrigation interval for Kidwebezi is 7 days; means that each farm plot is irrigated once per week for duration of 8 hours per day. The major factors which influenced the water distribution schedule were mainly availability of water and reducing of conflicts among farmers. However, the duration which was planned to fulfil the requirement was 12 hours per day, but the actual 8 hours per day was just a decision from the Government agency (SRDI) to reduce the conflicts between legal (planned for irrigation) and illegal farmers (developed after). The information from the key informants indicates that there were repetitive conflicts between legal and illegal famers before adjustment of the schedule. The problems of inequity in water distribution were also expressed by many farmers during focus group discussion; they said that the inequity is caused by the deliberate action of unruly farmers poaching water or by poor design structures at the scheme. As consequence, downstream farmers complained to suffer the low distribution of water while the upstream farmers are over distributed leading to low production.

Table 5. *Actual water allocation schedule for Kidwebezi Irrigation Scheme.*

Day	Location	Type of canal	Area irrigated (ha)	Irrigation schedule
Monday	Head	SC1	10	TC 1-1 to TC1-5
Tuesday	Middle	SC1	16	TC 1-6 to TC1-10
Wednesday	Tail	SC1	14	TC 1-11 to TC1-15
Thursday	Head	SC2	11.5	TC 2-1 to TC2-5
Friday	Middle	SC2	16	TC 2-6 to TC2-10
Saturday	Tail	SC2	15.5	TC2-11 to TC2-15

Table 6. *Discharge and volume delivered, target and required.*

Reach	Canal name	Actual Del. (l/s)	Target (l/s)	Volume delivered (m^3)	Target volume (m^3)	Volume required (m^3)
Head	SC1	143.20	144.90	69981.12	50077.44	48 963.51
	SC2	151.85	166.64	78028.42	57589.06	56308.04
Middle	SC1	129.63	231.84	63008.64	80123.90	78341.62
	SC2	136.61	202.86	67343.04	70108.42	68548.92
Tail	SC1	97.1	231.84	57425.76	80 123.9	78341.62
	SC2	102.33	224.60	63184	77620.03	75 893.44
Total				398970.41	415642.76	406397.15

3.5. Comparison of Volume of Water Delivered, Target and Required in Canals

The results in Table 6 show that only the upstream farmers have water delivery exceeding the water required and this applies to the two secondary canals while farmers of the middle and tail have less amount of water than the targeted and required in all the secondary canals. The results imply that there was a mismatch between the delivered, the intended and the required over canal reaches. This mismatching in water supply is a result of shortage of water resulting from increasing sizes of paddy fields which were not planned for. Similar findings are reported by Ndayizigiye

[14] who found that the mismatching of water in Imbo region was caused by the uncontrolled rice farmers demanding more water than the available amount.

3.6. Delivery Performance Ratio and Water Delivery Performance

The results in Table 7 show that the average delivery performance ratio (DPR) was 0.95, 0.61 and 0.54 at the head, the middle and the tail respectively. That means that the distributaries received only 95%, 61% and 54% of the target discharge at the head, middle and tail end respectively. According to Murray-rust and Halsema [32] classification the delivery performance ratio ranging from 0.9 to 1.1 is taken as good while the values outside this range were considered as poor. Base on that classification, the results show that the delivery performance ratio was good at the head and poor both at the middle and tail. The table 8 shows also that Water delivery performance (WDP) was found to be 1.37, 0.62 and 0.67 at the head, the middle and the tail respectively. It can be assumed that, if the water delivery performance is close to unity, then the management inputs must be effective. It is evident that the water delivery performance was not effective; the upstream farmers got more water than the targeted amount while those in the middle and the downstream farms got less than the targeted amount of water.

Table 7. *Delivery Performance Ratio and water delivery performance.*

Location	Head			Middle			Tail		
	SC1	SC2	Mean	SC1	SC2	Mean	SC1	SC2	Mean
DPR	0.98	0.91	0.95	0.56	0.67	0.61	0.51	0.57	0.54
WDP	1.4	1.35	1.37	0.56	0.67	0.62	0.71	0.81	0.76

A value of water delivery ratio equal to unity means that, the system is able to deliver the intended amount. The values less than one reveal inadequate portion of the intended for the direct users. But a value greater than one means that extra water than scheduled is being delivered to the area under assessment [17].

3.7. Conveyance Efficiency for the Lined Main, Secondary Canals

The result in Table 8 shows the average conveyance efficiency of 82.48%, 80.40% and 66.38% for the lined main canal, lined secondary and unlined secondary canal respectively. According to the standard value of conveyance efficiency for the canal adequately maintained which are 95% for lined and 75% for unlined canals [28]. Our results of conveyance efficiency both for lined and unlined are below the standards. The low conveyance efficiency observed at the unlined secondary canal is explained by the poor maintenance of the canal. Inefficiency could be due to weeds in some locations, seepage losses and conveyance losses. The same finding was reported by van Halsema *et al.* [32] where the conveyance in the main, secondary and tertiary canals of the Haleku Irrigation Scheme to be ranged from 70.2 to 82%.

Table 8. *Average conveyance efficiency for main and secondary canals.*

Month	Lined main canal	Lined secondary canal	Lined secondary canal
January	82.39	80.90	67.90
February	82.35	80.60	64.09
March	83.79	79.24	67.97
April	81.39	80.84	53.95
Average	82.48	80.40.	66.38

3.8. Efficiency of Surface Irrigation System

The calculated measures of adequacy (P_A), efficiency (P_F,) dependability (P_D) and equity (P_E) provide combined summaries of system performance. The values determined for the secondary and tertiary canals are presented in Tables 9 and 10.

Table 9. *Summary of Performance Measures for Secondary canals.*

Parameters	Head	Middle	Tail	Average
P_F	0.71	1.13	1.28	1.04
P_A	1.39	1.25	0.90	1.18
P_D	0.20	0.18	0.06	0.14
P_E	0.26	0.16	0.15	0.19

Table 10. *Performance values for tertiary canal.*

Parameters	Head	Middle	Tail	Average
P_F	0.63	0.99	0.98	0.96
P_A	1.47	1.06	0.71	1.10
P_D	0.25	0.18	0.12	0.17
P_E	0.17	0.12	0.09	0.12

i. Efficiency

The results in Table 9 show that the irrigation efficiencies of the secondary canals was 0.71 at the head, 1.13 at the middle and 1.28 at the tail with an overall average of 1.04. The results in Table 10 show also that the efficiency of the sampled tertiary canals was 0.63 at the head, 0.99 at the middle and 0.98 at the tail with an average of 0.96. According to the standard values of efficiency (Appendix Table A3) proposed by Molden and Gates [18], the findings further indicate that irrigation efficiency in all the reaches both on secondary and tertiary canals are poor because the upstream farmers get more than they need while the farmers of middle and downstream farmers get less than they need. Poor efficiency can be attributed to water scarcity due to uncontrolled field developed in that area. Lack of operation and maintenance of water infrastructures has also been reported by farmers during focus group discussions to increase water losses along the canal water supply systems. The results align with the findings of other researcher [33] who reported that the water delivery efficiency was 0.70 and 0.82 for 2018 and 2019 and emphasized the need of scheme rehabilitation in order to improve water supply, allocation and application.

ii. Adequacy of irrigation water supply

At the secondary canals, Table 9 shows that the average values of relative water supply (RWS) were 1.39 at the head, 1.25 at the middle and 0.90 at the tail while at the tertiary canals sampled the RWS was 1.47 at the head, 1.06 at the middle and 0.71 at the tail (Table 10). According to Molden and Gates [18] classification and performance standards, the RWS ranging from 0.90 to 1 is taken as good while the values of less than 0.8 are taken as inadequate water delivery and all value above one are accepted as adequate regardless of the amount of excess (Appendix Table A3). Based on this classification, the adequacy of irrigation water supply is good. However, adequacy seemed to reduce towards the downstream as the RWS values at the tail reach plots were low compared to the ones upstream and in the middle. This could be due to conveyance losses due to the lack of maintenance. The findings are low compared to those reported by Mchelle [34] where she found 1.78 for the upstream, 1.65 for the middle and 1.25 at the tail and stated that the significant reduction in RWS at the tail was due to seepage losses occurring in the water conveyance.

iii. Dependability of irrigation water supply

The results in Tables 9 and 10 show that the average values of dependability (P_D) were 0.20, 0.18 and 0.06 respectively at the head, at the middle at the tail with an average of 0.14 for the Secondary canals and 0.25, 0.18 and 0.12 at the head, the middle and the tail respectively for the tertiary canals with an average of 0.17. According to Molden and Gates [18] dependability's classification, the values ranged between 0-0.11 are good, 0.11-0.25 are fair and above 0.25 are poor; in this respect, the dependability in this study can be classified as fair for both the secondary and tertiary canals. Sibale et al. [33] reported the values of dependability of 0.11 and 0.21 classed as fair and poor for 2017. He argued that there were a lot of water losses in the conveyance and distribution systems. On the other hand, Mchelle [34] showed the value of dependability ranged between 0.62 and 0.70 showing poor dependability, attributes it to poor water management practices caused by poor timeliness in water distribution by the water allocation and distribution committee. The poor dependability observed at Kidwebezi is due to the shortage of water and poor share among farmers. That was confirmed by majority of farmers during focus group discussion where more than 90 per cent of the participants attribute it to the water scarcity caused by the uncontrolled paddy fields developed at the upstream.

iv. Equity of irrigation water supply

The results in Table 9 show that the average values of equity for secondary canals were 0.26, 0.16 and 0.15 at the head, the middle and the tail respectively with an average of 0.19. The results in Table 10 show that the equity of tertiary canals was 0.17, 0.12 and 0.09 at the head, the middle and the tail respectively. According to Molden and Gates [18] classifications, the values between 0-0.1, 0.1-0.20 and above 0.20 are taken as good, fair and poor respectively. Taking consideration of that classification of equity, the average equity was fair for both the secondary and the tertiary canals. The low level of equity may have been caused by poor allocation of water, poor maintenance of canals and remarkable shortage of water due to an increasing of fields demanding more water which was not planned for. These findings generally fall in the range given by Sibale *et al.*[33] who showed the values of equity as 0.15 and 0.20 classed as fair and poor for the period of 2017 and 2018.

Table 11. *Physical and Economic water productivity at KIS.*

Parameters	Head	Middle	Tail	Average
Actual water use per ha (m^3)	6,884.4	4345.1	3828.8	5019.4
Target water use per ha (m^3)	5007.7	5007.7	5007.7	5007.7
Total Yield per ha (kg)	6,666	5883	5380	5976.3
Actual physical WP (kg/m^3)	0.97	1.35	1.41	1.191
Target physical WP (kg/m^3)	1.33	1.17	1.07	1.193
Total Yield cost per ha ($)	3076.6	2715.2	2483.1	2758.3
Actual economic WP ($\$m^{-3}$)	0.45	0.63	0.65	0.50
Target Economic WP ($\$m^{-3}$)	0.62	0.54	0.49	0.55
Water productivity performance	0.72	1.15	1.31	0.91

3.9. Physical and Economic Water Productivity

The results in Table 11 show the average production per hectare as 6666, 5883 and 5380 kg at the head, the middle and the tail, respectively. That result show further that the upstream farmers have got higher yield than did those in the middle and the downstream locations. The difference in yields can be attributed to the lack of fair share of water delivery. However, although high yield were observed at the upstream farmers, the highest water productivity was found at the tail with 1.41 kg per m^3 using 3828.88 m^3 as irrigation water per ha, followed by the middle with 1.35kg per m^3 per ha and finally the lowest average was 0.97 kg per m^3 found at the head of the scheme using 6888.4 m^3 per ha as irrigation water. The low values of output observed especially at the head suggest that a lot of water was being diverted to that area but most of it is wasted. In other hands, the tail-enders of the scheme appears to use water more efficiently. Even though farmers located at the tail-end reach suffer from inequity in water distribution, they re-use drainage water head and middle reaches to irrigate their crops, which saves them from suffering from water stress and allows them to perform well in water productivity. The findings are in agreement with others findings by other scholars who reported water productivity to vary between 1.0 and 1.7 kg per m^3 in China, USA and Brazil and between 1.7 and 2.4 kg per m^3 in Western European countries [35].

The results in Table 11 show also that actual economic water productivity for the head, the middle and the tail were 0.45, 0.63 and 0.50 US$ per m^3 respectively. These results showed that downstream farms had the highest income per unit of irrigation water diverted to the network with 0.65 US$ per m^3 and the lowest income was found to upstream farmers with 0.45 US$ per m^3 indicating that the farmers need to know how to use water efficiently. The results is in agreement with the study finding of Degirmenci *et al.* [36] who reported water productivity ranged from 0.13 to 2.16 US $ m^{-3} at Hancagiz and Derk- Dumluca irrigation schemes in Turkey.

4. Conclusion and Recommendation

In this study, the water delivery performance of Kidwebezi Irrigation Scheme was evaluated using adequacy, efficiency, dependability, and equity. The examination of overall performance in terms of water allocation shows the head to perform well and poorly for both the middle and the tail. According to the performance indicators, the results show that the irrigation system was good for adequacy, fair with respect to dependability and equity, while it was poor in terms of efficiency. The amount of water which is being diverted to the KIS was more than adequate at the head but inadequate at the middle and tail end for irrigation water requirements. However, the scheme faces a problem of a fair share of water, which continues to decrease due to an increase in the number of paddy fields. Due to the challenges of a water deficit in the Kidwebezi Irrigation Scheme, the study recommend to the government to increase water supplies from the Mpanda River, which might assist lessen the water shortage and provide education to farmers and committee members on water equality and sustainability. The branch committees should be given more attention by providing them with more training on water allocation and water requirements.

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Appendix

Table A1. *Suggested criteria for irrigation water base on conductivity.*

Class of water	Classification	Electrical conductivity (dS/m)
Class 1	Excellent	≤ 0.25
Class 2	Good	0.25-0.75
Class 3	Permissible	0.76-2.00
Class 4	Doubtful	2.01-3.00
Class 5	Unsuitable	≥3.00

Table A2. *Normal ranking in irrigation water.*

Parameters	symbols	Units	normal
Electrical conductivity	EC_W	Ds/m	0-3
Calcium	Ca^{2+}	meq/l	0-20
Magnesium	Mg^{2+}	meq/l	0-5
Potassium	K^+	meq/l	0-0.052
Sodium	Na^+	meq/l	0-40

Table A3. *Evaluation standard for performance indicators.*

Parameters	Performance Classes		
	Good	Fair	Poor
P_F	85-100%	70-85%	< 70%
PA	0.9 - 1.0	0.8 - 0.9	< 0.80
PD	0 - 0.10	0.1 - 0.25	> 0.25
PE	0 - 0.10	0.1 - 0.20	> 0.20

Source: Molden and Gates (1990).

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