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Hydraulic performance evaluation of the water conveyance system of Doho Rice Irrigation Scheme in Uganda

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Abstract
Poor water distribution is a major problem in many surface irrigation schemes in Uganda, especially at the tail reaches. This has led to reduced crop yield from these water-stressed fields. This study reports the results of evaluating the hydraulic performance of the water conveyance system of Doho Rice Irrigation Scheme for one cropping season for the first quarter of 2019. For the main canal, the conveyance efficiency indicator was used while for the lateral canals indicators of adequacy, efficiency, dependability, equity, and the equity ratio of head to tail were used to evaluate the hydraulic performance. Performance indicators were computed at the head and tail ends of the canals thus comparing the inlet and distribution processes. Field measurements coupled with simulation techniques were used to obtain the delivered and required flows. It was found that the acceptable average hydraulic performance indicators of the scheme were 0.84, 0.79, 0.07 and 0.26 for adequacy, efficiency, dependability, and equity respectively, the tail reaches suffer in performance with the adequacy, dependability, and equity ratio at 0.68, 0.12, and 3.13 respectively. Improving hydraulic performance of the scheme necessitates reduction of water conveyance losses, adherence to distribution plans and monitoring of diversions to the canals..

Keywords: Conveyance; Efficiency; Evaluation; Hydraulic performance; Indicators

1. Introduction

Irrigation development has gained significant importance across the globe because of its potential to improve food security and reduce rural poverty [1]. The Agricultural sector in Uganda contributes about 24.6% of the gross domestic product (GDP), provides a livelihood for over 72% of the economically active population, and supplies most of the raw materials for agro-processing industries [2]. Agriculture is responsible for, on average, 70 percent of all water withdrawals worldwide, and an even greater share of consumptive water use owed to the evapotranspiration requirements of crops [3]. According to [4], 60% of the world's freshwater diverted for agriculture does not contribute directly to food production. Losses stem from poor on-farm water management practices, water leakage along the conveyance system, and obsolete control structures. The productivity of irrigated lands in Africa can only be increased and sustained by periodical performance evaluation [5].

Performance evaluation of an irrigation system can be defined as the systematic observation, documentation, and interpretation of activities related to irrigated agriculture with the objective of continuous improvement

[6]-[7]. The ultimate purpose of performance evaluation is to attain an efficient and effective use of resources by providing relevant responses to management at all levels [8]. According to [9], performance assessment evaluates the existing situation of irrigation performance, identifies the constraints to proper performance, and implements management interventions to improve the performanceTherefore, in an irrigation scheme, hydraulic performance evaluation contributes to system management in determining whether the performance is satisfactory and, if not, which counteractive actions need to be employed in order to remedy the status quo [8]. Low levels of hydraulic performance are common on many surface irrigation schemes in sub-Saharan Africa [10]. Factors contributing to low hydraulic performance in large scale irrigation schemes in sub-Saharan Africa range from canal sedimentation, inadequate institutional setup, deteriorating infrastructure and poor water management [11]-[12]. As a result, there have been conflicting opinions about further investments directed towards new irrigation projects, primarily due to the questions about the performance of existing projects [10]-[13].

Hydraulic performance evaluation has not been incorporated in the monitoring and evaluation framework of public irrigation schemes in Uganda despite it being a tool for determining performance of the water delivery and control systems within the scheme [14]-[15]. In a study conducted by [16] to determine the household contribution to irrigation management, farmers' refusal to pay for irrigation water was reported which has led to reduced rice yields at the tail reaches [17]. Although water delivery was qualitatively determined, this research addresses this deficiency by quantitatively evaluating the performance of the water conveyance system. Quantitative determination of hydraulic performance indicators provides vital information to scheme managers necessary in decision making in regard to hydraulic performance improvement. Poor water allocation methods, deteriorating irrigation infrastructures, silted canals and lack of water measurement structures are the major challenges at Doho Rice Irrigation Scheme. The effect of these challenges on hydraulic performance of the water conveyance system were determined using performance indicators namely adequacy, equity, efficiency, and dependability were used to evaluate the performance of the conveyance system [7]. [18] suggested common efficiency terms for irrigation system evaluation such as application efficiency, conveyance efficiency, distribution uniformity, storage efficiency, runoff ratio, and deep percolation ratio. However, most of the seepage losses, deep percolation and runoff are considered by water conveyance and water application efficiencies and thus for the main canal of Doho Rice Irrigation Scheme, the conveyance efficiency indicator was used for evaluation.

A water delivery system that is not adequate, dependable, equitable or efficient can have adverse effects on crop productivity in the irrigation scheme. Timely information on performance related metrics (e.g. water delivery, drainage control, water shortage) is required by the operational managers on time to make relevant decisions in regard to water allocation, maintenance, and modernization plans and cropping systems [7].

2. Materials and methods

2.1 Description of the study area

Doho Rice Irrigation Scheme spans in both Mazimasa and Kachonga Sub-Counties of East Bunyole County in Butaleja District of Uganda as shown in Fig 1. It is located at Longitude 34°02' East of the Greenwich and Latitude 0° 56' North of the Equator on the right bank of Manafwa River. It is 49 km from Tororo town, 25 km from Mbale town and 260 km from Kampala city and 70 km from Malaba, Uganda-Kenya border. Doho Rice Scheme is located in the Lake Kyoga basin and covers an area of 494.2 km2 [19]. The scheme covers an area of 2500 acres (1000 Ha), 2380 of which is cultivated while the remaining 120 acres are covered by irrigation infrastructures like farm roads, embankment, water conveyance channels, and bridges. The Scheme is partitioned into 11 main blocks namely: 1A, 1B, 2A, 2B, 3, 4A, 4B, 5A, 5B.6A, and 6B as shown in Fig 2. This division was made to create administrative units purposely to ease management during water distribution [16]. The main canal which is unlined conveys irrigation water from River Manafwa to the scheme branches out into 2 secondary canals, the Southern canal, and the Northern canal. The northern canal also acts as a drainage channel for wastewater from the blocks and serves tail end blocks. From the secondary canals, water is conveyed through lateral canals and then to the blocks. After flowing through the paddy fields, water is collected in the main drainage channel through the tertiary and sub-drainage channels and drained back into River Manafwa [16]. Water distribution at Doho Rice Irrigation Scheme is done on a rotational basis amongst the canals where irrigation water is fed in a canal for a set time and then closed until its turn comes around again.

2.2 Data Collection

Data was collected from primary and secondary sources. The primary data was collected through direct measurement from the field. Actual flows within the canals were measured at the headworks, Kapisa control gates, and in selected canals from the sampled blocks at the head end, middle end and the tail end of the scheme as shown in Fig 2. Flows were measured five times in a month for a period of 3 months from February to April 2019. Comprehensive field observations and surveys were carried out to understand the irrigation practices, water distribution system and cropping patterns. Focused group and key informant interviews were conducted with irrigation attendants at Doho Rice Irrigation Scheme to understand the scheme water distribution schedule. The secondary data was collected from Doho Rice Irrigation Scheme offices, Ministry of Agriculture Animal Industry and Fisheries (MAAIF), and Tororo Meteorological Station. From this data, information on actual cropping patterns, command area, Scheme design document, and climate data was obtained.

2.3 Actual irrigation water measurement

In the study, flows were measured using a current meter. The discharges were measured at two points along the main canal, and at 8 off-take canals located at the headend, middle and tail ends. The flows were measured for 15 days in three months i.e. 5 days per month and average monthly flows were calculated. Flows were measured following the procedure described in the WMO Stream gauging manual No. 1044 [20]. Discharge along the main canal was measured at two points namely intake point and Kapisa intake gate. Flows in the secondary canal were measured at the diversion point from the main canal and at the point where it supplies a tertiary canal. Flow measurements

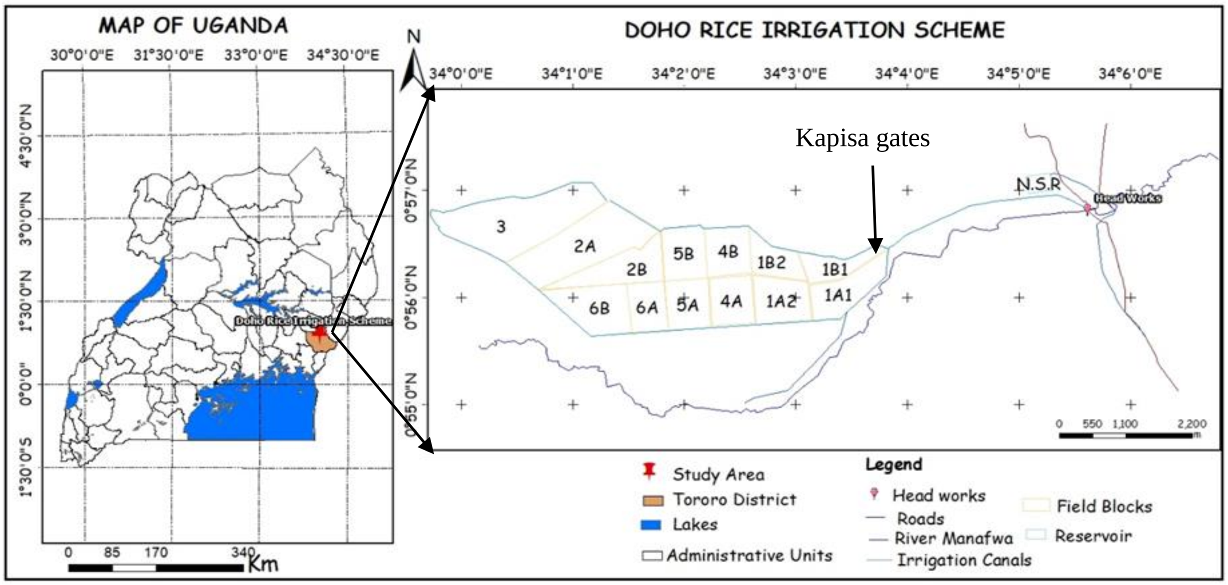

Figure 1: Study Area

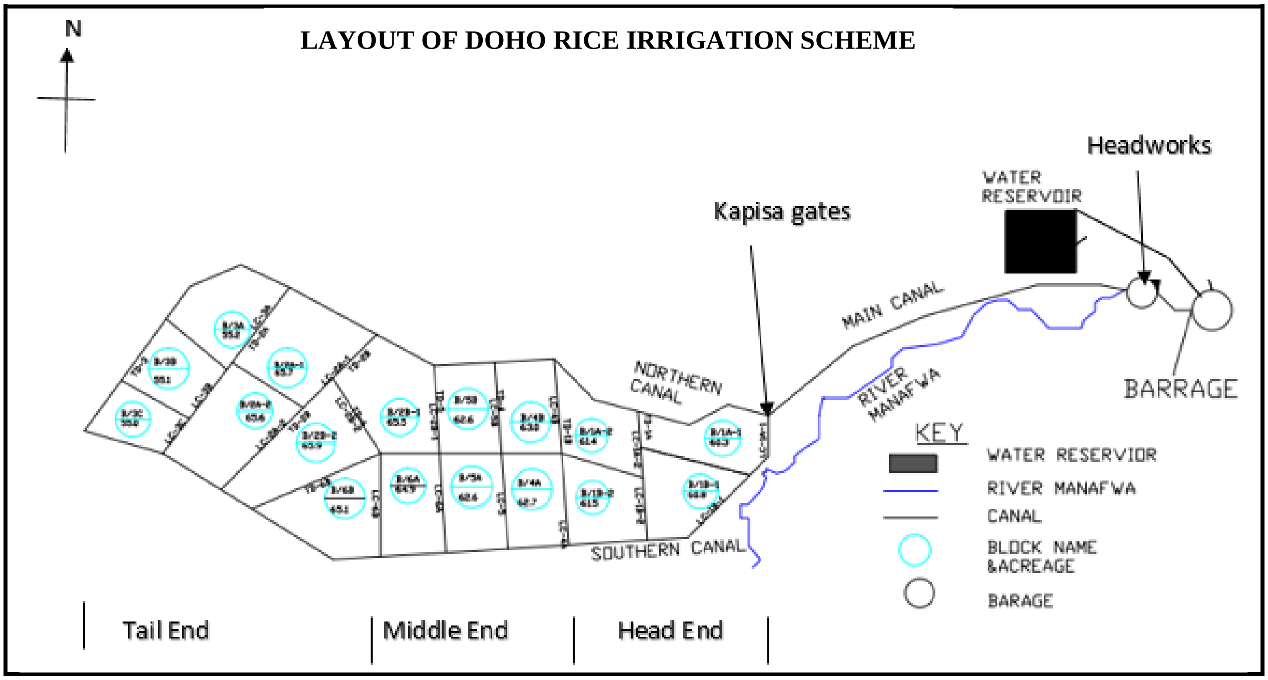

Figure 2: Layout of Doho Rice Irrigation Scheme

were taken at the head end, middle end, and the tail end of the scheme. The discharge of the canal was computed using the mean section method following ISO 748. The total discharge (Q) at a section was determined as a sum of discharges in each subsection as in (1).

$$Q = \sum_{x=1}^{n} W_x \left(\frac{V_x + V_{x+1}}{2} \right) \left(\frac{y_x + y_{x+1}}{2} \right) \qquad (1)$$

Where:

Q = total discharge (m^3/s)
W = width between two adjacent verticals (m)
V = depth average velocity (m/s)
x = the number of verticals
y = flow depth (m)
n = number of sections

3. Data processing and Analysis

Field data were first processed to obtain variables for calculating hydraulic performance indicators.

3.1 Crop water requirement

The total volume of water needed to meet the evapotranspiration demand of the crops was estimated using weather data and area under each crop for each season. Climate data was used to calculate monthly potential evapotranspiration (ET_0) using CROPWAT 8.0 software which is based on the Penman-Monteith equation [21].

3.2 Hydraulic performance indicators

Hydraulic performance of the irrigation system was evaluated using four indicators. These indicators were evaluated using the data collected during the February to April 2019 in one irrigation season. The main canal system performance with respect to water delivery was estimated based on the monthly required and delivered discharge. Whereas at the field level, water delivery performance was according to indicators of adequacy, dependability, equity, equity ratio for head to tail, and efficiency.

3.2.1 Adequacy

Adequacy of water is a measure of the degree to which water deliveries meet soil-plant-water requirements [7]. It shows the ability of the system to reach targeted deliveries in terms of quantity. Adequacy of water delivery is dependent on water supply and the water demand by the crops. Adequacy (P_A) was calculated using (2) [22].

$$P_A = \frac{1}{T} \sum_{T} \left(\frac{1}{S} \sum_{S} \frac{Q_D}{Q_R} \right) \qquad (2)$$

Where:

$$P_A = \begin{cases} \dfrac{Q_D}{Q_R} & Q_D \le Q_R \\ 1 & otherwise \end{cases}$$

$T =$ Time period (months)

$S =$ Site where the canals are located

$Q_D =$ The actual amount of water delivered (m^3/s)

$Q_R =$ Required discharge (m^3/s)

3.2.2 Dependability

According to [23], dependability deals with the quality of the irrigation service rather than the quantity and it covers both the reliability of discharges and timing of deliveries. Dependability is defined as the temporal uniformity of the ratio of the delivered amount of water to the required or scheduled amount. Dependability indicator (P_D) is given as [24].

$$P_D = \frac{1}{S}\sum_S CV_T \frac{Q_D}{Q_R} \quad (3)$$

Where:

$CV_T =$ Temporal coefficient of variation of the ratio Q_D/Q_R over a region S and a time T

$Q_D =$ The actual amount of water delivered (m^3/s)

$Q_R =$ Required discharge (m^3/s)

3.2.3 Equity

Equity, as related to water delivery system can be defined as the delivery of the fair shares of water to the users throughout the system. Equitable water distribution is attained when the ratio of water delivered at head end to water delivered at tail end outlets is 1. A perfectly equitable distribution will result if all locations receive an adequate water supply or if each location receives the same supply or what they are entitled to. Equity indicator P_E is given as [22].

$$P_E = \frac{1}{T}\sum_T CV_S \left(\frac{Q_D}{Q_R}\right) \quad (4)$$

Where:

$CV_S =$ Spatial coefficient of variation of the ratio Q_D/Q_R over a region S and a time T

$Q_D =$ The actual amount of water delivered (m^3/s)

$Q_R =$ Required discharge (m^3/s)

3.2.4 Efficiency Indicator

Efficiency Indicator, P_F in terms of hydraulic performance is defined as the degree to which water is conserved in the system. The conservation of water resources which plays an important role in water delivery for the authority and government because water saved may result in less expenditure on infrastructure and can possibly be allocated to fully meet the existing requirement or irrigate more land. It is defined as the ratio of the volume of water required for a specific purpose to the volume of water delivered for this purpose. The ratio is given as

$$P_F = \frac{1}{T}\sum_T \left(\frac{1}{S}\sum_S \frac{Q_R}{Q_D}\right) \quad (5)$$

where:

$$P_F = \begin{cases} \dfrac{Q_R}{Q_D} & Q_R \le Q_D \\ 1 & otherwise \end{cases}$$

$P_F =$ is the spatial and temporal average of the ratio of Q_R/Q_D indicator over a region S and time period T

$Q_D =$ The actual amount of water delivered (m^3/s)

$Q_R =$ Required discharge (m^3/s)

3.2.5 Equity Ratio for Head and Tail

Equity ratio for head and tail (ERHT) is both a conveyance and water delivery indicator. It focusses on the equity of water distribution for head and tail at different levels of a system. It is expressed as

$$ERHT = \frac{\frac{1}{n}\sum_{t=1}^{t=n}\frac{Q_D}{Q_R}(headend)}{\frac{1}{n}\sum_{t=1}^{t=n}\frac{Q_D}{Q_R}(tailend)} \quad (6)$$

Where:

n = number of periods monitored

$Q_D =$ The actual amount of water delivered (m^3/s)

$Q_R =$ Required discharge (m^3/s)

3.2.6 Conveyance Efficiency

The conveyance efficiency was employed for the main canal. It indicates how much water is lost along the canal. The conveyance efficiency was obtained using (7) [25].

$$E_c = \frac{V_m}{Q_0} * 100 \quad (7)$$

where:

V_m = volume of water delivered to the distribution system (m^3/s)

Q_0 = amount of water abstracted from the river (m^3/s)

3.2.7 Delivery performance ratio

The amount of irrigation water supply can be evaluated using water delivery performance ratio (DPR). It is the ratio of the actual volume of delivered water to the intended. [26] provided the use of average seasonal values of the ratio of intended and actual volumes of water delivered to the tertiary units in performance evaluation of a secondary channel of an irrigation scheme. The delivery performance ratio allows determination of the extent of actual water delivery during a selected period and at any location in the system [27]. It is obvious that if the actual delivered volume of water is based on frequent flow measurements, the greater the likelihood that managers can match actual flows to intended flows. To obtain sufficiently accurate flow data, discharge measurement structures with water level recorders must be available at key water delivery locations [6]. To facilitate the handling of data, recorders that write data on a chip are recommended [26]. DPR in irrigation system indicates the problems related to sediment deposits, erosion, and vegetation of some water conveyance structures. Generally, delivery performance ratio is the ratio of the amount of actual delivered to the intended amount of water to be delivered [26]. The ratio is given as shown in (8) by [9] ;

$$DPR = \frac{Q_{act}}{Q_{des}} \quad (8)$$

where:

Q_{act} = actual flow in the canal (m^3/s)

Q_{des} = design capacity of canal (m^3/s)

After computation of the indicators, the water delivery canals are evaluated based on water delivery performance indicators standards presented in Table 1 developed by [22].

4. Results and Discussions

4.1 Hydraulic Performance Indicators

Table 2 presents the discharges at various outlets QD and the required flows QR to meet the crop water requirements.

4.1.1 Adequacy

Results of the adequacy indicator of the selected canals at Doho Rice Irrigation Scheme are presented in Table 3. Fig 3 and Fig 4 present the temporal and spatial variability of Adequacy indicator within the scheme respectively.

The adequacy indicator (P_A) at Doho Rice Irrigation Scheme has temporal values of 1.00, 0.84 and 0.68 at the head, middle and the tail ends of the system respectively. The spatial values of adequacy are 0.85, 0.78 and 0.89 in February, March, and April 2019 respectively. The adequacy indicator is measured against a standard by [22] presented in Table 1 where 0.9-1.0 is classified as good, 0.80-0.90 as fair and < 0.80 classified as poor. In March, there is poor adequacy, crop water requirements were much greater than the water supplied by the canals. This was because no rains were received in this month and hence less flows in the River Manafwa. The spatial variation of adequacy reduces from good to poor from the headend to the tail end. This can be explained by two factors. Supply was not well carried out in accordance with the crop water requirements in the different periods within the irrigation season. The average adequacy for the scheme was 0.84 suggesting a fair distribution of irrigation water among block.

Table 1.Hydraulic performance indicators

Performance Indicators	Range		
	Poor	Fair	Good
Adequacy	<0.80	0.80-0.89	0.90-1.00
Dependability	>0.20	0.11-0.20	0.00-0.10
Equity	>0.25	0.11-0.25	0.00-0.10
Efficiency	<0.70	0.70-0.84	0.85-1.00

ERHT	<0.7	0.7-0.79	0.8-0.9

Table 2. Delivered flows and Required flows in Canals

Location	Canal	Month	$Q_D(m^3/s)$	$Q_R(m^3/s)$	Q_D/Q_R
Head reach	LC $1A_1$	Feb	0.040	0.024	1.000
		Mar	0.035	0.015	1.000
		Apr	0.050	0.028	1.000
	LC 1A2	Feb	0.035	0.010	1.000
		Mar	0.030	0.015	1.000
		Apr	0.038	0.028	1.000
Middle reach	LC 4A	Feb	0.015	0.016	0.940
		Mar	0.050	0.069	0.720
		Apr	0.050	0.008	1.000
	LC 4B	Feb	0.008	0.010	0.800
		Mar	0.012	0.016	0.750
		Apr	0.024	0.029	0.830
Tail reach	LC 2A1	Feb	0.011	0.017	0.650
		Mar	0.035	0.073	0.480
		Apr	0.005	0.009	0.560
	LC 2A2	Feb	0.008	0.011	0.730
		Mar	0.012	0.016	0.750
		Apr	0.028	0.030	0.930

These findings are similar to results by [12] who reported average adequacy of 0.89 while evaluating the hydraulic performance of Metahara large scale irrigation scheme in Ethiopia. [28] obtained decreasing values of the spatial variation of adequacy from good to poor (head to tail end) owing to water losses along the canals. [29] while evaluating the water delivery system of Jayakwadi Irrigation Project in India reported an average adequacy value of 0.5 indicating inadequate delivery of irrigation water. [30] qualitatively reported inadequate irrigation water deliveries at the tail end of Doho Rice Irrigation Scheme which relates the adequacy values obtained at the tail end.

Table 3. Average Adequacy of Water distribution in the system

	Head		Middle		Tail		
Month	LC-$1A_1$	LC-$1A_2$	LC-4A	LC-4B	LC-$2A_1$	LC-$2A_2$	Spatial P_A
Feb	1.00	1.00	0.94	0.80	0.65	0.73	0.85
Mar	1.00	1.00	0.72	0.75	0.48	0.75	0.78
Apr	1.00	1.00	1.00	0.83	0.56	0.93	0.89
Temporal	1.00	1.00	0.89	0.79	0.56	0.80	
Average P_A	1.00		0.84		0.68		0.84

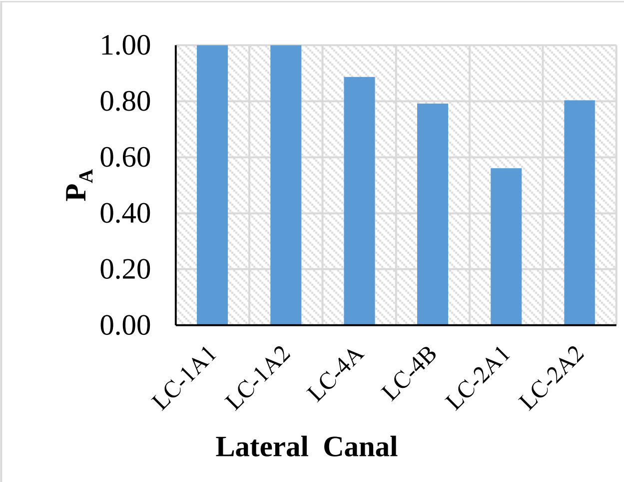

Figure 3. Temporal Variation of adequacy

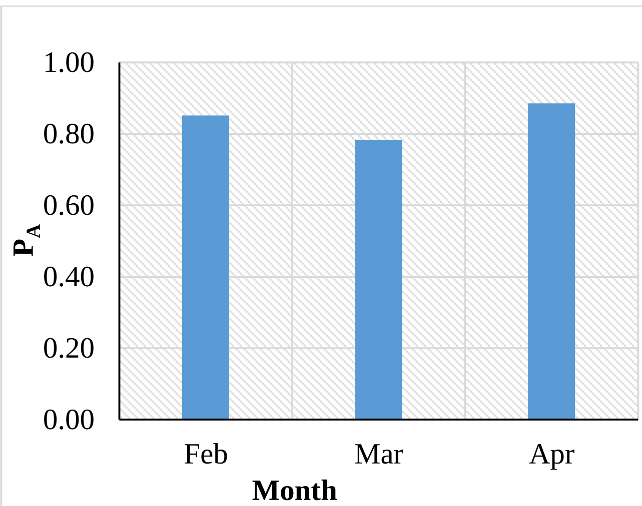

Figure 4. Spatial variation of Adequacy

4.1.2 Dependability

Dependability or reliability expresses the consistency of a system for delivery of water on time. Table 4 shows the calculated value of Temporal Coefficient of Variation (CV_T) which is the ratio of Q_D / Q_R over time T for the canals.

The average dependability (temporal coefficient of variation values of the head, middle and tail end of DRIS range from 0.09 to 0.12 with average dependability of 0.07. The dependability indicator is measured against a standard by [22] presented in Table 1 where 0.00-0.10 is classified as good, 0.11-0.20 as fair and > 0.20 classified as poor. The average dependability of the head end canals LC-1A$_1$ and LC-1A$_2$ is 0.00 which represents a reliable delivery of water. This means that farmers got water at the required time to meet the crop water requirements. The coefficient of variation at the tail end of DRIS is 0.12 which means that water delivery is fairly reliable. This further suggests that the water delivery plan formulated by the Doho Rice Irrigation Scheme management was followed irrespective of the inadequate flows. [31] while evaluating the water allocation and delivery performance of Jiamakou Irrigation Scheme that grows apples and cotton under surface irrigation reported a CV_T of 0.23 indicating poor dependability for the entire scheme. This was attributed to the unscientific water allocation methods employed at the scheme. In evaluating the hydraulic performance of Hare Community managed irrigation scheme in Ethiopia, Tebebal, [32] found that the dependability indicator at the headend was good with a CV_T of 0.00 while at the tail end it was poor with a CV_T greater than 0.2. [33] reported a CV_T of 0.13 at Menemen left bank irrigation district in Turkey indicating fair dependability.

Table 4. Dependability of water supplied in the system

	Head		Middle		Tail	
Month	LC-1A$_1$	LC-1A$_2$	LC-4A	LC-4B	LC-2A$_1$	LC-2A$_2$
Feb	1.00	1.00	0.94	0.80	0.65	0.73
Mar	1.00	1.00	0.72	0.75	0.48	0.75
Apr	1.00	1.00	1.00	0.83	0.56	0.93
Average	1.00	1.00	0.89	0.79	0.56	0.80
Standard dev	0.00	0.00	0.12	0.03	0.07	0.09
CV_T,(P_D)	0.00	0.00	0.13	0.04	0.12	0.11
Average	0.00		0.09		0.12	

4.1.3 Equity

Equity is another important parameter for evaluating water hydraulic performance from an equitable distribution perspective. This indicator measures the spatial coefficient of variation given as CV_R. Table 5 shows the spatial coefficient of variation calculated for lateral canals located at head, middle and tail end sections of the Doho Rice Irrigation Scheme.

The equity indicator is measured against a standard by [22] presented in Table 1 where 0.00-0.10 is classified as good, 0.11-0.25 as fair and > 0.25 classified as poor. At the head end of the scheme, the CV_R value obtained is 0.00 between February to April indicating good equity, and at the middle-end of the scheme, the CV_R is 0.09 indicating good equity while at the tail end a CV_R of 0.26 was obtaining which indicates poor equity. This suggests that head-end farmers receive more water than tail-end farmers. Water to the tail end blocks undergoes seepage losses owing to the fact that the canal lining material is earth.

The same results were obtained by [34] while comparing two management scenarios in Doho Rice Irrigation Scheme and Lwoba Scheme. In addition, [28] found good values of equity at the head end that reduces to change to fair towards the tail end. While evaluating the water delivery performance of smallholder irrigation schemes in Ethiopia, [35] found CV_R values greater than 0.6 which indicated inequalities in water allocation. The authors attributed this inequality to poor water allocation methods and water conveyance losses along the earth canals.

Table 5. Equity of water supplied in the system

	Head			Middle			Tail		
Month	LC-1A$_1$	LC-1A$_2$	CV_R	LC-4A	LC-4B	CV_R	LC-2A$_1$	LC-2A$_2$	CV_R
Feb	1.00	1.00	0.00	0.94	0.80	0.11	0.65	0.73	0.08
Mar	1.00	1.00	0.00	0.72	0.75	0.02	0.48	0.75	0.32
Apr	1.00	1.00	0.00	1.00	0.83	0.13	0.56	0.93	0.36
Average CV_R			0.00			0.09			0.26

4.1.4 Equity Ratio for Head and Tail

Equity Ratio for Head and Tail (ERHT) was calculated using (6). It estimates how water was managed and delivered fairly in head and tail reach of the main canal. Table 6 shows the equity ratio for head and tail. The value of ERHT ranges from 2.11 to 3.76 which is a poor indicator. [34] also found out that farmers cultivating paddy fields located downstream of quaternary canals in Doho Rice Irrigation Scheme were not satisfied with water supply. It is reported that the water distribution system along each strip is not working well and head end farmers got more water than tail end farmers. This shows that equitable water delivery was not achieved at the tertiary level.

Table 6. Equity ratio for Head and Tail

	Head		Tail		
Month	LC-1A$_1$	LC-1A$_2$	LC-2A$_1$	LC-2A$_2$	ERHT
Feb	1.67	3.50	0.65	0.73	3.76
Mar	2.33	2.00	0.48	0.75	3.52
Apr	1.79	1.36	0.56	0.93	2.11
Average ERHT					3.13

4.1.5 Efficiency

The efficiency indicator was assessed for each of the sampled offtake locations and Laterals at Doho Rice Irrigation Scheme. The tabulated results of the temporal value of efficiency for each outlet point at the head, middle and tail end laterals are presented in Table 7. The temporal P_F value at the head end, middle and tail end of DRIS were found to be 0.52, 0.86 and 1.00 respectively. With a value of 0.53 at lateral canal-1A_1, and 0.51 at Lateral canal-1A_2, the efficiency at the head end was categorized as poor which means excess water was supplied at the head end than what was required. At the tail end, the water supplied for irrigation was efficiently used by paddy for crop development. The off taking efficiency indicators mean that the excess water in the lateral canal is lost due to seepage and evaporation [12]. However, the overall scheme efficiency is found to be 79 % which is a fair indicator based on the evaluation criteria presented in Table 1. These results show that at the times when the requirement for irrigation water was high, irrigation water was used more efficiently by the farmers. The results of the efficiency indicator are consistent with what [36] obtained while evaluating the water delivery and irrigation performances at field level of the Menemen left bank irrigation district in Turkey that mainly grows cotton and cereals. However, the water delivery of the scheme is somewhat organized compared to that of Doho rice scheme. In both schemes, the water delivered to the farmers is unknown as there are no measuring devices. [31] reported an average efficiency indicator of 68% which means in some areas of the Jiamakou Irrigation Scheme, more water was supplied than was required. While evaluating the water delivery performance of secondary canals in Pakistan, [37] also observed oversupply and undersupply of irrigation water to head end and tail end respectively. This resulted in average efficiency of 89% with consistent overflows at the head end while the tail-end suffers from minimum flows.

4.1.6 Conveyance Efficiency

The conveyance efficiency (E_C) was determined for the Doho main canal between the intake point and Kapisa control gates where the rice blocks start. Conveyance efficiency was calculated as shown in (7). The results of the conveyance are presented in Table 8.

The conveyance efficiency of the 3.5km Doho main canal is 68%. The canal losses 32% of the water through seepage owing to the fact that it is an earthen canal. Siltation and vegetation growth within the canal interferes with water flow reducing the conveyance efficiency. According to the FAO guidelines, the indicative conveyance efficiency of adequately maintained earth canals with loam soils should be 70% [38]. This means that the maintenance at Doho main canal is not adequate enough and hence there is a need for routine maintenance.

Table 7. Efficiency Indicator

	Head		Middle		Tail		
Month	LC-1A_1	LC-1A_2	LC-4A	LC-4B	LC-2A_1	LC-2A_2	Spatial P_F
Feb	0.60	0.29	1.00	1.00	1.00	1.00	0.81
Mar	0.43	0.50	1.00	1.00	1.00	1.00	0.82
Apr	0.56	0.74	0.16	1.00	1.00	1.00	0.74
Temporal P_F	0.53	0.51	0.72	1.00	1.00	1.00	
Average P_F	0.52		0.86		1.00		0.79

Table 8. Conveyance Efficiency of Doho main canal

Location	Parameter	Feb	Mar	Apr	E_c
Headworks	$V_m(m^3/s)$	1.38	1.33	1.56	
Kapisa gates	$Q_0(m^3/s)$	0.92	0.95	1.02	
		67%	71%	65%	68%

4.1.7 Delivery Performance Ratio

The value of delivery performance ratio, DPR at the main, southern and northern canals of Doho Rice Irrigation Scheme ranges from 0.45 to 1.05 as presented in Table 9. In the main Canal, DPR is low due to fluctuation in the quantity of water abstracted at the intake since it varies with water availability in River Manafwa. Another reason is the reduction in volume as a result of siltation and deposition of planktons and water weeds along the canal. This reduces the canal carrying capacity leading to a low delivery performance ratio. The DPR in the southern canal in March is 1.05 meaning more water was diverted to the southern canal at the Kapisa gates in March. The overall DPR of the conveyance system was 0.78

5. Conclusion

In this study, an evaluation was made of the water delivery performance on the main and lateral canals. At the main canal, the water conveyance efficiency parameter was used while at the lateral canals the indicators of adequacy, dependability, equity, and efficiency were used. These indicators were calculated from the amounts of irrigation water which was supplied and the crop water requirements for rice for the three-month period of February, March and April 2019.

The average water delivery performance to the lateral canals within the scheme is fair in terms of adequacy 0.84(fair), dependability 0.07(good), equity 0.26 (poor), and efficiency indicator 0.79(fair). However, the Equity ratio of head and tail shows that there are inequalities in water distribution. The conveyance efficiency in the main canal was found to be 68 %. It is important to make certain management structural changes in order to improve performance at the tail end. In this regard, greater importance must be placed on repair and maintenance work so as to reduce water losses during conveyance. There is need to modernize the irrigation scheme to improve irrigation efficiency, water delivery services to all users, and enhance resource utilization including cost-effectiveness of operation and management. Water allocation plans and schedules need to be drafted and strictly adhered to promote equity of water distribution among the irrigation blocks.

Table 9.Delivery Performance Ratio

Canal	Month	Q_{act}	Q_{des}	DPR	Average
Main	Feb	1.38	3.6	0.38	
	Mar	1.330	3.600	0.37	0.45
	Apr	2.100	3.600	0.58	
Southern canal	Feb	0.540	0.700	0.77	
	Mar	0.680	0.700	0.97	1.05
	Apr	0.980	0.700	1.40	
Northern canal	Feb	0.480	0.500	0.96	
	Mar	0.212	0.500	0.42	0.86
	Apr	0.600	0.500	1.20	
					0.78

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