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Performance assessment of water delivery to a smallholder irrigation scheme in Zimbabwe: Nyanyadzi case study

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The potential benefits from smallholder irrigation schemes are rarely realised due to unsatisfactory performance of their water delivery systems. A study was conducted to quantify and evaluate water delivery performance indicators of adequacy (A_d), equity (E_q) and dependability (D_p) in three sub-blocks of Nyanyadzi smallholder irrigation scheme using water requirement analysis and a questionnaire survey. The water delivery performance evaluation was carried out between October 1996 and January 1997 for two maize crops under supplementary irrigation and for two consecutive irrigation cycles. Water supply adequacy (ratio of supply to demand) in the first cycle was good (A_d>1.21) and became marginally good (0.96 to 1.01) and poor (A_d<0.74) in the second cycle. Adequacy of water supply to the sub-blocks decreased with increase in water requirement (r=-0.87). Water distribution equity (a spatial indicator) was poor in both cycles and E_q values ranged from 0.33 to 1.14. The management capability to distribute water fairly decreased with increase in irrigation requirement (r=0.67). The dependability of water supply was poor (D_p>0.2) at 73 percent of the 42 locations studied in the canal network. Results of a questionnaire survey revealed that the performance of the water delivery system was consistently low. Poor adequacy, equity and reliability of water supply were perceived respectively by 57 percent, 53 percent and 77 percent of the 30 irrigators interviewed. It was concluded that management input should be intensified in head block A to ensure better water deliveries to the scheme.

Keywords: Performance indicators, delivery system, irrigation management.

Introduction

Smallholder irrigation is viewed as an answer to Africa's food crisis, since there is untapped irrigation potential in many countries. In Zimbabwe the total irrigation potential is about 600 000 ha and only 150 000 ha are irrigated of which only 5 percent is under smallholder irrigation (FAO, 1987; Manzungu and Van der Zaag, 1996). This irrigation sector offers an opportunity to improve productivity of peasant agriculture and alleviate pressure on land resources in rural areas (Jayne and Rukuni, 1994; Manzungu and Van der Zaag, 1996).

The performance of smallholder irrigation is constrained by, among other factors, poor water delivery systems. Adequacy of water supply, equity of water distribution and dependability of water supply constitute the main performance indicators of water delivery systems. These indicators are interrelated, though treated separately and their assessment fully describes irrigation performance in respect of water delivery (Murray-Rust and Snellen, 1993; Bos, *et al.*, 1994).

Adequacy is a measure of the degree to which water deliveries meet soil-plant-water requirements. It can be managed by matching cropping plans and calendars with estimated seasonal water availability before the start of the season or by adjusting operational targets in response to actual demand during the season (Sagardoy, *et al.*, 1986; Murray-Rust and Snellen, 1993). Supply adequacy is influenced by water availability at the source, delivery capacity and the operational situation of the scheme (projected water demand in relation to supply) and type of division system.

Equity of water distribution is an expression of the share for each individual or considered fair by all system members. 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. The water allocation process principally affects the equity performance indicator (Murray-Rust and Snellen, 1993). Inequitable water distribution in Zimbabwean smallholder schemes has resulted in the head tail-end problem and in extreme situations, irrigators vandalise water control structures (Pazvakavambwa, 1984; Manzungu, 1996) in a bid to improve water availability in their holdings.

Dependability of water supply is an expression of confidence in the irrigation system to deliver water as promised and is indicative of the timeliness and adequacy of promised deliveries (Rey, *et al.*, 1993; Makadho, 1994). This indicator was described by Murray-Rust and Snellen (1993) as the most subjective and deals with the quality of the irrigation service. Water supply dependability is influenced by the mode of water delivery and type of distribution system. Depending on the mode of water delivery, variability and predictability of water supply are important aspects of dependability on water delivery system. Variability of water supply is important under continuous flow conditions and predictability becomes important under intermittent or rotational flow conditions.

Improvements of the performance of the irrigation water delivery systems have the potential of increasing the irrigated area, minimizing conflicts among users and increasing crop production at farm level. There is need to carry out research on the performance evaluation of water delivery to smallholder schemes. In the past, performance evaluation of such schemes was mostly agro-economic using productivity, profitability and financial viability as performance indicators (Rukuni, 1988; Meinzen-Dick, Sullins and Makombe, 1994). However, research work on performance evaluation of a delivery system was limited to questionnaire survey work at scheme scale (Meinzen-Dick, Makombe and Makadho, 1994). Quantitative performance evaluation was also limited except for work done by Makadho (1993) and Makadho (1994) based on water requirement analysis at the scheme level. The study reported herein was driven by the paucity of data and information on water delivery performance and the implications on water management in smallholder schemes. The objectives of this study were to:

1. Assess adequacy, dependability and equity of water distribution in sub-blocks A1, An and Am of Nyanyadzi smallholder irrigation scheme in southeast Zimbabwe.
2. Relate adequacy, equity and dependability of water supply to management of the scheme.

Materials and Methods

Description of study site and water delivery system

Nyanyadzi smallholder irrigation scheme is located about 100 kms south of Mutare in Manicaland province, Zimbabwe. The scheme benefits 509 plot holders in four blocks (A, B, C and D) covering 414 ha. Blocks A and C are at the head reaches of the Odzi and Nyanyadzi river water sources (Figure 1). The study was conducted in sub-blocks A1 (6.8 ha), An (43.7 ha) and Am (64.4 ha), which were equipped with rated water measurement devices (Figure 1) and irrigated during the same cycle.

The scheme falls in agro-ecological zone V (Vincent and Thomas, 1960), where rainfall comes in summer (October to March). The mean (30 years) annual rainfall is 490 mm and annual evaporation (class A) is 1 900 mm (DMS, 1981). The inadequate rainfall received adversely affects rainfed agriculture. The main summer crops (grown under supplementary irrigation) are maize, cotton and groundnuts.

The irrigation scheme has an integrated organisational structure (Sagardoy, *et al.*, 1986) and run by AREX with assistance from farmer elected irrigation management committees (IMCs) and water bailiffs (Bolding, 1996). AREX controls irrigation water flows from the Odzi and Nyanyadzi river sources and the night storage dam (NSD). The block IMCs draft by-laws for the smooth operation of the scheme. The water bailiffs notify irrigators of their turn to abstract water and regulate flows to them.

Most of the irrigation waters for Blocks A, B and D is pumped from the Odzi River and pipe conveyed to the primary distribution box, situated on a hill near the scheme. The water then gravitates into open channels directly or via the NSD to various sections of A, B and D blocks. It is then distributed by masonry lined trapezoidal canals, on a rotational basis between and within blocks.

Evaluation of water delivery to sub-blocks A1, An and Am of Nyanyadzi scheme

Questionnaire survey

A farmer's perception on quality of water delivery to block A was assessed using a close-ended questionnaire survey. The questionnaire was used for perception

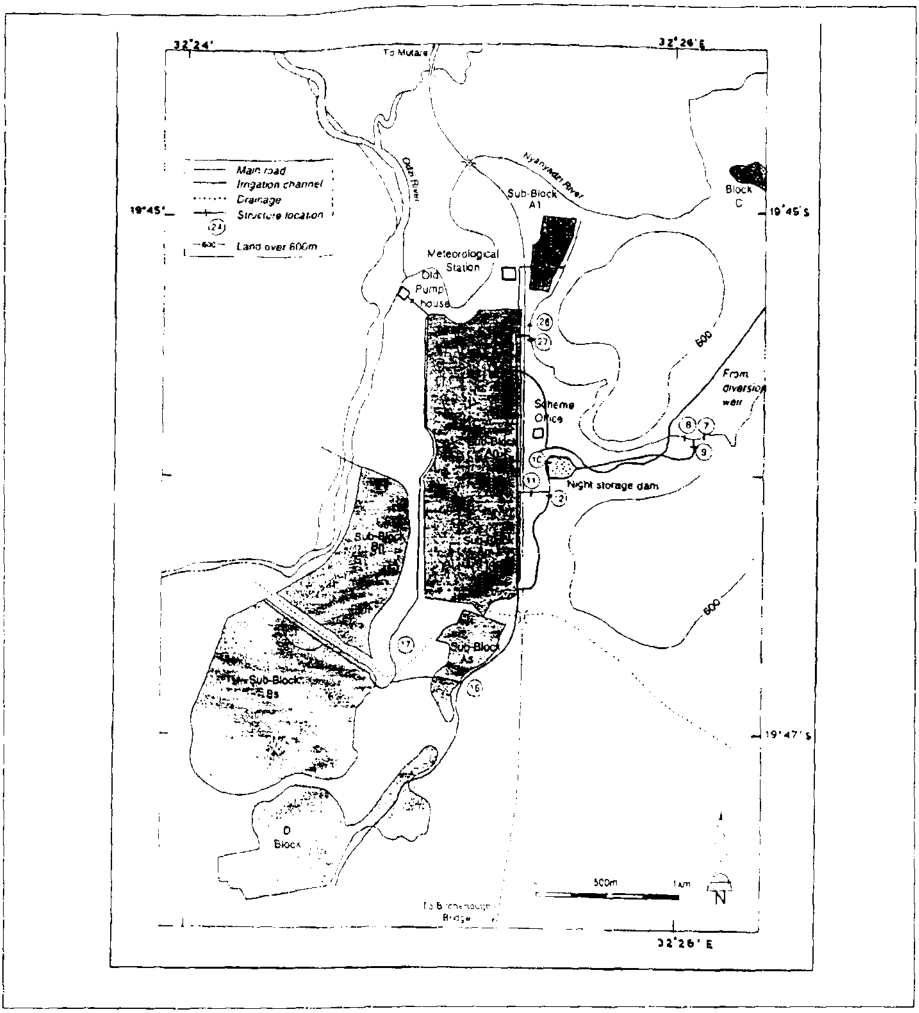

Figure 1: Layout of Nyanyadzi smallholder irrigation scheme, south eastern Zimbabwe.

analysis of the water delivery system. Guidelines by Meinzen-Dick, Makombe and Makadho (1994) for Zimbabwean smallholder irrigation schemes were adopted for sampling of informants. Thirty out of 122 plot holders were randomly selected from the plot register for the interviews. Interviews were conducted between 15 November 1996 and 20 December 1996. The informants were asked to give an adjective performance class (good, fair or poor) of the water delivery performance indicators (adequacy of water supply, dependability and equity of water distribution).

Quantitative performance evaluation

This evaluation entailed determination of the adequacy, dependability and equity performance indicators basing on water supplied to the sub-blocks and water demanded over two irrigation cycles.

(a) Irrigation water supply

Two methods were used for measuring irrigation water supply. One was through the use of a current meter, and the other was by way of calibrated hydraulic structures.

Discharge measurements using the Velocity-Area method

This involved velocity measurement with a current meter and flow area computations from the flow geometry.

A Valeport "Braystroke" BFM002 miniature current flow meter was used to measure flow velocities in lined canals of known geometry. The measurements were taken at canal off-takes and just after abstraction points along distribution or feeder canals. Three velocity measurements were made at every point. The flow velocity was derived from the rotation speed (**n**) measured by the control unit. The mean flow velocity was then computed from rate equations depending on the average rotation speed (Table 1). Flow area was derived from flow depths and canal geometry at each position. The flow area in the trapezoidal canals was computed as:

$$A = d(w + z^{-1}d) \qquad (2.1)$$

Where: A = flow area (m^2); d = flow depth (m); w = bottom width of canal (m) and z = side slope of canal (m/m)

Discharges were calculated by multiplying the mean velocities and computed flow areas. The actual volumes (V_a) delivered to the fields below the measuring positions were calculated from the average supply duration (10 hrs) obtained from the pump operator and computed discharges.

Table 1: Rate equations of a BFM002 current meter.

Rotation speed, n (revs/sec)		Flow speed, V (m/s)
Minimum	Maximum	
0.26	0.97	1. V = 0.034 + 0.0991**n**
0.97	4.71	2. V = 0.023 + 0.1105**n**
4.71	27.86	3. V = 0.039 + 0.1071**n**

Discharge measurement using structures

The measurement structures used were: (i) rectangular thin plate weir (Structure 11 in Figure 1), which monitored flows to sub-blocks Am and Bn and (ii) control gates (Structures 26 and 27 in Figure 1), which monitored flows to sub-blocks A1 and An.

The structures were rated and equipped with graduated gauge boards. Rating equations were applied to convert the stage/gauge to discharges for the three structures according to Lewis (1984). At each structure, measurements were taken in the morning and afternoon, to obtain a mean discharge value for the day.

The total volumes of water supplied (V_a) to the fields below the structures were computed as the product of the average daily supply duration (10 hrs) and the calculated discharges through the structures.

Irrigation water demand

The irrigation water demand was computed from secondary data (planting dates, cropped area and rainfall), which was obtained from the scheme office. Daily evaporation data was obtained from Agricultural and Rural Development Authority Middle Save Meteorological station (70 km away) with almost the same climatic characteristics. Daily and monthly reference crop evapotranspiration (Et_o) were estimated by the Pan method for the months of October to December 1996 inclusive. The crop water requirements (Et_c) were then computed from the Et_o and the crop factor (K_c) values for the maize crops planted on 15 October 1996 and 7 November 1996 (FAO, 1977; FAO, 1998).

The irrigation water requirements (IR) for the two maize crops were computed by adding the daily Et_c between consecutive irrigation events and subtracting effective rainfall (calculated using the dependable rainfall method) (FAO, 1974).

The volume of water required (V_r) at each measuring position was the product of IR and the cropped area served below that position (assuming an irrigation efficiency of 60 percent (Bos, 1990).

Water delivery performance indicators

(i) Adequacy of water supply, Ad

The adequacy values at the measuring position were computed according to Reddy (1986) as:

$$A_d = V_a / V_r \qquad (2.2)$$

Where: A_d=adequacy of water supply; V_a=actual delivered volume (total supply); and V_r=required volume (total demand). The weekly relative water supply (RWS, an adequacy parameter which considers all forms of water supply) in sub-blocks A1, An and Am was closely monitored from planting (on 16 October 1996) of first maize crop to 31 December 1996 (Levine, 1982).

(ii) Equity of water distribution, E_q

Equity was computed as the coefficient of variation of the adequacy values between different locations (Molden and Gates, 1990; Chancellor and Hide, 1996) as:

$$E_q = C_{vl} (A_d) \qquad (2.3)$$

Where: C_{vl} =coefficient of variation of the adequacy values between different locations and A_d is as previously defined.

(iii) Dependability of water supply, Dp

Dependability (D_p) of water supply was computed as the coefficient of variation of the adequacy values for individual locations over different time periods (Molden and Gates, 1990; Chancellor and Hide, 1996) as:

$$D_p = C_{vt}(A_d) \quad (2.4)$$

Where: C_{vt} = coefficient of variation of the adequacy values on different dates for specific locations and A_d is as defined in Equation 2.2.

Classification of performance indicators

The three performance indicators (A_d, E_q & D_p) were interpreted and adjectively classified using ranges developed by Molden and Gates (1990)(Table 2). The ranges of performance indicators have management implications. An Ad value of 1.0 is desirable; a value less than 1.0 indicates water deficiency and a value greater than 1.0 indicates that an amount of water is wasted (Table 2). Excess water results in inequity, water logging and salinity problems. An equity value of zero (E_q=0) indicates perfect equity and E_q values close to 1.0, indicate serious inequity of water distribution (Molden and Gates, 1990). D_p values were interpreted in a similar manner as Eq values.

Regression analysis

A simple linear regression was performed to establish the relationships between weighted mean irrigation requirement (IR) (computed from the respective IRs and area proportion of the two maize crops) and adequacy or equity of water supply on the different irrigation dates. Management would use the information from this analysis to improve water delivery in view of different demand and supply situations and achievement of performance indicators.

Table 2: Assessment ranges of performance indicators (Molden and Gates, 1990).

Indicator	Good	Fair	Poor
Adequacy, Ad	>0.9	0.8-0.9	<0.8
Equity, Eq	<0.1	0.1-0.25	>0.25
Dependability, Dp	<0.1	0.1-0.2	>0.2

Results

Adequacy of water supply

The water requirement analytical results (Table 3) show that the A sub-blocks received excess supplies of irrigation water (1.2<Ad<2.8) during the first irrigation cycle (5 December 1996 to 8 December 1996). The water demand (IR) ranged from 16 to 28 mm. The adequacy of water supply in the first cycle was classified as good (Molden and Gates, 1990; Table 3).

In the second irrigation cycle (17 December 1996 to 20 December 1996), the water supply adequacy fell drastically, since on only two out of four days was adequacy marginally good and the rest recorded poor adequacy (Table 3). The demand for irrigation water was higher in this cycle and IR ranged from 47 to 55 mm.

Table 3: Water delivery indicators (adequacy and equity) and mean Irrigation Requirement in sub-blocks A1, An and Am on the irrigation days for Nyanyadzi irrigation scheme.

Irrigation date	Irrigation interval (days)	Mean IR (mm)	Performance indicator Mean A_d	E_q
5/12/96	-	16.3	2.80g	0.45p
6/12/96	-	19.6	1.99g	0.48p
7/12/96	-	23.4	1.59g	0.76p
8/12/96	-	27.6	1.21g	0.33p
17/12/96	12	47.8	0.74p	0.48p
18/12/96	12	50.1	0.96g	1.14p
19/12/96	12	52.7	0.64p	0.91p
20/12/96	12	54.7	1.01g	0.91p

NB: g=good; f=fair; p=poor, A_d=adequacy; E_q=equity.

Trends of weekly water supply/demand to the block are depicted in Figure 2. Figure 3 similarly depicts the RWS of the sub-blocks between 16 October 96 and 31 October 1996. Excess (RWS>>1) water was supplied to the sub-blocks in weeks 4, 5, 6, 8, and 11, whilst the other weeks had inadequate (RWS<1) water from both rainfall and irrigation (Figure 3).

The ability of management to supply adequate water to the sub-blocks decreased with an increase in irrigation requirement. Figure 4 shows a negative correlation (r = -0.87) between mean A_d values attained and Irrigation requirements on the irrigation days.

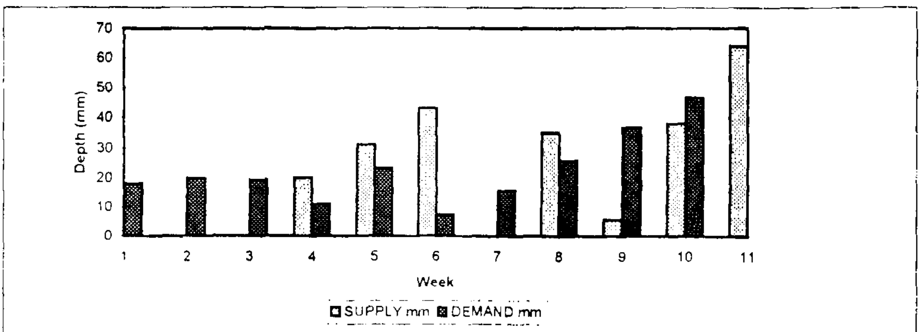

Figure 2: Water supply and demand to block A sub-blocks.

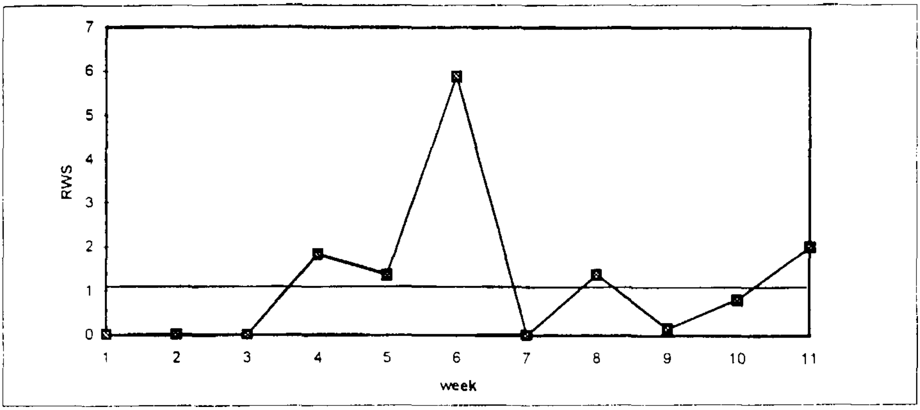

Figure 3: Weekly variation of the relative water supply (RWS) in block A sub-blocks.

Equity of water distribution

The analytical results show that equity of water distribution during the two cycles was poor (Table 3) as the computed E_q values were very high (0.33<Eq>1.14). However, poorest water distribution equity was attained in the second cycle (when the Eq parameter reached a high value of 1.14).

The management capability to distribute water fairly decreased with increase in irrigation requirement. The E_q values computed were positively correlated (r = 0.67) to irrigation requirement (Figure 5), indicating that as demand increased the system distributed water less equitably among the irrigators. This trend confirms the findings of Keller (1986) and Sampath (1988).

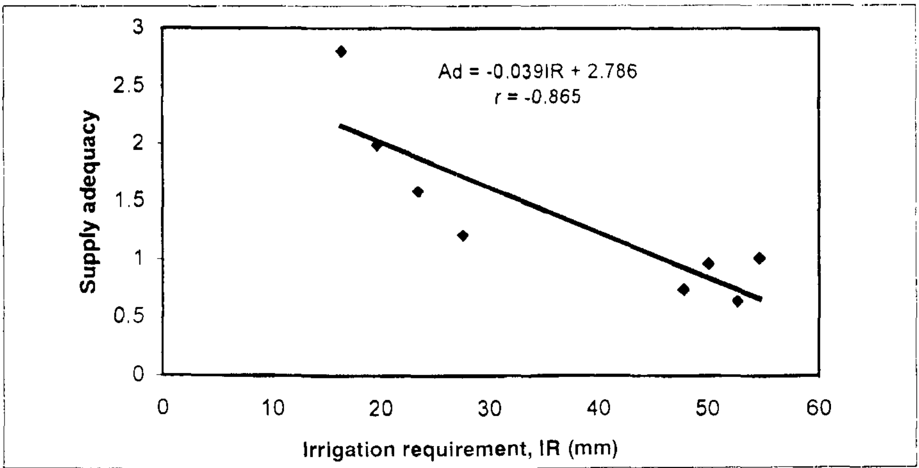

Figure 4: Supply adequacy as a function of irrigation requirement.

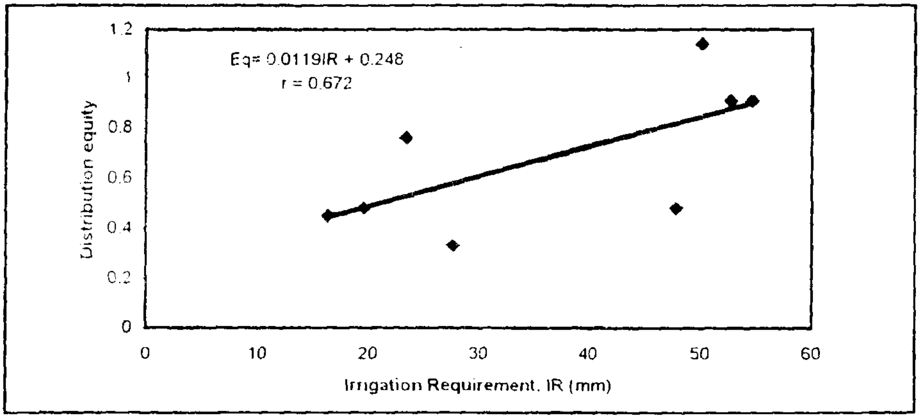

Figure 5: Distribution equity as a function of irrigation requirement.

Dependability of water supply

Water supply dependability was quantified at specific locations in the distribution network for different irrigation days. Out of 42 locations assessed during the study, only four had good (Dp<0.1), six fair (0.1<Dp<0.2) and the rest (76 percent) poor (Dp>0.2) dependability (Table 4). All the locations with good dependability were on feeder canals, implying that the delivery system performed better at this hierarchical level of the distribution network.

Table 4: Dependability of water supply in sub-blocks A1, An and Am at different locations in the canal network: Nyanyadzi scheme.

Location	Locations with dependability class (Dp range)		
	Good (Dp<0.1)	Fair (0.1<Dp<0.2)	Poor (Dp>0.2)
Feeder canals	4	3	22
Distribution canals	0	3	9
Weir (Structure 11)			1

N.B: D_p calculations were based on A_d values at canal off-takes or measurement structure.

Farmer assertion on performance of water delivery system

Farmers interviewed in the sub-blocks perceived that the performance of the delivery system with respect to adequacy, equity and dependability of water supply was consistently poor and followed the order: dependability<adequacy<equity. For example, about 77 percent of the 30 irrigators interviewed in the sub-blocks asserted poor dependability; 57 percent poor adequacy and about 53 percent poor equitable distribution of irrigation water by the management (Table 5). Conversely good equity, good adequacy and good dependability were perceived respectively by: 37 percent; 27 percent and 7 percent of the irrigators interviewed (Table 5).

Table 5: Farmer perception on the performance of water delivery system in sub-blocks A1, An and Am of Nyanyadzi irrigation scheme.

Performance indicator Type	Adjective class	Farmer response (n=30) Frequency	%
Adequacy	Good	8	26.7
	Fair	5	16.7
	Poor	17	56.7
Dependability	Good	2	6.7
	Fair	5	16.7
	Poor	23	76.7
Equity	Good	11	36.7
	Fair	3	10.0
	Poor	16	53.3

Discussion

The performance of the water delivery system with regards to adequacy was poor. The delivery system supplied more water than was required (when Ad or RWS were greater than 1.0) in the A sub-blocks resulting in water wastage, for example in week 8. The best delivery performance was achieved in the 10th week, when the amount of irrigation water supplied to the sub-blocks complemented the supply from rainfall to achieve an RWS value close to 1.0 (Makadho, 1994). At other times, e.g., weeks 2, 3, 7 and 9 there were water deficiencies resulting in wilting of crops when the requirements were not met. The water deficit in the sub-blocks was likely to result in low economic efficiencies at the end of the growing season because the RWS values were far much less than the 0.8 threshold value for the maize crop as explained by Keller (1986). Even lower economic efficiencies were expected from the first maize crop which was water stressed during the sensitive silking stage in the 9th week.

The poor performance with respect to adequacy was attributable to firstly; a high irrigation water demand especially in the second cycle when the IR ranged from 47 to 55 mm and water inadequacy was inevitable. Secondly, a 3 day pump breakdown at Odzi River extended the irrigation interval to 12 days (between the rotation turns) instead of the recommended 9 days (Table 3; Bolding, 1996). The delivery system failed to meet the water requirements of the irrigated maize crops. The adequacy of water supply to these sub-blocks is, therefore, a function of effective rainfall, irrigation requirement and efficiency of the delivery infrastructure (e.g. pumps). The scheme management could use IR as a guide to supplying adequate irrigation water to the sub-blocks.

The water supply between the sub-blocks was on a rotational basis, depending on the command area. Sub-blocks A1 and An, with a combined command area of about 60 ha had an irrigation cycle of 2 days and an interval of 9 days. Sub-block Am (64 ha) had identical irrigation timing (Bolding, 1996). The equity of water distribution was in a way inherent in this rotation schedule.

Poor equity in the sub-blocks was a direct consequent of inadequate management of water delivery in the sub-blocks and there are several reasons for this. Firstly, there was lack of information on precise planting dates and thus on areas requiring water (i.e. IR). This was due to the violation of the one acre (0.4 ha) rule by the farmers who did not plant an acre (0.4 ha) each of the first maize crop and difficult to control the cropping of land at the onset of the summer rains (Marwa, pers. comm). The magnitude of IR in block A also affected the performance of the water delivery system with respect to equity.

Secondly, extension of irrigation intervals resulted in water distribution problems (social tension or conflicts) when the water came next. In this case study, pump breakdowns extended the irrigation interval by 3 days for the second cycle and irrigators panicked due to delays in water allocation and head-enders over abstracted water to irrigate their wilting crops. This affected the flow consistence in the canals and equity of water distribution among the users. Water supply adequacy was also lower (mean RWS=0.825) and more social conflicts were reported unlike in the first cycle. It was consequently more difficult to distribute the supplies equitably in the second cycle as many (53 percent) farmers in the sub-blocks perceived poor equity (Table 5). This required a strong management system to distribute water equitably to all the land within the sub-blocks, especially when low values of RWS were recorded (Keller, 1986).

The third reason is that, water bailiffs with the mandate of controlling and distributing irrigation water in the sub-blocks were not executing their duties as required. They were not operating water control structures properly to ensure equitable water distribution. For example, it was reported that one hole adjustment (24 mm) of a standard lift gate was enough to supply water to eight siphons (Manzungu, 1999; Sithole, pers. comm.). The actual volumes released from such adjustments were not known and some irrigators were reported to be using more siphons than recommended. Furthermore, the bailiffs were plot holders in the scheme and impartiality was not guaranteed.

The water users in the sub-blocks lacked confidence in the irrigation system to deliver water as promised or expected. According to the irrigators, performance of the delivery system with respect to dependability was poorest (Table 5). Because the irrigators believed that the delivery system was always undependable, they hoarded water resulting in supply inadequacy at lower reaches, which in turn caused inequitable distribution. Hence a vicious circle of these performance indicators occurred (Replogle, 1986).

Conclusions and Recommendations

The results from this study indicate that the A1, An and Am sub-blocks of Nyanyadzi scheme are not exempted from poor performance of the water delivery system, despite their location on head reach of the conveyance system. Worse performances of the water delivery system could, therefore, be expected in lower reach blocks (B and D). The irrigation water supplied to the sub-blocks did not accurately complement the natural rainfall to meet the water requirements. The performance of the delivery system is not expected to be better in the winter season (when crops are grown solely under irrigation). Performance assessment of the delivery system should therefore be carried out all year round and at other reaches (blocks B and D), so that the management would be equipped with better information on how to improve water delivery to the entire scheme.

Farmers should be encouraged to furnish the management with their intended seasonal cropping programmes for improved performance of water delivery systems. The programmes would be well timed to match peak demand with peak supply from rainfall.

The water distribution equity depended on the effectiveness of water bailiffs in executing their duties and the behaviour of irrigators in the canal network. The bailiffs should further be trained on technical issues related to water distribution. The irrigators on the other hand should be instituted on yield response to water to minimize water wastages. In addition, adoption of water conservation techniques (mulching, ridging etc) and practices (e.g. weeding) by irrigators would improve water supply adequacy.

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