

Evaluation of the Effectiveness of Proportioning Water Division Weirs in Herman Canal Farmer-managed Irrigation Scheme, Usangu Plains, Tanzania

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Abstract

In Tanzania, irrigated land is less than 5% of the cultivated area much of which being under traditional irrigation systems. Unfortunately, water in agriculture is indeed too often misused and mismanaged due to lack of know-how of people and weakness of institutions. This study therefore aimed at evaluating a simple approach for equitable distribution of irrigation water using proportioning water division weirs with a view to improving system performance in general. Five proportioning water division weirs were constructed along the main canal to deliver water to eight branch canals of a typical farmer-managed irrigation scheme. Flows to each of the branch canals were measured using calibrated staff gauges. The discharge data along with climatic and crop data were used in the computation of various irrigation performance indicators. Results showed productivity to be rather low, which was attributed to low-level use of inputs including sub-optimal cropping intensities. The relatively low values of output per unit irrigation supply suggest that the efficiency with which water was being used in the scheme is rather low. Overall, equity of water supply ($P_E = 0.14$; $AU = 0.52$) appeared to be fair, which was an improvement over past experiences before installation of the proportioning weirs. However, in spite of improvements in water distribution, farmers still lacked basic understanding of irrigation scheduling which led to some areas being over-irrigated while others faced water shortage.

Key Words: Proportioning weirs, performance indicators, farmer-managed irrigation

Introduction

Maximizing production on a sustainable basis and satisfying the diverse needs of society while at the same time trying to conserve a fragile ecosystem and genetic heritage is indeed a challenging undertaking. Nevertheless, productivity in agriculture must grow rapidly to

keep food supply in balance with the ever-increasing demand. It is estimated that in the developing countries, a large increase in grain production of around 150% must materialize to meet the projected food demand in the year 2025 (Yudelman, 1993). Part of the demand can be met by expanding the area under rainfed cultivation but prospects for this to happen are rather

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poor due to a number of reasons, the most important being unreliable rainfall in much of the tropics. Recent studies have shown rather disturbing trends of rainfall characteristics in parts of Tanzania (Kingamkono *et al.*, 1999) including the Usangu Plains. Hence, the benefits from additional inputs on rainfed land are often low and as a consequence, risk-averse farmers are reluctant to make substantial investments on the land.

This means that much of the increase in agricultural production has to come from the expansion of the irrigated area or through increased productivity per unit area of irrigated land. In real terms, the current contribution of world food supplies from irrigated land, which currently stands at around one third, will need to increase to 50% in order to meet demand projections for the year 2025 (Yudelman, 1993).

The total potential area for irrigation development in Tanzania is estimated to be 29.4 million hectares, with varying potential levels. Of this total area, which includes over 250,000 hectares already under agricultural water management, 2.3 million hectares are of high potential, 4.8 million hectares are of medium potential and 22.3 hectares are of low potential (URT, 2002). Eighty percent of the irrigated area is under traditional schemes utilising surface irrigation methods with low-level water use efficiencies. The traditional irrigation systems consist of numerous channels or ditches, which convey water from rivers, streams and springs, employing simple and traditional methods (Omari, 1997). These systems have

been built by local communities with little or no government support. However a major problem faced by traditional irrigation schemes is that of inequity in water allocation caused by poor hydraulic performance and poor water management (Chambers, 1988). Typical causes of poor hydraulic performance of canals are wear and tear, lack of maintenance, illegal intervention, and inappropriate or improper operation of water control structures. Inequity in traditional irrigation schemes may also arise from deliberate action by unruly farmers to poach water or from poor design of water distribution structures. Therefore water distribution inequity among farmers is a function of both technical and social factors (Ambler, 1995).

Studies done in irrigation schemes elsewhere show that inequitable water supply has a clear impact on production and ability to meet costs of operation and maintenance (Molle *et al.*, 1998). Farmers in some Asian countries for example have traditionally developed mechanisms to divide the total water available to the system into shares (Ambler, 1995) to ensure equity. To do this, farmers often use small structures to act as proportioning water-division devices. Such devices (also referred to as proportioning weirs) are simple water control structures placed in the canal perpendicular to the direction of flow although in some cases they may be placed along or at an angle to the direction of flow depending on the topography. A proportioning water-division device divides water in a canal into two or more parts that correspond to the water shares due to each farmer

or farmer group served by branching canals (Parajuli, 1995). The width of the slots in the structure is determined by the agreed proportion of the water to be delivered to the respective areas. Other attributes of the proportioning weir are that it does not contain any moving parts, except perhaps when a flush board is fitted for on-off operation; it is cheaper to construct and maintain; it works continuously and so reduces the need for resource mobilization to pay an operator (Ambler, 1995).

In a bid to achieve self-sufficiency and food security, the Government of Tanzania with development partners including the World Bank have since the early 1990s undertaken steps towards the improvement of all traditional and farmer-managed irrigation schemes (Omari, 1997). However these initiatives have not fully addressed the issue of equitable water distribution including serious conflicts, which exist between water user groups. Control over scarce water resources is the key to sustainable local food production in arid and semi-arid regions. The ability to regulate water distribution is a fundamental requirement of all irrigation systems and the extent to which it is achieved determines performance of the system.

In order to obtain information on the extent to which irrigation systems are achieving the required performance, a set of performance indicators has to be agreed upon. In research, performance indicators make it possible to compare the projects studied. Without agreed standards of performance, there is no basis for saying whether one system is

performing better or worse than another (Abernethy, 1986). The International Water Management Institute (IWMI, 2000) describes performance indicators as a tool for measuring the relative performance of irrigation systems or tracking the performance of an individual irrigation system. Such indicators are also needed for the proper evaluation of policy alternatives. Performance indicators range from water distribution to agricultural, economic, social, and environmental aspects (Bos *et al.*, 1994). In the light of current trends in water availability, the issue of improvements in irrigation efficiencies will undoubtedly take centre stage if there is to be enough water for all on a sustainable basis. Based on experiences elsewhere (Ambler, 1995), it would seem that use of water-proportioning devices is more likely to result in a high degree of equity in distribution and acceptability among farmers. Such devices are not common in many of the traditional irrigation schemes in Tanzania where control of water is still rudimentary. This study was thus aimed at evaluating the performance of a typical farmer-managed irrigation system in the country after the introduction of proportional water distribution technology so as to validate the above hypothesis.

Materials and Methods

Study area

The study was conducted at Herman canal irrigation scheme located within the Chimala sub-catchment of the Great Ruaha River basin. The sub-catchment also forms part of the

Usangu catchment within the Rufiji basin. A lot of irrigation activities take place within the Rufiji basin, which also supports three major hydropower stations. The Usangu Plains do experience water shortage problems during the dry season while at the same time exhibiting a degree of anthropogenic pressure.

The scheme is within the Mkoji sub-catchment which lies between latitudes 8°77'S and 9°09'S, longitudes 33°48'E and 34°06'E and at an altitude of 1000 m to 1150 m above sea level (Hazelwood and Livingstone, 1982). The rainfall in the Usangu Plains is unimodal and erratic, and is concentrated between December to May. Annual rainfall is highly variable with an annual mean of 900 mm.

Temperatures are highest in October/November and lowest in June/July whereas, the minimum and maximum daily temperature vary from 12-19°C and 28-32°C, respectively (Hazelwood and Livingstone, 1982).

The soils of the Usangu Plains in general consist of fertile alluvial clays, clay loams, loams and alluvial sandy clays that can extend to depths of more than 3m (Hazelwood and Livingstone, 1982).

Installation of proportioning weirs

The canal network is typical of supply driven systems. Five proportioning weirs (Fig. 1) were constructed along the main canal to deliver water to seven branch canals serving a total area of approximately 200 ha. Burnt clay bricks, stones, concrete and mortar were used in the construction of the structures. The location of the

structures along the canal is critical due to the energy loss associated with small openings typical of such structures. To compensate for the unequal energy of water, the structures were installed in a straight stretch of canal and provided with a stilling pond.

The basic concept of proportional distribution is that the irrigation water supply is proportionally distributed at every off-take. This means, water flowing in parent and off-taking canals is equally affected by variation of water level in the parent canal. In order to judge the proportionality of the structures, the hydraulic sensitivity is to be considered.

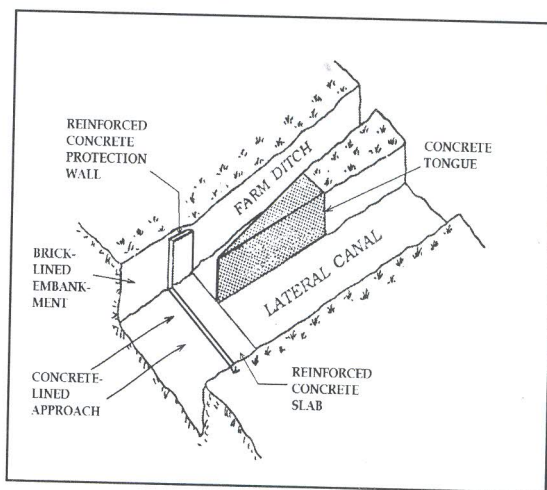


Figure 1: Sketch of a proportioning weir (After: Viernes (1986) with slight modifications)

Climatic data collection and analysis
 Daily maximum and minimum temperatures, humidity, sunshine hours, wind speed, and rainfall data were collected from Kapunga weather station about 26 km from the study area. These data were used to estimate reference crop evapotranspiration (ET_o) by the Penman-Monteith method

(Allen *et al.*, 1998). Crop evapotranspiration (ETc) and net irrigation requirements for various crops grown during the season were derived using appropriate crop coefficients (k_c) (Doorenbos and Pruitt, 1977).

Discharge data collection

Flows to each of the branch canals along the Herman canal, which abstracts water from Chimala River were measured using calibrated staff gauges. The daily water level elevation (stage) for each branch canal were read and recorded for a cropping period of 153 consecutive days. The discharge data was used in the computation of various irrigation performance indicators.

$$\text{Output per cropped area} = \frac{SGVP}{\text{Irrigated cropped area}} \dots\dots (1)$$

$$\text{Output per unit command} = \frac{SGVP}{\text{Command area}} \dots\dots (2)$$

$$\text{Output per unit water supply} = \frac{SGVP}{\text{Diverted irrigation supply}} \dots\dots (3)$$

$$\text{Output per unit water consumed} = \frac{SGVP}{\text{Volume water consumed by ET}} \dots\dots (4)$$

Where:

SGVP is the Standard Gross Value of Production, which makes it possible to compare the performance of systems, no matter where they are or what kind of crop is being grown. It is expressed as:

$$SGVP = \left(\sum_{\text{crops}} A_i Y_i \frac{P_i}{P_b} \right) P_{\text{world}} \dots\dots(5)$$

Determination of irrigation performance indicators

The International Water Management Institute (IWMI) performance indicators were adopted for this study for the reason that they could be applied within the limited time, financial, and information resources available to the typical managers or water users associations as advocated by Değirmenci *et al.*, (2003).

(a) Indicators of irrigated agriculture output

The following indicators of productivity of land and water as described by Sakthivadivel *et al.*, (1999) were used:

Where: A_i is the area cropped with crop i , Y_i is the yield of crop i , P_i is the local price of crop i , P_b is the local price of the base crop (the predominant locally-grown, internationally-traded crop), and P_{world} is the value of the base crop traded at the world prices.

The data regarding cultivated area, yields and prices during the season were obtained from existing records.

Beans (*Phaseolus vulgaris*) was chosen as the test crop due to the relatively high cropping intensity in the study area and its importance both at the local and international markets.

(b) Indicators of water supply

These indicators have been referred to as performance measures (Molden and Gates, 1990) and can be incorporated in an irrigation system-monitoring programme to provide a framework for assessing system improvement alternatives. The following measures of performance were used:

(i) Equity of irrigation water supply (EIWS)

The equity of irrigation water supply for the scheme was determined on a weekly basis as proposed by Gates and Ahmed (1994).

The data for the amount of water delivered (Q_D) and amount required (Q_R) were obtained from the discharge records and computed net irrigation requirement respectively.

The Area Uniformity (AU) concept proposed by Nelson (2001) was also used to calculate equity and the results were compared with those from the first method.

(ii) Adequacy of irrigation water supply (AIWS)

The discharge values for each station were used to calculate the amount of water received at the field inlet and water directly available to the crop. An indicator of adequacy as defined by Molden and Gates (1990) was used in this study.

Another indicator of adequacy that was used is the Relative Water Supply (RWS) as recommended by IWMI (2000).

Sensitivity analysis of the canal network

The hydraulic performance of canals designed to deliver water by proportional allocation is highly dependent on the accuracy of water division structures. If construction is inaccurate then inequity of water delivery is built into the system from the outset. Even with the most favourable operational scenario it is impossible to meet performance targets within the tolerance established standards, and requires further physical intervention if performance targets are to be met in future (Murray-Rust and Halsema, 1998). In order to describe the behaviour of the irrigation system of Herman canal scheme as a whole, sensitivity analysis was conducted using the discharge data collected. Sensitivity (S) was calculated using the following equations (Renault, 2000):

$$S = \frac{u}{h} \Delta h \dots\dots\dots(6)$$

Where: S = sensitivity
 h = depth of water
 Δh = change of discharge caused by unit rise of the upstream head (m)
 u = constant (in practice, u can take values between 1.6 and 1.8 for canals)

If Q is the canal discharge (l/s), then the water level fluctuation Δh caused by a change of flow ΔQ , can be expressed

as:

$$\Delta h = \frac{h}{u} \left(\frac{\Delta Q}{Q} \right) \dots\dots\dots(7)$$

Hence, $S = \frac{\Delta Q}{Q} \dots\dots\dots(8)$

Results and Discussion

Water and land productivity

Figure 2 shows the output per unit cropped area and output per unit command over the season for the seven branch canals calculated by the method explained by Sakthivadivel *et al.*, (1999). The output per unit command is consistently lower than the output per unit cropped area indicating that not all the land under command was cultivated during the season. Compared to other projects elsewhere, for example the Alto-Rio Lerma Project in Mexico and the Anatolia Project in Turkey where the output per unit command has been found to vary between 105-1,800 and 308-5,771 \$/ha respectively (Değirmenci *et al.*, 2003), the output per unit command from this study seems to be on the low side. This would appear to suggest low productivity in the scheme, which is indicative of low-level use of inputs including sub-optimal cropping intensities. According to Değirmenci *et al.*, (2003), the most important factors contributing to higher output per unit command are the cropping intensity and the type of crop grown.

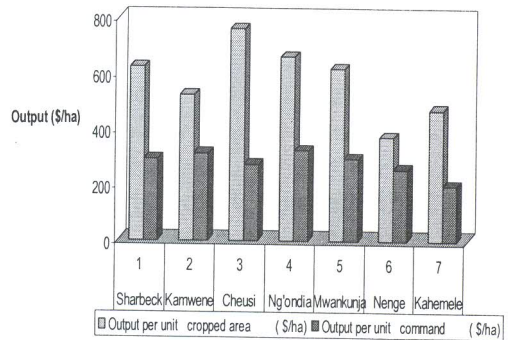


Figure 2: Output per unit cropped area/unit command for various branch canals

Figure 3 shows a comparison of output per unit irrigation supply and output per unit water consumed corresponding to the seven branch canals calculated by the method explained by Sakthivadivel *et al.*, (1999). The low values of output per unit irrigation supply (0.02 – 0.44 \$m⁻³) especially in the Head and Middle reaches of the main canal suggest that a lot of water was being diverted to those areas but much of it is wasted. On the other hand, Tail-enders such as those along Kahemele branch canal, appear to use water more efficiently as the output per unit water consumed is almost the same as that per unit irrigation supply. Compared to other projects such as Hancagiz and Derk-Dumluca irrigation schemes in Turkey where values of the output per unit irrigation supply of between 0.13 and 2.16 \$m⁻³ have been reported (Değirmenci *et al.*, 2003), it would appear that the efficiency with which water is being used in Herman canal irrigation scheme is rather low.

Values of output per unit water consumed obtained in this study varied from 0.16 to 2.79 \$m⁻³.

Değirmenci *et al.* (2003) obtained similar values ranging from 0.45 to 2.92 \$m⁻³ for a number of schemes in the Southeastern Anatolia Project in Turkey. Low values of output per unit of water consumed reflect the level of stress the crop has been put under, as consumed water is the actual evapotranspiration from irrigated crops.

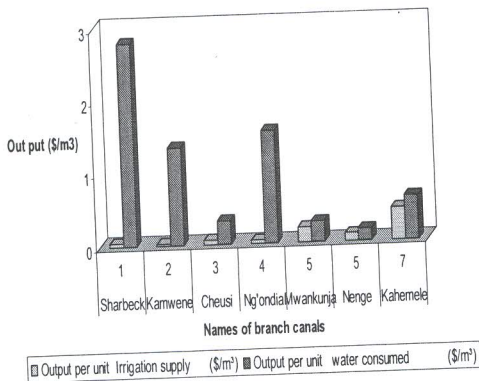


Figure 3: Output per unit irrigation supply/unit water consumed for various branch canals

Equity and adequacy of water supply

Figure 4 shows equity (P_E) values calculated according to Gates and Ahmed (1994) and adequacy values (P_A) determined using the method by Molden and Gates (1990) as a function of time for the entire scheme for a period of 22 weeks. Adequacy values ranged from 0.59 to 0.9 with a mean value of 0.74 while equity values ranged from 0.05 in the 19th week to 0.22 in the 9th week with a mean value of 0.14. According to Molden and Gates (1990) P_A values less than 0.80 indicate a poor irrigation water supply while P_E values ranging from 0.11-0.25 indicate a fair distribution of irrigation water supply.

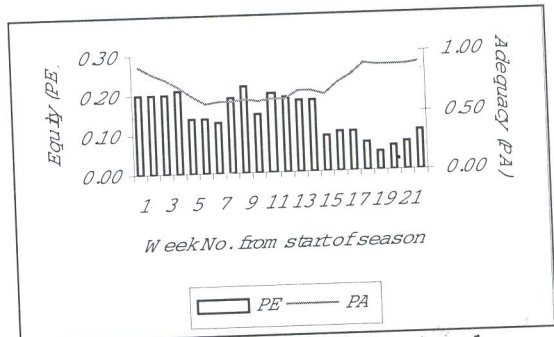


Figure 4: Variation of equity (P_E) and adequacy (P_A) with time for Herman canal scheme

According to Figure 4 it would appear that equity improves with time because a value of zero implies good water distribution. At the start of the season there is generally more water flowing in the river and requirements are low, and hence there is just about enough for everyone (high P_A values (0.8-0.9)) as a result of which there is a tendency of misuse of water especially by farmers in the upper reaches. However, towards the end of the season around October/November, flows get quite low and farmers fight for their share of water. This is the time when strict observance of shares among water users is done. The improved equity and adequacy of water distribution towards the end of the season (Figure 4) could also be due to the change in cropping pattern, especially for farmers in the upper reaches. According to the cropping calendar of the scheme, there is an indication that many farmers are engaged in harvesting irrigated crops and preparing paddy fields in readiness for the rainy season during the months of November and December. This reduces pressure on water requirements making it available to tail-end farmers.

Calculations of equity using the Area Uniformity (AU) index concept gave an overall equity value of 0.52. According to Nelson (2001), an AU index of one is perfect. Values less than one indicate the relative shortage suffered by the worst area. The AU index value obtained in this study closely reflects the mean P_E value of 0.14 previously obtained that was rated as fair. Before the installation of the proportioning water division weirs, one can only speculate as to what might have been the situation in terms of equity. Previously the tail-end farmers used to get little or no water at all throughout the season, a situation favouring low AU index values reflecting the inequity in water supply.

Other measures of adequacy such as the relative water supply resulted in higher values for the upper and middle branch canals that includes Sharbeck, Kamwene, Cheusi and Ng'ondya ($RWS >1$) and much lower values ($RWS <1$) for the lower reach canals, viz. Mwankunja, Kahemele and Nenge. Values of RWS less than one indicate inadequate supply for the respective canals. The results obtained from this study are symptomatic of the tail-end syndrome in many irrigation systems (Latif and Sarwar, 1994).

Sensitivity of the canal network

Table 1 shows the sensitivity values for seven of the branch canals of Herman canal scheme. The mean value of 0.41 suggests that sensitivity is low. According to Renault (2000) sensitivity values less than 1.5 indicate a low sensitivity of proportioning water division devices. This implies that the proportioning weirs were

properly designed and constructed, as the hydraulic performance of canals served by these structures seems to be less sensitive to perturbations in input. However, the branch canals may need some operational effort considering the fact that the partial coefficient of variation ($CV = 0.7$) is high (Renault and Makin, 1999).

Table 1: Sensitivity of the branch canals

Names of branch canals	Sensitivity values
Sharbeck	0.06
Cheusi	0.31
Kamwene	0.74
Ng'ondya	0.15
Mwankunja	0.79
Nenge	0.74
Kahemele	0.11
Mean	0.41
CV	0.70

Conclusions

Results from this study show that productivity in the Herman canal scheme is low, which is indicative of low-level use of inputs including sub-optimal cropping intensities. Farmers located at the Head and Middle sections of the scheme tend to over-irrigate (water wastage) the crops as shown by the low values of water productivity in terms of irrigation water supply. However, it appears that due to irrigation water scarcity, the Tail-enders use the water more efficiently. The low mean value of consumed water productivity for the whole scheme is an indicative of water stress on the crop as a result of poor supply and distribution of irrigation water.

Nevertheless the proportioning water division weirs appear to have solved to some extent the problem of

inequity in water allocation and distribution.

Acknowledgements

The authors are greatly indebted to NORAD for the financial support through TARP II-SUA Project on Food Security and Household Income for Smallholder Farmers in Tanzania.

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