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MATCHING CANAL FLOW RATE WITH POTENTIAL FLOWS FOR IRRIGATION IN RUANDA MAJENJE IMPROVED TRADITIONAL IRRIGATION SCHEME IN MKOJI SUBCATCHMENT

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Abstract

A study of flow rate in canals was necessary to analyze the capacity for irrigators to overcome managed their irrigation system, curb water scarcity problems and release more water for other sectors. The aim was to assess amount of water in canals and compare with Gross Irrigation Requirement (GIR) in order to generate empirical information to upscale water sharing practices in communal based improved traditional irrigation systems. However, the complex nature of water flow, through variable canal cross sections, made it difficult to determine accurately the limited range of water flows. There is a need to capacitate small scale irrigators in improved traditional irrigation systems to institute optimum water flows in canals by applying simple technologies to control water flows in conveyance and distribution canals.

Key Words: Flow rate, Gross Irrigation Requirement.

Introduction

Irrigation is the largest use of water in Mkoji subcatchment such that improved management of water within irrigation systems is essential if scarce water resources are to be used in an equitable manner. Recent studies in Mkoji sub catchment (Kashaigili et al., 2003; Lankford and Franks, 2000; SMUWC, 2001 and Sokile et al., 2003) have been concerned with increased benefits for poor people, the environment and other river basin stakeholders by application of new knowledge to enhancement of productivity of irrigation and transference of water to meet other needs. However, a steady increase both in population and agricultural and industrial activities has shown that water as a resource, is no longer available on an ad-lib basis (Usman, 2001) and water levels in many parts of the world are low and getting lower (SPORE, 1995).

Ruanda Majenje irrigation scheme is one of the potential irrigation schemes that were improved in the year 2002 in collaboration with the World Bank through Smallholder Irrigation Improvement Project (SIIP). Despite these efforts and investments done to improve infrastructure in traditional irrigation schemes, less work has been done to capacitate irrigation farmers with skills required to monitor water flow rate in irrigation canals. Controlling flow rate in irrigation canals is a step towards an integrated approach; it takes into account the meteorological, physical and social factors as a whole and aims for a balance. In the context of small holder irrigation canal systems, deliberate participatory efforts are needed to enable stakeholders be part of the decision making process and undertake their roles of controlling water flows in canals more effectively.

Ruanda Majenje Irrigation system has been designed to supply certain quantities of water to the soil for use by crops. These quantities of water are carried in channels to irrigated fields. The characteristics of the channel, which are predominantly cross sectional area, longitudinal slope, hydraulic radius, roughness and velocity of flow influence flow rate. In order to proportion correctly the flow rate in the canal under specific conditions that include weather, efficiency of the system, crop type and size of irrigated land, routine monitoring and evaluation of water measurements should coincide with predetermined irrigation water requirements for the canal system.

Since Ruanda Majenje irrigation scheme is owned by farmers, they are obliged to undertake effective operation and maintenance of their infrastructures. Obviously, they are not equipped to use technical data for operation of their canals but occasionally served by irrigation technicians who are prepared to apply technologies to bring about economies reflected in those assets.

The study of water flow in canals was necessary to determine flow rate at any point of the canal cross sections and device practical and user friendly methods for the community to control flow rate for irrigated fields. It is obvious that such a study of water flow has wide applications not only to farmers but scholars as well. The study was based on field measurements and application of various water measurement mathematical formulas to various conditions in practice.

Methodology

Description of the study area

Location

The experiment was carried out at one of the improve traditional irrigation schemes (Ruanda Majenje) which is located in the Usangu plains in middle Mkoji at altitude of about 8.33^0 South and longitude 33.53^0 East, and an altitude of 1100 to 1120 m above sea level. The source of water for the scheme is Lwanyo River which is one of the perennial rivers in the Mkoji sub catchment of the Great Ruaha River Basin. Figure 1 shows Mkoji sub catchment and location of the study area.

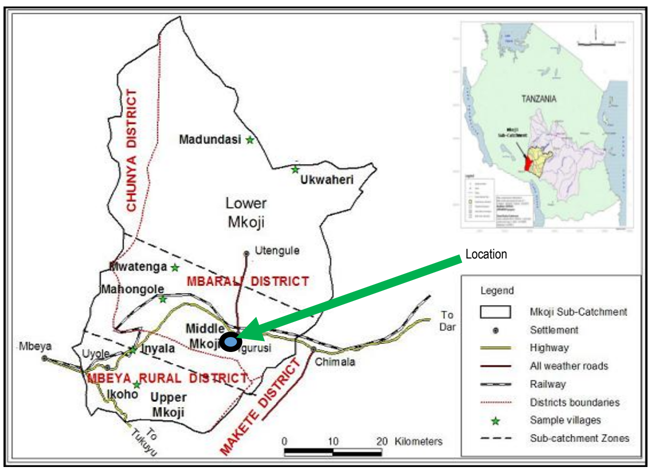


Figure 1: Location of the study area

Climate

Mean annual rainfall in the study area is about 800mm in wet years and 450mm in dry years. The rains fall between November and April. The area has a unimodal type of rainfall. The mean daily, maximum and minimum, temperatures range from 280C to 320 C and 9.5 to 19.50C respectively. The highest values are recorded in October and November while the lowest values are experienced in June and July. The mean daily net solar radiation varies from 7.5 MJ/m2/day to 12.3 MJ/m2/day. The average annual evaporation is 1701mm. The total evaporation from July to October when dry season farming takes place is 640mm. The climate of the area, which is typical of Usangu Plain, favors the cultivation of cereals, legumes and vegetables under irrigation during the dry season.

Water resources

Mkoji sub catchment draws its name from Mkoji River which is the main River draining the whole sub catchment. The river originates from the northern slopes of the Poroto Mountains. From the mountains it flows to the Usangu Plains, collecting *enroot* Makali and Itambo Rivers before joining the Great Ruaha River. Other important rivers that drain the Mkoji Sub-catchment are Meta, Lunwa, Lwanyo, Mambi, Mswiswi, Ipatagwa, Mlowo, Mwambalizi and Gwiri. All the rivers draining the Mkoji Sub-catchment, including the Mkoji River itself, are perennial upstream of the Tanzania-Zambia Highway, but seasonal downstream of irrigated areas. This is mainly due to dry season irrigated agriculture, which uses all the water that would have kept it flowing during the dry season. Figure 2 shows rivers that drain into the Mkoji sub catchment.

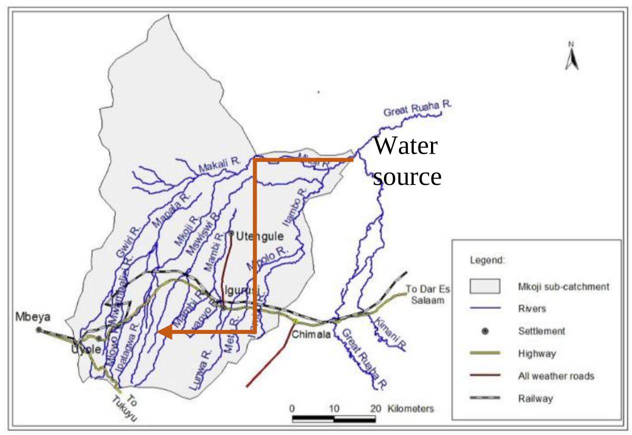


Figure 2: Rivers in Mkoji sub-catchment

Soil

The soils of the study area are typical of Usangu plain as described in SWMRG (2004). The soil textural class is predominantly sandy clay loam. The mean water holding capacity of the soil is about 100 mm/m. Figure 3 shows soils in Mkoji sub catchment.

Flow Rate Assessment

The aim was to assess amount of water in communal managed canals of improved traditional irrigation systems in order to understand the status of flow rate in irrigations canals. Canal cross sectional area and longitudinal slopes and velocity of flow were measured at the head of the distribution system. Mathematical analysis was done to establish canal flow rate and to verify measured data.

Canal Cross Sectional Area

The cross sectional area of a canal is determined according to the shape of their cross-section. Common canal shapes are called rectangular (a), triangular (b), trapezoidal (c), circular (d), parabolic (e), and irregular or natural. The designed cross sectional area of Ruanda Majenje improved traditional irrigation scheme is trapezoidal shape hence canal cross sectional area was calculated using the following formula;

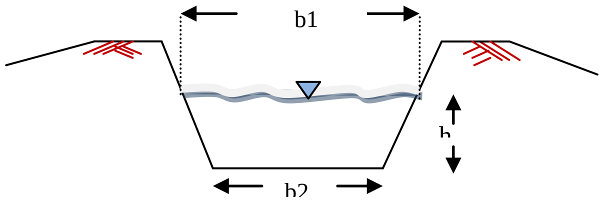


Figure 3: A Trapezoidal canal cross section

$$A = \frac{1}{2}(b1 + b2)h \qquad (1)$$

Where b_1+b_2 is the sum of top and bottom width at flow level (m) and h the depth of flow (m).

Canal Longitudinal Section

An Automatic level and staff were used to establish slope along the longitudinal section of the main conveyance canal, at a stretch 10 meters along the representative cross sectional areas. The slope was calculated as the difference in elevation between two points containing the upstream of the distribution canal which is expressed as follows;

$$S = \frac{Y1 - Y2}{X1 - X2} \qquad (2)$$

Where S is the longitudinal slope, Y1 and Y2 refer to the elevation of the bed of the canal between two points and x the horizontal distance.

Velocity of Flow in the Canal

In collaboration with farmers, floatation method was used to determine the flow velocity (m/s). The aim was to capacitate farmers sustain practices of estimating flow velocities in order to manage their system effectively. Floatation method included selecting and placing 2 stakes at a distance 10 meters long perpendicular to the centerline of the canal, where the flow was as uniform as possible. A floating object was placed on the center line of the canal 5 m upstream of the first peg and a stop watch used to mark the time taken for the float to move from the start to the end point. The Velocity (V) was calculated as;

$$V = 0.75 \times l / s \qquad (3)$$

Where, L/s is the distance taken per second for the float to cover the 10m and 0.75 is the reduction factor for subsurface which flows slower.

The velocity obtained was compared with that derived from mathematical equations as follows:

$$V = \frac{1}{n} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}} \qquad (4)$$

Where V is the flow rate (m/s), n the Manning's roughness coefficient, A the cross-sectional area of flow (m^2), R the hydraulic radius (m) and S the canal bed slope (%).

Mathematical analysis of Flow rate

The study used two common methods of flow measurement for surface water which are velocity area method and weir gauging. Cross sectional area was calculated from field data and shape of the canal. Velocity of flow was estimated using floatation method and standard tables. Analysis of water flow was done using Manning's equation. Furthermore, crop water requirements were estimated using Penman Monteith method, which was then used together with the canal efficiency to appraise the canal water duty. The intended canal water duty was compared to the measured stream flow in the canals with respect to cropped area.

Velocity area Method

This method uses the continuity equation that is expressed as follows;

$$Q = AV \qquad (5)$$

Where A is the cross-sectional area of flow (m2) and V the Velocity (m/s)

Manning's Equation

Mathematical analysis was done using Manning's equation as follows

$$Q = \frac{1}{n} \times A \times R^{\frac{2}{3}} \times S^{\frac{1}{2}} \quad (6)$$

Where Q is the Flow rate (m3/s), n the Manning's roughness coefficient, A the cross-sectional area of flow (m2), R the hydraulic radius (m) and S the Bed slope (%).

Manning's Roughness Coefficient

This is a dimensionless coefficient of which the values are developed through experimentation. Table 2 shows the Manning's coefficient values for open channels.

Table 2. Manning's n for natural stream channels (surface width at flood stage less than 30 m)

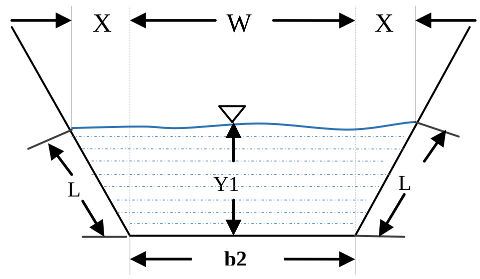
Na	Natural stream channels	n
1.	Fairly regular section:	
	Some grass and weeds, little or no brush	0.030 - 0.035
	Dense growth of weeds, depth of flow materially greater than weed height	0.035 - 0.050
	Some weeds, light brush on banks	0.050 - 0.070
	Some weeds, heavy brush on banks	0.060 - 0.080
	Some weeds, dense willows on banks	0.010 - 0.020
	For trees within channel, with branches submerged at high stage, increase above values by	0.010 - 0.020
2.	Irregular sections, with pools, slight channel meander; increase values given above by	0.010 - 0.020
3.	Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage:	
	Bottom of gravel, cobbles, and few boulders	0.040 - 0.050
	Bottom of cobbles with large boulders	0.050 - 0.070

Hydraulic Radius

A parameter used often to countercheck flow rate in canals. The Hydraulic Radius (H) is calculated from measurements taken in the field which are cross sectional area (A) and Wetted Perimeter (WP).

$$H = \frac{A}{WP} \quad (7$$

In Ruanda Majenje irrigation scheme the channel cross section was trapezoidal shape thus H was determined as follows;



A = WY1 + XY1

WP = W + 2L

Bed slope

Slope (S) can be expressed as; an angle (degrees), percent (%) or fraction e.g. 0.01 or 1 in 100

In Manning's equation, other than the S term, all other terms are related to channel cross section and its features. These terms together are referred to as the Conveyance (K) of the channel and the relationship is as follows;

$$K = \frac{1}{n} \times A \times R^{\frac{2}{3}} \quad (8)$$

Gross Irrigation Requirement (GIR)

It is the amount of water required at the head of a canal. The aim was to determine the flow rate required at the head of distribution canals (GIR) and compare this with measured flow rate in order to generate empirical information necessary to improve water sharing practices in communal based improved traditional irrigation systems.

$$GIR = \frac{FIR}{ec} \quad (9)$$

Where ec is the Conveyance efficiency and FIR is the amount of water required to be applied to the field.

The ec represents efficiency of water transport in canals and mainly depends on length of canals, soil type or permeability of canal banks and condition of the canals. In large irrigation schemes more water is lost than in small schemes, due to a longer canal system. From canals in sandy soils more water is lost than from canals in heavy clay soils. When canals are lined with bricks, plastic or concrete materials they lose very little water. If canals are badly maintained, bund breaks are not repaired properly and rats dig holes, a lot of water is lost. Conveyance efficiency is determined as; Output/Input x 100 or water delivered into the field divided by water supplied into the canal at the head times 100.

$$FIR = \frac{NIR}{ea} \qquad (10)$$

Where Ea is the application efficiency and represents the efficiency of water application in the field. This is also given as Output/Input x 100 (at field/basin level).

NIR is the Net Irrigation given as follows;

$$NIR = ETc - \mathrm{Re} - Ge - SW \qquad (11)$$

Effective Rainfall, Re is the precipitation falling during the growing period of a crop that is available to meet the evapotranspiration needs of the crop (ETc), Ge the ground water contribution, SW the Stored soil-moisture. For the purpose of this study Ge and SW were ignored.

Once the conveyance and field application efficiency have been determined, the scheme irrigation efficiency (e) can be calculated, using the following formula:

$$e = \frac{ec \times ea}{100} \qquad (12)$$

Where e is the scheme irrigation efficiency (%), ec the conveyance efficiency (%), and ea the field application efficiency (%).

Estimating ETc

This part describes measurement and computation of all data that were required for the calculation of the reference evapotranspiration. ETo was estimated using Penman Montieth empirical equation and multiplied by crop coefficient to get the consumptive use by the crop (ETc). Various climatological and physical parameters that were used include radiation, air temperature, air humidity and wind speed.

$$ETo = \frac{0.48\nabla(Rn - G) + \gamma \dfrac{(es - ea)}{ra}}{\nabla + \gamma\left[1 + \dfrac{rs}{ra}\right]} \qquad (13)$$

Where, ETo = Reference crop (green grass) evapotranspiration (mm/day) = Slope of saturation vapor pressure vs temperature curve at mean air temperature, kPa per ^{o}C

Rn is the net radiation, G is the soil heat flux, (es - ea) represents the vapour pressure deficit of the air, ρa is the mean air density at constant pressure, Δ represents the slope of the saturation vapor pressure temperature relationship, γ is the Simplified representation of the (bulk) surface and aerodynamic resistances for water vapour flow soil stomatal air flow rs and ra are the (bulk) surface aerodynamic resistance.

For monthly value,

$$G = 0.14 \times \left(T_I - T_{i-l}\right) \qquad (14)$$

For monthly value, G = 0.14 × (Ti – Ti-1, Where, Ti = Mean air temperature for the month (oC), Ti-1 = Mean air temperature for the previous month (oC), G = 0 for 10 days or short period.

$$es = \frac{e^0 \times T_{\max} + e^0 \times T_{\min}}{2} \qquad (15)$$

Where es = Saturation vapor pressure of the evaporating surface at mean air temperature, kPa ea = Actual vapor pressure, kPa

$$ea = \frac{RH_{mean}}{100} \times es \qquad (16)$$

Where RH is the relative humidity

Crop Evapotranspiration

The crop evapotranspiration is the consumptive use: commonly known as the sum of two terms:

(i) Transpiration: Water entering plant roots and used to build plant tissue or being passed through leaves of the plant into the atmosphere

(ii) Evaporation: Water evaporating from adjacent soil, water surfaces, and surfaces of leaves of the plant or intercepted precipitation

ET of a specific crop is given by;

$$ET_{crop} = K_c \times ET_O \quad (17)$$

The crop co-efficient (Kc) is basically the ratio of the crop ET to reference ET and represents the integral effects of four primary characteristics: Crop height, Albedo, Canopy resistance, Evaporation from soil. The Kc value of a crop varies with growth stages of crops. FAO developed software, CROPWAT was used and the Input data were: Latitude, altitude, temperature, relative humidity, daily sunshine, wind speed

Effective Precipitation

Generally a percentage of total rainfall is taken as effective rainfall (Re) and is determined as follows,

$$\mathrm{Re} = R - Rr - Dr \quad (18)$$

Where, R is the Precipitation, Rr the Surface runoff and Dr the Deep percolation.

Results

Types of Structures

Ruanda Majenje irrigation scheme was improved in the year 2002, funded by the World Bank under the Smallholder Irrigation Improvement Project (SIIP) component of the River Basin Management Project. Major improvement works done in the irrigation scheme include construction of headworks and main canal system. The headworks comprise an improved intake with concrete weir and walls, sluice gates for regulating stream flow and a disiltation structure. The scheme has a main conveyance system that contains an unlined trapezoidal shaped main canal with drop structures, division boxes and turnout structures. Water is supplied into the fields through distributary canals, radiating from the main canal.

While improved structures in the irrigation scheme were designed to control water abstractions, reduce unnecessary water losses through leakages at the intakes, regulate and divert flows through drop and turnouts structures, some self-centered farmers abuse these structures by abstracting, conveying and distributing more water to their fields than required. In addition maintenance works particularly canal cleaning and repair of damanged infrastructures has not been done adequately.

Water flow in the Irrigation Canal

Results in Table 1 show daily water flow in irrigation canals of Ruanda Majenje scheme were more in February, March and April. The highest water flow rate was 1,359 l/s (2.718l/s/ha) was recorded in March 2015, which was intended to irrigate 500 ha. This flow is higher than recommended flow of 1.68 l/s/ha (SMUWC, 2001) normally taken as the gross water requirement for paddy in the Usangu Plains. However, the overall mean water flow rate, in the canal, for the cropping season was 0. 61l/s/ha, this explains some periods of decreased water flows in the canal.

Table 1: Monthly Water Flow Rate Recorded for Ruanda Majenje Irrigation Scheme

STATION (M)	MONTHLY DISCHARGE (l/s)						
	DEC	JAN	FEB	MAR	APR	MAY	MEAN
0	675	900	1,08	1,35	788	495	883.
42	658	855	1,04	1,29	749	473	845.
123	286	409	503	617	358	225	399.
188	193	275	339	416	241	160	270.
314	105	137	168	206	120	75	135.
507	150	211	247	318	184	120	205.
685	155	194	238	293	170	112	193.
1,046	162	210	225	317	184	122	203.
1,452	134	182	206	275	160	106	177.
1,722	55	55	65	83	48	32	56.3
1,967	26	34	34	51	29	20	32.3
2,237	200	257	263	389	225	149	247.
MEAN	**233.**	**309.**	**368.**	**467.**	**271.**	**174.**	**304.**
MEAN	**0.47**	**0.62**	**0.74**	**0.94**	**0.54**	**0.35**	**0.61**

Results in Figure 1 show that peak daily water flow in the canal was highest in March compared to February and April. For all three months there was an abrupt change of flow within 500 m stretch of the main canal. This explains the possibility of farmers located within 500 m upstream to divert and distribute more water compared to downstream water users. Generally water flow in the main canal decreased with distance from the Headworks.

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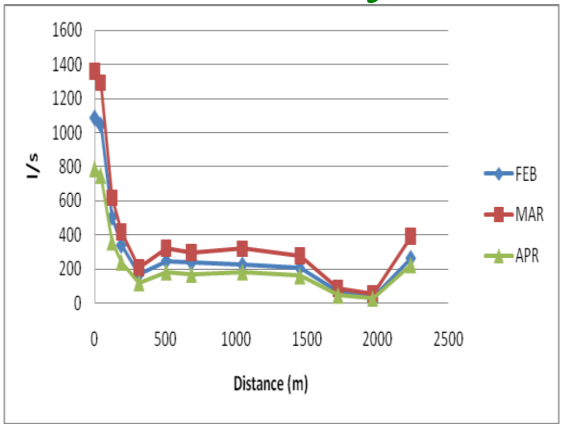

Figure 1: Trend of Daily Water Flows for Periods with Peak Canal Water Flows

Mean Monthly Rainfall

Results in Figure 2 show the mean monthly rainfall received in the area was highest in January and March whereby mean monthly Rainfall records were; January (157mm) and February (155mm). Low rains were recorded in October and November.

Despite having more rain in February and March irrigation water flows in the canal were highest in the same months. This is contrary to the principles of irrigation whereby the Net Irrigation Requirement is given as the difference between crop water requirement and effective rainfall (FAO, 1977). This could explain the possibility of inadequate management of regulatory infrastructures particularly at the Head-works. Moreover the abrupt increased flow within 500 meters stretch, as observed above, elucidates high possibility of over conveyance of water.

In general trend of water flow in the irrigation canals is such that during the wet season, maximum water flows occur between February and April when the crop is in mid development season. During this period water requirement by paddy is at the maximum, precipitation rate is high and also water availability in rivers is at the maximum. Apart from this another month with relatively large canal water flows is January; when plants are in initial growing stage such that water requirements are high for paddling and in June whereby most of the farmers do not divert water from the main canal system (Late growing stage).

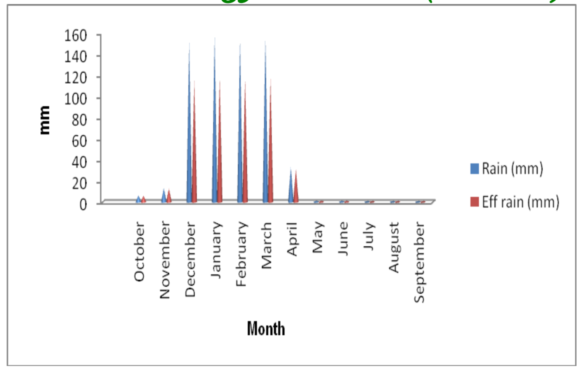

Figure 2: Mean Monthly Rainfall

During the rainy season rice is the sole crop grown in Ruanda Majenje Irrigation scheme thus it was assumed that 100% of the irrigated area (500ha) was cultivated. The current study used Climwat/Cropwat 7.0 to determine Gross Irrigation basing on climatic data from Igawa Meteorological station, which is located at latitude 8.76^0 South, Longitude 34.38^0 East and Altitude 1070 meters above mean sea level. The soils in Ruanda Majenje Scheme are sandy clay loam.

Table 2 shows results of the hydro-module for Ruanda Majenje Irrigation scheme whereby the mean Gross irrigation depth is 40.49mm giving a mean flow rate of 1.21l/s/ha. This flow rate is 72% of 1.68 l/s/ha recommended by SMUWC (2001) for the Usangu Plains in which Ruanda Majenje Irrigation scheme is located.

Table 2: Hydro-module for Ruanda Majenje Irrigation canal

Date	Net Irr	Deficit	Loss	Gr. Irr	Flow
	mm	mm	mm	mm	l/s/ha
15-Dec	62.7	0	0	89.6	10.37
22-Dec	25.9	0	0	37	0.61
1-Jan	24.9	0	0	35.6	0.41
2-Feb	26.5	0	0	37.9	0.14
2-Apr	27.1	0	0	38.7	0.08
11-Apr	24.7	0	0	35.3	0.45
19-Apr	25.6	0	0	36.6	0.53
26-Apr	26.6	0	0	38	0.63
2-May	25.1	0	0	35.9	0.69
8-May	25.1	0	0	35.8	0.69
14-May	26.1	0	0	37.2	0.72
20-May	26.3	0	0	37.6	0.72

26-May	26.3	0	0	37.5	0.72
1-Jun	26.3	0	0	37.6	0.72
7-Jun	25.9	0	0	37.1	0.71
12-Jun					
MEAN	**28.34**	**-**	**-**	**40.49**	**1.21**

Relationship between Canal Water Flow and Water Requirement

The hydro module for Ruanda Majenje irrigation scheme was evaluated. Results in Figure 3 show a mean water flow of 1.15l/s/ha is required for the scheme and a mean water flow of 0.62 l/s/ha is conveyed in the main canal of the irrigation system.

The mean ratio of water flow in the irrigation canal to that required by the scheme was highest in March and February. The mean water flows were 0.74 l/s/ha and 0.94l/s/ha in February and March respectively; these water flows were higher than the irrigation water requirement for the irrigation system that was 0.14l/s/ha and 0.08l/s/ha for February and March respectively.

During the study it was observed that low irrigation water requirement for Ruanda Majenje Irrigation scheme is due to, among other things, the presence of clay loam and sandy clay loam soils, which permit low to moderate seepage rates as water travels only a short distance and, the fact that command area is concentrated in one core area and thus water need to be only conveyed to a relatively short distance; about 2.23 kilometres along the main canal and about 0.5 km along the distributaries, to reach the farthest field.

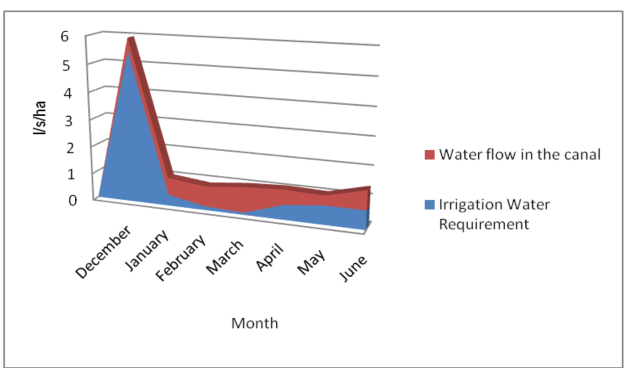

Figure 3: Relationship between mean daily irrigation water requirements and actual water flows in canals

Relationship between Canal Water Flow and Water Permit

Results in Figure 4 show that mean water flows are higher than the water permit the irrigation system. The highest water flows was 0.47 m^3/s and mean flow was 0.311m^3/s, while the water right for the scheme is 0.18m^3/s.

The water right intent is to control the amount of water used by water users and to halt or reduce over-abstraction and over conveyance of water. Water permit is offered by the River Basin Water Office whereby for the case of Ruanda Majenje irrigation scheme Rufiji River Basin Water Office is responsible for offering water permits. The water permit for irrigation use is based on flow rate and issued taking into consideration the long-term mean flows in River Ruanyo, which supplies water for the scheme. The water flows in the canal are much higher than the cultivated area implying that irrigators exceed limits set in the water rights. Furthermore not all the developed 500 ha's cultivated each year because of unreliable rainfall, hence river flows. Therefore this makes it easy to over irrigate as compared to the areas under cultivation with/without exceeding the limits set in the water rights.

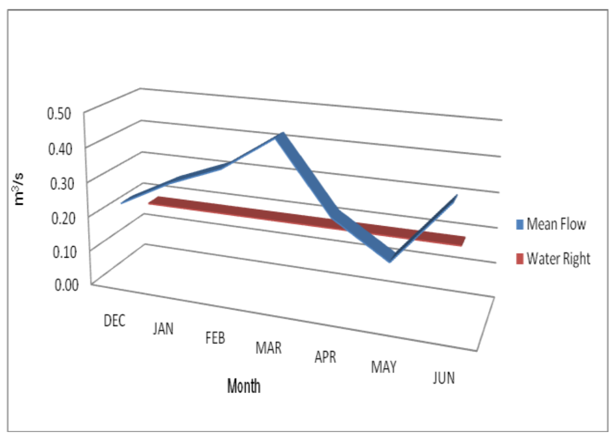

Figure 4: Relationship between mean daily irrigation water flows and water permit

Conclusion

An improved understanding of water flows in improved traditional irrigation systems, under varying hydrological conditions, is crucial to the design and implementation of effective operation strategies that ensure water is shared fairly among users.

In this research the dynamics of water flows using multiple climatic data against predetermined irrigation water requirements has been assessed. Ruanda Majenje irrigation scheme shows very inefficient water flows in the irrigation canals. The relationship between water flow in the main canal and gross irrigation water requirement indicates that water flow in the canals was more than that required for growing rice. The relationship between water flow in the canal and water right revealed that the water flow was more than the water permit for the scheme. Average ratio of Irrigation water required to water flow in the canal was 26.2%.

The increased water flow in the canals is closely linked to poor operation of regulatory structures. This is a result of among others some selfish farmers conveying more water to their farms than required and lack of adequate knowledge on water management. Canal flows of the required quantities can only be maintained by reducing current water flows for irrigation and other uses. Proper monitoring and control is necessary to ensure optimum water flows are conveyed in the canals for crop production. There is a need to install an evaporation pan and gauges along the main canal to guide irrigators so that they can estimate crop water requirements using an Evaporation Pan and regulate water flows as depth of water.

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