Chapter 6

Productivity of Water in Large Rice (Paddy) Irrigation Schemes in the Upper Catchment of the Great Ruaha River Basin, Tanzania

Makarius Victor Mdemu and Theresia Francis

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/52471

1. Introduction

The concept of productivity of water (PW)[1] is increasingly becoming a cornerstone for sustainable river basin water resources management. Improving water productivity (WP), a measure of performance generally defined as the physical quantity or economic value derived from the use of a given quantity of water (Molden *et al*., 2003), is one important strategy towards confronting future water scarcity. Increasing WP to obtain higher output or value for each drop of water used can play a key role in mitigating water scarcity (Molden *et al*., 2001; UNDP, 2006). Global projections show that increases in WP and expansion of irrigated areas are required to account for half of the long-term increase in global water requirements for a food supply that will ensure food security of the projected 2050 population (Tropp *et al*., 2006). Further, projected increases of WP by 30% and 60% in rain-fed and irrigated agriculture, respectively, are required to meet the demands for food security for the period 2000-2025 (Cook *et al*., 2006; Rijsberman and Molden, 2001). WP is currently considered a more appropriate indicator of water system performance than the most widely used efficiency indicators, both classical and neo-classical (Seckler *et al*., 2003). Under classical efficiency indicators, surface and groundwater drainage are counted as losses even when beneficially reused downstream, while neoclassical efficiency integrates water recycling into the concept of water-use efficiency (Sekler *et al*., 2003; Xie *et al*., 1993). Unlike irrigation efficiency indicators, WP provides more information on the amount of output that can be produced with a given amount of water (Guerra *et al*., 1998). Also, WP can capture differences in the value of water for alternative uses

1 In this presentation, the terms "productivity of water (PW)" and "water productivity (WP)" are interchangeably used to mean the same thing.

(Wichelns, 2002). However, physical WP is not different from water-use efficiency (WUE) when expressed in terms of yield per unit amount of water consumed.

Water productivity may vary when evaluated at different spatial scales due to influencing factors such as crop choice, climatic patterns, irrigation technology and field-water management, land, and inputs including labor, fertilizer and machinery (Rosegrant *et al*., 2002; Kijne *et al*., 2002). Due to spatial variability in WP, several options exist for improving WP in agriculture at different scales. At plot and farm scales for example, options may involve combined research on plant physiology, agronomy and agricultural engineering that focuses on making transpiration more efficient or productive, reducing non-productive evaporation and making water application more precise and efficient (Molden *et al*., 2003). At irrigation system and basin scales, options may include reducing non-beneficial depletion, reallocating water among uses and tapping uncommitted outflows resulting in more output per unit of water consumed (Molden *et al*., 2003). As a result of climatic differences between locations, many options for improving WP need to be adapted to specific local conditions. However, local variation makes it difficult to upscale and downscale WP findings easily (Bouman, 2007). It is understood, though, that increased WP as a result of improved water management strategies at lower scales can result in either positive or negative linkages to WP at higher scales. For example, when low-value farm crops are supplied with the same amount of water that could supply high-value uses, overall productivity of basin supplies may be reduced when viewed in economic terms (Molden *et al*., 2003). Irrigation supply in many cases is used for multiple purposes. Failure to account for other uses of irrigation water has resulted in undervaluation of irrigation water, and by extension, of investments in irrigation infrastructure by water managers. Understanding the value of water in its alternative uses is essential for improving WP, and guides the management and allocation of water supplies among competing users (Renwick, 2001).

The river basin is a preferred unit of analysis for water resources management. Strategies for improved water management are now typically attuned to river basin scale. Seckler *et al*. (2003) argue that, in a river basin where drainage from upstream users can be reused downstream, water losses occurring at lower scales are not true losses as long as they are or can be recovered and reused downstream. Although this argument has been useful in redefining the irrigation efficiency concept (Winchelns, 2002), which is important at basin scale in particular, it tends to downplay the importance of field-scale WP improvement interventions (Bouman, 2007). Reuse of water in many cases entails additional costs to users such as added cost to pump drain water, which many poor farmers cannot afford (Hafez, 2003; Bouman, 2007), and reductions in water quality. Improvement of WP at lower levels is also important, since it can be directly translated to improved livelihoods of farmers. Wichelns (2002) further emphasizes that improvements in farm-level water management enhance the economic values generated with limited water resources even if measures of basin WP are within desirable ranges.

Definitions and frameworks of analysis for understanding WP exist (Molden, 1997; Bouman, 2007; Molden *et al*., 2003). Similarly, general principles underlying WP improvements and water saving at different spatial scales are elaborated (Molden *et al*., 2003 and Cook *et al*., 2006; Guerra *et al*., 1998). However, these assumptions and principles are derived largely from studies conducted in Asia, and as such are not geographically applicable uniformly (Renwick, 2001; Molden *et al*., 2001; Dong *et al*., 2001; Singh, 2005). In particular, few such detailed studies (Mdemu *et al.*, 2004; Kadigi *et al.*, 2004; Igbadun *et al.*, 2006) have been conducted in the Great Ruaha River Basin. Since the current levels of WP in most large and small rice irrigation systems are not well understood, it is difficult to determine at which level WP can be increased from improved water management practices. A clear understanding of WP at different spatial scales was important as a precondition to implementation of any improvement strategies. The current study therefore addressed this knowledge gap by providing WP analysis of the large rice irrigation within the Usangu plains in the Great Ruaha River Basin (GRRB) in Tanzania.

2. Problem statement, rationale and research objectives

The Usangu plains in the upper part of the GRRB is important regionally and nationally due to the fact that more than 30,000 households directly depend on rice irrigation and more than 250,000 peoples indirectly depend on the rice farming from the plains. Increased abstraction of water for irrigation which is associated with poor irrigation water management practices in the Usangu plains, have resulted into significant reduction in downstream flows. As a result, conflicts between water users and uses are rife. Sustaining water allocation of compteting uses for sustainable management of water resources in the basin depends on among others decisions informed by understanding of productivity of irrigation water, both in large and small scale irrigation schemes. However, the current understanding of productivity of water to inform such decisions by water managers in the basin is inadequate. This study address this knowledge gap through assessment of water productivity of a large scale irrigation scheme from Usangu Plains in the South-western highland zone of Tanzania.

While modeling techniques can be used to assess productivity of water for different sectors over a large area within a relatively reasonable manageable time and cost, such results cannot be taken directly for policy implementation at local levels due to aggregation that obscure small but important livelihood based water uses. Therefore, the research was relevant locally because it provides an insight on the inclusive value of water at local level that can be taken into consideration during a day to day management of irrigation water resources. Once the value of water for rice plus the additional irrigaion water uses is known, then different strategies for improvements can be explored to improve socio economic activities of rural communities i.e. farmers, livestock keepers, fishers, and natural resource harvesters who depend on the availability of water in the basin. Also, sustainability of wetlands and Ruaha National Park ecosystems is vested on the sustained river flows in the basin. Regionally, the research was relevant due to the fact that the GRRB provides water to sectors of National importance and the Government is comitted to ensuring sustainable management of water in the basin is restored. This research feeds into a pool of research findings for the GRRB basin, but with significant contributions to key questions important for strategies for improving productivity of water. The main objective of this research was to determine productivity of water in large rice irrigation schemes in the GRRB. The specific objectives were: 1) to develop seasonal water balances at field and scheme levels for rice irrigation; 2) to estimate seasonal productivity of water for irrigated rice; 3) to estimate the value of water for rice production; and 4) to propose water management related strategies for improving the current productivity of water.

3. Description of the study area

3.1. Location

The research was conducted in Kapunga rice irrigation scheme in the Usangu plain. The Usangu plain, an upper catchment of the Great Ruaha River, is located in the Southwest of Tanzania between approximately latitudes 7°41′ and 9°25′ South, and longitudes 33°40′ and 35°40′ East (Figure 1). Kapunga Rice is one of the mechanized irrigation schemes which were developed by the Government in the 1990s under the management of the then National Food Corporation (NAFCO). The scheme has about 3500 hectares of mechanized rice farm. A small holder farm of about 850 hectares was developed alongside the large rice farm to carter for the need of rice small holder farmers. The two farms share the same primary irrigation canal, but have different management arrangement. This research, although covers the entire water system of these two separate farms, focused on the large rice paddy mechanized farm. The farm was privatized in 2006 to Export trading Ltd of Dar es Salaam, Tanzania.

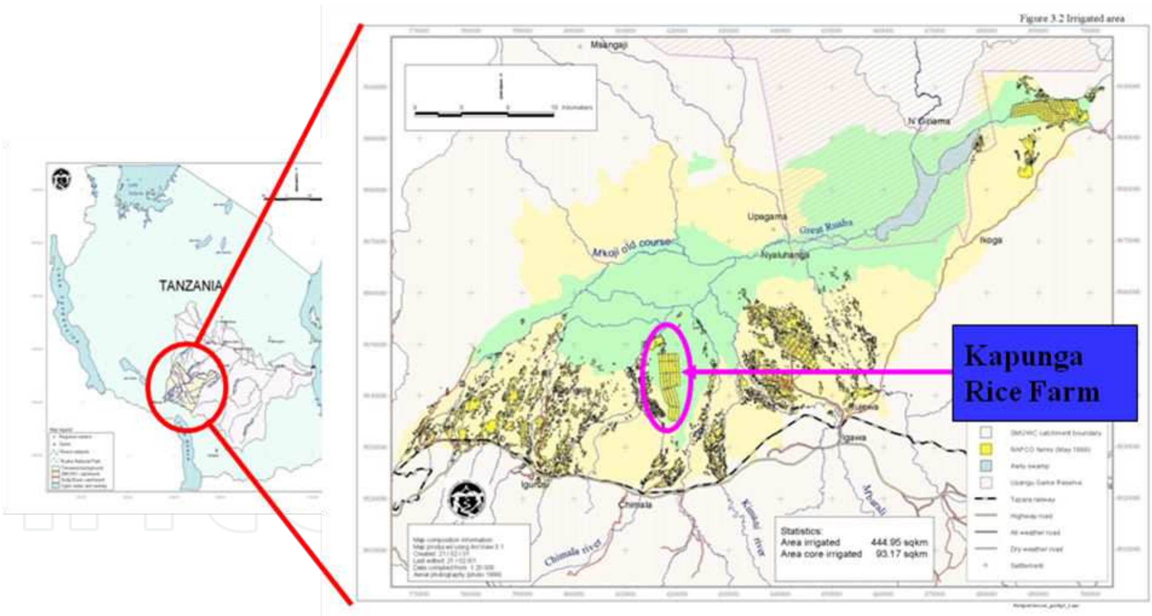

Figure 1. Location of Study Area (Adapted from SMUWC, 2001)

3.2. Climatic conditions

The general climatic pattern of the study area is tropical wet-and-dry characterized by uni-modal type of rainfall, moderate to high temperature, low wind speeds, and high relative humidity. Temperature varies between 17°C and 29°C with average mean temperature of 25°C.

The mean annual and effective rainfall received in the study area is about 669 and 479 mm, respectively. The mean relative humidity and wind speed is 62% and 2.2m/s, respectively. The rain falls between the last decads of November and April. February is the month with peak rainfall (Figure 2). The annual potential evapotranspiration is almost thrice the annual precipitation. With an exception of February, monthly evapotranspiration is higher than monthly rainfall throughout the year. This underscores the importance of irrigation water, especially for rice to facilitate crop growth, maturity and harvest.

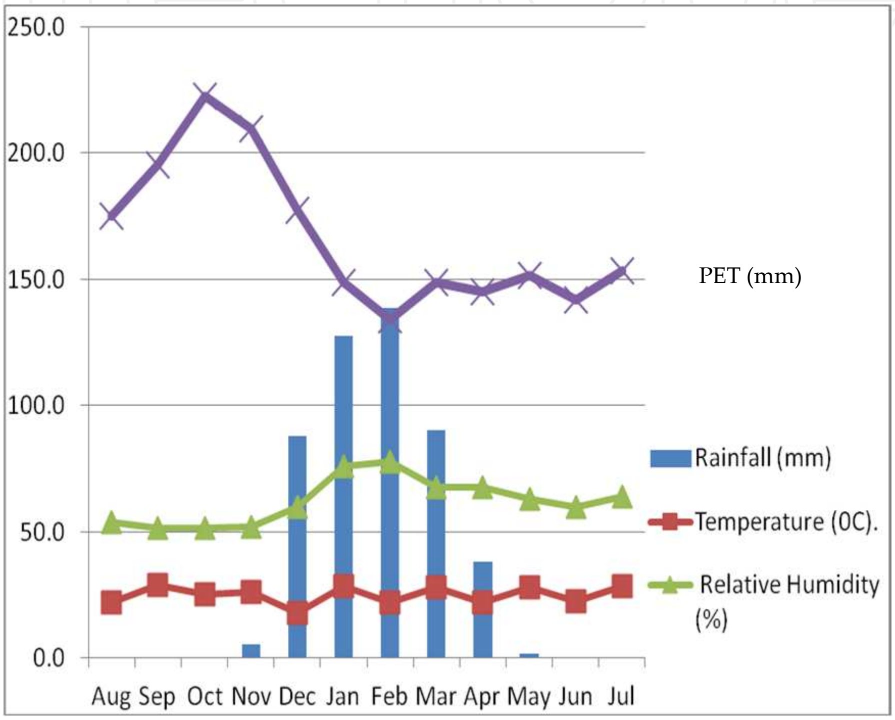

Figure 2. Long term (1980-2010) monthly average rainfall, relative humidity (RH), potential evapotranspiration (PET) and Temperature for Usangu Plain (Data Source: Kapunga Rice Farm)

3.3. Topography and hydrology

The Usangu plain is situated at 1040 meters above the sea level. The altitude on the South, South West and South East rises to above 2000 masl. A number of rivers radiates from the South and South East highlands of the plain (Figure 3). The major rivers include Ndembera, Mbarali, Ruaha, Kimani, and Chimala. These main rivers together with small rivers and tributaries provide the main source of irrigation water to all irrigation schemes in the plains.

Rivers from the upper catchments of the GRR form a life-line to the following important sectors: rainfed and dry season irrigation along the slopes of the catchments; domestic and other water use enterprises when the rivers crosses villages and towns along the Tanzania-Zambia highway; large and small scale rice irrigation in the Usangu flood plains; river rine and wetlands ecological funtions within the plains; wildlife water use in the Ruaha National Park; and hydroelectric power generation in the Mtera/Kidatu hydropower systems. From the

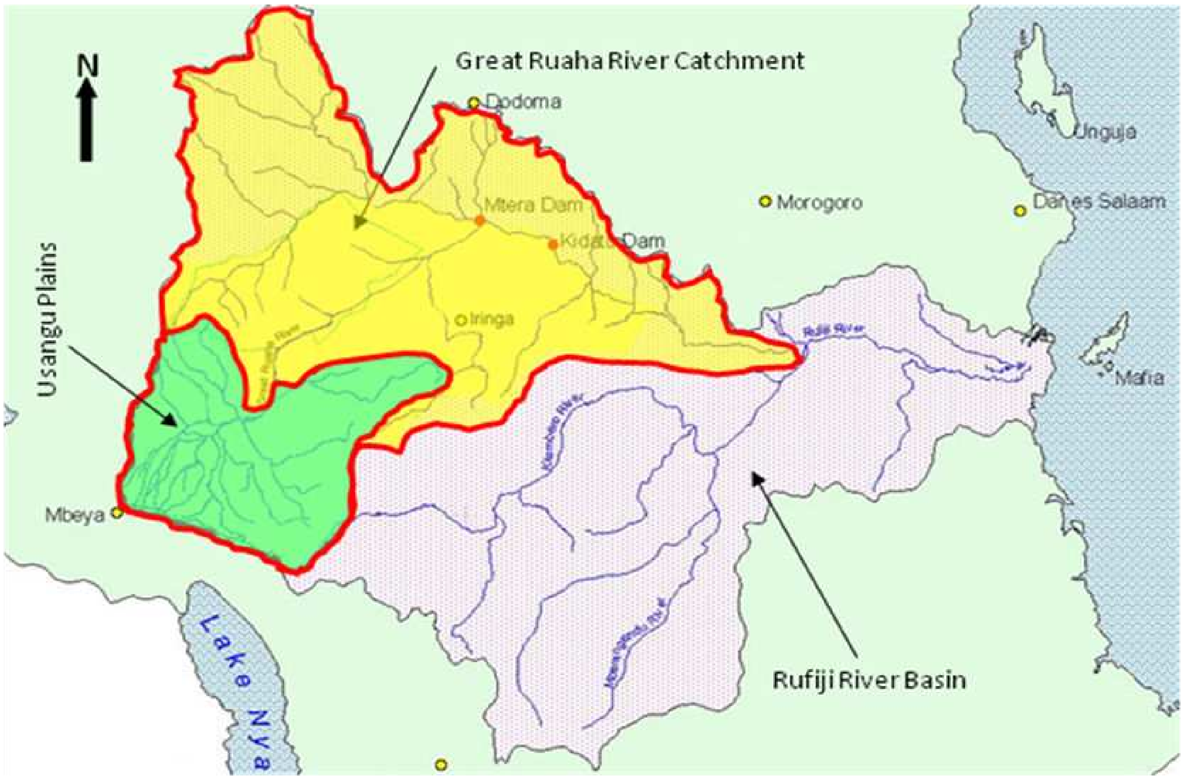

Figure 3. River drainage network, (Adapted from WWF, 2006)

Kidatu hydropower, the GRR is joined by Kilombero River and it flows into the Rufiji River. Rufiji river floods the Rufiji Delta, which is one of the most important ecological areas in Tanzania before flowing into the Indian Ocean (Figure 4).

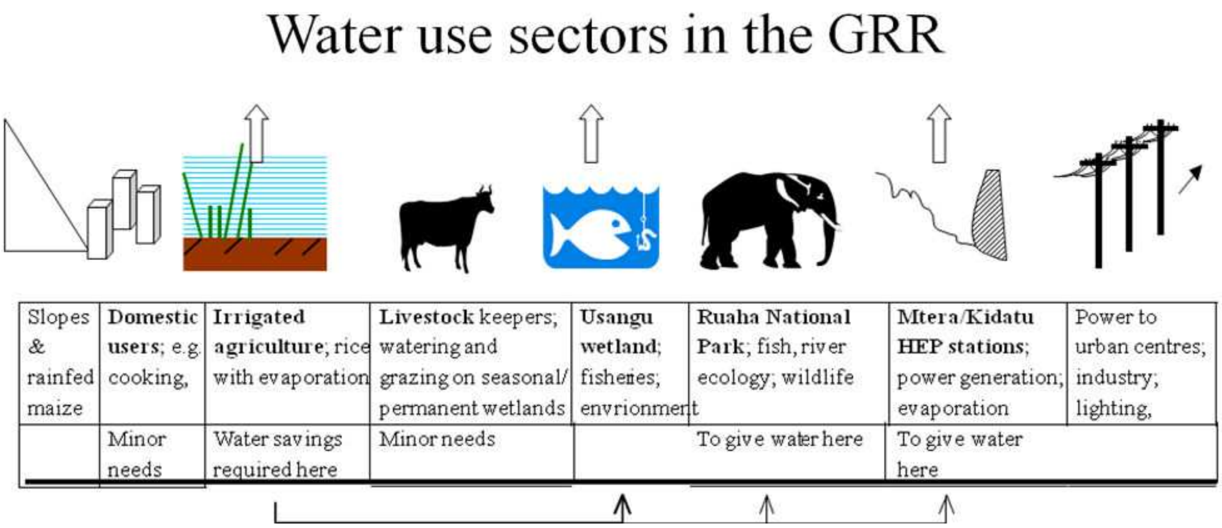

Figure 4. Water use sectors in the Great Ruaha River (Adapted from Lankford *et al*., 2004)

4. Methodology

4.1. Research process and methods

4.1.1. Soil water balance analysis

Before water balance analysis is carried out, the irrigation system was identified and defined to consist of Kapunga large rice farms, Kapunga small holder farms and associated irrigation and drainage canals surrounding the rice irrigation farms (Figure 5). The water level gauging station in the main irrigation canal was adapted to record irrigation flows into the irrigation system. Two water level gauges were installed on the main drains of the Kapunga small holder farm and at the drainage exit from the Kapunga irrigation water system. The rating curve (water level-flow relationship equation) in the primary irrigation canal was updated through snapshot measurements of irrigation water and drainage flows using the current meter. The rating curves of the drainage canals were established and water levels in all three gauges were recorded twice per day during the period between January and December, 2010. Within the Kapunga rice farm, one rice plot was identified and monitored in terms of plot irrigation and drainage flows, standing water levels, crop season, crop yield and farm operations.

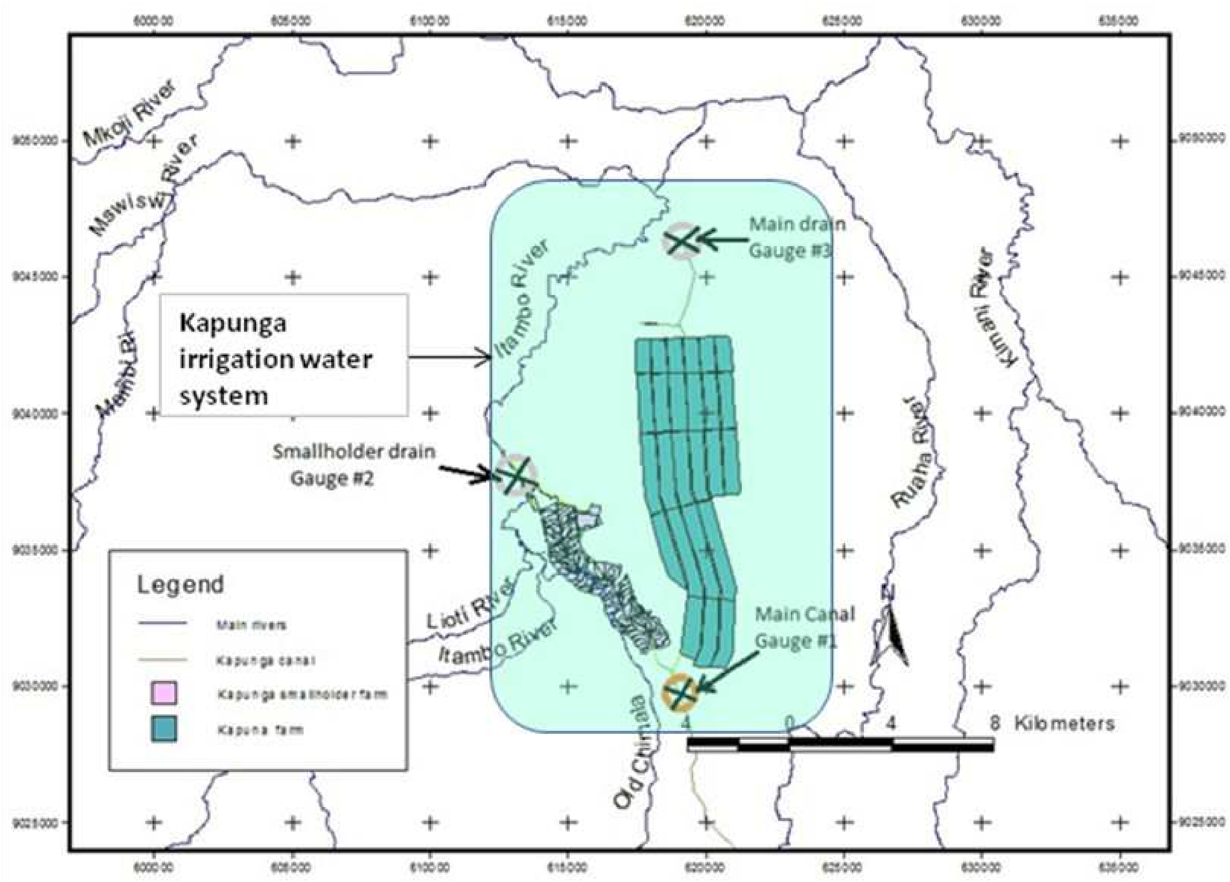

Figure 5. Kapunga Irrigation water system (Adapted from SMUWC, 2001)

Both, at irrigation system and plot levels, the soil water balance analysis was applied to partition water balance components based on equations 1 and 2:

$$Qi_{\Delta t} = Qo_{\Delta t} + \Delta S \tag{1}$$

where;

$Qi_{\Delta t}$ = total irrigation inflows (mm)

$Qo_{\Delta t}$ = total irrigation outflows (mm)

ΔS = change in soil moisture storage, +ve or -ve (mm)

$$(P + I) = (ET_c + SD + Q_{bot}) + \Delta S \tag{2}$$

where;

P = precipitation (mm),

I = irrigation (mm),

ETc = crop evapotranspiration (mm),

SD = surface drains (mm),

Q_{bot} = percolation losses (mm)

ΔS = change in soil moisture storage, +ve or -ve (mm)

The average season irrigation inflow ($Qi_{\Delta t}$) and drainage outflows (*SD*) at system and field levels were obtained from daily average water flows calculated from water level records and the rating equation established through currentmeter measurement and flow weirs installed in the sample plot. Crop evapotranspiration (ET_c) was calculated using FAO CROPWAT model with minimum and maximum temperatures (T_n & T_x), relative humidity (*RH*), wind speed (m/s), solar radiation (*R*) being the main input parameters to the model. Percolation (Q_{bot}) or ground water losses was estimated as difference in the water balance equation. Secondary soil data were collected from Uyole Agricultural Research Institute (ARI-Uyole) and used in the CROPWAT model to estimate ET_c. Change in soil moisture (Δs) was estimated based on field soil moisture content at the beginning and at the end of crop season.

4.1.2. Physical water productivity determination

Water balance components together with crop yield measurements were used to empirically determine crop water productivity as the ratio of crop yield (kg) to amount of water (available and or depleted) at field level *(Eqns. 3-5*). Three indicators were applied to estimate productivity of irrigation water. These indicators include: total inflows (*P+I*); Irrigtion water (*I*) and crop evapotranspiration (ET_c).

$$WP_{(P+I)} = \frac{Y}{(P+I)} \tag{3}$$

$$WP_{I} = \frac{Y}{I} \tag{4}$$

$$WP_{ETc} = \frac{Y}{ETc} \tag{5}$$

where;

WP = water productivity (kg/m^3)

Y = crop yield or biomass (kg)

P, I, and ETc are precipitation, irrigation water and crop evapotranspiration for the irrigated area respectively (m^3)

4.1.3. Value of irrigation water for paddy

The value of irrigation water (economic productivity of water) for paddy was estimated using a theoretical generalized profit model. In the model, each agricultural producer is assumed to maximize profit by chosing the volume of irrigation water, capital, labour, and a vector of non-water inputs for rice production. Also, producers face water constraint, reflecting their water use right or water scarcity.

For a single product of rice (paddy), Y, produced by the factors of production: capital (K), labor (L), other inputs (Z) and water (W), the production function can be written (Eq. 6):

$$Y = f(K, L, Z, W) \tag{6}$$

According to Euler's theorem (Chiang, 1984), the total value of product (TVP) will be exhausted if each input is paid according to its marginal productivity (VMP). Assuming competitive factor and product markets, prices may be treated as constants (constant returns to scale). By the second postulate of the residual imputation method (Eq. 7) the TVP can be written:

$$TPV_{Y} = \sum_{i=j}^{N} VMP_{i} Q_{i} \tag{7}$$

Where:

TVP is the total value product Y, VMP*i* and Q*i* are the value marginal product and quantities of resource from i=j to N. N is the number of marginal products and quantities of resources, respectively.

The first postulate of the residual method, which states that P_i = VMP_i allow replacement of P_i into (Eq. 7), which after rearranging gives (Eq. 8):

$$TVP_Y - \sum_{i=j}^{N} P_i Q_i = P_w Q_w \tag{8}$$

When all the variables in equation 6 are known, then the unknown P_w can be solved to impute the value of residual claimant (water), Pw (Eqn. 9)

$$\frac{TVP_Y - \sum_{i=j}^{N} P_i Q_i}{Qw} = P_W \tag{9}$$

A questinnaire survey was administered from a sample of rice farmers in the Kapunga large rice irrigation scheme. Inputs during the production process for different production factors were collected. The Participatory Rural Appraisal (PRA) was part of the sampling strategy using the list of rice farmers in the scheme as the main sampling framework. The survey covered a total of thirty rice farmers from the study site using semi structured questionnaire. The collected data from the questionnaire survey were used for analysis of the value of irrigation water for paddy (rice).

4.2. Results and discussions

4.2.1. Soil water balance at scheme level

For the water balance analysis, conservation of mass requires that, for the domain over the time period of interest, inflows are equal to outflows plus any change of storage within the domain. At scheme level, change in soil moisture storage between the beginning and crop harvesting is considered negligible and irrigation inflows is accounted by gross water use and surface drains. The irrigation inflows in this particular study is the amount of irrigatation water which flows for every second into Kapunga Irrigation Scheme from Ruaha river. Of the total inflows, 73% is depleted within the scheme for crop evapotranspiration, surface water evaporation, domestic uses within the scheme and groundwater losses. Twenty seven percent (27%) of the gross inflows are accounted by surface drains at the drainage exit from the Kapunga Irrigation scheme.

The amounts of water balance components at scheme level reflects the current field water use operation in the rice farms. The amount of water inflows rises in January and attains peak from February to May (Figure 6). The inflows peak months correspond to peak period of rice transplanting activities which requires sufficient amount of water for paddling of rice field, actual transplanting and maintaining standing water layer in transplanted rice fields. From May, both inflows and gross water use declines to the minimum amount (<500*l/s*) in July which is allowed for canal maintenance. The decline in inflows and gross water use in the indicated period coincides with rice harvesting activities and by July, almost all rice fields are completely harvested. Generally, water dependent rice farming activities in the scheme starts from October for early transplanted rice. Early transplanted rice is normally harvested starting from

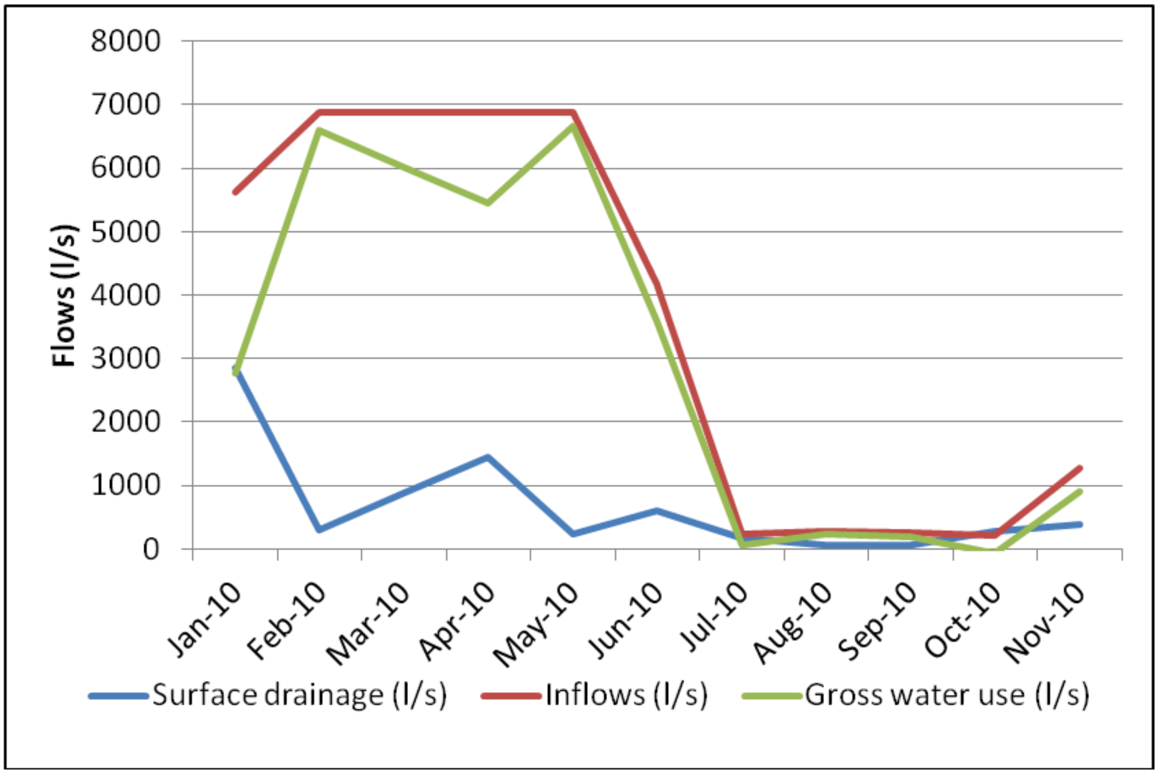

Figure 6. Irrigation inflows, gross water use and surface drainage for Kapunga water system

beginning of April while the bulk of the rice is harvested from the end of May to June. However, harvesting of late transplanted rice (April/May) may go up to July and early August.

Early transplanting has necessitated for extended rice farming season of about nine months from October to July or August, while the actual crop season of paddy rice varies between five and six months. The extended rice cropping season unnecessarily put more pressure on the limited water resources which would have been left to flow downstream for environmental uses in the wetland, Ruaha National Park and hydro-electric power generation in Mtera-Kidatu hydro system if rice crop season would have been restricted to within 6 months. For example, restricting rice crop season to six months from January would allow an extra of between 1.3m^3/s to 2.5m^3/s during November-December. This is the period when water is critically needed within the Great Ruaha River to sustain the ecosystem of the river in which portion of the river stream has been drying for the past ten years. During the 2010 crop season, a total of 3140ha were transplanted in the scheme. About 2290ha of the transplanted area belonged to Kapunga irrigation project while 850ha belonged to the Kapunga Smallholder farm. The gross irrigation inflows of 3579.21*l/s* is equivalent irrigation flows per second per hectare or irrigation hydromodule of 1.14 *l/s/ha.* The current irrigation hydromodule for Kapunga Irrigation scheme is slightly below commonly ratios (1.5-2 *l/s/ha*) used for design of irrigation systems in Tanzania. However, because of the lumped water balance for the current study, additional information would be required to determine the proportion of diverted water which is beneficially utilized for rice production at irrigation system level and ascertain performance of the scheme based irrigation flows.

4.2.2. Soil water balance at plot level

At field level, total inflows to the rice plot is partitioned into the amount of water used for rice nursery seedbed (150mm), rotavation or paddling (339 mm), transplanting (220mm) and effective rainfall- P_{eff} (480mm). Of the total inflows, 46% is lost outside the field in the form of percolation and evaporation into the atmosphere. Crop evapotranspiration (ET_c), which is only 202mm extra to effective rainfall, account for 28% of the total inflows (1). The water balance at plot level indicate that, at the end of crop season, there is a gain in soil moisture content of 34mm.

Water Balance Components	mm
Inflows (I+P)	2435.3
Nursery watering	150.0
Rotavation	339.9
Transplanting	220.0
Crop growth (up to harvesting)	1245.4
Rainfall (P)	480.0
ETc	682.7
Drains	186.5
Moisture change	-34.0
Losses (percolation, evaporation)	1120.1

Table 1. Soil water balance components at field (plot level)

Where the water losses, particularly percolation into the ground is not reclaimed for reuse within the system, then more than 54% of gross inflows at plot level is counted as water loss in the system. These water losses at plot level are influenced by use of large quantities of water during paddling, transplanting and maintaining a layer of water during the entire period of rice growth. High depth of standing water level have been observed to significantly contribute to groundwater percolation

The actual water requirement (ET_a) depends on climatic, water supply and crop growth conditions among other factors. Rice is one of the cereals with high crop water demand. Flooding, a common practice for rice farming in many rice-growing areas, increases demands for water in addition to ET_a. Rice may require over 1500 mm in tropics and sub-tropics (Guerra *et al*., 1998) because of the flooding practices employed in rice farming. In many rice farming areas, rice fields are flooded during land preparation to facilitate plowing and paddling the fields. Paddling reduces permeability of the plow layer, significantly reducing deep percolation losses during subsequent continuous flooding after rice transplanting. Increased depth of flooded water in rice fields may, however, contribute to increased percolation losses. Other functional roles of flooding in rice fields include weed suppression resulting in reduction of herbicides application, associated costs and environmental consequences, and atmospheric cooling that reduces heat stress to crop plants. Flooding also is applied to avoid crop failure due to unexpected delays in water supplies. Incorporating these functional roles of flooding, which do not necessarily contribute to crop evapotranspiration, certainly may complicate WP assessment. Increased demands for water for rice production are therefore inherent to the farming practices. For example, in Morocco, paddy rice water use during summer varied from 1700 to 2500 mm (Lage *et al.*, 2003). However, rice ET_a may vary from about 50% and more of the total rice water requirement (2).

ET_c [mm]	Source	Location
Rice		
450-700	FAO (1986)	General
665	Lage et al. (2003)	Morocco
586-599	Mohan et al. (1996)	Sub-humid south India
640	Jehangir et al. (2004)	Sub-tropical semi arid rice-wheat zone, Pakistan
Up to 800	Ahmad et al. (2004); Singh (2005)	Semi-arid climate (Pakistan and India)

Table 2. Estimates of ET_c for rice under different climatic conditions

Therefore, ET_c may vary from one location to another due to variations in climatic conditions, availability of water supply, length of crop growth, definition of crop evapotranspiration used, and crop yield.

The consumptive crop evapotranspiration in which significant proportion of water flow in an agricultural field pass through the crop (Bouman, 2007), would theoretically lead to higher estimates of the value of water if crop yield was much higher. Although using the ETc water productivity indicator would have been economically favorable, the underlying assumption, that water supplied to crop plants will only meet crop evapotranspiration is technically not feasible under flooded surface rice irrigation schemes. Apart from groundwater percolation, evaporation from standing water surfaces constitutes a part of irrigation water requirements. Therefore, the value of water based on consumptive ET is, in general, a primary target required to be attained by water management strategies at the scale of a plot, farm and irrigation scheme.

4.2.3. Physical water productivity

Productivity of water for rice in Kapunga irrigation scheme varies between 0.17kg/m^3 and 0.62kg/m^3 (3). Using the indicators: gross inflows, irrigation and crop evapotranspiration, water productivity increases as the amount of non beneficial water uses in the water balance equation is minimized. Ideally, it is desirable to increase irrigation water productivity (WP_I) to levels close or above to Crop evapotranspiration water productivity (WP_{ETc}). Although it is not possible to eliminate the amount of water which do not contribute to crop transpiration due to its functional roles such as cooling of crop plants, significant reduction of such water is critical for increasing productivity of water in the study area. Smaller values of $WP_{(I+P)}$ and WP_I compared to WP_{ETc} is primarily due to large quantities of water used for rice field operation during the crop season.

Water use components	mm of water	Equivalent volume of water (m³/ha)	Crop Yield (kg/ha)	Water productivity (kg/m³)
Inflows (*I+P*)	2435.3	24353		0.17
Irrigation (*I*)	1955.3	19553	4216.67	0.22
Crop evapotranspiration (ET_c)	682.7	6827		0.62

Table 3. Water productivity of rice

Crop water productivity may show wide ranges even in comparable agro-climatic and production situations. Using the kg/m³ ET measure from 82 literature sources, Zwart and Bastiaanssen (2005) found the range for rice to be 0.5–1.7 kg/m³. In the analysis of water productivity data for a total of 23 irrigation systems in 11 countries in Asia, Africa and Latin America using the $/m³ ET water productivity indicator, the International Water Management Institute obtained values in the range from US$ 0.03 per m³ (for a system in India) to US$ 0.91 per m³ (for Burkina Faso), with an overall average of US$ 0.25 per m³.

High spatial variability exhibited by WP_{ETc} (4), is mainly due to crop yield and climatic variation (Tuong and Bouman, 2003). WP_{ETc} values for rice in the current study fall within the ranges of global averages (Cai and Rosegrand, 2003), but values are below the average WP_{ETc} reported by Zwart and Bastiaanssen (2003).

WP_{ETc}	Source	Location
0.4-1.60	Tuong and Bouman (2003)	Literature under Asian field conditions
0.51	Ahmad et al. (2004)	Pakistan
0.94	Singh (2005)	India
1.08	Zwart and Bastiaanssen (2003)	Review of 82 publications of the last 25 years
0.15-0.60	Cai and Rosegrant (2003)	Global averages based on 1995 production scenarios

Table 4. Water productivity of rice in terms of yield (kg) per m³ of WP_{ETc} reported in literature

Although obtained water productivity based on gross water inflows and irrigation inflows are within WP ranges in sub-Saharan Africa (0.1-0.25kg/m³) and other parts such as India (0.19-0.22kg/m³) the values are low. Generally, there is potential for water productivity improvement at scheme and at plot level. Improvement in WP could be achieved through reduction of non beneficial outflows and minimizing extended crop seasons with critical implications on water use. Non beneficial water use already account for about 60% of gross water inflows on the rice plots.

http://dx.doi.org/10.5772/52471

5. The value of irrigation water for rice

5.1. Farming input in rice production

Apart from irrigation water, farmers need capital, non water inputs and labour to facilitate field operation during the crop season. In the current study, capital is referred to the amount of money the farmer pays to rent a 6 hectare plot, plow and rotavate the plot. The renting charge during the 2010 crop season was Tsh. one Million. After renting the plot, a number of field operations are undertaken before the paddy rice can be transplanted. The operations include clearing of the plot, plowing, preparation and raising of rice nursery. Depending on farmers circumstances, rice nurseries seedbeds can be prepared before plowing of the entire plot. When rice seedlings have reached enough height for transplanting, the field would be rotavated or paddled to facilitate for easier transplanting. All the mentioned operation requires water as an input or media to easy field operation. In the most cases, plowing and rotavating are mechanized operations.

Non water inputs in paddy rice farming include seeds, fertilizers, insecticides, herbicides sacks for bagging harvested rice (5). Seed application per hectare vary between 18.7kg and 160kg with an average application of 102.9kg/ha. Average fertilizer use during the study crop season was 156kg/ha. This amount of fertilizer is distributed into 3.7kg for rice nurseries, 87.1kg and 65.1kg during the first and second application after transplanting. Diammonium Phosphate (DAP), UREA and Sulphate of Ammonia (SA) were the common used types of fertilizers in rice farming in the study area. Herbicides (2-4D-Amine) and insecticide (*Lambda Cyhalothrin*-KARET) uses were only limited to an average of 1.5 litres and 1.2 litres per hectare respectively. Also about 32 sacks are used per hectare to fill harvested and threshed rice before they were directly sold or transported for storage.

S/N	Farm input	*N*	Minimum	Maximum	Mean
1	Seed (kg)	*31*	18.7	160.0	102.9
2	Amount of fertilizer application				
	Rice seedlings (kg)	*17*	0.7	30.0	3.7
	First application after transplanting (kg)	*29*	41.7	133.3	87.1
	Second application after transplanting (kg)	*18*	33.3	125.0	65.7
3	Herbicide (litres)	*12*	1.0	2.3	1.5
4	Insecticide (litres)	*25*	0.6	2.5	1.2
5	Sacks bagging for harvested rice	*31*	13.3	53.8	32.3

Table 5. Non water farm inputs per hectare for paddy rice in Kapunga large irrigation scheme

5.2. Labour input per hectare

A number of labour dependent activities are normally conducted during the rice crop season (6). Rice farming is one of the labour intensive activities. The average total labour requirement per hectare throughout the crop season is about 167 mandays. For rice with crop growth period of three months, the labour input is almost equivalent to two people continuously working on the farm during the entire season. Transplanting and weeding are the most labour intensive activities, each utilizing 41 and 60 mandays per crop season per hectare, respectively. Transplanting and weeding are manually done and weeds may become intensive where herbicides application is minimal and where plant spacing is high. Harvesting and bird scaring are also labor intensive activities after weeding and transplanting. Other manual field operations, i.e., farm clearing, preparation of rice nurseries, agrochemical application and bunds cleaning require less than 5mandays per hectare.

	Farm operations	N	Minimum	Maximum	Mean
1	Farm clearing	27	1.7	16.7	4.5
2	Ploughing	30	0.3	1.1	0.4
3	Preparation of rice nurseries	25	0.8	10.0	2.7
4	Rotavation	31	0.3	2.3	0.5
5	Transplanting	29	12.0	80.0	40.8
6	First weeding	27	6.3	95.0	30.4
7	Second weeding	23	9.0	60.0	29.6
8	Fertilizer application	11	0.0	0.2	0.1
9	Herbicide application	12	0.1	1.0	0.5
10	Insecticide application	12	0.0	1.0	0.3
11	Bunds clearing	30	1.0	4.5	2.1
12	Bird scaring	31	7.5	30.0	16.0
13	Canal cleaning	1	2.0	2.0	2.0
14	Harvesting	31	3.3	60.0	27.6
15	Winnowing, stitching bags and drying	6	2.7	20.0	9.1
	Total				167

Table 6. Labour use in field operation on paddy rice farm in Kapunga large irrigation scheme

5.3. Cost of farming operation, labour and farming inputs

The cost of rice farming can be divided into three main categories (7). The first category relate to direct costs of field operation, which include renting of rice plot from Export Trading Ltd,

http://dx.doi.org/10.5772/52471

plowing and rotavation. These farm operations are mechanized and account for about 38% of the farm operation and labour cost. The second category concern the labour cost for various field operations and it accounts for 62% of the farm operation and labour cost. The third category is cost of farm inputs which include seeds and agrochemicals (fertilizer, insecticides and herbicides). Depending on the amount of fertilizer use, the total cost of farm input per hectare varies between Tsh. 180,867 and 278,167. The cost of fertilizer under this category accounts for 80% and the remaining 20% represents the cost of seeds, insecticides and herbicides. Therefore, the total cost per hectare of farming rice paddy is about Tsh. 1,332,433. For the existing 6ha plots in Kapunga Rice Project, one would need to have about eight million Tanzanian shillings in order to produce rice in the scheme.

Farming operation and labour			**Cost of farm input**			
S/N	Field activity	Cost (Tsh/ha)	S/N	Farm Input	Quantity/ha	Unit cost (Tsh)
1	Renting of the farm	166,667	1	Seeds	103kg	500/kg
2	Plowing the farm	150,000	2	Fertilizers		
3	Rotavation	83,333		• DAP	100 kg	1000/kg
				• UREA	100 kg	700/ kg
4	Nursery seedbed preparation	7,000		• SA	75 bags	700/kg
5	Farm clearing	10,000	3	Insecticides (KARET)	1 litre	2000/litre
6	Transplanting	175,000	4	Herbicides (2-4D)	1 litre	2167/litre
7	Weeding (First and Second)	133,333				
8	Labour for fertilizer application	11,000				
9	Cost of insecticide application	8,333				
10	Cost of herbicide application	8,333				
11	Bird scaring	26,267				
12	Harvesting	125,000				
13	Thrashing, winnowing and balling	150,000				
	Total	1,054,266				

Table 7. Cost of farming operation, labour and farming inputs

5.4. Crop yield, input contribution and economic return to water

Rice crop yield varies between 1493kg and 6029kg with average yield of 3517kg. The average crop yield from surveyed farmers during the 2010 crop season is less by 17% to rice yield on the sample study plot monitored during the crop season. Based on farm gate price of 600 Tsh/ kg of harvested and threshed rice, the average revenue of rice production is Tsh. 2,110, 200. The revenue per hectare varies between Tsh. 895,000 and Tsh. 3, 617,400 (8).

Variable	Minimum	Maximum	Mean
Yield (kg)	1493	6029	3517
Total revenue (Tsh)	895,800	3,617,400	2,110,200
Capital (Tsh)	326,000	474,000	400,000
Labour (Tsh)	354,266	954,266	654,266
Non water inputs (Tsh)	212,167	344,167	278,167
Return to water (Tsh)	3,367	1,844,967	777,767

Table 8. Crop yield, total revenue and per hectare share of production inputs

The contribution of capital, labour and non water inputs to the average revenue stand at 19%, 31% and 13%, respectively. This implies the contribution of water to current estimated average revenue is about 37%. The contribution of water varies between 0.4% for minimum crop yield to 51% when the maximum crop yields of 6029kg/ha is attained. The estimated contribution of water to total rice production revenue shows that when capital and the value of marginal product for labour and non water inputs are higher at low crop yield in the study area, the contribution of water to the total revenue becomes much marginalized. However, the contribution of water to the total revenue is evident when the maximum crop yield is considered. The small contribution of water to the total revenue imply a low value of water for rice production.

5.5. Estimated value of water for rice production

The value of water for rice in the study area is estimated using the three water balance indicators established at plot level, i.e., gross inflows (P+I), Irrigation inflows (I) and crop evapotranspiration -ETc (9). Estimated value of water is based on the assumption that the influence of market irregularities on goods and services on farming operations during the study period was minimal and that costs were representative of local markets. The obtained value of water for rice using the three water productivity indicators is low and decreases as the volume of water considered in the productivity equation increases. This is due to the fact that there are significant proportions of non beneficial amount of water under irrigation and gross inflows.

Variable	Tsh/ha	Eq. US$/ha
Average economic return to water	777,767	519
Water balance components	Value of irrigation water	
	Tsh/m^3	Eq. US$/m^3
Gross inflows (P+I)	32	0.02
Irrigation inflows (I)	40	0.03
Crop evaptranspiration (ET$_c$)	114	0.08

Table 9. Estimated value of water for rice irrigation (The exchange rate of 1US$=1500 Tsh has been used).

The result above (9) represents typical and common characteristics of the value of water in agriculture, particularly for flood irrigated rice. Using the net value of output with and without charging family labour, Bakker and Matsuno (2001) obtained 0.03US$/m^3 and 0.05US$/m^3 as the value of water for paddy irrigated rice during the Yala season in Sri Lanka. Their estimated value increased by 75% to 0.12US$/m^3 when the gross value of output was used instead of the net value of output. However, gross value of the output includes other production inputs apart from water and therefore is not a good indicator of the value of water. In Bangladesh, the value of water for irrigated boro rice ranges from US$ 0.002 to 0.015 per m^3 (Chowdhury-undated). Rogers *et al.* (1998) estimate the value of water in agriculture in Haryana in North western India at US$ 0.02 per cubic meters. According to Sadoff *et al.*, (2003) the user value of water in irrigated agriculture is typically in the range of US$ 0.01 – US$ 0.25 per cubic meter. The lower end of this range is represented by large scale irrigation of rice and wheat while the higher end of the range is represented by high value fruits and vegetables. Comparing to municipal and other industrial water uses, the value of water for agricultural use is the lowest. Kijne *et al.*, (2003) obtained an average value US$ 0.19 per m^3 for agriculture while the value of water for industrial use was US$ 7.5 per m^3.

Hellegars (2005) argue that, where irrigation water is scarce, its marginal value ranges usually between US$ 0.05 and US$ 0.15. This value is, of course, strongly dependent on the price of agricultural products, which in turn are strongly affected by government interventions on marketing of agricultural commodities. Although the value of water estimated from the current study is within Hellegars's suggested range under irrigation scarcity, it is the farm operation, water management and price of agricultural input and outputs which determine the current estimated value of water for rice in Export Trading Ltd. This implies that there are potentials for improving the value of water through improved water management and agronomic practices in rice field operations.

6. Strategies for improving water productivity

Water related management strategies for improving WP include optimizing water use for raising rice seedlings in rice nurseries, reduction of water losses from intensive water use activities and synchronizing periods of increased water demand for rice farming activities with period of increased river flows.

Under the current practice, with an exception of Kapunga Rice Project operated plots, rice seedlings are raised in each of the 6ha plots rented by individual farmers. The number of raised nurseries for rice seedlings depends on the number of renting farmers and rented plots. Because the designs and layout of large plots lack provisions for water supply to small prepared nursery seedbeds, the entire plot is normally flooded with water when the seedlings are irrigated. As a result, about 25mm per hectare is used for water rice nurseries only. Assuming that 50% of the rice plots in Kapunga Irrigation Project are rented, then more than 40m of irrigation would be used for raising rice nurseries only. However, less water can be used if rice nurseries growing can be accommodated in few irrigation plots sparsely located within the farm. Under such arrangement, what has to be ensured is water allocation to different plots with rice seedlings.

Water intensive activities for rice production in the study area also included paddling or rotavation, transplanting and maintaining water layer throughout the crop season. Although the use of water facilitated some of the field operation, especially paddling, this softens the soil before transplanting and maintained water layer which controls weeds and therefore the cost of rice farming, increased use of water contribute to increased water losses through deep percolation and surface evaporation at plot level. For example, the average water level varied between 7cm during the first week after transplanting and 40cm during the mid of the crop season (Figure 7). Higher water levels in rice field are associated with increased deep percolation and evaporation losses.

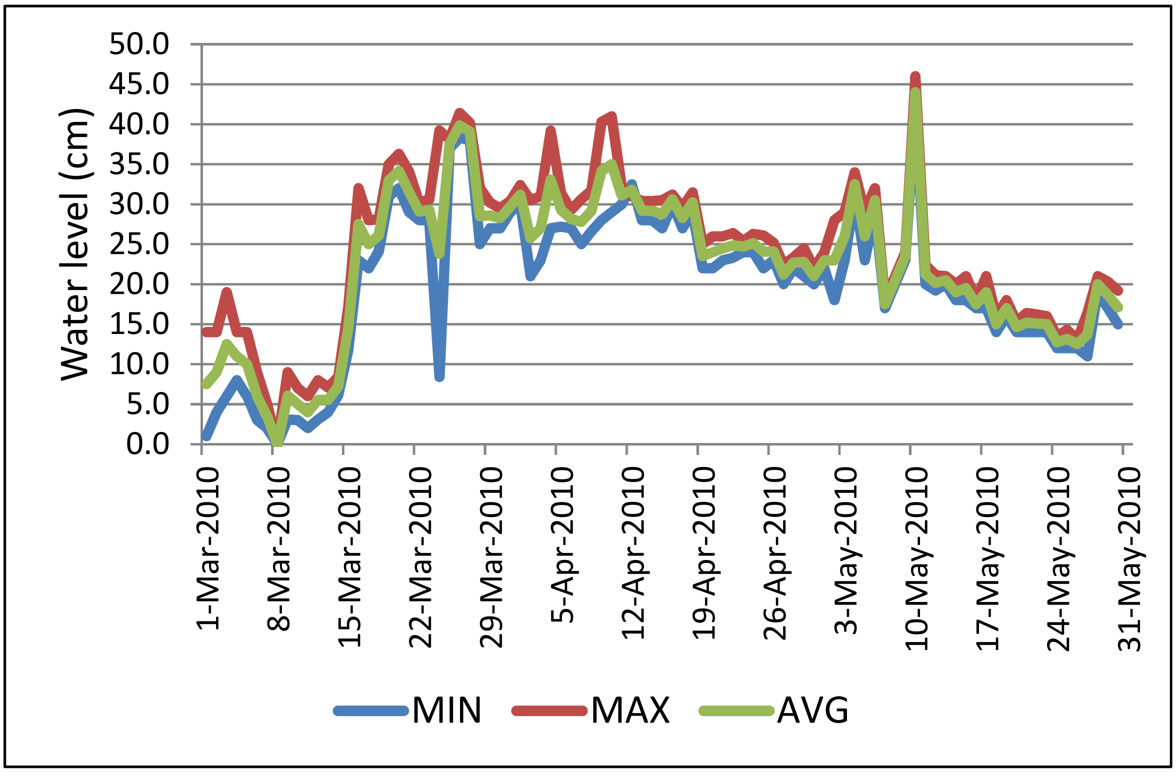

Figure 7. Water levels maintained in rice field during the crop season

Rice field preparation (farming season) in the study area normally starts between September and October each year. This is the period when river flows in the catchment including the Ruaha River which supplies water to Kapunga Rice Project are lowest. Water diversion during the period constrains the amount of environmental flows required for ecosystem services. The early start of rice farming activities prolongs crop season from the normal five months to nine months because it is only the upstream water users who get access to water at the beginning of crop season. However, if the timing for increased water demand activities (rotavation and transplanting) was synchronized with onset of rainfall and period of increased river flows (December-January) it would significantly reduce crop season and gross water use (Figure 8). For example, the effective rainfall received between mid December and end of January, which account for about 36% of the total amount of water used for land preparation, when effectively combined with irrigation water within the period, may result into reduction of gross water use to about 2100mm. The contribution of rainwater and the synchronization of peak water demand with increased river flows have not been given priority under the current management system of the Kapunga Irrigation Project.

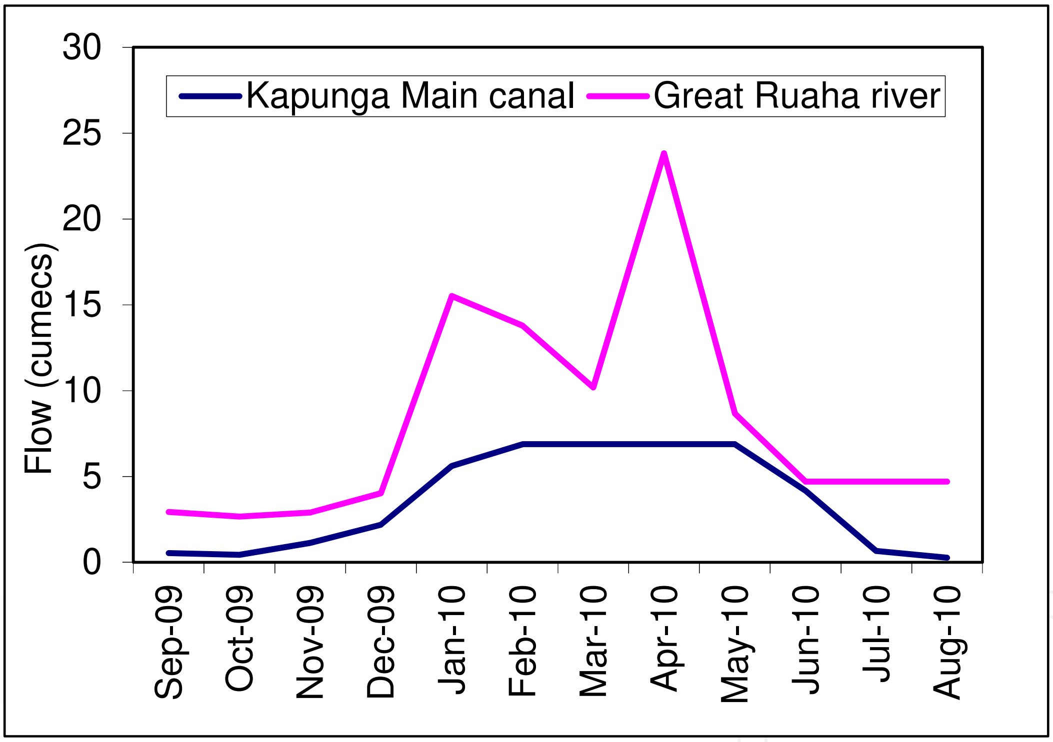

Figure 8. Seasonal hydrograph of Ruaha river and Kapunga Rice Project main canal

7. Summary and conclusion

Improving water productivity is one of the most important strategies toward confronting water scarcity. The main objective of the present study was to determine productivity of water in large rice irrigation schemes in the Great Ruaha River Basin. The specific objectives were to estimate the seasonal water balances at scheme and field levels for rice production; estimate physical productivity of water for rice; determine the value of water for rice production and propose strategies for improving productivity of water in large rice irrigation schemes.

At scheme level, 73% of the gross irrigation inflows are depleted within the irrigation scheme and the remaining 27% are counted as surface drains. However, due to lumped water balance approach in the current study, scheme depleted component of the water balance encompass groundwater and surface water losses, as well as other water use of the irrigation water. Disaggregating lumped water balance components will facilitate for precise quantification of the amount of water depleted by crops and the actual water losses into the system. At plot level, crop evapotranspiration represent only 28% of the gross inflows into the plot. Of these, effective rainfall account to 70% and the remaining 30% is provided by irrigation water. Surface drains and losses due to percolation into the ground and surface water evaporation account for 8% and 46% of the gross inflows respectively. The water balances, both at scheme and plot level, are influenced by field water dependent operation with increased volume of water use during field operation before transplanting and maintaining water layer after transplanting.

The estimated physical water productivity for rice based on gross water inflows, irrigation inflows and crop evapotranspiration vary between 0.17kg/m^3 and 0.62kg/m^3. Although obtained WP values are within the ranges of WP from different agro-ecological regions, the values are generally low, particularly for WP $_{(I+P)}$ and WP_I. However, potential for WP improvement exist through, among others, reduction of non beneficial outflows at plot and scheme levels and limiting extended rice growth period.

A number of field operations which require capital, labor and non water inputs are undertaken for rice farming. The contribution of capital, labour and non water inputs to the total revenue of rice production per hectare stand at 19%, 31% and 13%, respectively. This implies that the contribution of water to the total revenue is 37%. Based on gross inflows, irrigation inflows and crop evapotranspiration water use, estimated values of water are Tsh. 32/m^3 (US$ 0.02/m^3), Ths 42/m^3 (US$ 0.03/m^3) and Tsh 114/m^3 (US$ 0.08/m^3), respectively. The values are typical and characteristic of reported values of water in agriculture, particularly for flood irrigated rice. The obtained values of water in the current study are very much influenced by farm operations, field water management practices and the market of agricultural inputs and harvested rice product. However, as observed for estimated physical water productivity, potential also exist for improving the value of water for rice production.

A number of water management strategies can be applied to improve the current water productivity in large rice irrigation schemes. These strategies include optimisation of water use in rice field operations, reduction of water losses from rice water use activities and sychronisation periods of increased water demand for rice farming with period of increased rainfall and river flows. Such strategies, if implemented, will improve the value of water and at the same time allow sufficient flows of water to meet environmental demands in the downstream of the river.

http://dx.doi.org/10.5772/52471

Acknowledgements

The authors acknowledge SIDA through ARU-Sida Research Cooperation Programme for funding this research.

Author details

Makarius Victor Mdemu* and Theresia Francis

*Address all correspondence to: mmdemu@uni-bonn.de/mmdemu@aru.ac.tz

Department of Regional Development Planning, School of Urban and Regional Planning, Ardhi University, Dar es Salaam, Tanzania

References

[1] Ahmad M.D., Masih I and Turral H (2004) Diagonostic analysis of spatial and temporal variations in crop water productivity: A field scale analysis of the rice-wheat cropping systems of Punjab, Pakistan. J. Appl. Irrig. Sci. 39: 43-63

[2] Bakker, M. and Y. Matsuno 2001 A framework for valuing ecological services of irrigation water: A case of an irriagation-wetland system in Sri Lanka. Irrigation and Drainage Systemes 15:99-115

[3] Bouman, B.A.M. (2007) A conceptual framework for the improvement of crop water productivity at different spatial scales. Agric. Syst., 93 (1-3): 43-60

[4] Cai X. and Rosegrant M.W. (2003) World Water Productivity: Current Situation and Future Options. In: Kjine et al. (eds.) (2003) Water Productivity in Agriculture. CAB International, Wallingford, UK

[5] Chiang A.C. (1984) Fundamental methods of mathematical economics. Third edition. New York: McGraw-Hill

[6] Chowdhury, N.T. (undated) The economic value of water in the Ganges-Brahmaputra-Meghna (GBM) River Basin, Department of Economics, Goteborg University, Sweden

[7] Cook S., Gichuki F. and H. Turral (2006) Agricultural Water Productivity: Issues, Concepts and Approaches. Basin Focal Project Working Paper No. 1 (Draft). http://waterandfood.org/.../CPWF_Documents/Documents/Basin_Focal_Projects/BFP_restricted/Paper_1_Final_14JY06.pdf. Accessed 22 March 2012

[8] Dong B., Loeve R., Li Y.H., Cheng C.D. and Molden D. (2001) Water productivity in the Zhanghe Irrigation System: Issues of Scale. In: Barker et al. (eds) (2001) Water-

Saving Irrigation for Rice. Proceedings of an International Workshop, Wuhan, China 23-25 March 2001

[9] Guerra L.C., Bhuiyan S.I., Tuong T.P. and Barker R. (1998) Producing More Rice with Less Water from Irrigated Systems. SWIM Paper No. 5. Colombo, Sri Lanka, International Water Management Institute, 24 pp

[10] Igbadun, H.E., H.F. Mahoo, A.K.P.R. Tarimo and B.A. Salim 2006 Crop water productivity of an irrigated maize crop in Mkoji sub-catchment of the Great Ruaha River Basin, Tanzania. Agricultural water management, Vol.85 (1-2), 141-150

[11] Jehangir W., Turral H. and Masih I. (2004) Water productivity of rice crop in irrigated areas. 4th International Crop Science Congress, Brisbane, Australia. http://www.cropscience.org.au/icsc2004

[12] Kadigi, R.M.J, J.J. Kashaigili, N. S. Mdoe 2004 The economics of irrigated paddy in Usangu Basin in Tanzania: water utilization, productivity, income and livelihood implications, Physics and Chemistry of the Earth 29:1091–1100

[13] Kijne J.W., Tuong T.P., Bennett J., Bouman B. and Oweis T. (2002) Ensuring Food Security via Improvement in Crop Productivity of water. Challenge Program on Water and Food. Background Paper1.CGIAR, 44 pp

[14] Kijne, J.W., T. P. Tuong, J. Bennett, B. Bouman and T. Oweis (2003), Ensuring Food Security via Improvement in Crop Water Productivity, Challenge Program on Water and Food Background Paper 1.

[15] Kijne, J.W.; R. Barker; and D. Molden (eds.) (2003). Water Productivity in Agriculture: Limits and Opportunities for Improvement, CABI Publication, Wallingford UK and Cambridge MA USA

[16] Lage M., Bamouh A., Karrou M. and El Mourid M. (2003) Estimation of rice evapotranspiration using microlysimter technique and comparison with FAO Penman-Monteith and Pan evaporation methods under Moroccan conditions. Agron. 23: 625-631

[17] Lankford, B. A., van Koppen, B., Franks, T. and Mahoo, H. 2004. Entrenched views or insufficient science? Contested causes and solutions of water allocation; insights from the Great Ruaha River Basin, Tanzania. Agricultural Water Management 69:2 135-153

[18] Mdemu, M.V., M.D. Magayane, B. Lankford, N. Hatibu, R.M.J. Kadigi 2004 Conjoining rainfall and irrigation seasonality to enhance productivity of water in rice irrigated farms in the Upper Ruaha River Basin, Tanzania Physics and Chemistry of the Earth 29: 1119–1124

[19] Mohan S., Simhadrirao B. and Arumugam N. (1996) Comparative Study of Effective Rainfall Estimation Methods for Lowland Rice. Water Res. Manage. 10: 35-44

[20] Molden D., Murray-Rust H., Sakthivadivel R. and Makin I. (2003) A water-productivity framework for understanding and action. In: Kijne W, Barker R and Molden D (eds) Water productivity in agriculture: Limits and opportunities for improvements. CAB International, Wallingford, UK

[21] Molden D., Sakthivadivel R. and Habib Z. (2001) Basin-level use and productivity of water: Examples from South Asia. Research Report 49. Colombo, Sri Lanka: International Water Management Institute (IWMI) 24 pp

[22] Molden, D. (1997). Accounting for water use and productivity. SWIM Paper 1. Colombo, Sri Lanka: International Irrigation Management Institute. 26pp.

[23] Renwick M.E. (2001) Valuing water in a multiple-use system: Irrigated agriculture and reservoir fisheries. Irrig. Drainage Syst. 15: 149–171

[24] Rijsberman F.R. and Molden D. (2001) Balancing water uses: water for food and water for nature, thematic background paper. International conference on freshwater, Bonn, 18 pp

[25] Rogers, P., R. Bhatia and A. Huber (1998), Water as a Social and Economic Good: How to Put the Principle into Practice, paper prepared for the meeting of the Technical Advisory Committee of the Global Water Partnership in Namibia.

[26] Rosegrant M.W., Cai X. and Cline S.A. (2002) World Water and Food to 2025, Dealing with Scarcity. International Food Policy Research Institute, Washington D.C. 322p

[27] Sadoff, C., D. Whittington and D. Grey (2003), Africa's International Rivers: An Economic Perspective, World Bank, Washington DC.

[28] Seckler D., Molden D. and Sakthivadivel R. (2003) The Concept of Efficiency in Water resources Management and Policy. In: Kijne et al. (eds.) (2003) Water Productivity in Agriculture. CAB International, Wallingford, UK

[29] Singh R. (2005) Water productivity analysis from field to regional scale: integration of crop and soil modeling, remote sensing and geographical information. Doctoral thesis, Wageningen University, Wageningen, The Netherlands, 146 pp

[30] SMWUC, (2001) Main Report. The Usangu catchment Baseline Report.

[31] Tropp H., Falkenmark M. and Lundqvist J. (2006) Water governance challenges: Managing competition and scarcity for hunger and poverty reduction and environmental sustainability. Background paper (Final draft): Human Development Report 2006, Water for Human Development, 46 pp

[32] Tuong T.P. and Bouman B.A.M. (2003) Rice Production in Water-scarce Environments. In: Kjine et al. (eds.) (2003) Water Productivity in Agriculture. CAB International, Wallingford, UK

[33] UNDP (2006) Beyond scarcity: Power, poverty and the global water crisis. Human Development Report 2006, 422 pp

[34] Wichelns D. (2002) An economic perspective on the potential gains from improvement in irrigation water management. Agric. Water Manage. 52: 233-248

[35] WWF, 2006 Integrated water resource management in the Great Ruaha River Catchment, Tanzania, Project Proposal

[36] Xie M., Küffner U. and Le Moigne G. (1993) Using Water Efficiently. Technological Options. World Bank Technical Paper No. 205. Washington D.C., World Bank

[37] Zwart S.J. and Bastiaanssen W.G.M. (2003) Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agric. Water Manage. 69(2): 115-133