Water re-use in river basins: a solution to increase water efficiency and productivity? The Usangu case study, Tanzania

Machibya Magayane. Independent Consultant, ITECO Consult (T) Ltd, P.O.BOX 67371, Dar Es Salaam, Tanzania, Emails: Machibya_m@yahoo.com

Makarius Mdemu. Center for Development Research (ZEF), Bonn - German. Email: mak_mdemu@yahoo.co.uk

Many river basins in Tanzania are experiencing competition over scarce water resources such that runoff and drainage, if any, from one user located in the upstream, is intensively utilized by immediate downstream users. Research was conducted to explore how water use efficiency and productivity, at system level that have water reuse, could be related to the efficiency and productivity of individuals within the water reuse systems. Two irrigation systems having a chain of three users (Top, Middle and End users) reusing the runoff from upstream farms were sampled for investigation in the Ruaha river sub basin.

Using limited existing method of assessing irrigation efficiency and productivity of water reuse systems, it was observed that the system which consisted of farmers with lower individual efficiency and productivity resulted on lower water reuse efficiency (90%) and productivity ($0.55 kg/m^3$). Alternatively, the system consisted of individuals with relatively higher efficiency resulted on higher water reuse efficiency of about (93%) and productivity ($0.72 kg/m^3$).

However the paper concludes that current methods of assessing irrigation efficiency and productivity of water reuse does not accurately assess key conditions inspired by the Usangu situation and which affect the irrigation efficiency and productivity of water reuse in the area. The paper further concludes that irrigation efficiency and productivity of individual farms in any water reuse system is the major contributor towards high water reuse efficiency and productivity.

Key words: Upstream, Downstream, Irrigation, Water reuse, efficiency, Productivity, irrigation systems

Introduction

The Usangu basin

The Usangu Basin (USB), which is located in South West of Tanzania, forms an important part of the upper catchment of the River Rufiji, Tanzania's largest river basin. Usangu basin covers an area of about 20 800 km^2 and is home to over 300 000 people, most of whom depend for their livelihoods on the natural resources of the basin (Lankford and Franks, 2000; SMUWC, 2001). .

The basin consists of a mountainous and well-wooded area with high rainfall in the south, falling to an extensive flat plain in the north. Within the plain there are large areas of alluvial fans, supporting the majority of the settlements in the catchment, as well as irrigated and dryland farming. The alluvial fans in turn give way to an extensive wetland, comprising seasonally flooded grassland and a much smaller area of permanent swamp. The outflow from the swamp is controlled through a weir in the form of a natural rock outcrop, from where all downstream flows from Usangu are channelled through the Great Ruaha River. The Great Ruaha flows first through the Ruaha National Park, and then to the Mtera/Kidatu hydropower reservoirs on the Rufiji River.

The mountainous area which forms the upper part of the catchment reaches a height of 3 000 m in some places, and has a rainfall between 1 000 and 1 600 mm annually. It is well drained by means of a number of perennial rivers falling sharply over an escarpment to the plain below. The plain is at a mean altitude of 1 100 m, with a much lower rainfall, at around 700 mm annually. This rainfall is concentrated in the period of December to March, and is followed by a prolonged dry season. River flows are at their lowest in November.

The basin and its downstream reaches can be considered as five linked sub-systems hydrologically: the upper catchment; the alluvial fans; the wetland; the riparian reach through the Ruaha National Park; and the Mtera/Kidatu hydroelectric system (Machibya, 2003; SMUWC, 2001). All these subsystems provide a significant contribution to Tanzanian economy. The linkage and coordination of these subsystems is vital because they impact in one way or another the water resources of the Usangu basin.

Irrigation and water reuse in Usangu

Irrigation, particularly rice irrigation is a key activity for the livelihood of over 30,000 households residing in the Usangu basin. As mentioned earlier, the Usangu basin has considerable water resources provided by six major rivers that flow from the upper catchment to the plain. These are Ruaha, Kimani, Mkoji, Chimala, Mbarali and the Ndembera. Water in these rivers is abstracted for rice production and domestic use immediately after the high catchment before they enter into the Usangu wetland (also called the Ihefu). The Usangu wetland has a natural exit at Ngiriama which releases water to the Ruaha National park and thereby to the Mtera and Kidatu hydro power stations, further downstream.

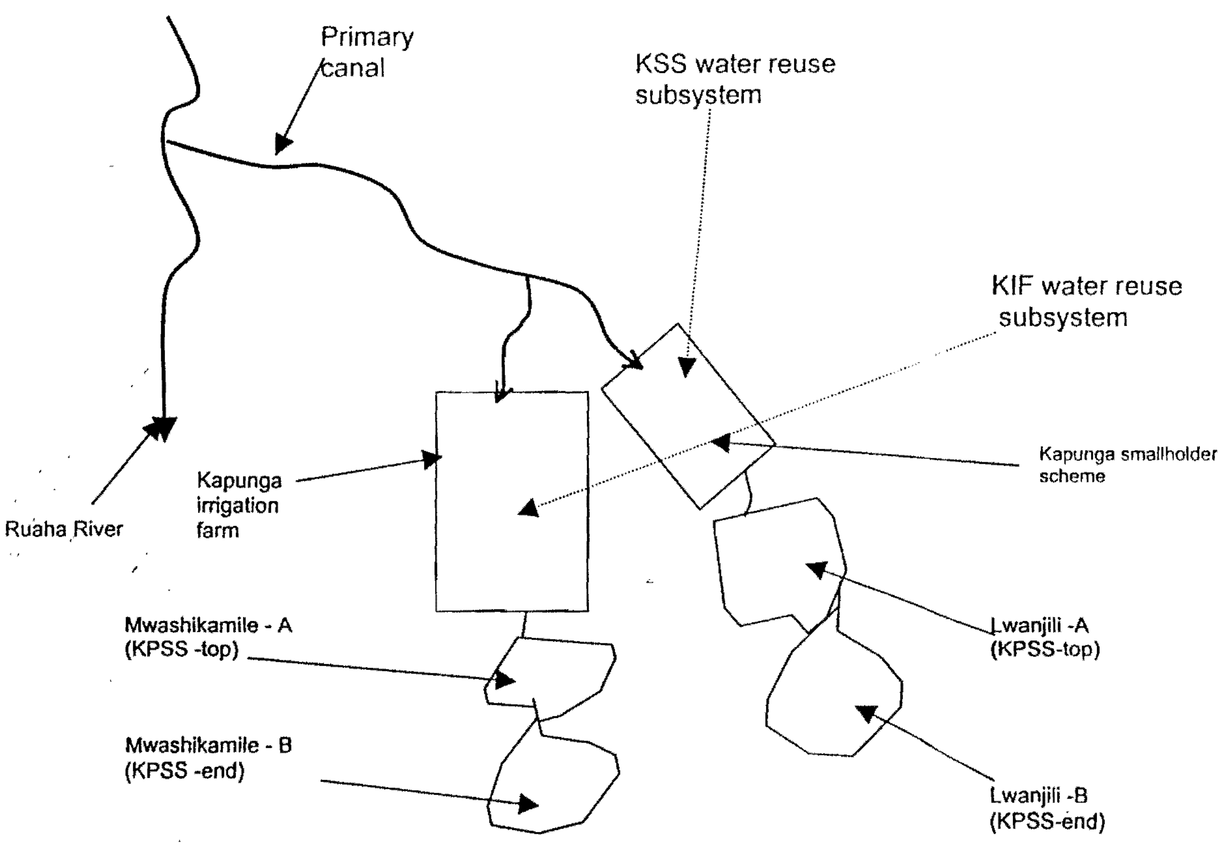
Due to this connected multiple use and increase in population; the rivers have increasingly been subject to utilisation for different sectors. The Usangu basin is now well known in Tanzania as being water scarce. Within irrigation, farmers access water either directly from rivers through intakes or via the utilization of runoff from the upstream users, the process known as "water reuse". Water reuse has received an international recognition in river basins as a mechanism that increases water efficiency and productivity (Keller et al., 1996; Perry, 1999). The concept reveals that if say "X" amount of water is abstracted by farmer A and then released as runoff to farmer B and later on to farmer C both efficiency and productivity of the system comprising the three farms will increase. This paper discusses the extent of efficiency and productivity gain in such systems and limitations of the existing methods to evaluate the water reuse in the Usangu water reuse systems.

Materials and Methods

Materials

Two water reuse subsystems (Figure 1) were selected for study during the 1999 - 2001 in the Usangu basin to investigate the impact of water reuse to irrigation efficiency and productivity. The first chain of water reuse consisted of three farms Kapunga irrigation farm, Mwashikamile (A) and Mwashikamile (B) and the system was acronymed as "KIF-water reuse subsystem". The second chain consisted of Kapunga smallholder scheme (KSS), Lwanjiri-A (KPSS-top) and Lwanjili – B (KPSS-end). This was acronymed as "KSS-water reuse subsystem".

Figure 1: Schematic presentation of KIF and KSS water reuse systems



Detailed measurement of gross and net crop water requirement in each of the selected water reuse system was monitored through out the research period using standard procedures (Machibya, 2003). An experimental plot was chosen for installation of the following equipment to monitor the water balance: flumes to monitor inflow and outflows, rain gauges for rainfall monitoring, oil drums (lysimeters) to monitor paddy transpiration, evaporation, lateral and deep percolation, and subsurface movement across field. Oil drums (plastic or steel) are acceptable lysimeters, in which water losses, seepage, evaporation and then crop water requirements could be estimated (Machibya and Mdemu, 2005) The lysimeters applied during this study were made of plastic, having a height of 900 mm and diameter of 350 mm. The installation process took place on puddling day. This was done in order to create similar soil environments in the lysimeter and in the field. The installation was done as explained below.

Each lysimeter was buried into the paddy experimental plot to a depth of 400 mm and then filled with the puddled soil from the same field. The soil filling into the lysimeters was done whilst ensuring that the soil level in the main field was equal to the soil level in the lysimeter. When the water was allowed into the main field up to a certain level, the same level was made in the lysimeter, and this was carried out on a daily basis, as explained later. Each installed lysimeter, in each plot, was treated differently to fulfill the objectives of the water balance experiment as described next.

For determination of deep percolation, a lysimeter had its bottom lid removed so that it was hollow in nature. Daily recording of changes in water levels (evaporation and deep percolation) in the lysimeter was done with the assistance of a level hook, as discussed later.

Evaporation from a cropped field was monitored using a lysimeter fully sealed at the bottom. The only way water exited from this lysimeter was through evaporation. The main purpose of this lysimeter was to assess the actual annual amount of water that evapotranspirated from a field with paddy plant in it. The lysimeter was therefore installed in a paddy field but no paddy was planted inside it.

Paddy transpiration was estimated using a lysimeter fully covered at the bottom and planted with paddy inside. The paddy planted inside the lysimeter was planted the same day and had the same planting spacing as in the main fields.

Methods of evaluating efficiency and productivity of individual farms

In order to obtain the gross annual crop water requirement of each rice plot, the collected data were balanced and computed using model equation (1) below at the end of each season. The purpose here was to obtain the component which could not be directly measured (lateral and subsurface movement of water).

$$\{R + I\} = \{Ev + Tr + ADp + R_o + (Lp + {}^{*}s)\} \qquad (1)$$

Where:

R = Annual rainfall, I = Annual irrigation water, Evt = Annual evaporation, Tr = Annual transpiration, ADp = Annual deep percolation, Ro = Annual runoff from the field
(Lp + *s) = Annual lateral percolation and subsurface movement of water in the field.

The individual farm efficiency in the water reuse system was computed using the model equation (2) below.

$$Efficiency(\%) = \frac{Annual\ crop\ water\ requirement\ (ACWR)}{Annual\ crop\ water\ requirement\ (ACWR) + Losses} X100 \qquad (2)$$

In addition the water productivity of each individual farm in a chain of water reuse was evaluated using one indicator (yield per cubic meters of water used - kg/m^3) as per equation 3 below

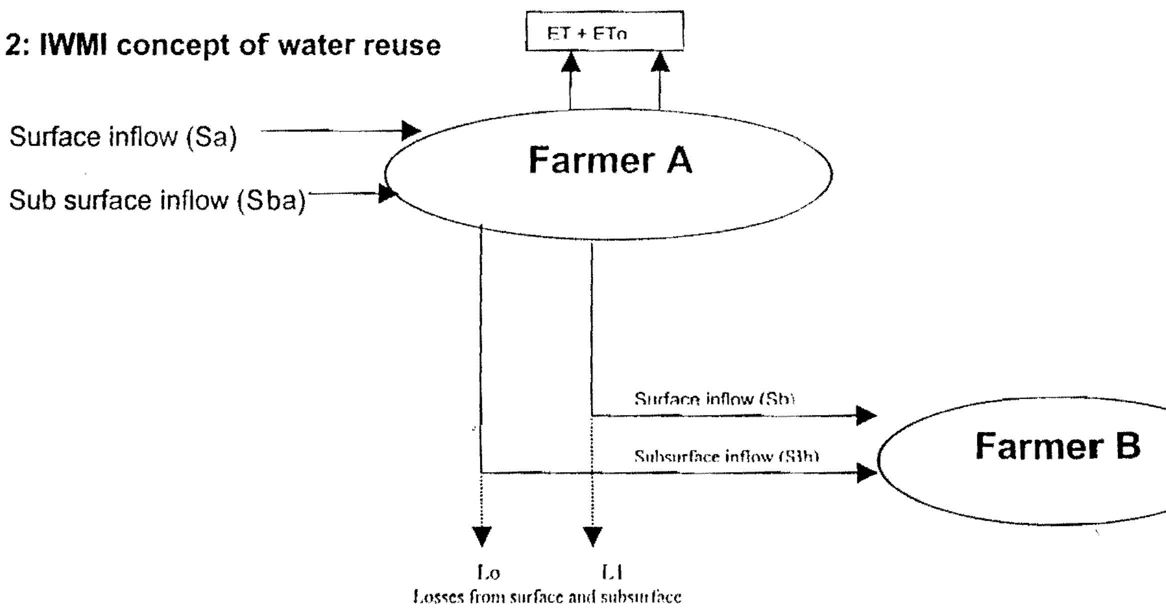
$$Productivity = \frac{Weight\ of\ crop\ grains\ (kg)}{Annual\ crop\ water\ requirement + Losses(m^3)} \qquad (3)$$

Efficiency and Productivity of water reuse systems-IWMI method

Efficiency

The latest IWMI concept (Figure 2) assumes that there are two types of inflows that reach any farm; surface and subsurface flows. And furthermore beneficial (ET) and non-beneficial (ETo) evaporation on the farm depletes water, either through crops or as fallow soil evaporation (Keller et al., 1996). IWMI method assumes that water released from an upstream farmer 'A' going to farmer 'B', leaves farmer 'A' in two forms i.e. surface (Sb) and sub-surface (SBb). However, some water is permanently lost on the way through deep percolation and does not reach farmer B. The water which reaches farmer 'B', therefore, is less (L1 +Lo) than that which leaves A.

Figure 2: IWMI concept of water reuse



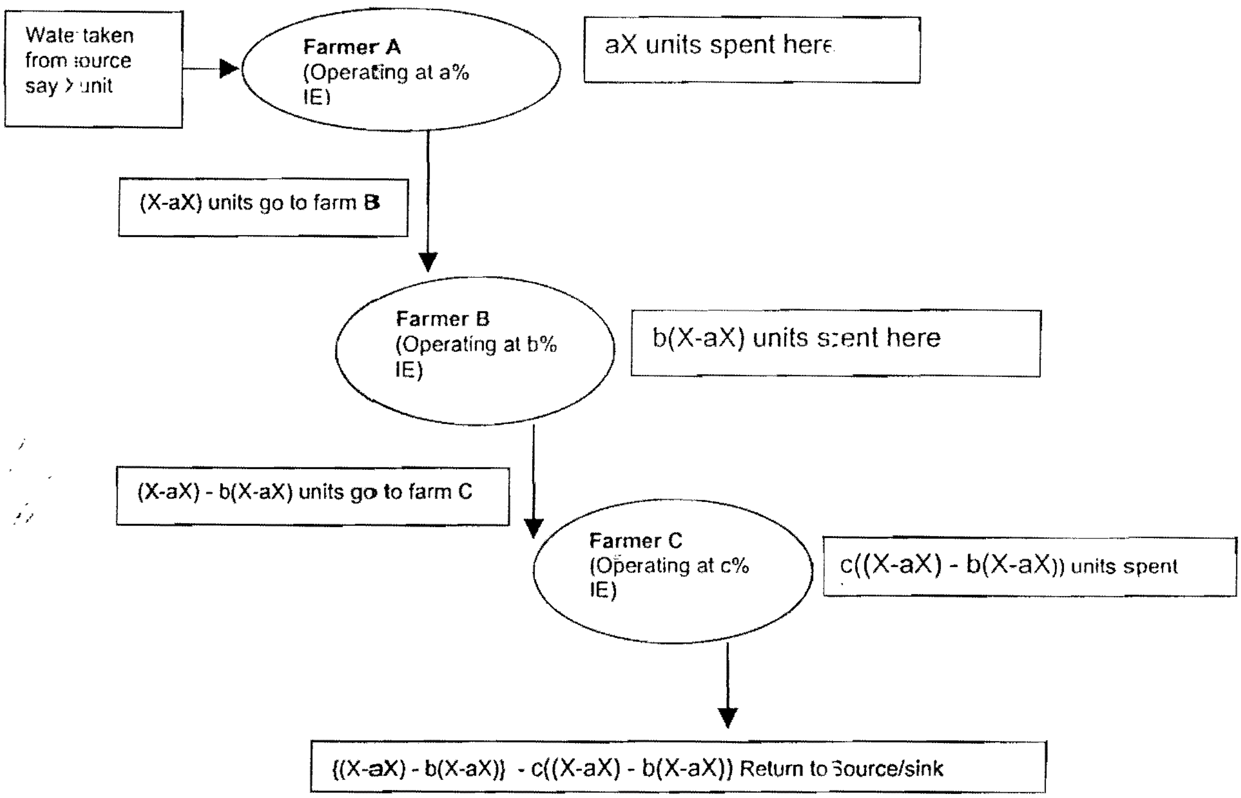
The method here is termed "Effective Irrigation Efficiency" and is calculated as demonstrated in equation 4 below.

$$EE(\%) = \frac{crop\ water\ requirement\ (CWR\ \ )}{crop\ water\ requirement\ (CWR\ \ ) + Unrecovered\ losses(Lu)} X100$$

$$EE(\%) = \frac{crop\ water\ requirement\ (CWR)}{Total\ depleted} X100 \qquad (4)$$

Applying the theoretical framework above, efficiency of water reuse systems of up to three times in Usangu can be evaluated (Figure 3). If ***X*** units of water were diverted from the source river to farm A, which operates at ***a%*** efficiency, according to IWMI-P this mean that ***(X-aX)*** of the abstracted water would move to the next farm, and only ***aX*** units will be used in farm A. If the next farmer B is operating at ***b%*** efficiency, it means that ***b(X-aX)*** units will be spent in that farm. The amount that will move ahead to farm C will be ***(X-aX) - b(X-aX).*** In farm C the amount that will be spent there is ***c((X-aX) - b(X-aX)*** and the amount leaving that farm, the return to source/sink in this case is ***{(X-aX) - (X-aX)} - c((X-aX) - b(X-aX)).***

Figure 3: Irrigation efficiency calculated using IWMI-P method



If the losses and subsurface movement of water from one user to another are obtained as per balance equation (1) above, and the efficiencies of the individuals farms a%, b% and c% are calculated from net crop water requirement as measured by lysimeter divided by the gross water requirement as estimated from the balance equation (1).

Then the usable units from the three reuse systems would be the sum of all the units spent by farmers A, B and C. This is given as follows:

$$Usable\ units = CWR = aX + b(X - aX) + \{c(X - aX) - b(X - aX)\}$$

Since the chain of reuse in river basin is assumed endless such that the total depletion is equal to X, then the effective irrigation efficiency would be calculated as follows

$$EIE = \frac{aX + b(X - aX) + c\{(X - aX) - b(X - aX)\}}{X}$$

$$= a + b - ba + c - ac - bc + abc$$

$$EIE = a + b + c - (ba + ac + bc) + abc \qquad (5)$$

Irrigation productivity

On the other hand the productivity would be the sum of yields in each of the water reuse farms. The addition of all the three productivity will give the effective productivity of the water reuse system as per equation 6 below. This equation was used to evaluate the productivity in all the two seasons.

$$EIP = IP_1 + IP_2 + IP_3 \qquad (6)$$

Whereby IP = irrigation productivity in each of the ndividual farms

Results

Efficiencies and productivities at farm level

The results on crop water requirement (net annual water requirement - NAWR) and total water depleted (gross annual water requirement - GAWR) and efficiencies of the individual farms for the period of two seasons 1999/2000 (dry year) and 2000/2001 (wet year) were calculated and are shown in Tables 1-3 and discussed in the subsections that follows.

Table 1: Summary of water use, efficiency and productivity 1999/2000 season

Site Name	GAWR (mm)	NAWR (mm)	Kg/ha	Kg/m^3	Efficiency (%)
KIF	2038	985	3333.33	0.17	**48%**
KSS	1993	989	3666.67	0.18	**50%**
KPSS-top	1668	1151	3666.67	0.22	**69%**
KPSS-end	1789	999	3033.38	0.16	**56%**

Table 2: Summary of water use, efficiency and productivity 2000/2001 season

Site Name	GAWR (mm)	NAWR (mm)	Kg/ha	Kg/m^3	Efficiency (%)
KIF	3010	1063	4770	0.16	**35%**
KSS	2327	986	4217	0.18	**42%**
KPSS-top	1722	1095	3680	0.21	**64%**
KPSS-end	1730	976	4037	0.23	**56%**

The results in the tables above show that there was no significant difference in net crop water requirement in the different individual farms. However the gross annual water requirement (total water depleted) in modern and traditional farms, differed significantly. In the dry year (Table 1) the state farms (so called "modern systems") used a maximum annual sum of 2038 mm, whereas the average net crop water requirement was 987 mm, giving an efficiency of about 48%. In the wet year (Table 2) however, the period when water was available in excess and the competition for water was less, modern system depleted a maximum of 3010 mm and the efficiency went down to 35%.

Table 2 shows a maximum recorded annual depletion for the "traditional systems" during the wet year of 1730 mm. The calculated net water requirement was 976 mm results in an efficiency of 56%. During the dry year, more or less the same amount of water is applied. The same efficiency of 56% was obtained from a gross water use of 1789 mm and a net paddy water requirement of 999 mm. It is worth noting however that the efficiency in traditional system can go up to nearly 70% in some fields paricularly during the dry year (Table 1).

Alternatively the productivity results from the first year indicate that productivity was higher in the KPSS - top (0.22 kg/m^3), while the productivity of the upstream user (KIF) was 0.17 kg/m^3 and the KSS produced 0.18 kg/m^3. On the other hand, the KPSS - end productivity was relatively lower (0.16 kg/m^3).

In the second year, the wet year, the KPSS-top maintained to have higher productivity than all (0.31 kg/m^3). It was followed by the KPSS - end (0.23 kg/m^3), then KSS at 0.18 kg/m^3 and KIF was the last, producing 0.16 kg/m^3.

Irrigation efficiencies and productivity as a result of water reuse (IWMI-Method)

Recapping equation 5 and 6 above the effective irrigation efficiency and productivity of the two water reuse systems were estimated. Tables 3 and 4 show the results of the KIF and KSS water reuse subsystems. It is clear from the results that the effective irrigation efficiency and productivity will increase if the individual farm efficiencies increase. This is demonstrated by Tables 3 and 4 whereby the high individual farm efficiency in

1999/2000 resulted into high (93%) effective irrigation efficiency. Also when the individual farm efficiencies wet down in 2000/2001, the effective irrigation efficiency also went down to (90%). Alternatively, low individual farm productivity resulted on low effective irrigation productivity (Tables 5 and 6).

Table 3: Effective irrigation efficiency of KIF – water reuse subsystem

Seasons	KIF (%)	KPSS-top (%)	KPSS - end (%)	EIE (%)
1999/2000	48	69	56	**93**
2000/2001	35	64	56	**90**

Table 4: Effective irrigation efficiency of KSS– water reuse system

Seasons	KSS (%)	KPSS-top (%)	KPSS-end (%)	EIE (%)
1999/2000	50	69	56	**93**
2000/2001	42	64	56	**91**

Table 5: Effective irrigation productivity in KIF water reuse subsystem

Seasons	KIF (kg/m3)	KPSS-top (kg/m3)	KPSS - end (kg/m3)	EIP (kg/m3)
1999/2000	0.17	0.22	0.16	0.55
2000/2001	0.16	0.31	0.23	0.70

Table 6: Effective irrigation productivity in KSS water reuse subsystem

Seasons	KSS (kg/m3)	KPSS-top (kg/m3)	KPSS - end (kg/m3)	EIP (kg/m3)
1999/2000	0.18	0.22	0.16	0.56
2000/2001	0.18	0.31	0.23	0.72

Discussion of the results

The results obtained here appeals for the high irrgation efficiency and productivity in water reuse system. However taking the Usangu context several weakness of the IWMI method could be drawn and if reassessed taking into consideration key conditions which affect efficiency and productivity of water reuse systems inspired by the Usangu nature probably the results could absolutely change.

Conditions inspired by the Usangu water reuse systems

In Usangu the reuse process and the efficiency and productivity are much controlled by a range of factors such that they depend on timing of the cropping window and water availability, swings of market for irrigated products and technologies of irrigation infrastructures. Irrigation efficiency and productivity in Usangu irrigation systems need to recognise: delay of water from one user (upstream user) to another (downstream user) - timing, Changes in irrigated area; Changes in irrigation seasons (wet and dry); Changes in water availability for different years; Amounts of drainage water re-used for downstream irrigators and lack of groundwater recovery/re-use.

To adequately capture the efficiency resulting on water reuse in Usangu the factors narrated above need to be considered. The IWMI method however, misses a considerable number of these factors and therefore cannot accurately be used to assess irrigation efficiency and productivity in systems and conditions inspired by the Usangu basin. Table 7 shows the nature in Usangu against recognition of the IWMI method.

Table 7: Nature of water reuse in Usangu against recognition of the IWMI method

Nature	Usangu Context	IWMI-P Method
Water reuse	Exist	✓
Water losses	Exist	✓
Delay in reuse between users	Exist	x
Longevity of cropping season	Extended season exist	x
Management	Differ between users	x
Irrigation types	Two types exists	x
Product price fluctuation	product prices differs between upstream and downstream users	x

Delay in reuse between users

In Usangu cropping window is defined to be between end of November and end of February. Any rice transplanting beyond this period will result on relatively low or no yield. This fact emphases the significance of early release of drain water from the upstream users to downstream users in the water reuse process in Usangu. In addition, any ponding of excess water with upstream users subjects the downstream to delay in starting their operation and thus missing the correct cropping window. Further elongated water ponding in upstream fields results in excess water evaporation which is very much in the tropical areas. Table 8 shows how the delay of water reuses exist in the Kapunga large and smallholder water reuse systems.

Table 8: Water delays between individuals in water reuse systems in Usangu

	Assessed field operations				
	Pre-saturation +		Water depth +	Delays to next + drain user	Duration of water in field
Site	Amount (mm)	Duration in days	mm)	(days)	(days)

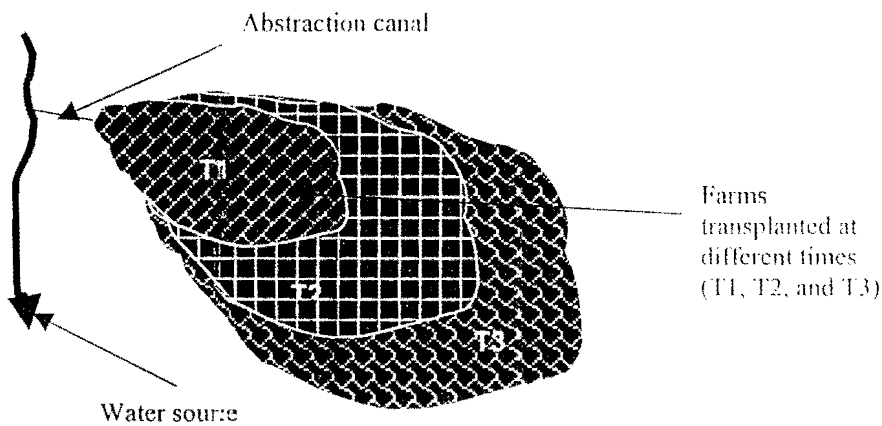
KIF	665	19	121	30-60	200
KSS	205	4-6	119	5	165
KPSS	156	4	116	4	165

Longevity of cropping season

The longevity of cropping season is a problem which is caused by a delay of water to downstream users. The delayed downstream water users will require more time of water supply for their crops to mature. As recorded in the Kapunga water reuse systems that the delays were between 30-60 days, this means that the cropping season is pushed ahead for up to two months. There are two problems which emerge out of this consequence:

The first problem is that during this time the crop will not perform well regardless how much water is been supplied to the crop. Crops in Usangu are temperature sensitive and the cropping window has to be met in order to have good yield. But again the water losses during this time are high since water is diverted and transported far away to irrigate the late transplanted fields. There are a lot of losses which occur in the middle especially with the field to field irrigation system of the Usangu (Figure 4). In this type of irrigation, canals are limited and water is passed on to next field via cuts on bunds. In Figure 4 if T1 is the earliest farmer/farm to transplant/harvest and the T3 is the latest farmer/farm then for the T3 farm to irrigate, water will have to go via harvested farms T1 and T2. This is not covered in the IWMI method.

Figure 4: irrigating late transplanted fields in water reuse systems



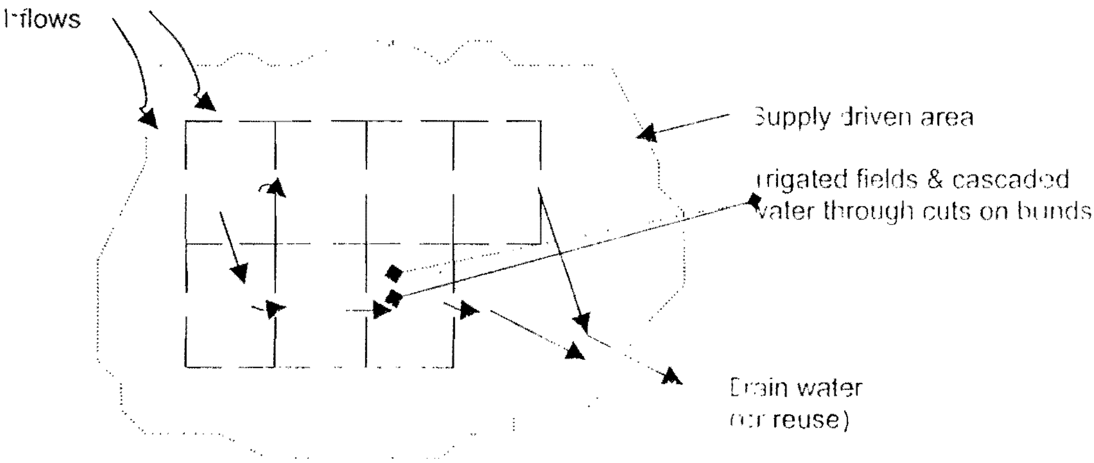
Management

The management of water differs in each of the farms/farmers in the water reuse system. This has a point to do with water use efficiency and productivity. Farmers in the downstream are water scarcity and cares about water. This is unlike the upstream farmers. This fact is exemplified by the results of water used, for example, for wetting up between downstream users 205 mm and the 665 mm of the upstream users in the Kapunga water reuse system (Table 8 above). Looking at the wetting up duration of the upstream users (19 days – using water as a tool to suffocate weeds) and of the downstream users (4-6 days – strangling to meet the suitable cropping window), the amount spent for wetting in the two is the true reflection of the time spent.

Irrigation types

There exist two types of irrigation in Usangu. The modern/improved irrigation systems are equipped with concrete intake, primary, secondary and tertiary canals to distribute water to each of the plots available in the farm. in addition the fields are made of big bunds which are capable of withholding sufficient amount of water over a long period. The other type is the traditional system whereby limited number of canals is made available in the field. Mainly the water is distributed through cuts made on the small bunds which make up the fields in this type of irrigation. This type of irrigation is called "field- to - field" irrigation.

Figure 5 Cascading water in traditional system of irrigating "field-to-field"



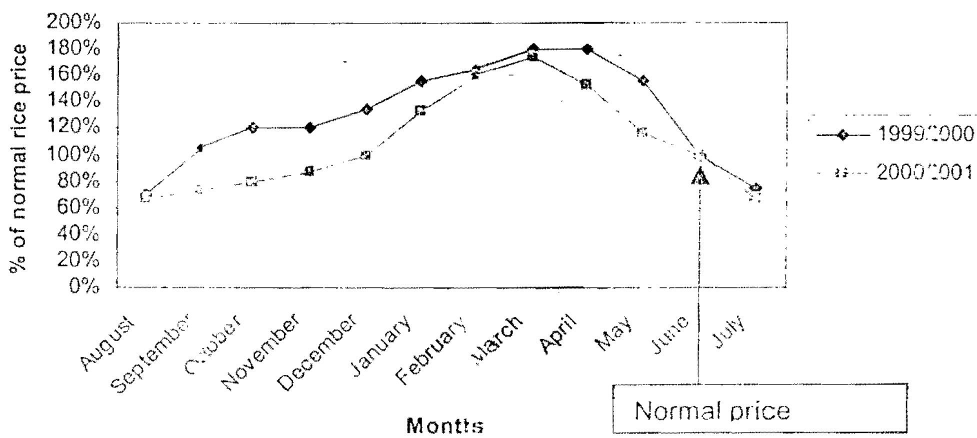
Product price fluctuation and market timing

Price fluctuation for agricultural products is a major challenge for local markets in many developing countries. Prices are always higher at the beginning of the harvesting season and lower when more farmers start to harvest in Tanzania (Kajiru *et al.*, 1998). Farmers upstream who transplant early (mostly wealthier farmers) - benefit from this situation as prices of rice harvested early in the season could be as high as three times that harvested later in the season (Kajiru *et al.*, 1998).

Due to the difference in selling prices, the returns for the upstream and drain water users in forms of $\$/m^3$ becomes different. There is a lower return from drain water as compared to the fresh water abstracted by the upstream users. The loss is inevitably caused by unstable market (Figure 6) but mainly due to delay of water from the upstream users. On the other hand, the production costs are the same and sometimes the inputs for the downstream farmers (late transplanting) become expensive due to labour scarcity. The labour becomes expensive during this time because every farmer in the basin has water and there is limited number of people doing paid labour. Thus analysis of the water reuse is a complex issue, which in areas like Usangu requires consideration of product price fluctuation. Alternatively, the product price fluctuation in Usangu is very much related/influence by poverty as explained in the next paragraph.

Poor people, who cannot secure land in the upstream in Usangu, are located in the downstream and are subjected to tremendous delays to start the transplanting. They, therefore, always harvest late in the season as they transplant late. Their daily needs, however, directly depend on rice produce i.e. they cannot store their yields to wait for a good price later in the season or in the next season. They then start selling their produce at any available price soon they start harvesting which is always the lowest price in the season. This does not affect the productivity in forms of kg/m^3 but rather affects productivity \$/m^3 cash returns which is interesting to a farmer). In other words although the productivity in terms of kg/m^3 might be higher, the same productivty analysed in terms of \$/m^3 becomes less. Thus efficiency of the end users in Usangu is likely to be lower than pictured by the IWMI method which does not consider this factor.

Figure 6: Product price fluctuation



Conclusion

The efficiencies which arise as a result of water reuse, using the IWMI method, appear to be incredibly high. However, the method ignores major factors which are necessary to be considered if anyone is to evaluate the efficiency and productivity of the Usangu irrigation systems

This paper therefore conclude that for the IWMI methods to be applicable in Usangu a way to assess the five mentioned factors (delay of water between users, longevity of cropping season, management, irrigation types and product price fluctuation) which affect both efficiency and productivity has to be found.

This study further concludes that the effectiveness of the water reuse in increasing both irrigation efficiency and productivity lies on the hand of the efficiency of the individual farmers forming the reuse. This is to say that the lower the efficiency of the individual farms/farms the lower the resulting water reuse efficiency and vice versa. In other words, water reuse alone without proper management in the individual farms constituting the system will by far less increase the efficiency and productivity in such systems.

References

Keller, A.A., Seckler, D.W. and Keller, J. 1996. Integrated Water Resource Systems : Theory and Policy Implications. Research Report 3. International Irrigation Management Institute, Colombo, Sri Lanka.

Kajiru G.J. (1998). Diagnostic survey of eighteen irrigation schemes. Smallholder Development Project for Marginal Areas (SDPMA). International Funds for Agricultural Development (IFAD), Loan srs-024-tz; grant srs-020-tz, Ministry of Agriculture, Ukiriguru Agricultural Research Institute, Mwanza, Tanzania, pp 98 - 1'4.

Lankford, B. and Franks, T., 2000. The Sustainable Coexistence of Wetlands and Rice Irrigation: A Case Study From Tanzania. Journal of Environment & Development, 9(2): 119-137.

Machibya, M., 2003. Challenging Estabished Concepts Of Irrigation Efficiency in a Water Scarce River Basin: A Case Study of the Usangu Basin, Tanzania., PhD Thesis, University of East Anglia, Norwich.

Machibya, M and Mdemu M. 2005. Comparison assessment of water use and damage between large "modern" and small "traditional" rice irrigation schemes: The case of Usangu basin, Tanzania. Accepted paper to be published in the International Journal of Environmental Research and Public Health. Volume 2, Issue 1-2, USA.

Perry, C.J., 1999. The IWMI water resources paradigm - definitions and implications. Agricultural Water Management, 40(1): 45-50.

SMUWC, 2001. Final Project Reports., Project: Sustainable Management of the Usangu Wetland and its Catchment. Directorate of Water Resources, Ministry of Water, Government of Tanzania., Dar es Salaam.