The Value of Water for Irrigated Rice and Hydropower Generation in the Great Ruaha, Tanzania

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Abstract

The need for achieving efficient, equitable and sustainable use of water resources to meet water demands of different sectors is pressing, particularly in areas where water resources is dwindling due to increasing human population and economic activities, which require water. In Tanzania, examples include the cases of Rufiji and Pangani basins, where conflicts and competition over water resources between irrigated agriculture and other sectors [e.g., wildlife conservation and hydroelectric power (HEP) generation] have escalated. The major irrigated areas in these basins for example, are located upstream from the major HEP generating facilities. The two sectors are therefore in direct conflict and competition over water resources especially in dry years. Achieving long-term economic benefits from water utilization in these areas will depend on how well the available water resource is shared among sectors and how these sectors perform in terms of producing "more benefits per drop". Central to this is the need for having a good understanding of the value of water in its different uses. Based on this argument this paper presents an assessment of the value of water in irrigated rice and HEP using the case of the Great Ruaha (GR) in Tanzania. The paper is a first step in the assessment of the total economic value (TEV) of water utilization in the GR. The values of water were calculated using the Change in Net Income *technique - a variant of the* Residual Imputation Approach. *The seasonal water demand in irrigated rice was modelled using the CROPWAT model developed by FAO. The Productivity of water (PW) was determined as the ratio of crop yield to either gross water uses (*abstracted*) or actual water* consumed *through crop evapotranspiration (ETa). In HEP, the following water uses were considered: a) the turbine discharge (non-consumptive use) b) the net evaporation (consumptive use), c) the combined turbine discharge and net evaporation (non-consumptive and consumptive uses), and d) the inflows to the system's reservoir (non-consumptive and consumptive uses).*

Key Words: Water value, Productivity of water, Irrigated rice, Hydropower generation

Introduction

Many countries in the world are facing the challenge of effectively managing and allocating the available water resources to meet the increasing demands for water resources resulting from increasing human populations and economic activities which require water. This is becoming increasingly imperative particularly in agricultural based economies, where competition between water utilization in irrigated agriculture and other sectors is escalating. Examples include the cases of Rufiji and Pangani basins in Tanzania, where there is potential competition between three uses: irrigated agriculture, environment and hydropower generation. The major irrigated areas in these basins are located upstream from the major HEP generating facilities. In the upper catchment of the Rufiji basin (the Great Ruaha Catchment), for example, irrigated agriculture has expanded dramatically over the past 30 years, particularly in the Usangu plains. Several irrigation schemes have been established and have attracted more cultivators from highland regions and pastoralists from northern and central Tanzania (Mbonile *et al.*, 1997). This in turn has caused not only a rapid expansion in irrigated agriculture but also growing conflicts and competition over water resources. Water demand for irrigated agriculture has increased enormously causing serious water shortages downstream to other sectors (including the fragile ecosystems in the Usangu wetland and

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Ruaha National Park as well as the hydropower sector at the Mtera and Kidatu plants), particularly during the dry seasons (SMUWC, 2001; Mbonile *et al.*, 1997; DANIDA/World Bank, 1995).

The GR case is not unique in Africa and has been used in this paper only as an illustration of the existing challenge of balancing water demands between irrigated agriculture and other sectors. The challenge calls for a need to develop policies and mechanisms that encourage better management and allocation of water resources. This in turn requires a good understanding of the value of water in its different uses and the implications of water transfer from one sector (let say irrigated agriculture) to other sectors. In other words, decision makers and other stakeholders need to be precisely informed of the value of water in its various uses and the opportunity costs of water transfer from one sector to another, if efficient management and allocation of water resources are to be achieved. The quantification of the value of water is , however, a relative new area of research particularly in the developing world. In Tanzania, for example, it is only during the last few years that some studies have emerged with some estimates of the value of water (FBD, 2003 and Turpie *et al.*, 2003). This paper is therefore, a contribution towards addressing that drawback. It is a first step in the assessment of the Total Economic Value (TEV) of water utilization in the GR. The analysis of the value of water in this paper covers only two sectors (i.e., irrigated rice and hydropower generation) and draws on the information collected during a study, which was conducted between September 2002 and June 2004 as part of the RIPARWIN (Raising Irrigation Productivity And Releasing Water for Intersectoral Needs) project research activities in the GR under the topic entitled: "Evaluation of Livelihoods and Economic Benefits of Water Utilization in the Great Ruaha."

RIPARWIN is a DFID (Department For International Development) - funded research project implemented by the Overseas Development Group (ODG), University of East Anglia (UEA), United Kingdom; the Soil Water Management Research Group (SWMRG) of Sokoine University of Agriculture (SUA), Tanzania; and the International Water Management Institute (IWMI) through its Africa Regional Office, South Africa (SA). RIPARWIN looks more closely at the aspects of water management, specifically on irrigation efficiency by examining the premise that if irrigation efficiency can be raised then water can be released to meet downstream and intersectoral needs. The components of the project include: a) productivity of water (PW) in irrigation systems, b) livelihoods and economic benefits of water utilization, c) hydrological analysis and a Decision Aid for the Rufiji basin, d) institutional arrangements and requirements at various levels, e) environment of wetlands and rivers, and f) small-scale irrigation (SSI) management. This paper falls under the second component, i.e., "livelihoods and economic benefits of water utilization." The paper is organised into the following four main sections: a) description of the study area, b) the research approaches and methods, c) results and discussion, and d) conclusion.

Description of the study area

The Great Ruaha (GR) covers an area of about 68,000 km^2 and is located in the southwestern part of Tanzania within the Rufiji basin, which covers an area of 178,000 km^2. The GR encompasses the Usangu area, which covers a total area of 20,811 km^2 and is located at approximately latitudes 7^{0}41' and 9^{0}25' South, and longitudes 33^{0}40' and 35^{0}40' East (Figures 1 and 2). The Usangu area encompasses the Usangu Plains, which include the Usangu wetland (with an area of about 1,800 km^2) and the Usangu Game Reserve (with an area of 4,148 km^2).

The major food crops grown in the GR include rice, maize, sorghum, and beans. Other crops include onions, tomatoes, sugarcane, vegetables and fruits (mainly citrus, mangoes and pawpaw). Irrigated crops include paddy, maize, beans, cassava, sweet potato, sugar cane, onions, and vegetables. Paddy is the major crop under irrigation and is normally grown during the wet season, on the lower alluvial fans having clay soils. Maize and dry season irrigated crops are grown on the upper alluvial fans and foothills, where the soils are sandy loams containing less clay. Water resources in Usangu supports local livelihoods through irrigation of about 40,000 ha of rice, grass growth in the wetland for livestock, and fishing in the rivers and wetland.

The Great Ruaha River (GRR) is the major source of water in the GR. It originates from the Usangu highlands and flows through the Usangu Plains and Wetland to the Ruaha National Park (RNP). Just downstream the RNP, the GRR joins another river (the Little Ruaha) to supply water to the Mtera hydropower plant. The GRR provides 56% of runoff to Mtera. The Little Ruaha River provides an additional 18% and the Kisigo River 26% of the total runoff to Mtera. The Mtera plant was commissioned in 1988 and it generates about 80 MW to the national power supply.

Downstream the Mtera plant, the GRR joins another major feeder river (the Kilombero), to form the Rufiji River after supplying water for hydropower generation at another hydropower station called Kidatu, which was commissioned in 1975 and generates 204 MW of the total national power supply. The Mtera-Kidatu hydropower system has therefore, a total installed capacity of 284 MW. The system has the biggest installation capacity in Tanzania. It provides more than 50% of the total 559 MW available in the national hydropower grid. In terms of water storage the Mtera and Kidatu reservoirs, with their combined capacity of 3,325 Mm^3, account for about 80% of the total storage in the existing hydropower plants in the country.

Figure 1: Map of Tanzania showing the Rufiji Basin and Usangu Plains

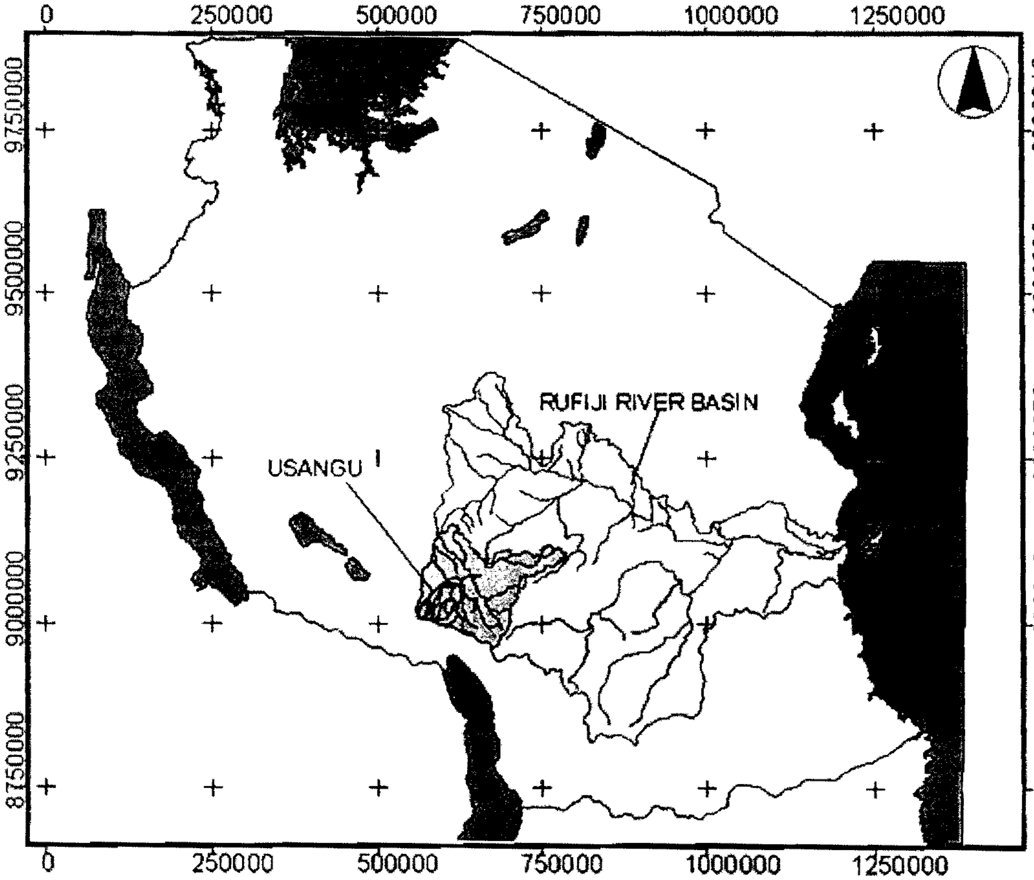
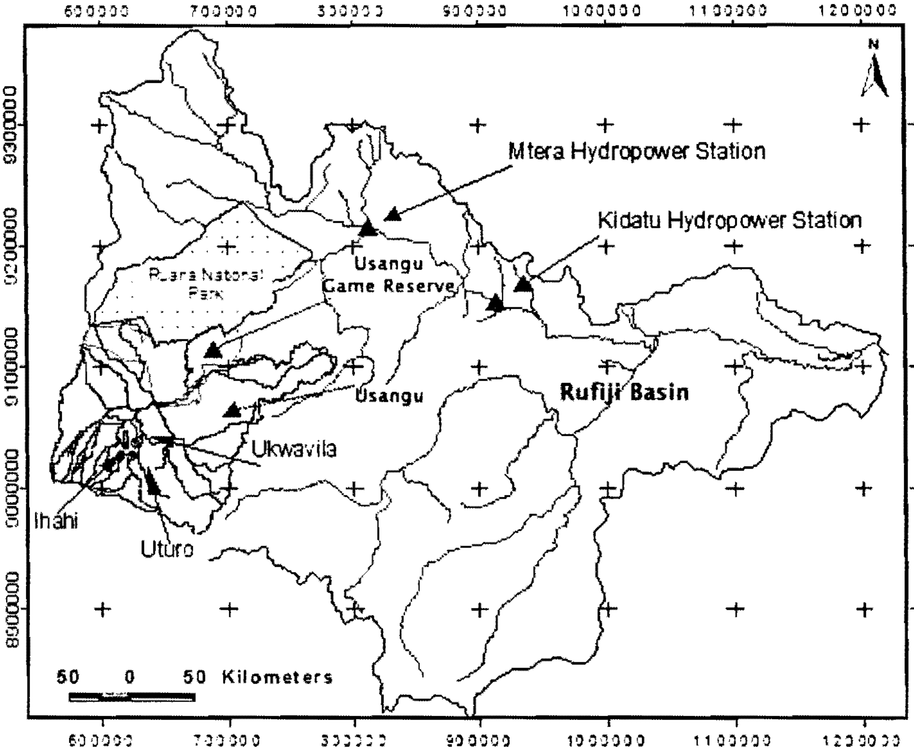


Figure 2: The map of Rufiji Basin showing the Usangu Plains, Usangu Game Reserve, Ruaha National Park and locations of study villages and hydropower stations



Research approach and methods

Data collection

The study involved the collection of both primary and secondary data. In irrigated rice, the primary data was gathered from three villages in the Usangu plains, namely: Uturo, Ihahi and Ukwavila. The sampling frame for the study was obtained through Participatory Rural Approaches (mainly *livelihood analysis* and *wealth ranking* exercises) and a total number of 140 sample households, constituting five rice production systems were covered (Table 1).[1]

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[1] *The sample villages were selected based on the existing production systems, with the purpose of capturing the wide range of livelihood typologies dependent on paddy production. All the three villages are also located adjacent to a National Agriculture and Food Corporation (NAFCO) rice farm – the Government owned farm, which is in the process to be privatised. Farmers from the sample villages also hire plots for rice production.*

Table 1: Types of rice production system covered in the study

Type	Denomination	Description	Sample households
1I	Subsistence farmers	Smallholder farmers who cultivated rain-fed rice in 2002/03, using hand hoe and family labour	29
2	High-input rainfed paddy growers	Smallholder farmers who cultivated rain-fed rice in 2002/03, using tractor, fertilizer and hired labour	8
3	Irrigated paddy growers on NAFCO plots	Smallholder farmers who hired irrigated NAFCO rice plots in 2002/03 and cultivated them using tractor, fertilizer and hired labour	11
4	Peri-NAFCO paddy irrigators	Smallholder farmers who cultivated irrigated rice in smallholder schemes outside the NAFCO farm in 2002/03	72
5	Average Usangu paddy irrigators	Farmers ranked under the 'middle' wealth class who cultivated irrigated rice in 2002/03	20
Total			140

The sample households were interviewed using structured questionnaires encompassing among others the questions of paddy and non-paddy crop production (acreage, inputs, outputs, prices, quantities produced, sold and consumed domestically, quantities in store and produces received or given in-kind), other sources of income, access to sources of irrigation water and amount of money paid as water fee.

For hydroelectric power (HEP), the study benefited from the information gathered from the Mtera-Kidatu hydropower plants and the Tanzania Electric Supply Company (TANESCO) Head Office in Tanzania (i.e., the information on power generation, dam levels, turbine discharge volume, spill/valve discharges and generating costs (including repair and maintenance costs, transport, security payments, salaries and other costs).

Data analysis

In both irrigated rice and hydropower generation, the values of water were analysed using a simplified approach derived from the *Residual Imputation Method*, that is, the *Change in Net Income Technique*. The reasons for the choice of this technique include its simplicity and low data requirements.[2] Using this method, Hussain *et al.* (2001) define the average value of water as the ratio of the difference of net output values between the situation *with* water and the situation *without* water, on the volume of water used. That is:

$$AW_V = (NVO_w - NVO_{wo})/W$$

$$NVO_x = GVO_x - C_x,$$

Where, AW_V is the average value of water

W is the volume of water used

NVO_w is the net output value with water,

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[2] *Depending on the period of adjustment of economic decisions, which is considered and the associated costs, different values may be estimated (Young, 1996): for short term allocation decision only operational and maintenance costs are computed, whereas for long term decision allowing new investments, capital costs of assets (land, farm machinery and equipment, irrigation system, power plant and dam) are also subtracted. In this paper, we only calculate the short-term values.*

NVO_{wo} is the net output value without water
GVO_x is the gross output value
And C_x is the total cost of production

In irrigated rice, the Crop Water Requirements (CWRs) were modelled using the CROPWAT model (developed by FAO) taking into account local precipitation, potential evaporation, crop growth coefficients, and cropping patterns (e.g., planting dates). The Productivity of Water (PW) was then calculated as the ratio of crop yield to either gross (abstracted) or actual (net consumed) water. In HEP, the portion of total value of electricity output attributable to water was valued used the economic Long-Run Marginal Cost (LRMC)[3] of $ 0.1271 (Tsh 135.19) per kWh - given in the Tanzanian Power System Master Plan, 2001 Update Report by TANESCO (2002). The values of water in HEP were calculated based on the following volumes of water: a) the turbine discharge (non-consumptive use) b) the net evaporation (consumptive use), c) the combined turbine discharge and net evaporation (non-consumptive and consumptive uses), and d) the inflows to the system's reservoir (also including non-consumptive and consumptive uses).[4]

Results and discussion

Value of water for irrigated rice

The value of water in irrigated agriculture is a function of several factors including the level of production, extent to which other agricultural inputs/other farm management practices are employed as well as the levels of input and output prices, just to mention a few. While most of these aspects were covered in the household survey, scaling up the analysis to a national level may also help enriching the discussion on the value of water for rice production.

The analysis of rice production at the national level, shows an increasing production trend for rice with the contribution of Mbeya region to the national rice production increasing sharply since early 1990s making the region to be the largest rice-producing area in Tanzania (Figure 3). About 60% of the regional rice production comes from Usangu Plains in the upper GR. The Usangu plains alone contribute between 14 to 24% of the national rice production in Tanzania.

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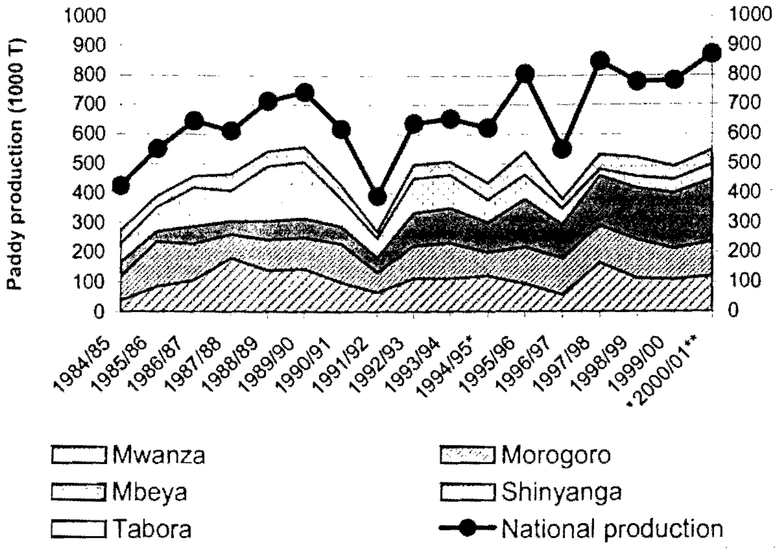
[3] *LRMC is taken as a lower bound of short run value.*

[4] *Different expressions of water values can also be computed according to the volume of water, which is considered. Generally, two types of volumes are distinguished: abstraction from the natural environment and net consumption. The former does not include return flows that may be reused downstream and therefore provides a downward biased water value; the latter does not include system losses and then leads to an overestimation of water value. In the case of irrigation Renwick (2001) recommends a value per unit of depleted water (evaporation plus drainage outflow) as a performance benchmark of system wide allocation efficiency. For cross-sectoral comparison it may be useful to refer to a common denominator such as the raw untreated water flowing in the stream. This implies to subtract treatment and transport costs from the value of water at its off stream use location. In our case, we assume that there is no major difference in terms of water quality requirement for the two uses (i.e., no treatment costs). In addition, there is no transport costs for hydropower as the plant is located directly on the river; for irrigation, transport costs are embedded in investment costs of irrigation systems, which are not integrated in short-term values.*

Figure 3: Paddy production trend for the five major producing regions in Tanzania and for the country as a whole, 1984/85 - 2000/01



Producer prices are also important in the assessment of the values of water, because low producer prices will very often imply low values of water and vice versa. With this regard, a trend analysis for rice producer prices was also done using price information obtained from the Mbarali District Agriculture and Livestock Office.[5] The results of analysis showed that the producer prices are increasing only in nominal terms. In real terms these prices have declined over time (Figure 4), despite the increase in paddy production volume. This has resulted in falling trends for real values of paddy production, [6] with not only obvious consequence on farmers' income but also possible effect on the value of water.

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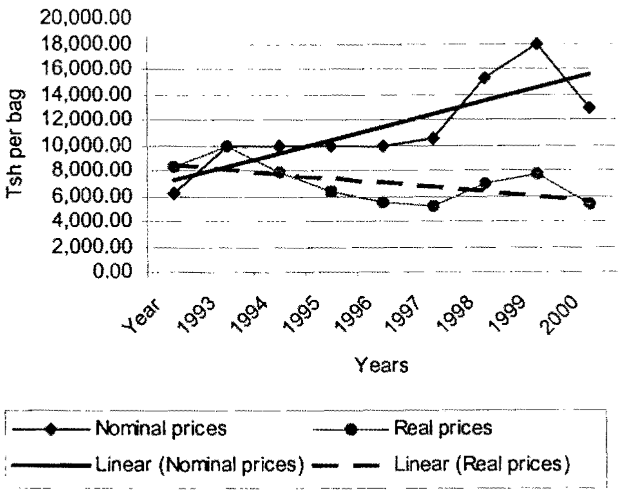
[5] *Mbarali District is located in Usangu area (the upper part of the Great Ruaha)*

[6] *In Mbarali district the average real producer prices for rice (from 1993 to 2001) are negatively correlated with rice production (correlation coefficient = −0.584, P < 0.10).*

Figure 4: Mbarali district: The trend of average nominal and real producer prices for rice, 1993 - Mid Dec. 2002



The results of analysis of PW for rice during the 2002/03 growing season are summarized in Table 2. The Productivity of water for rice - based on net water consumption (PW_{ET}) was estimated to range from 0.12 - 24 kg per m^3 or Tsh 28.45 per m^3 with that for smallholder farmers within the NAFCO systems being relatively lower than that for their counterpart smallholder farmers outside the NAFCO system (Peri-NAFCO farmers). Based on the gross water use (abstraction), the PW figures are as given in Table 4 under the column PW_w and the respective values of water for irrigated rice for both abstracted and consumed water as estimated using the *Change in Net Income* Method are given in Figure 5.

Table 2: Productivity of Water by rice farming type, 2002/03

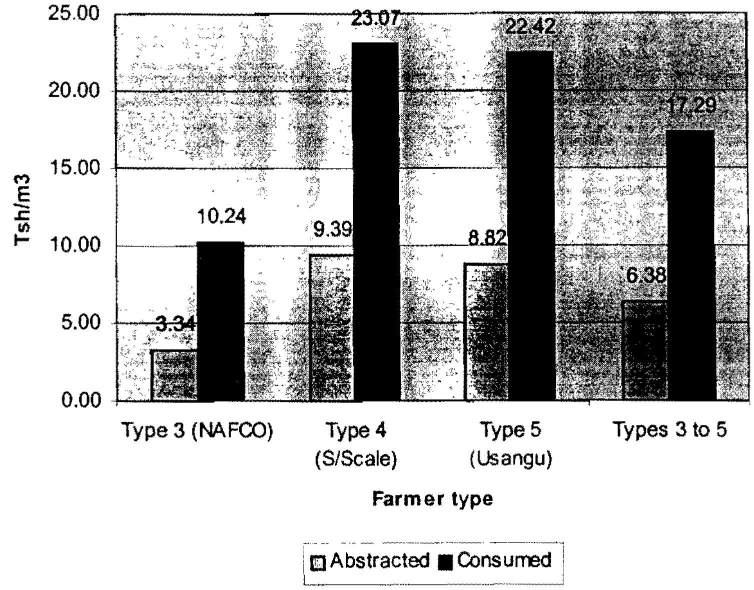
Irrigated	CWR (mm)	Perc (mm)	Lprep (mm)	**RiceRq** (mm)	EFR (mm)	IrReq (mm)	Yield (kg/ha)	PW_W (kg/m^3)	PW_{ETc} (kg/m^3)
3 (NAFCO)	1340	660	850	2850	480	2370	1600	0.06	0.12
4 (S/holder)	1240	560	370	2170	480	1690	3028	0.14	0.24
5 (Usangu)	1260	570	443	2273	480	1793	2500	0.11	0.20

Rainfed	CWR (mm)	RF (mm)	ERF (mm)	TRL (mm)	RE (%)	Yield (kg/ha)	PW_{RF} (kg/m^3)	PW_{ERF} (kg/m^3)	PW_{ETa} (kg/m^3)
Types 1&2	628.5	666.9	480	186.9	72.0	981.5	0.15	0.20	0.16

NOTE: PW_w (for irrigated types) and PW_{RF} (for rainfed types) = abstracted/gross water use; PW_{ETc} = consumed water; PW_W = Yield/RiceRq; PW_{ETc} = Yield/CWR; PW_{RF} = Yield/RF; PW_{ERF} = Yield/ERF; PW_{ETa} = Yield/ETa; RiceRq = CWR + Perc + Lprep; IrReq = RiceRq – EFR; ETa = Actual water use consumed (approximately equal to actual CWR modelled by CROPWAT); RF = Total Rainfall received during the respective crop growth period; EFR = Effective Rainfall; and RE (%) = ERF/RF (Rainfall Efficiency = the ratio of Effective Rainfall to Rainfall).

Generally, the PW_{ETc} figures for the GR can be compared with findings of other works in Sub-Saharan Africa (SSA). Productivity of water for rice in this region ranges from 0.10 to 0.25 kg per m^3, with average yield of 1.4 metric tonnes per ha and water consumption per hectare close to 9,500 m^3 (Rosegrant, *et al*, 2002). Among developing countries, China and some Southeast Asian countries have higher water productivity for rice, ranging from 0.4 to 0.6 kg per m^3. IWMI's research has also shown that the value of water consumed in agriculture ranges from US $ 0.05 to 0.90 per m^3, with the great majority of observations falling in the order of US $ 0.10-0.20 per m^3 (Perry, 2001).

Figure 5: The value of water for irrigated rice – real prices, 2002/03



The inter-farming system comparison showed highest average real values of water for the Peri-NAFCO smallholder farmers (Type 4) of Tsh 23.07 per m^3 of consumed water or Tsh 9.39 per m^3 of abstracted water (Figure 5). The NAFCO farmers (Type 3) recorded the lowest (Tsh 10.24 and Tsh 3.34 per m^3 of net water consumed and abstracted respectively. These findings support the argument given in SMUWC (2001) that average productivity on the NAFCO rice irrigation system is lower than that on the traditional smallholders irrigation system. The main causes of low yields in the NAFCO systems appear to be low planting densities, weed infestation and poor water level control arising from large plot sizes. The soil surface is uneven and farmers do not use smaller plots (*vijaruba*) to control water level and movement. On the traditional smallholders irrigation system (Type 4), plots are smaller enabling greater care over water levels.

Value of water for hydropower generation

As for irrigated rice, a trend analysis of output prices (i.e., electricity tariffs for this case) and existing pricing mechanisms would help assessing the dynamics of the value of electricity and hence the value of water for HEP generation. The average electricity tariffs in Tanzania (for the period from 1992 to 2003), for example, have generally increased in the local currency (i.e., in Tsh per kWh of electricity sold), while the same has almost remained constant in US $ per kWh (Figure 6). This can partly be attributed to the effects of inflation[7] and distortions brought by government interventions in markets (i.e., the effects that stem from the government administered tariffs or prices that do not reflect the real economic value of electricity inputs and outputs or prices which deviate from the competitive equilibrium prices).

Figure 6: Average electricity tariffs in Tsh and US cents per kWh, 1992 - 2003

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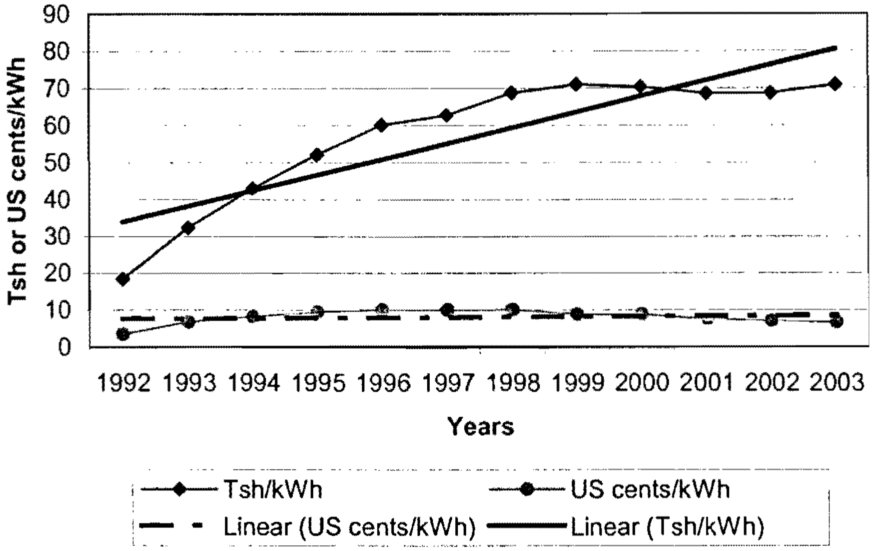
[7] *Note that, electric tariffs in Tanzania are not frequently adjusted in line with the devaluation of the shilling.*



Summarized in Table 3 are the values of water in HEP generation for the Mtera-Kidatu hydropower system for the different types of water considered as estimated using the *Change in Net Income Technique*. In real terms, the average values of water range from the lowest of Tsh 21.60 ($ 0.02) per m^3 - when combined net evaporation and turbine discharges are considered to Tsh 82.02 ($ 0.08) per m^3 - when only consumptive use (combined net evaporation from the Mtera-Kidatu system reservoirs) is considered.

Table 3: The Mtera-Kidatu system: Value of water in hydropower generation, July 2002 – June 2003*

Type of water use considered	Water Used (Mm^3)	PW (kWh/m^3)	Nominal (Tsh/m^3)	($/m^3)	Real (Tsh/m^3)	($/m^3)
Turbine Discharges at Kidatu (TDK)	3,001.83	0.61	79.08	0.08	29.63	0.03
Mtera-Kidatu Combined Evaporation (MKCE)	1,094.43	1.68	218.88	0.21	82.02	0.08
TDK plus MKCE	4,096.26	0.45	57.65	0.06	21.60	0.02
Corrected Inflows at Mtera (CIM)	1,860.78	0.99	128.27	0.12	48.07	0.05

*Values calculated using the Long Run Marginal Cost (LRMC) of $ 0.1271 (Tsh 135.19) per kWh as given in the TANESCO Power System Master Plan (2001 Update Report)
PW = Productivity of Water.

Comparison of the value of water for irrigated rice and HEP

Summarized in Table 4 is the comparison of the value/benefits of water utilization between the two sectors (i.e., irrigated rice and hydropower generation). Looking closely at the figures in Table 4 one would conclusively argue that HEP generates higher economic returns than irrigated rice, but a number of other aspects need to be considered as well. These include, for example, the question of whether HEP is superior to irrigated rice, in terms of generating both higher economic benefits and livelihood returns. Never the less, the question of benefit sharing is also important and it needs a closer analysis as well. Recognizing that only 10% percent of the total population in Tanzania (1% in the rural areas) benefit from electricity connections versus, for example, the share of the GR rice in the total national production (which ranges from 14 – 24%), and the fact that more than half (60%) of all the rice produced in the GR is sold outside the area through inter-regional trading to other regions in Tanzania, one would also see the role that irrigated rice plays, particularly in enhancing both the local and national economies as well as the national food security.

Table 4: The benefits of water utilization in irrigated paddy and hydropower generation, July 2002 - June 2003

Indicator	Rice	HEP
Production (Tonnes for rice) or (kWh for HEP)	105,000	1,839,424
Gross Revenue (Million US $)	15.9	128.4
Share of the national total supply (%)	14 - 24	59 - 65
Amount of water abstracted Mm^3	1,073.28	4,096.26
Amount of water consumed Mm^3	703	1,094.43
Kg/m^3 (for rice) or kWh/m^3 (for HEP) water abstracted	0.11	0.45
Kg/m^3 (for rice) or kWh/m^3 (for HEP) water consumed	0.20	1.68
Tsh/m^3 water consumed (real value)	22.42	84.72
Tsh/m^3 water abstracted (real value)	8.82	22.32
$\$/m^3$ water consumed (real value)	0.03	0.08
$\$/m^3$ water abstracted (real value)	0.01	0.02

Conclusions

While the values of water for rice production (in Tsh or $ per m^3 of water used) are lower than those for hydropower generation in the GR, the role that irrigated rice plays, as the major source of income for the majority of poor households in the GR, and in enhancing the national food security, needs not to be undermined. Rice production from the Usangu plains alone contributes about 14 - 24 percent to the national production and supports about 30,000 agrarian families in Usangu plains with average gross income per family of Tsh 546,875 or US $ 531.0 per annum. Understanding these benefits is key in fostering informed debate on water management and allocation. It helps identifying the base for making 'agreeable' trade-offs, identifying the potential for improvement and creating a linkage with water allocation options. It should however be noted that, the analysis presented in this paper serves only to provide some highlights of the values of water in the two sectors. More research is still needed, particularly on the value of water in its multiple uses, and in both short run and long run values, so as to inform sustainable water management and reallocation decisions. It is worth noting that the approach used in this case i.e., the *Change in Productivity* method calculates only average values and not marginal values of water and therefore cannot be suitable for making decision on cross-sectoral water allocation. Ideally, estimating the marginal values of water would require the use of optimization models that in turn demand a large amount of data, which are seldom available. Never the less, establishing values for irrigation water also presents several practical problems. All methods to value irrigation water, and specifically the *Change in Net Income method*, rest on observing response of crop yields to various water applications. Water productivity may vary according to soil type; fertility; climate of the year; farmer (management ability, experience, scale of farming operation, attitude towards risk and financial constraints); irrigation schedules and level of other inputs. In the absence of field observation of yield response to various levels of water application, water requirements can only be estimated using models like the FAO's CROPWAT model as used in this study.

Again, in farming systems of developing countries, a large part of the production is usually used for household consumption. The economic value of total output includes the value of marketed output as well as the one of home consumption. The choice of appropriate price for the latter is problematic, especially when no market exists for these products.

Just as important, the analysis of the value of water in HEP, must distinguish between base load generation and peak load output. Peaking power electricity is more valuable than base load because of the cost of bringing less efficient and more expensive alternative capacities rapidly on line (thermal power). Alternative cost valuation of peaking power is particularly difficult because of site-specific characteristics of alternative capacities and the problem of allocating fixed costs between peaking and base load operations. For this reason, only base load values were estimated in this paper.

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