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

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Abstract

The need to achieve efficient, equitable and sustainable use of water resources to meet water demands of different sectors is pressing, particularly in areas where water resources are dwindling. Along with this is the quest for a good understanding of the value of water in its different uses. Using the Change in Net Income method, this paper presents an assessment of the value of water in irrigated paddy and hydroelectric power (HEP) generation in the Great Ruaha (GR) Catchment in Tanzania. The average values of water for irrigated paddy were estimated at \$ 0.01 and 0.04 per m^3 *for abstracted and consumed water respectively. For HEP, the values were relatively higher (\$ 0.06-0.21 per* m^3 *for gross and consumed water respectively). Yet irrigated paddy also contributes much: it supports the livelihoods of about 30,000 agrarian families in Usangu with average annual gross income of about US \$ 911.90 per annum per family and the GR paddy contributes about 14-24% to national paddy production. Understanding these benefits is key to fostering informed debate on water management and allocation, identifying the base for making 'agreeable' trade-offs, the potential for improvement, and creating linkages with water allocation options*.

Key words: Water value, Productivity of water, Irrigated paddy, Hydropower generation

Introduction

Many countries in the world are facing the challenge of effectively managing and allocating their available water resources to meet increasing demands from increasing human populations and economic activities which require water. This is becoming increasingly imperative, particularly in agricultural based economies where competition for water utilization between irrigated agriculture and other sectors is escalating. Examples include the cases of the Rufiji and Pangani basins in Tanzania, where there is potential competition between irrigated agriculture and other uses [notably the environment, domestic uses and hydroelectric power (HEP) generation].[1] In the upper catchment of the Rufiji basin [the Great Ruaha (GR) Catchment], for example, irrigated agriculture has expanded dramatically over the past 30 years, particularly in the Usangu area. 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; Kadigi and Mdemu, 2004). This in turn has caused not only a rapid expansion in irrigated agriculture but also growing conflict 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 Ruaha National Park, as well as the hydropower sector at the Mtera and Kidatu plants), particularly during the dry seasons (DANIDA/World Bank, 1995; Mbonile *et al.*, 1997; SMUWC, 2001; Kadigi *et al.*, 2004).

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[1] Note that the major irrigated areas in the Rufiji and Pangani basins are located upstream from the major HEP generating facilities.

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 the development of 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 (e.g. 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 relatively new area of research, particularly in developing countries. This paper is therefore a contribution towards addressing this drawback. It is a first step in the assessment of the Total Economic Value (TEV) of water utilization in the GR in Tanzania. The analysis of the value of water could be made for several other sectors, but given the scope of this paper, it was limited to irrigated paddy and hydropower generation. The paper draws on both the primary and secondary information collected during research work 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 title: "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 closely at aspects of water management, specifically in 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) research approaches and methods, c) results and discussion, and d) conclusion.

Description of the study area

The Great Ruaha catchment covers an area of about 68,000 km^2 and is located within the Rufiji basin (178 000 km^2), in the southwestern part of Tanzania. It encompasses the Usangu area, which has a total area of 20,811 km^2 (Figure 1). The Usangu area is located at approximately latitudes 7^{0}41' and 9^{0}25' South, and longitudes 33^{0}40' and 35^{0}40' East. It encompasses the Usangu Plains, in which the Usangu Wetland (which has an area of about 1,800 km^2) and the Usangu Game Reserve (4 148 km^2) are situated. The Usangu area is not located within a single administrative entity; it falls into two regions and eight districts, with the larger part (about 60%) falling within the Mbeya Region, but primarily in Mbarali District (54.69%). Small parts of the Mbeya Rural District (3.17%) and Chunya (2.3%) also fall within the Usangu area.

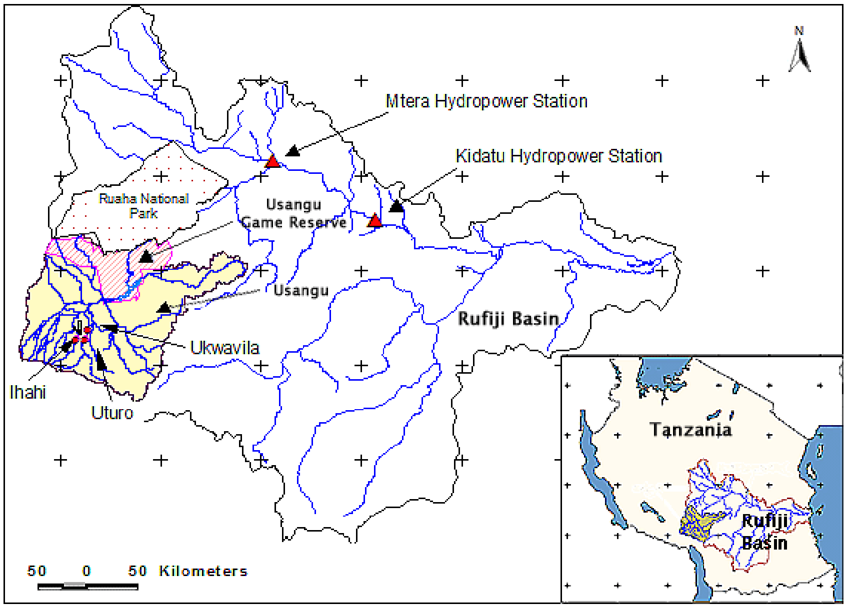

Figure 1. Map of Rufiji Basin showing the Usangu area, the study villages, Usangu Game Reserve, Ruaha National Park and locations of hydropower stations

The Usangu area has a total population of about 750,000 people, of whom more than 80% depend on agriculture as their major source of income. The major food crops grown 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 clay soils of the lower alluvial fans. 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 support 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 area under paddy in Usangu depends on the river flows and rainfall in each sub-catchment. The maximum irrigated land under paddy amounts to about 42,000 ha, during a normal-to-wet year when average weather conditions are favourable, and when irrigation is essentially supplemental to the water provided by rainfall (SMUWC, 2001). In dry years, the area under irrigation is comparably smaller: the core irrigated area is 24,500 ha, including a rice crop of 22,000 ha and a non-rice crop of 2,500 ha. During these bad years, both rice and non-rice crops are irrigated using mostly river flows, with less reliance on rainfall than in good years, and some land is therefore left idle.

The irrigated non-rice mixed cropping in Usangu (2,500 ha) includes maize, beans, vegetables and fruits, and extends throughout the year, mainly in the Chimala and Mkoji subcatchments. Dry season irrigation plots are usually very small (about 0.1 - 0.2 ha) and the main crops irrigated in these plots include maize, beans, tomatoes, sugar cane, onions and vegetables. As at the national level, land for rain-fed agriculture in Usangu varies from one year to another between 50,000 and 65,000 ha depending on the amount and distribution of rainfall.

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). The RNP has a higher diversity of terrestrial and aquatic wildlife (including birds and reptiles) than most other parks in Tanzania, and supports approximately between 6,000 and 8,000 elephants. 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. Downstream the Mtera plant, the GRR joins another major feeder river (the Kilombero), to form the Rufiji River after supplying water for power generation at another hydropower station called Kidatu. The Mtera - Kidatu system has a total installed capacity of 284 MW - the biggest installation capacity in Tanzania. It provides more than 50% of the total 559 MW available in the national hydropower grid.

The Mtera-Kidatu hydropower system was constructed as part of the Great Ruaha River Power Project (GRPP), which was implemented in three phases. The first phase started in 1970 and ended in 1975. This involved construction of a 40m high and 350m long earth-rockfill dam (with storage capacity of 125 Mm^3) and an underground power plant at Kidatu (installed with two generating units each with a capacity of 50 MW totalling 100 MW).

The second phase commenced in 1977 and ended in 1981. It consisted of additional installation of two 50 MW units at Kidatu, thus bringing the ultimate capacity of the plant to 200 MW. However, it was realized that the Kidatu reservoir volume was too small for annual regulation and continuous operation of the four generating units. To take care of water availability during the dry season of normal years as well as a series of dry years, adequate storage had to be provided upstream of Kidatu. A main storage dam was, therefore, constructed during phase II at Mtera (about 170 km upstream of Kidatu). The Mtera dam is the largest dam in the country in terms of height, crest length and concrete volume. Its impounded reservoir is also the largest man-made lake in Tanzania. The dam has a maximum storage capacity of 3700 Mm^3 and a minimum capacity of 500 Mm^3. The maximum capacity for the reservoir corresponds to a maximum supply level of 698.50 m above sea level, with the minimum level corresponding to 690.00 m above sea level. The average annual evaporation from the water surface of the reservoir is estimated at 2,440 mm (SWECO, 1981a,b) or 2,100 mm when the evaporation or actual loss of water is considered; that is, when the evaporation reduced by rainfall on the surface is considered and some allowance is made for unspecified losses such as evapotranspiration through aquatic plants and ground water seepage (SWECO, 1997).

The third phase started in 1984 and ended in 1988. This comprised the construction of an underground power plant at Mtera and installation of two generating units each of 40 MW, totalling 80 MW. The Mtera power station is the second largest powerhouse in Tanzania after Kidatu (204 MW). Electrical power generation at this station started in May 1988 with annual production for the period 1989 to 1994 averaging at about 429 GWh (SWECO, 1997).

Research approach and methods

Data collection

The assessment of water value in irrigation draws on both primary and secondary data collected between September 2002 and June 2004. The primary data were gathered from three villages in the Usangu area, namely Uturo, Ihahi and Ukwavila. 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 three villages are located adjacent to the Kapunga NAFCO farm, where farmers from these villages also hire plots for rice production.

The study started with collecting the names of all farming households in the sample villages, using village registers. Wealth ranking and livelihood analysis were then employed (using key informants in each sample village) to provide a sampling frame for the study. These exercises also served to provide a general understanding of the characteristics of the existing paddy production systems and their reliance on water resources. The following five types of production systems were identified:

- *Farming System Type 1: "Rainfed subsistence farmers"* - a system involving smallholder farmers who cultivated rain-fed paddy in 2002/03, using hand hoe and family labour
- *Farming System Type 2: "Rainfed paddy growers using high level of inputs"* - involves smallholder farmers who cultivated rain-fed paddy in 2002/03, using tractor, fertilizers and hired labour
- *Farming System Type 3: "Irrigated paddy growers on NAFCO plot" -* involves smallholder farmers who hired NAFCO plots in 2002/03 and cultivated irrigated paddy using tractor, fertilizers and hired labour
- *Farming System Type 4: "Smallscale irrigated paddy growers using high level of inputs" -* involves smallholder farmers who cultivated irrigated paddy outside the NAFCO farm in 2002/03 using tractor, fertilizers and hired labour
- *Farming System Type 5* "*Smallscale irrigated paddy growers*" - represents the most common smallholder cultivating irrigated paddy using hand tools and family labour.

A total number of 140 sample households were then selected randomly from each farm type and wealth category. The sample farmers were interviewed using semi-structured questionnaires. The questionnaire sought to elicit a set of information that would help in analysing the value of water and benefits accrued from irrigated paddy. The questionnaire encompassed issues of paddy and non-paddy crop production (acreage, inputs, outputs, prices, quantities produced, sold and consumed domestically, quantities in store and produce received or given in kind), other sources of income, aspects of water resource management (water conservation practices, sources of water for irrigation, type of irrigation system, irrigation practices) and utilization, access to sources of irrigation water and amount of money paid as water fee. The main characteristics of the farming systems as revealed by the sample are summarised in Table 1.

Table 1. Main characteristics of paddy farming systems in the GR

	Type 1 Rainfed Subsistence farmers	Type 2 Rainfed paddy growers with high inputs	Type 3 Irrigated paddy growers on NAFCO plot	Type 4 Small irrigated paddy growers with high inputs	Type 5 Small irrigated paddy growers with low inputs
Average plot size (ha)	0.35	0.54	6	1.27	1.25
Average family labour (mandays/ha)	206	183	102	113	167
Hired labour (mandays/ha)	0	39	41	52	0
Average operational costs (Tsh/ha)	22,600	135,200	200,852	229,080	70,500
Share in the total paddy area (%)	7	3	15	35	40

The current costs of non-water inputs, yields and output prices were derived from the household interviews.

The primary data collected were complemented by secondary information collected from the following sources:

- Mbarali District Agricultural and Livestock Development Office: paddy production (area and volume), marketing and price data at district level for a series of years (1994 to 2003)

- SMUWC's database and other literature: background information about the study area (including location, land uses, acreage, crops grown, water resources and utilization at catchment level)

- Ministry of Agriculture and Food Security (MAFS): land use, paddy production, marketing and price information, at national and regional levels

- Bank of Tanzania (BoT): National Consumer Price Indices (NCPIs).

The gross margins and returns to labour were calculated for each farming system and for each year from 1994 to 2003 using the following assumptions:

- Operational costs were assumed to be constant over the period and equal to those observed in the 2003 survey

- The variability of yields over the period was assumed to be constant across farming systems and equal to the one observed at district level: series of yields for each farming system were calculated using the average yield observed in 2003 for the farming system, and the series of yield at district level

- Paddy prices were assumed to be identical for all farming systems. The district level series of real prices was used (all converted into 2003 Tsh).

For HEP, the study benefited from the information gathered from the Mtera-Kidatu hydropower plants and the Tanzania Electric Supply Company (TANESCO) Head Office in Dar es Salaam, Tanzania (e.g., 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 paddy and hydropower generation, the values of water were analysed using the *Change in Net Income* method. The reasons for the choice of this technique include its simplicity and low data requirements.[2] Using the *Change in Net Income* method, Hussain *et al.* (2001) defined 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:

$$AW_V = (NVO_w - NVO_{wo})/W \qquad [1]$$

$$NVO_x = GVO_x - C_x, \qquad [2]$$

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,
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 paddy, the Crop Water Requirements (CWRs) were modelled using the CROPWAT model developed by FAO (1992), 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 net (consumed) water. In HEP, the PW and values of water were calculated based on the following volumes of water: a) the turbine discharge (non-consumptive use), b) the net evaporation (consumptive use) and c) the combined turbine discharge and net evaporation (non-consumptive and consumptive uses).[3] The portion of total value of electricity output attributable to water was valued using the economic Long-Run Marginal Cost (LRMC)[4] of \$ 0.1271 (Tsh 135.19) per kWh - given in the Tanzanian Power System Master Plan, 2001 Update Report by TANESCO (2002).

The analytical method used in this study (the *Change in Net Income*) is a simplified approach derived from the *Residual Imputation Approach.* The *Residual Imputation Approach* entails identification of the incremental contribution of each input to the value of total output or the 'residual' value of water. The derivation of the 'residual' value of water in this approach is based on two principal postulates (Young, 1996):

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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.

[3] 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 subtracting 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 are no transport costs for HEP 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.

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

- competitive equilibrium, which requires that the prices of all resources be equated to returns at the margin. "Profit-maximizing" producers are assumed to add productive inputs up until the point when the Value Marginal Products (VMPs) are equal to opportunity costs of the inputs, and
- the Total Value of Product (TVP) can be divided into shares, so that each resource is paid according to its Marginal Productivity and the TVP is thereby completely exhausted.

For an agricultural production process, for example, in which paddy output (Y) is produced by the following factors of production: capital (K), labour (L), and other natural resources [e.g. land (R) and irrigation water (W)]. The production function can be written as:

$$Y = f(K, L, R, W) \qquad [3]$$

If competitive factor and product markets are assumed, prices can be treated as constants. By the second postulate, it then follows that:

$$TVP_Y = (VMP_K \times Q_K) + (VMP_L \times Q_L) + (VMP_R \times Q_R) + (VMP_W \times Q_W) \qquad [4]$$

Where, TVP represents Total Value of Product, Y; VMP represents Value Marginal Product of resource i; and Q is the quantity of resource i. The first postulate, which asserts that $P_i = VMP_i$, permits substitution of P_i into [4] and rearrangement of the same equation as follows:

$$TVP_Y - [(P_K \times Q_K) + (P_L \times Q_L) + (P_R \times Q_R)] = P_W \times Q_W \qquad [5]$$

On the assumption that all variables in [5] are known except P_W, that expression can be solved for that unknown to impute the value (shadow price) of the residual claimant, (water) P_W^*, as follows:

$$P_W = \{TVP_Y - [(P_K \times Q_K) + (P_L \times Q_L) + (P_R \times Q_R)]\}/Q_W \qquad [6]$$

Results and discussion

Value of water for irrigated paddy

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

The analysis of paddy production at national level shows an increasing production trend for paddy with the contribution of Mbeya region to the national paddy production increasing sharply since early 1990s, making the region the largest paddy-producing area in Tanzania (Figure 2). About 60% of the region's paddy production comes from Usangu Plains in the upper GR. The Usangu plains alone contribute between 14 and 24% of national paddy production in Tanzania.

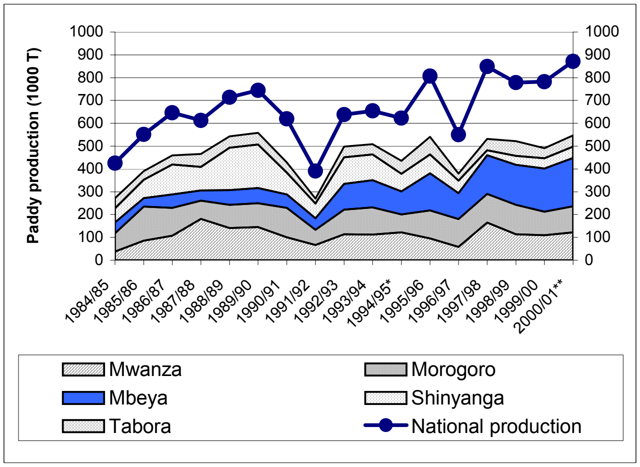

Figure 2. Paddy production trend for the five major producing regions in Tanzania and for the country as a whole, 1984/85 - 2000/01

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. In this regard, a trend analysis for paddy producer prices was also carried out using price information obtained from the Mbarali District Agriculture and Livestock Office.[5] The results of the analysis showed that producer prices are increasing only in nominal terms. In real terms, these prices have declined over time (Figure 3), 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 in farmers' income but also possible effect on the value of water.

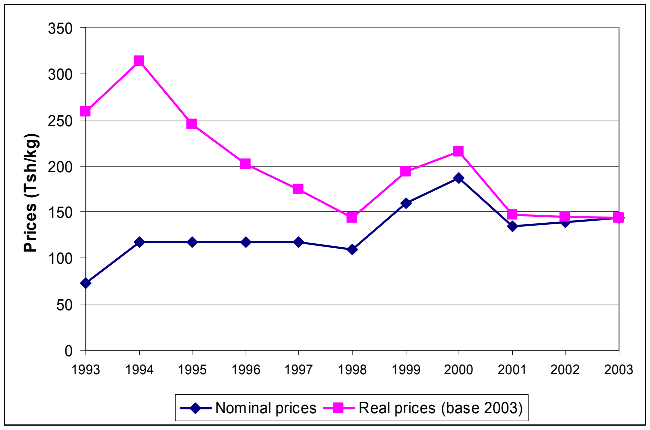

Figure 3. Mbarali district: The trend of average nominal and real paddy producer prices, 1993 - Mid Dec. 2002

Source: Mbarali District Agricultural Office and own calculation
Prices from 1993 to 1997 were controlled prices (Cooperative prices).
2002 price, not available, was calculated as an average between 2001 and 2003 prices.

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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 paddy (from 1993 to 2001) are negatively correlated with paddy production (correlation coefficient = –0.584, $P < 0.10$).

The average productivity of irrigation water ranges from 0.059 to 0.250 kg/m^3 for abstracted water depending on the farming system and from 0.126 to 0.265 kg/m^3 for consumed water (averages calculated over the 1994-2003 period). Among irrigated farming systems, smallholder farmers growing irrigated paddy using high levels of inputs (Type 4) show the highest productivity and smallholders on NAFCO farms (Type 3), the lowest.

In terms of value of irrigated water, smallholders growing irrigated paddy with low inputs (type 5) obtain the best results because of their very low costs of production and relatively high yields (Figure 4). Smallholders on NAFCO plots (type 3) get negative values because their gross margins per hectare are lower than those in rainfed farming systems and they abstract and consume more water. As expected, in all farming systems, the value of abstracted water is less than that of consumed water.

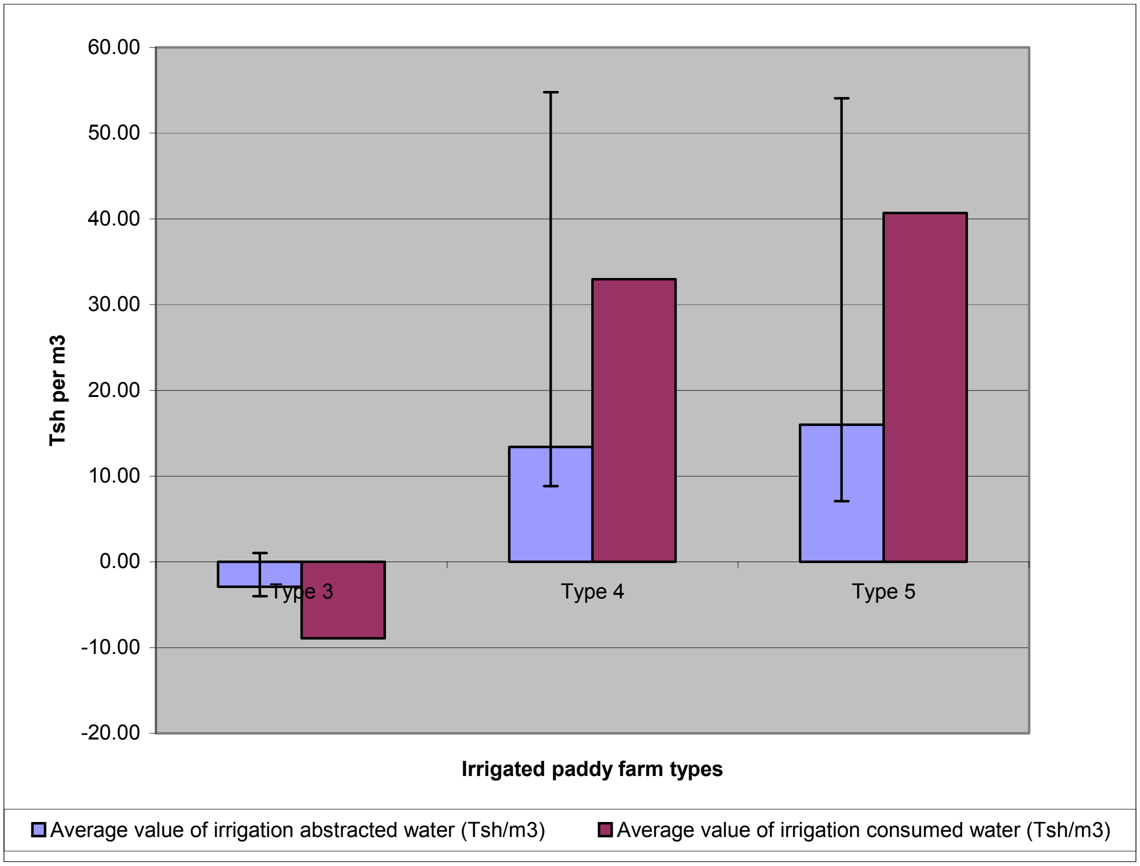

Figure 4. Irrigation water value per farming system calculated from gross margin (without family labour)

The above findings support the argument given in SMUWC (2001) that average productivity on the NAFCO rice irrigation system is lower than that on the traditional smallholder's irrigation system. The main cause of low yields in the NAFCO systems appears 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 (Types 4 and 5), plots are smaller, enabling greater care over water levels.

These figures are comparable with findings of other works in Sub-Saharan Africa (SSA). In the Pangani River basin in Tanzania, Turpie *et al.* (2003) estimated the average gross income per unit of water used in irrigation at the range of Tsh 100 to 1,400 per m^3, depending on area of the basin and type of irrigation[7]. Using the same criteria, the gross income per m^3 of water consumed in irrigation in the Usangu would range from 23 to 47 Tsh/m^3 in the irrigated farming systems, which is 4 to 30 times less than in the Pangani river basin. The differences may be attributed to higher water consumption and lower yields in Usangu than in the Pangani river basin. Generally, water productivity of rice in Sub-Saharan Africa 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 South-East 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).

The value of irrigation water varies from year to year depending on paddy prices, yields and climatic conditions. The standard deviation of the value of irrigation water for abstracted water ranged from 0.90 (for type 3) to 10.72 (for type 4), and for consumed water from 2.77 (for type 3) to 26.35 (for type 4). The lowest values were recorded in 1999, a year which had also recorded the minimum average yield with water use close to the average for 1994 - 2003. The highest values correspond to the 1994 figures, where the highest paddy price was recorded and the difference in water use between rainfed and irrigated systems was minimal.

Value of water for hydropower generation

As for irrigated paddy, a trend analysis of prices (e.g., electricity tariffs in this case) and existing pricing mechanisms would help in 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). In US $, the same have been increasing only in the period 1992-1996 but declining from 1998 to 2003 (Figure 5). This can be partly attributed to the effects of inflation[8] and distortions caused by government interventions in markets (i.e., the effects that stem from 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).

Summarized in Table 2 are the values of water in hydropower generation for the Mtera-Kidatu Hydropower System for three different scenarios. The value of water in hydropower generation showed different figures depending on the scenario chosen. As expected, the highest values are obtained when only consumptive use of water is considered (scenario S2), and the lowest when both consumptive and non-consumptive uses are taken into account. The water value is also extremely sensitive to electricity value, with values obtained using the average electricity tariff being a half of the values computed using the long run marginal cost. They also probably depend on the dam operation, but because data on power production and water releases and evaporation were only available for one year, it was not possible to assess this assumption.

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[7] The outputs, inputs and prices used by Turpie *et al*. (2003) are based on small sample sizes and should therefore be viewed with caution as the authors themselves note.

[8] Note that electricity tariffs in Tanzania are not frequently adjusted in line with the devaluation of the shilling.

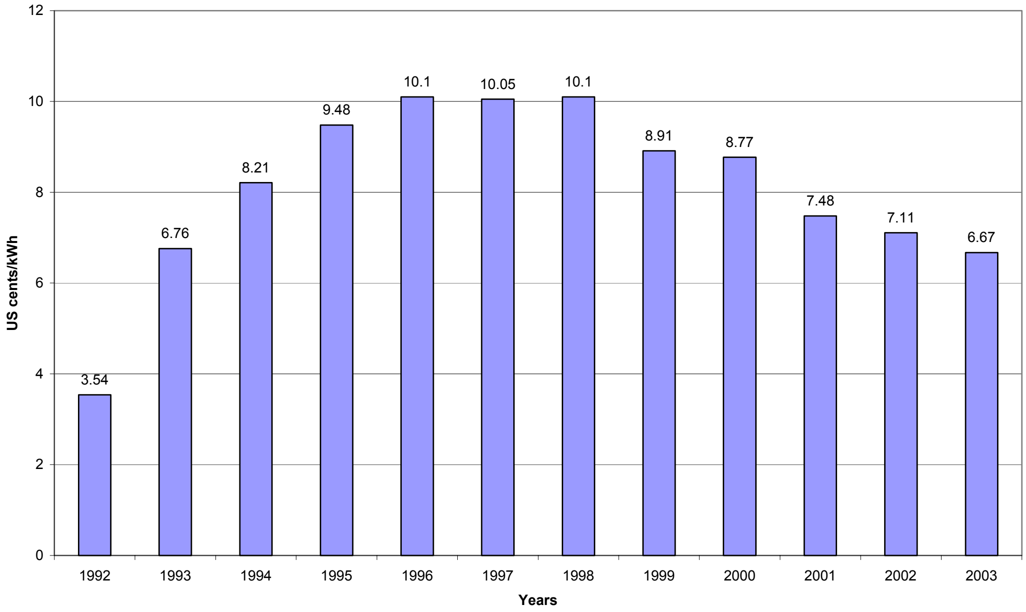

Figure 5. Average electricity tariffs in US cents per kWh, 1992 - 2003

Table 2: Value of water in hydropower production for the Mtera-Kidatu system in 2002/03

	Water scenarios		
Item	S1: Turbine Discharges at Kidatu (TDK)	S2: Mtera-Kidatu Combined Evaporation (MKCE)	S3: TDK plus MKCE
Electricity production (kWh)	1,839,424,000	1,839,424,000	1,839,424,000
Water used (Mm^3)	3,002	1,094	4,096
Energy efficiency (kWh/m^3)	0.61	1.68	0.45
Generating costs (Tsh/kWh)*	1.14	1.14	1.14
Electricity value**			
LRMC (Tsh/kWh)	135.19	135.19	135.19
(US $/kWh)	0.1271	0.1271	0.1271
Average tariff (Tsh/kWh)	69.79	69.79	69.79
(US $/kWh)	0.0656	0.0656	0.0656
Water value			
LRMC (Tsh/kWh)	81.7	226.08	59.57
(US $/kWh)	0.08	0.21	0.06
Average tariff (Tsh/kWh)	41.63	116.16	30.2
(US $/kWh)	0.04	0.11	0.03

(*) Excludes capital investment costs (e.g., costs for dam, reservoir and generating plant)
(**) Exchange rate in 2003: Tsh 1064/US $
LRMC = Costs or values estimated using the Long Run Marginal Cost of electricity. The LRMC is adapted from TANESCO (2002) and The East African Community (2004).
TDK = Turbine Discharge at Kidatu HEP plant
MKCE = Mtera-Kidatu Combined Evaporation from the HEP dams.

These figures can be compared with the estimates given by Turpie *et al.* (2003) in their preliminary economic assessment of water resources of the Pangani River Basin: they estimated the value of water used in hydropower generation at Tsh 3.8 per m^3 (for the Nyumba ya Mungu plant); Tsh 9.5 per m^3 (for the Hale plant); and Tsh 30.7 per m^3 (for the New Pangani plant), using an average electricity value of Tsh 73/kWh (the average revenue per kWh) and the volume of water flowing through turbine (equivalent to our scenario S1) for 2001. The differences of water value among the different power plants can be attributed to the difference in their hydropower systems and heads (energy efficiency of Nyumba ya Mungu, Hale and New Pangani plants are equal to 0.052, 0.130 and 0.420 kWh/m^3 respectively, compared with 0.61 kWh/m^3 for the Mtera-Kidatu system).

Trade-offs between irrigated paddy production and hydropower generation

Looking closely at the figures in Table 3 one would conclusively argue that HEP generates higher economic returns than irrigated paddy, but a number of other aspects need to be considered as well.[9] These include, for example, the question of whether HEP is superior to irrigated paddy in terms of generating both higher economic benefits and pro-poor returns. Nevertheless, the question of benefit sharing is also important and needs a closer analysis as well. Recognizing that only 10% of the total population of Tanzania (1% in rural areas) have access to electricity (URT, 2003) versus, for example, the share of the GR paddy in total national production (which ranges from 14-24%), and the fact that more than half of all the paddy produced in Usangu (60%, according to official records from the Mbarali District Agriculture and Livestock Development Office in Rujewa) is sold outside the area through inter-regional trading to other regions in Tanzania, one would also see the role that irrigated paddy plays particularly as enhancing both the local and national economies as well as national food security.

The amount of water currently consumed in irrigated paddy was estimated at about 542 Mm^3 per annum (Table 3).[10] By extrapolating the figures reported by SMUWC (2001) based on the actual field measurements of the annual depth of water applied in paddy fields for the NAFCO and Peri-NAFCO smallholder irrigation schemes (averaging 1850 mm), the mean annual rainfall (669 mm), effective annual rainfall (479 mm), irrigation annual demand (1371 mm) and mean wet season irrigated area for paddy (42,000 ha), the annual volumetric water consumption was estimated at 576 Mm^3 (Kadigi *et al.*, 2004). Having sixty percent of the total paddy produced in Usangu traded inter-regionally outside the area also implies that sixty percent or 325.2 Mm^3 (according to the current estimate) of the water consumed in Usangu for paddy irrigation or 345.6 Mm^3 (as per the estimate made after extrapolating the SMUWC (2001) water measurements), is traded outside the GR as "virtual water"[11]. Without irrigated paddy, this water would be utilized in alternative ways, either as evaporation from seasonal swamps within the GR or made available for other inter-sectoral uses.

According to the statistics collected from the Mtera-Kidatu hydropower stations, the annual net evaporation from the stations' reservoirs for the period July 2002- June 2003 amounted to about 1,094 Mm^3. If we consider this as equal to the total annual consumption (i.e., scenario 2 for HEP generation), then the gross revenue for the Mtera-Kidatu HEP system during the same period is

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[9] Other studies done elsewhere in Tanzania (e.g., the study by Turpie *et al.*, 2003) produce different results (i.e., higher values of water for irrigated agriculture than for HEP generation).

[10] The estimate considers only the wet season abstractions; if dry season irrigation is taken into account (August to November), then the figure might be higher, but the contribution of dry season flow downstream is considered insignificant because dry season irrigated paddy is uncommon in Usangu.

[11] "Virtual water" is defined as the water needed to produce a commodity or service (Allan, 2003).

estimated to amount to about US $ 232 million. In irrigated paddy, the same amount of water would enable an expansion of about 42,780 ha of land over the current area in Usangu (of about 42,000 ha) leading to total production of about 106,940 more tonnes of paddy than the current production level of about 105,000 tonnes.

Currently, irrigated paddy supports about 30,000 agrarian families in Usangu. In other words, the additional quantity of 106,940 tonnes of paddy could support extra livelihoods of more than the current number of paddy-farming families with average gross income per family of about Tsh 969,960 or US $ 911.90 per annum,[12] which implies that irrigated paddy plays an important role in lifting Usangu households out of poverty.

Table 3. The benefits of water utilization in irrigated paddy and hydropower generation, July 2002-June 2003

	PADDY		HEP		
	Abstracted Water	Consumed Water	S1 (Turbine discharge)	S2 (Evaporation)	S3 (S1 + S2)
• Production (tonnes for paddy) or (kWh for HEP)	105,000	105,000	1,839,424	1,839,424	1,839,424
• Gross revenue (Million US $)	15.9	15.9	232	232	232
• Share of the national total supply (%)	14 – 24	14 – 24	59 - 65	59 - 65	59 – 65
• Amount of water used (Mm^3)	979	542	3,002	1,094	4,096
• Productivity of water (kg/m^3 for paddy) or (kWh/m^3 for HEP)	0.11	0.19	0.61	1.68	0.45
• Net real value of water (Tsh/m^3)	15.31	38.6	81.7	226.08	59.57
• Net real value of water ($/m^3)	0.01	0.04	0.08	0.21	0.06

The opportunity cost of water transfer from irrigated paddy in Usangu (the upper part of the GR) to other alternative uses downstream (including HEP generation) is considerable, both at regional (Mbeya) and national levels. The Usangu paddy contributes about 105,000 tonnes of paddy or 66,000 tonnes of rice, about 70% of the total rice production in Mbeya region (which is the major contributor to national rice production). Assuming that farmers in this area are no longer producing irrigated paddy, there will be a shrinkage in annual rice production (both at local and national levels) of about 105,000 tonnes of paddy or 66,000 tonnes of rice valued at US $ 15.9 million per annum, unless this gap is covered by an increase in rice production from other regions. The net opportunity cost per m^3 of water used in irrigated paddy was estimated at Tsh 15.31 ($ 0.01) or Tsh 38.6 ($ 0.04) for abstracted and consumed water respectively (Table 3). It is, however, worth noting that this gap does not necessarily refer to the net loss of income to farmers in the Usangu, as the farmers may shift their resources from producing irrigated paddy to the production of rain-fed paddy or non-paddy crops or other income generating activities[13].

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[12] The value of paddy (in Tsh) is converted into US $ using the current (April 2003) exchange rate of US $ 1 = Tsh 1,063.62

[13] A more appropriate analysis for the net loss of household income would be achieved using models, which take into account the inter-regional markets (such as partial equilibrium models) to assess the effects of a decrease in local paddy production on the national economy, but data to enable such kind of analysis were not readily available.

Conclusions

Balancing water demands between sectors requires a good understanding of the value of water in its different uses and the opportunity costs of water transfer from one sector to another. This is imperative, particularly in agricultural-based economies, where agriculture competes with other sectors and water re-allocation decisions may imply transferring a significant amount of water from the sector generating the highest pro-poor returns (agriculture for this case) to the sectors generating the highest economic returns (HEP generation and industrial uses). Balancing water demands is therefore very tricky, often involving making hard choices as the evidences from the Great Ruaha in Tanzania show.

While the economic values of water utilisation for paddy production in the GR (in Tsh or $ per m^3 of water used) are lower than those for HEP generation, the role that irrigated paddy plays as the major source of income for the majority of poor households in the GR, and in enhancing national food security, must not be underestimated. Paddy production from the Usangu area (in the upper part of the GR) alone contributes about 14-24 percent to national production and supports about 30,000 agrarian families in Usangu with average gross income per family of Tsh 969,960 or US $ 911.90 per annum. Understanding these benefits is key to fostering informed debate on water management and allocation. It helps in identifying the base for making 'agreeable' trade-offs, identifying the potential for improvement and creating linkages with water allocation options.

It is, however, worth noting that the analysis presented in this paper serves only to provide some highlights of the value of water in the two sectors. The values of water estimated are based on a short time period (12 months from July 2002 to June 2003 for both irrigated paddy and HEP generation). Both short run and long run values are important in guiding re-allocation decisions. Furthermore, the approach used, that is the *Change in Net Income* method, calculates only average values and not marginal values of water and therefore cannot be suitable for making decisions on cross-sectoral water allocation. Ideally, estimating the marginal values of water would require the use of optimization models, which in turn demand a large amount of data which are seldom available. Again, in farming systems of developing countries, a large part of production is usually used for household consumption. The economic value of total output includes the value of marketed output as well as that of home consumption. The choice of appropriate price for the latter is problematic, especially when no market exists for these products. Just as importantly, 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.

There is also a need for integrating the environmental uses in the analysis. The issue of distribution of benefits is also important and probably needs new ways of approaching it. A massive reallocation of water from irrigation to hydropower, considering the share of GR production in total national paddy production, is also likely to have an impact on paddy prices and then change the value of water for irrigation. It is, therefore, important to go further in the analysis and include models that assess the marginal value of water, including all these scenarios as well as taking into account the risks of water transfer.

References

Allan J. A. (2003). Virtual Water - Problemshed solutions for water scarce watersheds: Consequences of economic and political invisibility. Paper presented at the 13th Stockholm Water Symposium, August 11 - 14, 2003. Drainage Basin Security - Balancing Production, Trade and Water Use. Stockholm International Water Institute. Sweden, 339-40 pp.

DANIDA/World Bank, 1995. Water resources management in the great Ruaha Basin: A study of demand driven management of land and water resources with local level participation. Rufiji Basin Water Office, Ministry of Water, Energy and Minerals, Dar es Salaam, Tanzania

Food and Agriculture Organization of the United Nations (FAO), 1992. CROPWAT: A computer program for irrigation planning and management. FAO Irrigation and Drainage Paper 46. Water Resources, Development and Management Service FAO Land and Water Development Division.

Hussain, I., Raschid L., Hanjra, M. A., Marikar F., van der Hoek W., 2001. A framework for analysing socio-economic, health and environmental impacts of wastewater use in agriculture in developing countries. Working Paper 26. International Water Management Institute (IWMI), Colombo, Sri Lanka. 12pp.

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.* Vol 29/15-18 pp 1091-1100.

Kadigi R.M.J. and M.V. Mdemu (2004). Opportunities for balancing water demands between irrigated agriculture and other sectors: what do the evidences in Tanzania tell us? A paper presented during the 14th Stockholm Water Symposium: Drainage Basin Management - Regional Approaches for Food and Urban Security, (16 - 20 August, 2004), Stockholm, Sweden.

Mbonile, M. J., Mwamfupe D. G., Kangalawe R., 1997. Migration and its impact on land management in the Usangu Plains, Mbeya Region, Tanzania. Report submitted to ENRECA, University of Dar es Salaam, Dar es Salaam, Tanzania.

Perry, C. J., 2001. Charging for irrigation water: The issues and options, with a case study from Iran. Research Report 52. Colombo, Sri Lanka: International Water Management Institute.

Renwick, M. E., 2001. Valuing water in irrigated agriculture and reservoir fisheries: A multi-use irrigation system in Sri Lanka. Research Report 51. International Water Management Institute, Colombo, Sri Lanka.

Rosegrant M. W., Cai X., Cline S. A., 2002. World water and food to 2025: Dealing with scarcity. International Food Policy Research Institute. Washington, D.C. pp. 79-80.

SMUWC (Sustainable Management of the Usangu Wetland and its Catchment), 2001. Main report - Annex 1: The Usangu catchment - baseline 2001. Available online at <http://www.usangu.org/>. Viewed 15/04/2002.

SWECO (Swedish Consulting Group) (1981a). Great Ruaha Power Project, Tanzania. Water Management Study. SWECO, Stockholm.

SWECO (1981b). Great Ruaha Power Project, Tanzania. Mtera Power Plant Preinvestment Study Volume 1. SWECO, Stockholm.

SWECO (1997). Great Ruaha Power Project, Tanzania: Environmental assessment of the Mtera Reservoir, Tanzania in a 20-year perspective. SWECO. Stockholm. 271pp.

TANESCO, 2002. Power System Master Plan, 2001 Update Report. Dar es Salaam.

The East African Community (2004). East African power master plan study. Final phase I report. BKS ACRES in association with Scott Wilson Piésold and Kagga & Partners.

Turpie J., Y. Ngaga and F. Karanja (2003). A preliminary economic assessment of water resources of the Pangani river basin, Tanzania: Economic value, incentives for sustainable use and mechanisms for financing management. A report submitted to IUCN - Eastern Africa Regional Office and Pangani Basin Water Office. 96pp.

URT (The United Republic of Tanzania) (2003). The National Energy Policy. Ministry of Energy and Minerals.

Young, R., 1996. Measuring economic benefits for water and investment policies. World Bank Technical Report Paper No. 338. The World Bank, Washington D. C.