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Water Productivity Indicators in Great Ruaha River Basin: Analysis and Implications for Decision-Making and Allocating Water

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Abstract

The assessment of benefits from water by applying the concepts of water productivity is gaining momentum for managing water resources in river basins. A number of institutions have been in the forefront of spearheading the concept. The attractiveness of the water productivity concept is partly due to its diversified nature in looking at benefits of water use, both intended and unintended in a particular system. The benefits may include area irrigated, number of families depending on a particular source of water, number of jobs created as a result of presence of water. This paper explores water productivity indicators and their implications for allocating water drawing the example from the Great Ruaha River Basin. In addition to the primary and secondary indicators of productivity, the paper develops the concept of tertiary indicators (labelled 'specific hydrovalue') to express the economic benefits gained per person per cubic metre of water used. The paper concludes that water productivity indicators (WPIs) can be used as a tool for analysing the tradeoffs and prioritising of water use and allocation in competing and non-competing water uses but that much more conceptual and computational analysis is required.

Introduction

Water productivity (WP) is an important concept in the contemporary science of water because of the unmatched increase in demand for water in the last fifteen years as a result of increasing population coupled with increase in per capita requirements per person and recognition of environmental water needs. Further to the challenge of meeting water demand in water scarce regions, there is an argument that more water should be directed to uses that generate a higher economic return per unit water, such as industries and high value crops that use less water. However there is a growing perception that many other uses, which are considered less productive, might also have a substantive call on water, either due to un-assessed value of water in such uses or because these uses have a comparatively important value in supporting poor rural livelihoods which would have a high social opportunity costs if that water was withheld. This paper explores some of these issues by examining practical indicators for irrigation systems and water sectors in the Great Ruaha River (GRR) basin in Southern Tanzania.

The productivity debate has wider implications. For example the unresolved debate on whether irrigation should increase worldwide by 20% to 30% to keep pace with growing population and food demand by 2025 (IWMI, 2000) or be subjected to a slowdown to an expansion between zero and 10% is partly perceived to be attributed to inadequate information on the benefits and costs of irrigation.

In addition, strategies for improving WP may be unsuccessful if productive indicators are not explicitly identified and clearly defined. In Sub Saharan African countries, where water systems have multiple uses, measures to increase or improve WP may not be appropriate in all circumstances. FAO (2003) urges that it is essential to consider the various uses of water, especially major users (e.g., irrigated agriculture) before measures are introduced that would increase productivity at the expense of other benefits from the same source of water, especially those benefits that accrue to local poor and landless people. Hence the need to define productive indicators of water.

Molden (1997) and Molden et al. (2001) defines water accounting indicators using a water balance approach. The water accounting indicates the water resource base and its flow paths. Pragmatic water accounting is considered to be a useful tool for assessing water productivity. Despite the fact that their definitions pay more attention to agricultural and its indicative physical components of water use, the approach is regarded as the first step toward defining water productivity indicators for multiple water uses. Indicators are perceived as a classical means of measuring and assessing impacts, both positive and negative on ecosystems. Indicators are useful tools in gauging the state of national economies: unemployment rate, the inflation rate, gross domestic product and others (Strzepek et al., 2001). For basin water resources, indicators are useful in deriving the benefits accrued from water use creating a linkage with water allocation options regarding its various uses. Also the concept is important for assessing the potential for increasing water productivity (output or benefit per drop) in different water use sectors.

Water productivity indicators can be defined in terms of physical, economical or social values. Physical indicators normally show the physical output such as ton or kilogram of crop biomass produced, the number of catches of fish from a given water resources/ecological system. The economic indicators derive from the physical ones in the sense that they represent the equivalent value in monetary terms ($) of the output from water given the market conditions. While some social indicators may fall into economic indicators they include benefits such as number of jobs created from the presence of the natural resource, livelihood sustenance directly from the natural resources, the social value (aesthetic) attached to the presence of water by rural communities, it is important to note that most social benefits are generally difficulty to value.

Where physical representation may generally apply to all water uses, economic indicators are mostly limited to uses (e.g. agricultural, industrial etc.) whose services or outputs can find a market. There are a number of methods to assess the economic value of water in agriculture: the method of integrating the demand function, the residual imputation method and the value –added method (Agudelo and Hoekstra, 2001). On the other hand indicators for uses such as domestic, environmental uses, whose services some time cannot find place in the market, are determined using alternative approaches by attaching an equivalent value to the goods and services derived from their use. These include method such as alternative costs, Contingency Valuation techniques and the Willingness To Pay for improved services among others. This is normally cumbersome and in most cases not done because of scantiness of data leaving such uses perceived as less productive.

Strzepek et al. (2001) argue that most of the benefits derived from ecosystem services carry no price tags that could alert society to changes in their supply or deterioration of underlying ecological systems that generate them because they are not traded in economic markets. However it is further argued that because of increasing threats to ecosystems, there is a critical need to identify and monitor ecosystem services both locally and globally. The conundrum of most water professionals (Agudelo and Hoekstra, 2001) emphasize that water allocation should be based on economic efficiency as outlined by Dublin principles. In this paper we urge that water allocation based on economic efficiency should be backed up with comprehensive assessment of the benefits accrued from each water user and should not necessarily be taken at face value. Productivity indicators primarily identify these benefits. In addition to that the Global Water Partnership (GWP, 2000) highlights that the value of water in alternative uses is important for the rational allocation of water as a scarce resource (using the "opportunity cost" concept), whether by regulatory or economic means. The information on WPI can be made available to all stakeholders as a means of fostering informed debate about management and allocation of water resources that sustain them with particular attention to poor families.

Our research also shows that WPIs can be classified as primary, secondary and tertiary indicators. (examples are given in Table 1). Primary indicators are simple counts and measurements of inputs (e.g. water in cubic metres, land in hectares) and outputs (tones rice, jobs etc). Secondary indicators employ division of output with input variables giving ratio indicators. This ratio definition is useful in comparing across case studies within one sector, e.g. yield/hectare from two different irrigation systems. It also allows investigators to calculate the benefit from each cubic metre depleted ($\$/m^3$), in doing so allows comparison within and between sectors. Thus irrigation can be compared with hydropower. Secondary indicators can be divided into biophysical and socio-economic, a distinction also shown in Table 1.

Tertiary indicators involve more variables in the ratio computation generating the so called 'specific' variables. This also enables a much more accurate comparison across sectors of water use because it includes both economic value and people supported by water. The main tertiary ratio calculation we propose is the "specific hydrovalue"; it is the economic output per person per volume of water used ($\$/capita/m^3$). The per capita variable, as it is in this case, could be an input as well as an output, with the former representing the number of people directly involved in production, and the latter representing the numbers of people involved in consuming the outputs. An alternative formulation could explore economic benefit per area per water used ($\$/ha/m^3$).

In addition, net and gross values can be determined, depending on whether the water input is net consumption or gross viewed as depletion from the river source. Furthermore, it may be possible in future to utilise net costs of infrastructural provision. It is these tertiary indicators, which are relatively new in water productivity research.

Productivity indicators and implications for allocating water in river basins

Irrigated agriculture and water productivity indicators

It is well recognized that for most irrigation schemes the primary purpose for their design and establishment has been the production of irrigated crops – a key indicator in this is yield per area. However, opportunities exist for other enterprises using the waters of such schemes. The many uses of water apart from irrigated crops include fishery and aquaculture, domestic and livestock use, brick making, production of fuelwood and fibre and environmental services. Livestock dependent on supplied water (either for a livestock farm or for irrigation) can be captured in this sector, in contrast to livestock that exist in the 'rangelands and wetlands'. Such multiple water uses are typical characteristics of irrigated systems in the Great Ruaha basin in Tanzania. These water-dependent enterprises are useful in supporting the livelihood of poor peoples who are sometimes unable to raise and manage irrigated crops. The enterprises are also a good source of revenues and employment to most rural youth in the villages and represent important local livelihood diversifications. The intensive fishery and wild duck hunting in NAFCO Kapunga for example employs more than 50 fish and duck artisans annually. Fish and duck produce is marketed in nearby town centres but some are transported outside of Usangu to Mbeya, Makambako and Makete towns bordering the Usangu plains.

Table 1. Water productivity indicators from water use in Upper Ruaha water systems

Water use	Primary	Secondary (bio-physical)	Secondary (socio-economic)	Tertiary (*selected*)
Irrigated crops	Number of farmers Area (ha) Yield (ton) Income ($) Water used, net & gross, (m^3)	Total biomass (ton/m^3) Crop Yield (ton/m^3)	Total revenue ($/$m^3$) Net revenue ($/m^3) No. of employment (Jobs/m^3) Inputs ($/$m^3$)	Specific net hydrovalue ($/pp/$m^3$ – net) Specific gross hydrovalue ($/pp/$m^3$ – gross)
Fishery	Number of fishers (n) Quantity of fish (n) Total income ($) Water used, net & gross, (m^3)	fishers (fishers/m3) Yield of fish (ton/m3) CPUE (kg/unit effort)	Income ($/m3) Livelihood supported (Lhood/m3) Artisan jobs (jobs/m3)	Specific net hydrovalue ($/pp/$m^3$ – net) Specific gross hydrovalue ($/pp/$m^3$ – gross)
Aqua-culture (duck hunting)	No of hunters (n) Quantity of ducks (n) Total income ($) Water used, net & gross, (m^3)	No of hunters (hunters/m^3) Quantity of ducks (ton/m^3)	Income ($/$m^3$) Livelihood supported (Lhood/m^3) Revenue to villages (revenue/m^3) Artisan jobs (jobs/m^3)	Specific net hydrovalue ($/pp/$m^3$ – net) Specific gross hydrovalue ($/pp/$m^3$ – gross)
Brick making	No bricks (n) No persons (n) Houses constructed (n) Total income ($) Water used, net & gross, (m^3)	No bricks (bricks/m^3) No persons (person/m^3) Houses constructed (houses/m^3)	Income ($/$m^3$) Livelihood supported (jobs/m^3)	Specific net hydrovalue ($/pp/$m^3$ – net) Specific gross hydrovalue ($/pp/$m^3$ – gross)
Firewood and timber	No of people (n) Total income ($) Volume or ton collected (m^3 or ton) Water evaporated (m^3)	Biomass (t/ha)	Income from sales ($/m3	Specific net hydrovalue ($/pp/$m^3$ – net) Specific gross hydrovalue ($/pp/$m^3$ – gross)
Domestic	Households (N) (n) Reduction of water related diseases (diseases/m^3) Total income ($) Water used, net & gross, (m^3)	Households (hh/m^3) Reduction of water related diseases (diseases/m^3)	Value added to water ($/$m^3$)	Incr. enterprises per area (Enterp/area/m^3) Increased sanitation (no of birth/ day/m^3)
Livestock (agricul-ture)	Livestock numbers (n) TLU (n) Total income ($) Area Water evaporated (m^3)	Livestock (No/m3) Cattle (No/m3) TLU/m3	Income generated from livestock ($/$m^3$)	Specific net hydrovalue ($/pp/$m^3$ – net) Specific gross hydrovalue ($/pp/$m^3$ – gross)
Environ-mental	Livelihood supported (n) Number of species available (n) Total income collected ($) Water evaporated ($m^3$)	Livelihood supported (N/ha) Number of species available (N/ha)	Income ($/$m^3$)	Specific net hydrovalue ($/pp/$m^3$ – net) Specific gross hydrovalue ($/pp/$m^3$ – gross)
Hydro-power	No of people engaged (n) Electricity produced (KW hrs) Water evaporated (m^3) or used Total income ($)		Income from sales ($/kWhrs) Economic output ($/m3)	Specific net hydrovalue ($/pp/$m^3$ – net) Specific gross hydrovalue ($/pp/$m^3$ – gross)

Analysis of water productivity considering the above factors may indicate the true value of water placing it in a better context for water allocation that could be jeopardised if only its primary target supply was considered. Table 1 summarizes the different water uses in irrigation systems common in the GRR and the productivity indicators that are important for water allocations consideration.

Domestic functions and water productivity indicators

Water has a critical role within the household for cooking, utensil and cloth washing, hygiene and bathing. Although some of these are difficult to quantify because they do not result in marketable goods, they do have livelihood benefits that can be quantified via contingency methods. There are two types of indicators of values of water or economic benefits received by a household from getting an improved water supply. The first type is the monetary value of savings in resources used to obtain water prior to the new system. These savings may be from not having to fetch water from a distant source or from boiled water or from not having to purchase water from vendors. The second type is the consumer surplus from the increased water purchased at a lower total cost.

For domestic water demand (in rural areas of developing countries), the Contingent Valuation (CV) approach has been successfully applied to impute monetary values for the above two types of indicators. In its preliminary research work in Mkoji Subcatchment (part of Usangu basin), for example, RIPARWIN has used this approach together with the market-based method to calculate the value of water in the domestic sector. The Willingness To Pay (WTP) approach was specifically used in the lower Mkoji where water resources are scarce especially during the dry season and where villagers often walk long distances in search of water for their domestic needs. The average amount that households were willing to pay per bucket was found to be Tsh 20.3 per basket of 20 litres, which was almost the same as for the market-based method (Tsh 20 per basket of 20 litres). The value of water was therefore found to be Tsh 1000 per m^3 and the per capita water consumption was found to be Tsh 12000 per person per year.

Livestock functions and water productivity indicators

Livestock numbers and their market value can be used in valuing water productivity but with careful definitions of where they were raised (in agriculture by livestock keepers, or in rangelands by pastoralists). Counting methods are also important, with perhaps the most reliable method being numbers that pass through livestock markets.

RIPARWIN has also calculated productivity of water in livestock sector (in Mkoji Subcatchment) using the Profit Margin Approach and the shadow price of Tsh 1 per litre (the value of water in the domestic sector). In the calculation livestock was considered as both an asset and income earner representing future income generating capacity and household saving. The values of water in the livestock enterprise were found to be Tsh 5,276; 5,831; and 6,295 per m^3 equivalent to Tsh 1,702; 870; and 113 per TLU per m^3 for the upper, middle and lower MSC respectively.

Environmental functions and water productivity indicators

An environmental function can be defined as the capacity of natural processes and components to provide goods and services that satisfy human needs (De Groot, 1992). The environment is difficult to assess both in terms of water used and benefits gained. Water productivity of the environment is not a well-developed science (Grenell, 1994 and Hollis, 1994). Many authors acknowledging the lack of a market to realise values, argue for the intrinsic non-monetary values of environment to be recognised and safeguarded.

The evaluation of environmental functions and derivation of water productivity indicators for the environment requires a concise understanding of the water flows regime as linked to ecosystem functioning and attributable benefits. This can be regarded, as an input-output relationship where the input variable in this case is water and the output are the benefits accrued from the ecosystem as a result of water inflow. Capturing the benefits, both direct and indirect require a clear quantitative data on the biophysical relationship between the environment and water flows. Further more, the attached social services need to be identified and the link to flows established.

The catalyst on the need for evaluation of the wetlands, which forms a large part of environmental bodies, is built on the realisation of the importance of wetlands in supporting peoples' livelihoods through subsistence utilisation of the services and outputs of wetlands. In addition to that, Seyam *et. al.,* 2001 argues that wetlands are also important for remote populations because they contribute to larger scale benefits such as climate regulation. Despite their obvious importance, wetlands have been vulnerable to increasing pressure of economic and population growth. This has been accentuated by the fact that wetlands have been poorly valued, and hence their loss was perceived as a minor cost compared to the expected benefits from wetlands development projects (Seyam *et. al.,* 2001).

RIPARWIN is undertaking a scientific research on the quantification of wetlands water productivity that will contribute to a new unresolved scientific research on environmental water productivity from which the water productivity indicators would be realised. The valuation approach consists of three steps; firstly the identification of wetlands (size of the wetland, status regarding protection and conservation and the main utilization of the wetland), secondly marginal values of the wetlands products and services are estimated based on market prices, and thirdly, the use of market surrogate methods in cases where the goods and services are not traded such as: the contingent valuation method (CV), the hedonic price method (HP) and the travel cost method (TC). The quantified environmental values may provide basis on the dialogue for environmental water allocation.

Hydropower functions and water productivity indicators

Electricity generation from hydroelectric power plants, in terms of economic value, represents one of the more important outputs of water resources. Energy production from hydropower depend on the amount of water that flows through the turbines, the distance that the water drops (effective head), and power plant efficiency, constrained by turbine and generator capacity.

Most economic evaluation of hydropower is to assess the overall economic feasibility of the hydropower production as an investment. Isolating the marginal value of water from total value requires additional steps. Because the electricity is produced from a combination of resources: capital investment in dam, reservoir and generators plus the operating maintenance and repair costs in addition to the water, the marginal contribution of water (productivity of water) should be derived from an additional analytic process employing the residual technique.

Two steps are required to derive the economic value of water for hydropower generation. The first step is to value the electricity produced from a specific hydro plant. Because electricity is typically sold into a power grid relying on a number of sources (hydropower plus thermal), it is not convenient or even possible to specifically derive demand for hydro portion of the region or nation's electrical supply. Also, because electricity prices are often set by government policy, which seldom reflects the marginal cost of new supply, observed electricity rates might be inappropriate for economic evaluation. Therefore, in the first step, the value (shadow price) of electricity is usually calculated via the alternative cost technique, based on an estimate of the cost of the next likely increment of electric power. The second step is to calculate, via the residual approach, the portion of the total value of electricity output attributable to the water used for generation.

Depending upon the case under study, the analyst may estimate several values of water for hydropower. One pair of cases includes short run and long run values. Short run values are derived by deducting only operation, maintenance and repair (OM & R) from total value of output, and are sustainable for short run reallocation decisions. Long run values are developed for long run investment and reallocation decisions, by further deducting capital investment costs (annualised equivalent costs of outlays for dam, reservoir, generating plant allocated to the power function).

The other pair of cases refers to the value for peaking versus baseload generation. Peaking power electricity is typically more valuable than baseload generation, because of the cost of bringing less efficient and more expensive alternative thermal capacity briefly on line. Thus, water for peaking is correspondingly more valuable in peaking than in base load generation.

Decision aids and water productivity indicators

A well-designed computer-based decision aid (DA) can have five important functions. Firstly, it can greatly facilitate the calculation of water productivity indicators and, secondly, a DA can then present that information in sectoral terms summed for the total volume of water allocated to each sector. Thirdly, the latter computation then allows direct comparison between sectors, plus, fourthly, the computation of total net gains in productivity and can in turn support decision-making over the re-allocation of water. The fifth function is to relate productivity gains to environmental and hydrological change indicators, such as timing and discharge of low and peak flows and the shape of advance and recession curves of the river hydrograph.

Conclusions

The above discussion is predicated on a quantitative input-output conceptualisation of water use. It does not however include activities (as measured by indicators) that affect productivity but are not demonstrably part of the productivity equation. Such activities cover for example institutional and legal-framework dimensions. Thus one might propose that a given sector can be assessed in terms of the numbers of functional water user groups that discuss how to raise productivity. Whether or not these governance ‘process’ inputs are useful in the analysis of water productivity has yet to be shown; but they are useful in terms of presenting or qualifying an overall ‘state of being’ of water productivity management.

Water productivity indicators (WPIs) can be used as a resourceful tool for analysing the tradeoffs and prioritising of water use and allocation in competing and non-competing water uses. Clearly, these lines of investigation open up a number of questions about the usefulness of such indicators in water management. For example, the work poses the question “Can we have a dialogue on water food and environment without explicitly defined productivity indicators?” Initial work in this area suggests that definitions and assumptions will have to be clarified considerably before these indicators can be used reliably. Until indicators become more familiar, and incorporated into models and decision-aids, decision-making over allocation patterns may have to rely on social articulations of priorities either in a partisan manner, emanating from within each sector, or by fostering trans-sectoral visions of water sharing, by creating and sustaining wider water forums and parliaments that target full stakeholder representation.

The authors also propose that such indicators will enrich the debate over whether water should flow to the sector representing the highest economic utility. It is arguable that widely dispersed agrarian poverty is difficult to sustain without water but can be alleviated via irrigation and domestic water provision. The social and economic opportunity cost that this water represents, if captured in WPI calculations, may counter-balance the move towards sending water to urban, industrial and power sectors that already benefit from concentrations of labour, markets and other inputs, and can find alternatives to water-sourced electricity, and moreover can 'afford' technologies to recycle and purify water.

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