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PWAIS

ANNEX 2

Methodological Tools for Assessing Productivity of Water in Agriculture and Interacting Systems With Respect to Tanzania and Ethiopia

Submitted to

COMPREHENSIVE Assessment of water management in agriculture

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ABBREVIATIONS

CWR = Crop Water Requirement
CWP = Crop Water Productivity
Eta = Actual Crop Water Used
MSC = Mkoji Sub-catchment
RIPARWIN = Raising Irrigation Productivity and Releasing Water for Intersectoral Needs
SUA = Sokoine University of Agriculture
SWMRG = Soil Water Management Research Group
TLU (s) = Tropical Livestock Unit (s)
TAS = Tanzanian shilling
USD = United States Dollar
WTP = Willingness To Pay
SMUWC = Sustainable management of Usangu Wetlands and the Catchments
GoSA =Government of South Africa

1 INTRODUCTION

Agriculture is one of the main consumers of fresh water resources in the world, second to natural ecosystems such as forests and grasslands from where a high proportion of rainwater is depleted back to the atmosphere through evapo-transpiration. The depletion of rainwater from natural and rain-fed agriculture ecosystems is what has been termed the *green-water* flow (Falkenmark and Rockstrom, 2004). It is also estimated that more than 70% of water withdrawal from rivers and lakes (the *blue-water*) is used for irrigation of agricultural crops (Seckler *et al.,* 1998). The UN World Water Development Report estimates that it takes on average 1,000 cubic metres of water to provide the 2,800 calories per person per day needed for adequate nutrition (UNESCO-WWAP, 2003). Other reports have estimated that it requires between 1 to 3 tones of water to produce 1 kg of rice (FAO, 2002). These figures are large mainly because of the failure to adequately account for transpiration processes within evapo-transpiration (FAO, 1998; Ziemer, 1979). In general the estimated water uses by crops include a large proportion of unproductive depletion of water through direct evaporation from crop fields. This report presents case studies from small basins in Tanzania and Ethiopia with respects to current knowledge, attitudes and practices by stakeholders with respect to productivity of water under these kind of complex agricultural and interacting systems.

The study was implemented as part of a component project of the Comprehensive Assessment (CA) of Water - global programme. The project titled Productivity of Water in Agriculture and Interacting Systems (PWAIS) was designed to contribute to the global objectives of the CA, by studying productivity of water in catchments dominated by smallholder agriculture in Tanzania and Ethiopia. The purpose of PWAIS is to *identify and verify knowledge demanded by relevant institutions regarding alternative and best options for improving productivity of water in agriculture and interacting systems in Eastern Africa* (Box 1). This is designed to contribute to the CA's aim of creating new knowledge base on all aspects of water management in agriculture for stakeholders dealing with agriculture and water solutions. The CA is coordinating global efforts for the aim of promoting rational and productive use of water to meet global food security among other objectives. The target areas for PWAIS include the upper parts of the Rufiji Basin in Tanzania (Map 1), supported by testing the options in Tekeze-Atbara Basin in Ethiopia (Map 2).

Box 1. Goal, purpose and outputs of PWAIS

GOAL:
Strategies for improving the productivity of water in rainfed and irrigated agriculture so as to ensure social, economic and environmental sustainability in river basins, ADOPTED.

PURPOSE:
New knowledge demanded by relevant institutions regarding alternative and best options for improving Productivity of water in Agriculture and interacting systems in Eastern Africa, identified and verified with stakeholders.

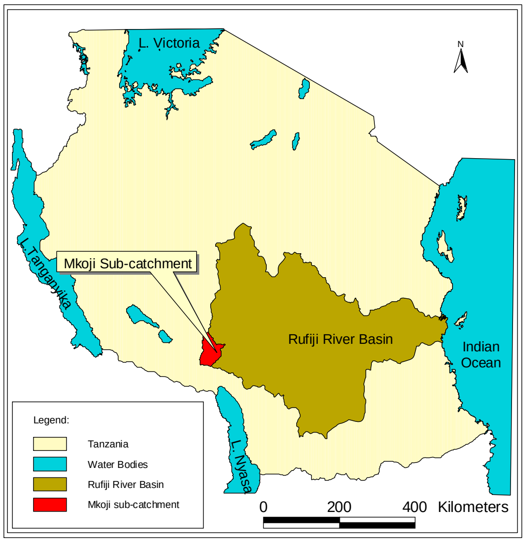
OUTPUTS:
i) Methodological tools for assessing the productivity of water in the case study basin
ii) Evaluation of the benefits and consequences of options for improving productivity of water in agriculture under different scenarios in the case study basin.
iii) River Basin Management Decision Aide (RBMDA) with robust modules dealing with selection of options for increasing productivity of water in agricultural and interacting systems.
iv) Knowledge sharing tools which are participatory and able to link stakeholders from community to basin level.

The Rufiji Basin is the largest and most important basin in Tanzania, supplying water to major hydropower plants producing 40 % of electricity in the country. There are also major irrigation schemes both large and small scale, large forest areas, game reserves and wetlands in the basin. The Rufiji Basin is made up of four sub-basins; namely, Ruaha, Rufiji, Luwegu and Kilombero. The current study focuses on only one of these, the Great Ruaha River Sub-basin. The study reported here is confined to an upper catchment of the Great Ruaha River Basin – the Mkoji with an area of

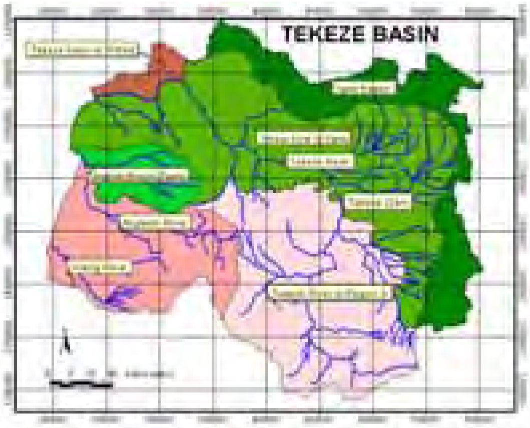
3,400 square kilometres covering about 2% of the whole Rufiji Basin. The main land uses – and thus water uses in the Mkoji include forest ecosystem, grasslands, wetlands and agriculture. Major water use entities in the Mkoji during the wet season is about 97.9% (77.7Mm^3) in agriculture production, 1.1% (0.9Mm^3) domestic, and 1.9% (1.5Mm^3) livestock production. A similar pattern of use of about 80.5% (12.4 Mm3) for agriculture, 10.04% (1.6Mm3) for brick making, 10% (1.5Mm3) for livestock and 5.8% (0.9Mm3) for domestic use was recorded during the dry season. Other water uses including forest ecosystem in Mkoji have not yet been determined.

The Kapunga Rice Farm (about 3800 ha), which is frequently mentioned in this review contain a scenario representing both smallholder and estate farms, multiple uses and reuse of water and complex water distribution problems leading to conflicts.

In Ethiopia, PWAIS is focusing on the Tekeze catchment with an area of 68,000 km^2 within the Nile River Basin. The catchment extends from the southern highlands of Ethiopia to the central and western Tigray pouring water into the Nile towards the Sudan. There has been an extensive irrigation development work in the catchment by local people, the government, and development agencies.



MAP 1. Location of Mkoji Catchment in The Rufiji Basin in Tanzania



MAP 2. Tekeze-Atbara Basin In Ethiopia

In this report both published and grey literature was used to assess the current understanding of the concept of productivity of water in agriculture in the study catchments. The report assesses the way different individuals and institutions estimate the productivity water under different and interacting uses, which are centered around agriculture. This report has been produced as part of output 1 of PWAIS. The report includes a review of general concepts of productivity of water both under rainfed and irrigated agriculture. The disparity and agreements in defining and understanding of productivity of water concepts is discussed. National policies and programmes on water resources are assessed to determine how the concept of productivity of water is presented and also to identify the suggested tools for its assessment. The report also explores how multiple uses of water in irrigation schemes complicate the assessment of productivity of water. Then knowledge and practices in measuring and assessing productivity of water by different stakeholders (i.e. farmers, researchers, engineers, academicians, designers and water resources planners/regulators) are explored. This includes the type of data being kept by the different institutions, which could assist in the assessment of productivity of water in smallholder rainfed and irrigated systems. The potential use of simulation models for crop growth and soil water balance, hydrology and functions for assessing productivity of water in the study areas is discussed. Their use in estimating benefits from water depleted in the process of producing the benefits, data input requirements and data gaps are also discussed. Finally the report also examines how GIS and remote sensing approaches can be used to assess productivity of water at basin level.

It must be emphasized here that this report is set in context of informing key stakeholders in the target areas. The aim is to use this report to raise the awareness of the target stakeholders on what productivity of water in irrigation is - and thus facilitate dialogue towards meeting of the objective of PWAIS.

2 CONCEPTS OF PRODUCTIVITY OF WATER IN AGRICULTURE

This section summarizes and synthesizes how different authors have defined the concept of productivity of water with particular reference to the conditions found in the PWAIS target areas. The section then reviews the current application of the productivity of water concept to both rain-fed and irrigated agriculture in the study areas.

2.1 Productivity of Water in Agriculture - Definitions

Agricultural productivity is normally and universally measured with respect to land and rarely with respect to water (Perry, 1999). This is perhaps due to the fact that in highly populated Europe, land became an expensive commodity during the expansion of agriculture. The Europeans were therefore justified to evaluate productivity against land – but this may not be valid everywhere. Indeed, it is now being realized that other factors of production, notably water and labor are becoming increasingly scarcer than land – especially in the semi-arid areas. For example, in many parts of the world, fresh water supply has become the most critical limiting factor in crop and other agricultural production systems. In order to ensure that adequate attention is paid to productive use of water it is imperative that performance of agricultural systems should also be measured with respect to water (Perry, 1999). It is this requirement, which led to the development of current efforts by leading water management institutions such as IWMI to introduce the concept of productivity of water in agriculture – *more crop per drop*.

However, no common understanding exists among different stakeholders on how to assess productivity of the water used for agriculture – especially the *green-water* flows under rain-fed systems. But even under irrigation systems there are hardly any efforts as yet to mainstream the assessment of productivity with respect to water. For example, irrigation schemes in Tanzania obtain water on the basis of permits defining volume per unit time but re-allocations of the same water and subsequent payments by individual users are determined by size of land being irrigated. Furthermore, amount of water given to farmers is not in terms of volume but through allocated hours of access to irrigation water and according to frequencies of irrigation decided by the WUAs (Tarimo *et al.,* 2004). In the end it is very difficult to calculate exactly how much water was actually used to produce a certain amount of products – hence difficult to gauge productivity of water. Even the farmers practicing micro-irrigation in small plots using buckets and cans to irrigate crops do not keep accurate records of the amount of water used. The same situation is true in the Tekeze/Atbara where most water for irrigation is supplied by small rainwater harvesting reservoirs. It would be a simple matter to keep records of how much water is used to produce what, but this is not kept. This lack of practice and procedures for estimating the amount of water used is a major challenge to the concept of productivity of water in agriculture.

Water Use Efficiency (WUE) is more commonly used by irrigation planners and is defined as a ratio of water used to amount supplied for a defined user type with specified boundaries. It is expressed without units (i.e. as a percentage) and requires the formulation of the net and gross amount of water utilized for the activity under study (FAO, 2003). Most researchers, engineers and water managers use the hydrological water use efficiency, which is defined as a ratio of evapo-transpiration to the water potentially available in the target area. This hydrological WUE is similar to the generally applied definition of irrigation efficiency, which is expressed as a ratio of water used to water diverted for the intended use. However, some of the definitions and practices of determining WUE can make a very good starting point in the determination of productivity of water, especially in irrigation. For example, Stanhill (1986) defined physiological water use efficiency as a measure of plant growth to volume of water used to affect that growth. They again define economic water use efficiency as the ratio of value of agricultural commodities per volume of water used to produce them. The latter two definitions are widely advocated as definitions of productivity of water (Molden *et al*. 2001) and not water use efficiency. However, some researchers (e.g. Shaozhong *et al.,* 2002, Stanhill, 1986, Cox and Pitman, 2002, Cox, *et al.*, 2002) have been using the same definition to represent water use efficiency. In a similar setting, the United States Department of Agriculture (USDA) defines three types of water use efficiencies (Ronald and Marlow, 2002); these are:

i) Water Use (technical) Efficiency: The mass of agricultural produce per unit of water consumed.
ii) Water Use (economic) Efficiency: The value of product(s) produced per unit of water volume consumed.
iii) Water Use (hydraulic) Efficiency: The ratio of water actually used by irrigated agriculture to the volume of water withdrawn.

These technical and economic efficiencies as defined by USDA are indeed measures of productivity of water in the *more crop per drop* paradigm.

Even for the agreed definitions of productivity of water, the general understanding of the concepts of productivity of water has not been uniform and is based on background of stakeholder (Table 1). According to Bastiaanssen *et al*. (2003), yields per drop may not be useful if comparison is needed between different crops in different regions. He urges that economic values per unit of water may be more logical. At the same time some economic values may neglect other benefits and therefore the most logical definition of productivity of water in agriculture will be the total benefits (however measured) per unit of water depleted in realising those benefits. However, this all-inclusive definition is difficulty to measure because:

i) It is very difficult to account for all water uses and put value on all the benefits (Renwick, 2001), and
ii) It is not easy to quantify the actual amount of water depleted in a particular process, especially where reuse of drainage water is occurring and there are very few gauging stations.

To overcome these two constraints, there is a need for robust approaches to accounting for water uses as discussed by Molden (1997).

Table 1. Examples of definitions of Productivity of Water by different stakeholders

Stakeholder	**Useful definition would be**	**Scale**	**Target**
Plant physiologists	Dry matter/transpiration	Plant	Productive utilization of light and water resources
Agronomist	Yield/evapo-transpiration	Field	Higher yields tons/ha
Farmer	Yield /water supply	Field	Higher yields tons/ha
Irrigation engineer	Yield/diverted water	Irrigation scheme	Demand management
Water resources planner	$/total depletion	River basin	Optimal allocation of water resources

Source: Modified from. Bastiaanssen *et al*., 2003

2.2 Perspectives in Water Resource Policies

Recent reviews of national water policies are putting emphasis on the conservation of water sources and reserving water for the environment. Specifically the water policy in Tanzania recognizes water as a common natural resource for socio - economic development, basic for various social and economic development activities such as industrial production, irrigated agriculture, livestock, mineral processing, hydropower production, navigation and recreation and tourism. This Policy has broadly adopted the Dublin Principles and provides a framework for the management and regulation of water resources by adopting the river basin as a planning and management unit. Also, it explicitly promotes multi-sectoral and integrated water resources planning and development so as to facilitate a process of broad-based, inclusive and sustainable poverty reduction (World Bank, 1996). However, the policy gives more priority to water for maintenance of human health, food security and ecosystem (URT, 2002). In Ethiopia priority is similarly on water uses in drinking and sanitation, then other uses such as livestock watering, agriculture, hydropower generation and industry follow in the priority list. Among other main objectives of Ethiopian water policy, the two related to productivity of water are:

i) The development of water resources and optimum allocation for the benefits of all people on an equitable, efficient and sustainable basis; and
ii) Managing effects of droughts and associated disasters through efficient allocation, redistribution, transfer, storage and efficient uses of water resources.

Deleted:

The Tanzania National Water Policy defines water use effectiveness and efficiency in a similar way as the classic water use efficiency; that is the proportion of water beneficially used to the water diverted or made available for the use. This is implied in the irrigation and water supply efficiency statements quoted by the policy document. The policy recommends the following strategies for improving productivity of water, from the perspectives of WUE:

i) Encouraging water management approaches which facilitate beneficial and efficient water use;
ii) Improving efficiencies of water supply entities such as hydropower generation, irrigation, industries, mining etc. to avoid wasteful use of water; and
iii) Gradually building economic incentives and pricing for water to encourage productive use.

However, the policy puts more emphasis on efficient use of piped domestic water supply, in terms of reducing losses due to leakages and unlawful water abstracting. With respect to water used for agriculture the policy encourage use of irrigation water and rainwater harvesting for drought mitigation and ensuring food security for the population. It also recognizes the need for water to be used in producing high value crops to increase productivity of irrigation water. The Water utilization (Control and regulation) Act of 1974 (WU Act) of Tanzania as amended in 1981, 1989, and 1997 and the accompanied regulations of 1975, 1994, 1996 and 1997are confined to water allocation procedures.

The regulatory bodies instituted by the law such as water basin offices have statutory obligations to offer water rights and water fee pricing, which can only work indirectly to influence productivity of water.

All in all, the Tanzanian government within her Agricultural Sector Development Strategy has strived to enhance the efficiency of water utilization though the promotion of better management practices (URT, 2001). The policy encourages farmers to focus on integrated soil and water management so as to promote optimum use of water. Furthermore, the Tanzania Land Policy of 1995, the subsequent Land Act of 1999 and Village Land Act of 1999, offer land tenure security, which create incentives for users and owners to make investments, which are necessary for increasing the productivity of land and water.

Trying to achieve increased productivity of water through pricing mechanisms has faced problems from the long held belief that water is a public property and entitles everybody to have access to it to meet livelihood needs. Market mechanisms are considered to be unable of solving many problems of water allocation where there are many poor and disadvantaged households trying to access water resources (e.g. Schreiner and van Koppen, 2001). According to this opinion, water should then be treated as a social good and people should be entitled to use it even when they cannot afford to pay the full price of its provision. However, water resources planners think that this approach has a negative effect on productivity of water. For example, Mutayoba *et al.,* (1998) stated in their report that low water fees has contributed to wasteful and inefficient use and needs to be adjusted to reflect real economic value of water. It is clear that it perhaps does not matter whether water is treated as an economic good or social good or both, what matters is how to measure and value the benefits (DANIDA/World Bank, 1995). Then the indicator of productivity of water in terms of total benefits per water depleted becomes very valid. At this juncture what is lacking is commonly agreed approach and tools for assessing and attributing the benefits to a given quantity of water.

2.3 Water development approach to concepts of productivity of water

In this section a review is made of appraisal reports from major development projects in Tanzania, especially in the study area of Mkoji to see how productivity of water is handled from the perspective of development planning and implementation of agricultural water projects.

2.3.1 Agricultural Sector Program Support (ASPS) – supported by DANIDA

Agricultural Sector Program Support (ASPS) is a multi – faceted initiative financed by the Government of Tanzania and Denmark (through DANIDA) executed by the Ministry of Agriculture and Food Security (MAFS), with the involvement of the Ministry of Water and Livestock Development (MWLD) and the President's Office, Regional Administration and Local Government (PORALG). The program included some components of on-farm seed multiplication, livestock development, environmental conservation and rehabilitation of traditional smallholder irrigation systems. The program has been implemented in the four regions of Mbeya, Iringa, Morogoro and Dodoma since 1998 to date (Kamuzora, 2003; Lekule and Lamosai, 2004). Under this project the issues of productivity of water in agriculture are raised in terms of improving the ability of farmers in the existing traditional schemes to achieve sustainable increase in agricultural productivity (Royal Danish Embassy, 2000). The project facilitated the public and private sector to promote improved and replicable approaches for participatory irrigation management and delivery of improved services to smallholder irrigators. The main approach was that of improving the intakes (i.e. increased the abstraction efficiency) with little improvements in the infield water management. A review of project appraisal and monitoring and evaluation reports show that very little attention was paid to increasing and or monitor productivity of water. This is surprising because water was recognized as the most limiting factor and hefty investments were made to assist farmers to divert more water to crop fields.

2.3.2 River Basin Management– Smallholder Irrigation Improvement Program

The smallholder irrigation component of the project was designed, mainly for improving smallholder traditional irrigation systems in the Rufiji and Pangani basins. RBM component provided the main support to the formulation of the Tanzania National Water Policy (World Bank, 1996). Under this project the issues of productivity of water in agriculture were handled in terms of improvements made to the smallholder traditional irrigation systems, which was presumed to improve irrigation efficiency and productivity (MAFS, 2004). The general approach used was that of improving the intake structure through the construction of a permanent weir or intake and a limited lining of the main canal. The conventional method of measuring irrigation efficiency was applied. In this method two points along the conveyance system were selected and the inflow and outflow were monitored and the conveyance efficiency or application efficiency were calculated and reported in percent. Therefore, again major investments in water diversion but little serious monitoring of the productivity of water at farm level.

2.3.3 National Irrigation Master Plan (NIMP) – supported by JICA

Under the master plan, the issues of productivity of water in agriculture will be handled through irrigation development, which is regarded as one of the effective approaches to poverty alleviation in rural areas (JICA/MAFS, 2002). It is envisaged that NIMP interventions will improve irrigation efficiency (based on classical definition of irrigation efficiency), which is expected to improve productivity in agriculture as a result of more efficient use of water. Hence, although there is no apparent definition of productivity of water in the project, NIMP has used both classical irrigation efficiency and crop yield per unit area as measures of productivity of water diverted for irrigation.

2.3.4 Participatory Irrigation Development Program (PIDP)

This is a project supported by the International Fund for Agricultural Development (IFAD), Government of Tanzania, Irish Aid and the World Food Program (WFP) and implemented by MAFS. The project was started in 1999 in six regions of the Tanzania mainland with the goal of improving production and income of smallholder farmers through irrigation schemes construction and improvement. The project puts a lot of emphasis on empowering the smallholder farmers to efficiently manage irrigation schemes through strong water user associations and introduce market oriented crop production in the irrigation schemes. The project emphasized on better management of water abstracted for irrigation, mitigating rainfall unreliability through rainwater harvesting and supplementary irrigation and therefore considering water as a major input in agricultural productivity (UNOPS, 2001). This project support many measures and approaches, which eventually lead to increased productivity of water. It however also suffers from the problem of lack of monitoring of the productivity of water.

2.3.5 Participatory Agricultural Development Empowering Project (PADEP)

This project aims to raise production of food, incomes and assets of the participating households and groups in a sustainable manner. Under this project the issues of productivity of water in agriculture are handled in terms of improving soil fertility, land management, soil and water conservation, conservation tillage and efficient use of inorganic fertilizers are given priority. Furthermore, the project works on rainwater harvesting techniques as well as rehabilitation and improvement of traditional irrigation systems. In this way PADEP strives to improve productivity of water by improving water use efficiency by the crops through promoting better husbandry practices, and improved rainfall and irrigation water management (including promoting use of drip irrigation and treadle pumps). As such, the project works to increase both productivity of land (i.e. Producing more crops per unit of land) and water. As this project is just being initiated there are opportunities to bring on-board appropriate monitoring of Productivity of water.

2.3.6 Sustainable Management of the Usangu Wetlands (SMUWC)

The World Bank and DFID supported this project. The SMUWC project used the modern concepts of productivity of water and water accounting for water use and productivity. For example, SMUWC (2001) when assessing the Kapunga irrigation system identified fishing, bird hunting, domestic, livestock use as some of the water use benefits. Also SMUWC (2001) promoted the concept of irrigation water reuse, which further improves productivity of water. For example, in the Kapunga Irrigation Project, the field water productivity for paddy was reported to be 0.17kg/m^3. However when water reuse was considered, the productivity of water increased to 0.42 kg/m^3. However, it must be noted that SMUWC was not an agricultural water development project, but rather a semi-research program designed to explore alternatives in water management. It therefore, brought to the surface some new thinking with respect to productivity of water, and certainly influenced the design of both RIPARWIN and PWAIS.

2.3.7 Summary

The brief evidence presented in this section has shown that productivity of water is not yet a mainstream issue in the planning of programs on management of agricultural water, in Tanzania. However, there are various interventions included in the reviewed programs, for increasing the productivity of water. These will provide the entry point for the dialogue to be conducted under PWAIS with the stakeholders.

2.4 Application of the Productivity of Water Concepts to Rain-fed Agriculture

In sub-Saharan Africa approximately 95% of agricultural land is under rainfed agriculture (FAO, 2000). Agriculture production supported only by direct rainfall is highly affected by climatic variability (Mahoo *et al.*, 1999) as well as dry spells, which occur during the growing season (Barron *et al*., 2003).

In rain-fed agriculture productivity of water is expressed in terms of either gross (total rainfall regardless of losses) or effective rainfall. Effective rainfall is determined as amount of precipitation that reaches and remains in the root zone. In calculations for effective rainfall, seasonal rainfall totals need to be used. However, due to high uncertainties in rainfall distribution in semiarid regions, probabilities of rainfall, or amount of rainfall that is considered dependable (Doorenbos and Pruitt, 1984) is taken into the equation rather than the absolute means of seasonal rainfall totals. Both gross and effective rainfalls are not realistic measures in gauging productivity because most of the rain is partitioned into runoff, deep percolation and soil evaporation. In practice, the crop uses a small proportion of between 15% and 30% by transpiration (Rockstrom *et al,*. 2003). Hence, the need to use rainfall use efficiency to explain productivity of rain-fed agriculture (Diarra and Breman, 2004). Rainfall use efficiency is expressed as a proportion of effective rainfall (i.e. evapo-transpiration) utilized in the synthesis and assimilation of biomass (Perrier, 1988). However, seasonal rainfall data is relatively much more available in the study area than evapo-transpiration data. Evapo-transpiration data is highly limited and inconsistent (SWMRG-FA0, 2003). Few attempts have been made to estimate consumptive evapo-transpiration using available weather data and FAO local climate estimator. But this has mostly been done by academicians and researchers (e.g. Chemka, 1996, SWMRG-FAO, 2003). Farmers on the other hand do not even consider rainfall measurements.

In the study area of Mkoji, the coefficient of variation of monthly rainfall ranges between 38% and 100%. Agriculture in this area is characterized by low yields due to frequent droughts and dry spells. Although rainfall is not usually measured, the productivity of rainwater is normally very low since a location can receive high rainfall amount but produce very little in the end due to effects of climate variability and dry spells. As an example the average harvest of maize in Mkoji is about 2300Kg/ha while the average rainfall amount is 900 mm. Assuming 65% rainfall efficiency it means that 585mm of water giving a productivity of water of 3.9kg/ha/mm. With supplementary irrigation to mitigate the effects of dry spells, the overall productivity of water can be increased to 6.3kg/ha/mm.

Similarly, around 90% of Ethiopian agriculture is rain-fed. In the Tekeze/Atbara catchment in Ethiopia rainfall is highly unreliable and in most of the seasons rainfall is lower than the seasonal crop water requirement. Rainfall variability ranges from 20% to 40% in western and eastern Tigray region, respectively (ECA/UNDP/FAO, 1994). Low yields and crop failures are very common. Supplementary irrigation has been effective in increasing productivity of water. For example there has been an increase of up to 89.3% of wheat yield in the Adigudom area in Tekeze river basin as recorded between 1995 and 2000 (Mintesinot *et al.,* 2004). Records show that without supplementary irrigation yields are as low as 3.6kg/ha/mm. With the supplementary irrigations estimation from existing records show that productivity can be increased to 6 kg/ha/mm. Furthermore, the small reservoirs and farm ponds provides other benefits mainly domestic water supply and livestock watering. This therefore leads to increased productivity of water in rain-fed systems. What is missing is again lack of monitoring and evaluation of productivity with respect to water.

2.5 Application of the Productivity of Water Concept to Irrigated and Interacting System

In irrigated agriculture productivity of water considers also the multiple products other than the crops. In most irrigation schemes, the water supply is often used for more than just crop production. Besides supporting crop production, diverted water is used for domestic purposes, fisheries, livestock, wildlife habitat, environmental preservation and enhancement (Renwick, 2001). This is the situation found in the Mkoji catchment, where non-irrigation activities in the basin include domestic water use, fishery, livestock watering, brick making and power generation (SMUWC, 2001; SWMRG-FAO, 2003). Therefore, assessment of productivity of water in irrigation systems requires adequate accounting for agricultural and non-agricultural water uses. Failure to recognize the non-agricultural uses of water can have serious implications for irrigation projects management, water rights, and the economic appraisal of the projects (Renwick, 2001).

The practice of assessing productivity of the products other than agricultural related is new in the study areas. The knowledge, existing facilities and methodologies were not robust enough to enable comprehensive assessment of all water use components and products. As it will be narrated in this section, the SMUWC and RIPARWIN projects may be the first pioneers trying to assess productivity in irrigation and interacting systems in the study area. The SMUWC project (SMUWC, 2001), which was an environmental development based, looked at productivity of irrigation water beyond the irrigation scheme. SMUWC's concept was that irrigation water produces crops and other interacting products within the irrigation system. Furthermore, the drain water is used down stream in the flood plains and swamps to enhance environmental productivity. The notion was picked up by RIPARWIN project which went further to assess productivity of irrigation water in multiplicity of uses within the schemes together with the productive roles of the water in the wetlands downstream (Mdemu *et al*., 2004; Kadigi *et al.,* 2004). The RIPARWIN project has also worked to measure all possible benefits from use of irrigation water of the Kapunga water system, using the water accounting components as proposed by Molden *et al*., (1997).

It is in the Kapunga water system where the scenario of multiplicity of uses and water reuse is clearly exhibited. The system abstracts between 4.8 m^3/s and 6 m^3/s of water to irrigate about 3000 ha of the main Kapunga rice farm together with some 700 ha of smallholder farmers' scheme. Drain water from Kapunga rice farm irrigates about 700 ha of paddy fields down stream supporting livelihoods of people in Yala village (SWMRG-FAO, 2003). Brick making is also an important user of irrigation water. All houses around Kapunga were built using bricks made by using water from the Kapunga water system. It is also estimated that the system supports about 50 fishermen activities producing around 59.8 tons of fish per year worth 27,504 USD (RIPARWIN, 2003). Such productivity values were not determined and recognized before. When Chemka (1996) assessed productivity of water for both smallholder and government managed Kapunga rice farm, productivity determinations neglected reuse and multiple uses of water in the system. Water accounting was not attempted, hence both actual water depleted and down stream reuse was not known.

In many cases, engineers do not consider concepts of productivity of water when designing irrigation systems. In practice irrigation efficiency rather than productivity is the major factor in irrigation design (Halcrow et al. 1992, FAO, 2001, URT-FAO 1979). Also performance of an irrigation system is mostly assessed based on efficiency of water use (i.e. ratio of volume of water required by plant to volume of water supplied (Bos, 1982; Chancellor, 1997, Tarimo, 1994, Chemka, 1996). Very few appraisals of irrigation systems have been done in the Rufiji Basin and only a handful of them have used productivity of water indicators as measures of performance. For example, Tarimo (1994) used measures of classical efficiency to assess performance of smallholder irrigation systems in the Usangu plains. This has been the practice for many other researchers in Usangu and elsewhere in Tanzania (e.g. Makongoro, 1997). Only recently that SMUWC (2001) and RIPARWIN projects have consistently used productivity concepts and indicators in assessing performance of Kapunga water system. Also Chemka (1996) when comparing performance between government and farmer managed irrigation systems at Kapunga used both productivity and efficiency measures.

The level of management limits the type of data kept and the practice of measuring productivity of water in many irrigation schemes in the Rufiji Basin. This further depends on the type of irrigation system and the way in which irrigation water is abstracted. For example, managers of gravity irrigation systems care little in the amount of water they divert from the rivers since there is little direct cost incurred (mainly in terms of manpower to open and close the gates). This explains the reasons for sparse record of amount of water going to fields from the main canal, despite having well calibrated gauges in the main canal and division structures (SMUWC, 2001).

On the other hand, the Mbarali rice farm records amount of water in the main canal because that data is needed for regulating water diverted to the hydropower plant, which is integrated in the Mbarali water system (Christopher, 2004, personal communication). Measurement of water diverted in these systems is neglected because the only major cost known is annual water user fees of which is not regularly paid. Monitoring system for water abstractions and enforcing water user fee (by the Rufiji Basin Water Office) is not efficient enough to motivate managers to keep data for assessing productivity of water (SWMRG-FAO, 2003). Productivity of water in such farms is gauged by cost benefit analysis (e.g Chemka, 1996), which considers annual water user fee as a minor component cost in the analysis (James, 1988).

It is in pumped systems such as Kilimanjaro Agricultural Training Centre (KATC) and Bagamoyo Irrigation Development Project in which cost of pumping water is a high input in the farm cost. For smallholders, the cost of water is included in the land rent and farmers normally measure productivity mainly as per combined cost of land and water (Kapilima, 2003, Personal communication).

As pointed out earlier in this section, the type of irrigation system also has influence on the level of management and type of data collected. Drip and sprinkler systems demand higher management levels than surface irrigation systems. That is the reason for the Kibena Tea Estate (KTE) in Njombe Tanzania to use a high level of management over the sprinkler and drip irrigation system it operates compared to management level offered to the gravity irrigation systems in the Rufiji Basin. As opposed to the latter, the estate collects and uses the whole range of weather data required for determination of crop water requirement and irrigation scheduling together with other data for assessing farm productivity (Kibena Tea Estate, 2001, 2002, 2003). The Kibena piped irrigation system is equipped with gauges and gadgets for measuring amount of water, constantly monitoring irrigation application uniformity, yield and above all the cost of pumping water. The management gives high weight to management of water to justify water pumping bill and profit optimization. As such they have incorporated in their management system a way to assess productivity of water because it is a very important input to the estate. But still the productivity of water is not featuring in the management audit reports. Nevertheless, these kind of records provide a very good data base for assessing the productivity of water in irrigated systems.

Over 80% of the irrigation systems in the Rufiji basin are farmer managed under irrigation water committees and water user organizations (SMUWC, 2001). As for the case of other gravity irrigation systems; Water User Associations (WUA) seldom practice recording the amount of water used or abstracted. In most of the make shift irrigation intakes, flow measurement devices are absent. They are installed in the few improved irrigation systems along the main canals only, and very seldom in secondary and tertiary canals. Even in the improved systems, intake flows are not regularly recorded by WUA's, because there is no regular monitoring of volume of abstraction for water user fee estimation, which would motivate WUA's to keep flow records.

In practice, water is allocated among farmers in terms of duration and frequencies of irrigation and not the specific volume of flow. Frequent data kept by WUA's and irrigation committees; include a list of farmers in the scheme, designated acreages, irrigation turns and yield that each farmer gets (Tarimo *et al*., 2004). This set of data is essential for estimation of quota of water user fee each farmer is supposed to pay, of which is remotely related to actual water use. When Chemka (1996) was assessing productivity of water in the small holder Kapunga rice farm, the only data he could retrieve from farmers' records were yield and acreages and not the water used or diverted. In this case, smallholder farmers record productivity of land rather than water, which they refer as good or poor yield and further related to good or poor access to irrigation water (in the head or tail end of the scheme). Hence for farmers, productivity of water is not necessarily an absolute number but a relative measure of water use, which is not most of the times quantified by measuring precise amount of water used.

It is only in micro irrigation systems in which most farmers have to carry and irrigate with buckets and other small containers, where the amount of water is measured in the process of use. In this case farmers can tell how much water has been used to produce a certain crop output. Even though, it will take some effort to extract such data from them. In summary, there is no deliberate effort among smallholder farmers to monitor and record water use and water productivity but there are several implied means of assessment suitable for their own situation. Furthermore, most of the benefits obtained from the interacting systems are not directly being measured.

2.6 Summary

We see in this section that no consistent and complete monitoring, reporting and auditing of the productivity of water is practiced along the continuum from policy to individual farms. However, where pumping is practiced for modern irrigation schemes, enough records are kept which could be used to piece together an assessment of the productivity of water. In the next chapter we assess how this reality can be used as a basis for designing methodological tools that are appropriate to the stakeholders of productivity of water under situations such as those found in the study areas.

3 METHODOLOGICAL TOOLS USED TO ASSESS PRODUCTIVITY OF WATER IN AGRICULTURE

Assessment of productivity of water entails estimation of the two main components of productivity of water; namely the physical mass of production or the economic value of produce and the unit volume of water depleted in the process. The presentation in chapter two has shown that there is very little direct assessment and measurement of productivity of water in all the farming systems in the study areas. In this chapter we assess how the current practices of different stakeholders can be a basis of methodological procedures for estimating/measuring the numerator and denominator of the productivity of water equation. Physical benefits such as yield, bricks, fish catch may be easily measured. However, some benefits are not easily recognizable and even complex to numerate (e.g. social amenity and environmental sustenance). The most important missing link is the patchy or non-existent quantification of water that is truly depleted during a particular production or service process. However, there are current practices of field measurements of water uses and in this chapter we assess how these kind of measurements can be a starting point for estimating the quantity of water that is truly depleted.

3.1 Meteorological and Hydrological Measurements

Water balance estimations, which are normally undertaken by researchers is the most regularly implemented component of the processes of determining the productivity of water. The direct measurements include the climatic data kept by the meteorological departments, hydro-metric monitoring implemented by water resources departments and soil water content normally measures by agronomic researchers. However, most of these are dependent on very few stations or experiments that are located far apart spatially and temporally. For example, in Mkoji (3,400 km^2) there are only two reliable rainfall-recording stations and one full meteorological station. Data from rainfall stations outside Mkoji had to be used in the comprehensive analysis of water resources of the study area. Similarly, the Makelle climatic data was used for water balance analysis of the Haiba scheme in Tekeze basin some 45 km away (Mintesiniot, *et al.,* 2004). The records or estimations that are done by researchers working in the study area include those of evapo-transpiration, run-off and deep percolation.

3.1.1 Estimation of evapo-transpiration

Crop evapo-transpiration (ET) is one of the most important process depletion of water in the production of crops and is normally estimated from weather data; namely, net solar radiation (MJM^{2}day^1), wind speed (ms^1) and mean daily air temperature (ºC). This data is used as input to the Penman-Monteith method described in the FAO Irrigation and Drainage Paper No. 56 (FAO, 2001). The Penman-Monteith equation has been incorporated in many soil-water balance, crop growth and hydrological models for estimation of crop evapo-transpiration (e.g. CROPWAT (FAO, 1992)). Among these models, CROPWAT has been the most widely used for estimation of evapo-transpiration and crop water requirement. Since there are few weather stations in the study areas, data required for the Penman-Monteith method has normally been extrapolated from representative weather stations nearby. Weighing lysimeters are also sometimes used in the estimation of water balance components including evapo-transpiration. However, use of weighing lysimeters in Tanzania and Ethiopia is limited by high cost of construction and operation (Howel, 1996, Allen *et al*. 1998, Evett *et al*., 1993, Khan *et al*., 1993). Where weather data is missing, Class A Pan method has been used for estimating evapo-transpiration (Christiansen, 1968). In the study areas in both Tanzania and Ethiopia, this is the most readily used approach. For example, evaporation data of Mkoji show that mean daily evaporation varies from 4.3 mm/day to 5.5 mm/day. In Tekeze/Atbara mean daily evaporation varies from 1.3 mm/day to 3 mm/day. This will give an estimated ETc as shown in Table 2.

Table 2: Daily Crop water requirement for the Major Crops:

a) Mkoji Tanzania

Crop	**Growth Stage**			**Seasonal crop water requirement (mm)**
	Initial	**Middle**	**Maturing**	
Paddy Rice	4.9	5.6	3.4	690
Maize	0.74	5.6	2.5	450
Beans	0.74	5.4	1.3	320
Potatoes	0.74	5.4	3.2	470
Millet	0.74	4.4	1	390
Sorghum	0.74	5.6	4.9	390

b) Tekeze/Atbara

Crop	**Growth Stage**			**Seasonal crop water requirement**
	Initial	**Middle**	**Maturing**	
Wheat	0.9	3.45	3.4	415
Maize	2.7	3.45	2.5	333
Beans	1.2	3.45	1.3	290
Potatoes	1.5	3.45	3.2	460

No record of past research was found in the Rufiji Basin on measurement of evaporation from moist soil surface and wetlands before RIPARWIIN. Currently, RIPARWIN is using micro-lysimeters according to Burt *et al*. (2001) and Tyler *et al*. (1997) to estimate evaporation from moist soil surfaces in Kapunga water system (Mdemu, Personal Communicatio). The project also uses the Class A pan to estimate evaporation from Ifushiro swamp in the Rufiji Basin in Tanzania, while Mintesinot *et al.,* (2004) used Penman equation to estimate evaporation from water surface of Haiba dam in Tekeze sub-basin.

GIS and remote sensing image techniques can also be applied to estimate both crop and non-crop vegetation evapo-transpiration. The principle behind is the ability to utilize refractive radiances of red and infrared bands from Satellite remote sensed images, which are used to calculate the normalized difference vegetation index (NDVI). Kite and Droogers (2000) have applied such procedures using NOAA-AVHRR and Landsat TM data to estimate evapo-transpiration at two specific sites in Turkey. Remote sensing and GIS have been used for land cover change detection in Chimala river catchment (Tarimo *et al.*, 2002), but there is no strong evidence of use of the same in estimating ecosystems evapo-transpiration and productivity of water in Rufiji Basin. The major inputs required to use this method are satellite remote sensing images, which are considered expensive and are used only when it is necessary.

3.1.2 Estimation of surface water flows and run-off – hydrological measurements

The next important measurement or estimation that is normally practiced by researchers is the determination of surface water flows in stream and rivers, and small extent in canals within irrigation systems. Runoff from catchments are not regularly determined but rather measured in experiments in runoff plots or small cathments (using runoff multi-slot divisor systems, weirs and flumes). For example weirs were used to measure runoff from a catchment in Mbeya (the upper most part of Rufiji basin catchment) (Blackie and Edwards, 1979). There are also several river flow gauging stations in Rufiji basin, five of them are in Mkoji where daily flow data is recorded (SWMRG-FAO, 2003). Water diverted for irrigation is measured only occasionally using stage recorders or portable flumes and or direct current metering.

Researchers have also widely adopted the USDA curve number method (Soil Conservation Service, 1972) to simplify the tedious and expensive procedures involved in physical measurement of runoff. The curve number method has also been incorporated in various soil water and hydrological models. Use of hydrological models in the Rufiji Basin can be traced to Mwakalila (2001) who modelled hydrological responses in the Great Ruaha sub-basin and SMUWC project (SMUWC, 2001), which developed the Usangu Basin Model to simulate the hydrological dynamics of the Usangu plains. The Usangu Basin Model is being used by Kashaigili (2003) to assess the effects of water allocation competition to the wetlands hydrology and productivity. However, this model lacks water demand and use modules, which are important to guide decisions of efficient water allocation and optimum productivity of water in the plains (Kossa, 2003). The RIPARWIN project is in the process of modifying the model in this line.

It is generally urged that Irrigation planners and designers seldom attempt to measure or estimate the productivity of water (SMUWC, 2001; Magayane, 2003; Magayane *et al*., 2004; Halcrow and Partners 1992). However, most of the planning and design uses assumed data or implied results from research results or design manuals (SMUWC, 1999; SMUWC, 2001). Even the monitoring of planned irrigation systems (SWMRG-FAO, 2003) is not regularly done and appraisals are prompted to respond to donor queries. Such appraisals mainly rely on questionnaire surveys and secondary data.

The facilities provided for collecting weather data and monitoring flows (i.e. measuring the denominator of water productivity equation) are not effectively used and most of the times neglected shortly after scheme commissioning. In very few traditional smallholder schemes only rain gauges are provided and most are dilapidated and not working (URT, 1999). Few irrigation managers use water control gates and measuring structures (i.e. staff gauges) to measure the amount of water going to the farm through the main canal (Tarimo, 1994). However the flow of water to individual fields is seldom measured and the quantity of water does not feature in the calculations of farm productivity. What is recorded and analyzed is the implied cost paid as water user fee and water system operation costs (mainly pumping cost), which are normally considered in farm cost benefit analysis..

Therefore, the information pertaining to water utilization, which can be obtained from irrigation managers and planners include the main canal flow records, irrigation schedules, cropping pattern, water user fee, cost of pumping water, water system operation and maintenance costs. There are also some weather data used during system design, historical rainfall data and other design data for the system.

3.1.3 Estimation of deep percolation

Another important element of water balance is deep percolation. Few researchers have tried to measure deep percolation in Rufiji Basin. SMUWC (2001) used micro-lysimeters to estimate deep percolation in Kapunga water system. The findings showed that some 370mm (about 14%) of the annual water depth applied to paddy (i2600mm) is lost as deep percolation in Kapunga water system.

3.1.4 Summary

A list of water balance components measured in the study areas are summarized in Table 3.

Table 3: Measurement of Water Use Components for the Assessment of Productivity of Water

Water flow	**Description**
Rainfall	Rainfall is easily measured using rain gauges. Arithmetic average and the Normal Ratio Method (Linsley et al., 1988) are normally used to estimate missing rainfall data. There exists many approaches for estimating aerial rainfall over an area (Singh, 1989)
Surface water flows	Stage measurements for irrigation and drainage canals are used. The measurements need to consider the amount of water reuse within the system and the amount of surface water leaving out of the system for downstream uses.
Water use components	
Crop evapo-transpiration	Crop evapo-transpiration is determined from the relationship between reference evapo-transpiration and crop factor at different crop development stages. $ET_{crop} = K_c \times ET_o$ Where: T_{crop} = crop evapo-transpiration (mm/day); K_c = crop factor (constant); ET_o = reference evapo-transpiration (mm/day) estimated using FAO modified Penman-Monteth equation.
Lysimeter measurements	Lysimeters are used to monitor crop and weed transpiration, deep percolation and free water surface from the fields. These are used to estimate the amount of water consumed by the crop during the growing season.
Evaporation from non-crop vegetations	Satellite images of good resolution for the respective seasons within the study period are used. These are analyzed using IDRIS/Arc View GIS for vegetation cover indexes. Composite images are developed for spatial and temporal variation in NDVI and vegetation evapo-transpiration is estimated according to the procedure outlined by Kite and Droogers (2000). For plant and field scale lysimeters of typical plants of the area are used for estimating respective evaporation
Evaporation from bare moist soil surfaces	Soil microlysimeters according to Burt *et al*. (2001) and Tyler *et al*. (1997) are used to estimate evaporation from moist soil surfaces. Continuous measurements of evaporation are influenced by a sealed bottom boundary (Tyler *et al*., 1997).
Evaporation from free surfaces water bodies	This begins with estimating total area and duration with free water surfaces in the study area. Evaporation of water from water bodies is determined from pan evaporation coefficient
Soil water storage - Change	Soil moisture content before land preparation and after harvesting is measured in the top active root zone and determined by gravimetric analysis. This is used to determine soil water storage change in the active root zone of cropped fields.
(b) Underground water storage – Change	Water levels in an existing or dug well is measured and the groundwater volume is calculated by multiplying the water level with the specific yield of the soil (Dong *et al*., 2001)
Other water uses	
Domestic, animal and other water use	A baseline survey can be conducted in the study area to establish the number of household and animals for the quantification of the amount of water used. Established water requirements from past work will be used to estimate the amount of water depleted from unit requirement per use and the total number of use items.
Water pollution	Water quality data as applied to the study boundary can be obtained from existing database. Otherwise water samples will be collected from drainage canals before and after application of herbicides, insecticides and chemical fertilizers in irrigated fields for additional water quality data during the study period. The samples can be analyzed for EC, temperature, dissolved oxygen (DO), biological oxygen demand (BOD), nitrates, ammonia and coliforms (Pearce *et al*., 1998).

3.2 Estimation of Benefits from Depleted Water

Crop yields in weight per unit area are the most frequent monitored and reported outputs from all water depleting agricultural activities. Researchers measure yield (marketable component and total biomass) as major indicator of effects of experimental treatments. It is a general contention that yield levels from research are higher and differ significantly with the yield realized from the experimental plots. For example, records of Uyole Research Institute for the major released varieties of maize, wheat, and beans show potential yield of up to 12, 4, and 1.8 tons per hactre, respectively. Field surveys have shown that farmers' yields are on average about 1.5, 0.5 and 0.6 tons per hactre per season (Extracted from ARI-Uyole progress reports for years 1999 to 2003). Similarly, farmers yields in Tekeze/Atbara are low and range between 0.8 tons per hectare for teff to 1.2 tons per hectare for maize. Total above ground biomass is recorded mainly for pasture and agro-forestry products for which every piece of biomass is considered useful. For example Kapinga *et al.,* (2004) recorded between 15 to 27 t/ha of non-grain biomass from rainwater harvesting research trials in Njombe district, within the Rufiji Basin. Farm managers go further to use the yield per unit area data of crop produce into farm assessments normally based on economic indicators (i.e. rate of financial returns) (e.g. URT-NAFCO, 1979) and returns due to use of water (which is a critical input to the irrigation farm).

Data of crop yields per unit area is also kept by district, regional and national levels for administrative and planning purposes. Usually the data is kept as a list of major crops grown in the area, yield data per unit area and total production for the district or region. These historical data are used for forecasting food situation for the area in question based on the prevailing rainfall situation.

Recording of yields of secondary products of water use are rare in the study areas. Mdemu (2003) identified extra benefits from water diverted for irrigation to include fishing, domestic and livestock water supply, and bird hunting opportunities. The fishing enterprises provide employment to many members of the households in the surrounding areas while increasing food security. It is estimated that 60 tons of fish valued at 30,000 US$ are harvested every year from the canal systems of Kapunga water system rice farms in addition to about 8000 tons of paddy valued at about 1 millUS$. This means that if the fish is left out of the equation, the productivity of water in the Kapunga will be reported to be lower than what it actually is. Furthermore, the Contingent Valuation (CV) method – that is asking beneficiary to state what they would be willing to pay for a service, can be used to put value to the indirect benefits of supplying water for domestic and other uses through diversions intended for irrigation (SWMRG-FAO; 2003 and Farrington; 2003). Again on this basis, the domestic benefit of the water diverted to the Kapunga rice farms are estimated at 1 US$/m^3.

3.3 Practice of Farmers (individuals and associations)

3.3.1 Estimation of depletion of water

In the study areas and under similar situation elsewhere, farmers rarely bother about the amount of water used in crop production. In rain-fed agriculture, farmers do not measure the actual amount of rainwater that is available for the season. They rather express the rain season as good or bad depending on the relative storm intensities and frequency for the season and whether seasonal crop demand has been satisfied. They also depend on indigenous forecasting methods to decide on planting time or type of crop for effective use of the prospective rainfall amount for the season. For farmers, rainfall amount is not necessarily an absolute number but adequacy or inadequacy of rainwater to meet crop demand.

In irrigated systems, farmers measure quantity of water use in agriculture in terms of time and frequencies of irrigation allocated as per the respective Water User Associations (WUA) plans (Tarimo, 2004). There is no practice of measuring amount of flows to the cropped fields. The interest of a farmer is to use the allocated time to saturate the irrigated fields, it doesn't matter how much water is used. In this case in order to estimate the amount of water applied to the soil, soil-water holding capacity need to be determined together with the amount of profile soil moisture remaining in the soil before each irrigation turn.

For farmers who use micro-irrigation - watering crops using cans and buckets or even simple drips often count how many buckets are used per unit of land over certain period (SWMRG-FAO, 2003). However the quantity of water does not feature in the farmers' economics analysis besides being the most limiting and most cared for. The records kept by farmers are water user fee paid and water allocation schedules.

3.3.2 Estimation of benefits from depleted water

Farmers recognize benefits from depleted water as the economic yield of the crop normally recorded as follows:

- Harvested yield – Normally recorded as bags or crates per unit area. The filling of bags or crates is so arbitrary and they can be of different weights. Also many farmers begin to consume the crops bit by bit before eventually harvesting. This amount of harvest in normally not counted in the final yield.
- Income from sale of produce –Only part of crop produce is normally sold for the case of food crops. Most farmers sale food crops in small portions when they face a serious demand for finance as such accuracy of such records is questionable. Cash crops are usually sold in bulky at ago normally at an official outlet, where a receipt or invoice is issued. Such records tend to be accurate.

3.4 Summary

In summary this review show that several components that are necessary in the estimation of productivity of water are measured with spatial and temporal inconsistence. Also different stakeholders approach the different measurements and records differently. A general summary of what is already being measured is summarized in Table 4.

Table 4: A summary of commonly measured parameters for assessing productivity of water

Parameter	**Normally Recorded or estimated by:**	**Spatial Consistency**	**Temporal Consistency**
Rainfall	Hydro-meteorologists	Rain gauges are sparsely located	The most frequently and consistently measured weather parameter
Evapo-transpiration	Researchers	Full climatic stations are Sparsely distributed	Many climatic stations have data gaps. Extrapolated climatic data is normally used
Runoff and river flows	Hydro-meteorologists	Runoff is measured only during research trials. River flows are regularly recorded at gauge stations	Gauged stations are sparsely located
Soil-moisture	Researchers	Measured only during a research trial. Sparsely distributed	Measured only during a research trial.
Deep percolation	Researchers	Difficult to measure and sometimes modeled	Irregular
Diversion to irrigation schemes	Water officers	Few diversions are gauged. Only allowed water as per water user permit is known	Sometimes done only once per annum
Drainage from irrigation schemes	Researchers	Done for the research only	Only done when there is research demand
Actual amount of water used in a given field	Researchers	Done for the research only	Only done when there is research demand
Yields per unit area – at farm level	Farmers, managers and researchers	Always done in every farm	It is done for all seasons
Crop production levels at district and national level	Administrators	Aggregates	Annual records
Supplementary benefits	Researchers	Done for the research only	Only done when there is research demand
Distribution schedules	Farmers and irrigation managers	Every scheme has a water distribution schedule	Every scheme has a water distribution schedule
Water user fees	Water office	Amount of water user fee is always communicated to respective schemes	Amount of water user fee is always communicated to respective schemes

4.0 CONCLUSIONS AND RECOMMENDATIONS

This review has focused on the current situation in the evaluation of productivity of water in catchments where the land/water uses include natural ecosystems, rain-fed farming, grazing and irrigation schemes. Equally the synthesis and recommendations given in this chapter are limited to this kind of catchments. The review proves that there is very little awareness and understanding on the concept of productivity of water, because the amount of water used in agricultural systems is seldom monitored or measured. Specific conclusions from this review are:

i) National policies for water and land resources management are not adequately articulating the concept of productivity of water in agriculture, especially rain-fed systems.

ii) Basin level programmes for improving the management of agricultural water have invested heavily in water abstraction systems but have paid sporadic attention to productivity of water. Although some have actually invested in measures that could improve the productivity of water – it seems that these have been more by accident rather than by design.

iii) As expected the general understanding, by different stakeholders, on productivity of water differs immensely and to some extent the understanding is non existent.

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iv) Furthermore, attempt to link benefits and the amount of water used to produce them is rarely monitored, evaluated or reported upon.

v) However, different categories of stakeholders assess and keep records of several aspects of the benefits and amount of water. On the basis of these records it is possible to make estimates on the current levels of productivity and thus initiate dialogue to develop the practice further. The following are the major proxies used by different stakeholders to represent some aspects of productivity of water:

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- Yield of grain per unit area
- Yield of biomass per unit area
- Farmers represent rainfall not as an absolute quantity but a relative measure of poor or good rainfall. They further assert that good rainfall results to good crop and vise versa.
- Farmers keep record of yield per unit area as related to frequencies and duration of irrigation water.
- Recording amount of water in-terms of number of buckets of water applied normally during the dry season when water is scarce.

It is recommended that the framework shown in Fig. 1 should be discussed with stakeholders to develop it into an acceptable tool for assessing the indicators proposed in Table 5. This framework outlines four stages, namely; defining the space and time boundaries of the domain for which productivity of water is measured, determine water balance components so as to identify water use for every benefit, taking inventories of all the benefits due to each water use and finally calculating productivity. The intensity of tools and data required to assess PW increases from plant scale to basin scale.

Figure 1: Proposed Framework

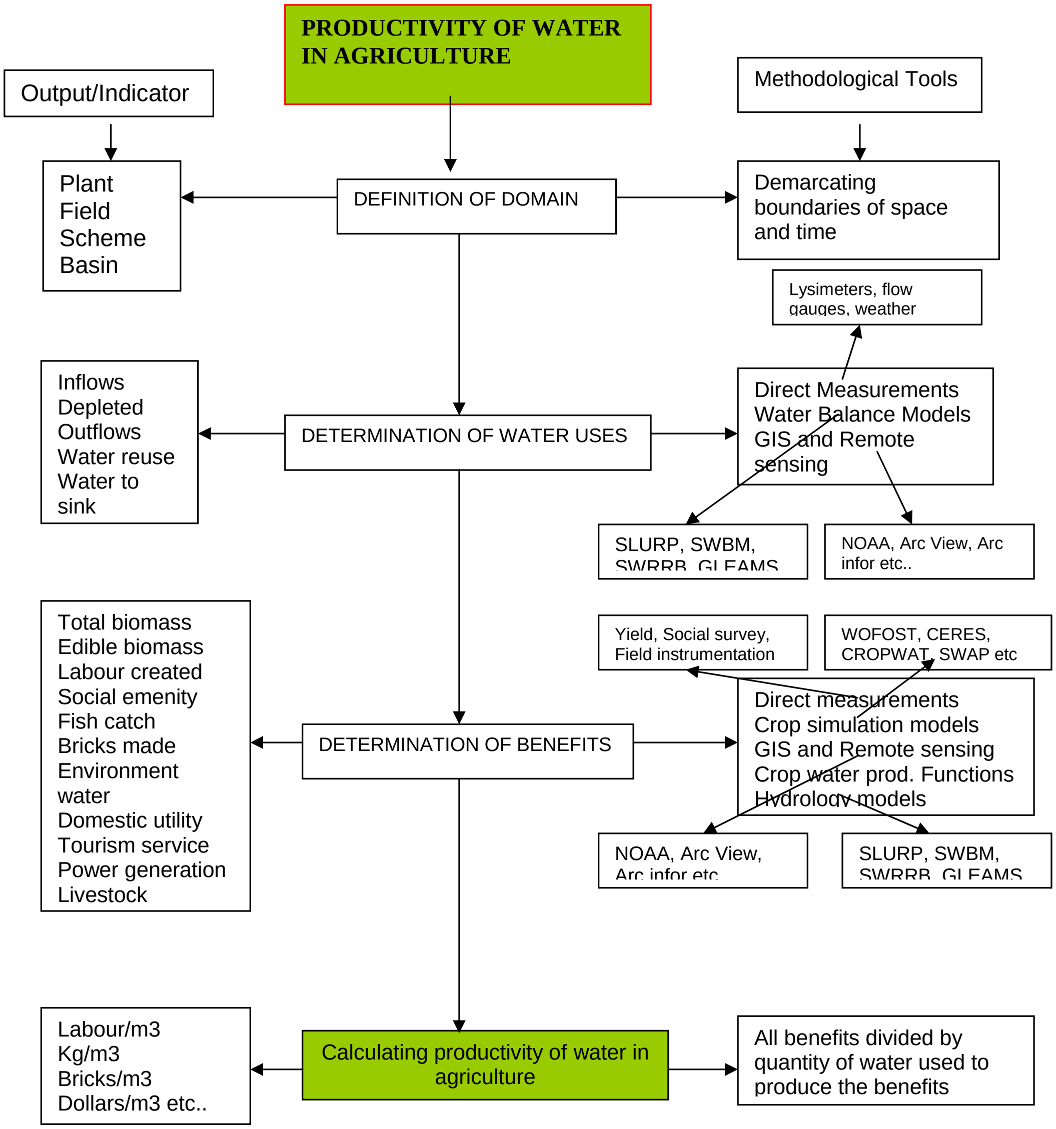

Table 3. Proposed indicators for productivity of water use in Mkoji

Water use	Primary	Secondary (bio-physical)	Secondary (socio-economic)	Tertiary (selected)
Rain-fed crops	Number of farmers Area (ha) Yield (ton) Income ($) Rainwater used, net & gross, (m^3)	Total biomass (ton/m^3) Crop Yield (ton/m3)	Total revenue ($\$/m^3$) Net revenue ($\$/m^3$) No. of employment (Jobs/m^3) Inputs ($/m3)	Specific net rainwater use ($\$/pp/m^3$ – net) Specific gross rainwater use ($\$/pp/m^3$ – gross)
Irrigated crops	Number of farmers Area (ha) Yield (ton) Income ($) Water used, net & gross, (m^3)	Total biomass (ton/m^3) Crop Yield (ton/m3)	Total revenue ($\$/m^3$) Net revenue ($\$/m^3$) No. of employment (Jobs/m^3) Inputs ($/m3)	Specific net hydro-value ($\$/pp/m^3$ – net) Specific gross hydro-value ($\$/pp/m^3$ – 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 hydro-value ($\$/pp/m^3$ – net) Specific gross hydro-value ($\$/pp/m^3$ – 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$) Livelihood supported (Lhood/m^3) Revenue to villages (revenue/m^3) Artisan jobs (jobs/m^3)	Specific net hydro-value ($\$/pp/m^3$ – net) Specific gross hydro-value ($\$/pp/m^3$ – gross)
Brick making	No bricks (n) No persons (n) Houses constructed (n) Total income ($) Water used, net & gross, (m^3)	No bricks (bricks/m^3) No persons (person/m^3) Houses constructed (houses/m3)	Income ($\$/m^3$) Livelihood supported (jobs/m^3)	Specific net hydro-value ($\$/pp/m^3$ – net) Specific gross hydro-value ($\$/pp/m^3$ – 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 hydro-value ($\$/pp/m^3$ – net) Specific gross hydro-value ($\$/pp/m^3$ – gross)
Domestic	Households (N) (n) Reduction of water related diseases (diseases/m^3) Total income ($) Water used, net & gross, (m^3)	Households (hh/m^3) Reduction of water related diseases (diseases/m3)	Value added to water ($\$/m^3$)	Incr. enterprises per area (Enterp/area/m^3) Increased sanitation (no of birth/ day/m3)
Livestock (agricul-ture)	Livestock numbers (n) TLU (n) Total income ($) Area Water evaporated (m^3)	Livestock (No/m3) Cattle (No/m3) TLU/m3	Income generated from livestock ($\$/m^3$)	Specific net hydro-value ($\$/pp/m^3$ – net) Specific gross hydro-value ($\$/pp/m^3$ – 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$)	Specific net hydro-value ($\$/pp/m^3$ – net) Specific gross hydro-value ($\$/pp/m^3$ – gross)

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