WATER AVAILABILITY AND USE DYNAMICS AND THE SUSTAINABILITY OF WATER RESOURCES MANAGEMENT IN THE GREAT RUAHA RIVER CATCHMENT IN TANZANIA

By

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A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA

2007

ABSTRACT

The purpose of this study was to investigate sustainability of water resources management in the Upper Great Ruaha River Catchment (UGRRC) and the impacts of water availability and use dynamics to the downstream river flows. Trend analysis, regime shift analysis, low flow analysis and generation of indicators of hydrologic alteration (IHA) were among the methods used to investigate variability of rainfall and river flows. Water abstraction and use patterns were investigated through intensive hydrometric monitoring and social survey methods. An integrated river basin decision-making framework was developed and used to assess the sustainability of water resources management.

The study found out that although river flows entering the UGRRC have not changed much between pre 1980 and post 1980 time windows, split sample analysis of the flows showed that the mean annual runoff exiting the UGRRC decreased from 2537.55 Mm^3 to 2053.77 Mm^3. The dry season flows also decreased by 57% between the two time windows and the decrease, found to be due to human interventions taking place in the plains, is statistically significance at 5% significance level. Analysis of IHA parameters revealed a progressive decline in flows lower than Q_{30}. The analysis showed that 1-day minimum flow exiting the UGRRC decreased from 2.572 m^3/s to 0.1221 m^3/s; Q_{90} decreased from 2.720 m^3/s to 0.266 m^3/s; zero flow days have increased from 0.25 days to 22 days per annum in the post-impact period; and the minimum flows now, start two weeks earlier as compared to the pre-impact window. This implies a faster depletion rate of dry season flows in the UGRRC.

Comprehensive assessment of water demands and water resources of the Mkoji sub-catchment revealed that during the dry season water resources are the limiting production factors as they are not enough to meet the current requirements for irrigation, let alone other water use sectors. The formal water rights were found to be problematic as in eight out of the 12 studied river systems water rights were higher than the actual river flows. However, the granted formal water rights were much higher compared to the actual water requirements resulting into over-abstractions of water above what is needed for crop production. As such streams run dry half way through the sub catchment as water that would have kept them flowing throughout the year are used up for irrigation. The result is that downstream water users suffer more from water shortages and some sub-catchments (e.g. Mkoji) are now closed during the dry season, contributing zero flows to the Great Ruaha River.

Assessment of sustainability showed that current water resources management practices in the UGRRC are unsustainable and if maintained, they could lead to severe social, environmental and economic consequences. The study concludes that there is a need to review the formal water rights to conform to current water availability and requirements and to improve monitoring and data management system in order to fulfil the mission, goals and objectives of water resources management in Tanzania. This study has demonstrated the value of combining different research methods and analyses and the role of simple decision support tools to assist in reaching and evaluating decisions concerning sustainable water resources management.

DECLARATION

I, KOSSA RUZEBELLE MNYIMVUA RAJABU, do hereby declare to the Senate of the Sokoine University of Agriculture that this thesis is my own original work and that it has never been submitted in whole or in part, for a degree award in any other University.

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ACKNOWLEDGEMENT

My sincere thanks are due to my supervisors, Prof. Henry Mahoo, Prof Damas Mashauri and Dr. Hilmy Sally for their constructive advice, guidance, criticism and helpful suggestions during the course of this study. I greatly appreciate the assistance extended to me by the Soil Water Management Research Group by providing fellowship to enable me undertake the study.

I would like to extend my sincere gratitude to Prof. Nuhu Hatibu, Dr. Siza Tumbo and Dr. Boniface Mbilinyi of Soil Water Management Research Group of the Sokoine University of Agriculture; and Dr. Bruce Lankford of the Overseas Development Group of the University of East Anglia for their various inputs during the course of this study.

Particular appreciation is extended to Dr. Doug Merrey and Dr. Matthew McCartney of IWMI Africa Office, Dr. Daniel Yawson of IUCN and Dr. Declan Conway of University of East Anglia for valuable inputs during my study and Prof. Filbert Rwehumbiza for his valuable inputs during quarterly reviews of the progress of this study.

I would also like to acknowledge my fellow Research Associates, who were of great help and sources of inspiration, especially Dr. Japhet Kashaigili, Mr. Makarius Mdemu, Dr. Reuben Kadigi, Mr. Julien Cour, Dr. Charles Sokile and Dr. Machibya

Magayane. Ms Eveliner Mwenga and Hamad Salum withstood long and late working hours to provide logistics for the study during fieldwork.

Special appreciation goes to my wife and children for their support and enduring long periods of my absence from home.

Last, but not least I would also wish to extend my sincere thanks to the staff at Ministry of Agriculture Training Institute (MATI) Igurusi, Rufiji Basin Water Office, Mbarali and Mbeya Rural District Council staff for their inputs during data collection, and many water users in the Mkoji sub-catchment who spared their time attending my lengthy demand and search for information during the study.

DEDICATION

This thesis is dedicated to my daughters, Hadija and Aisha through their love and affection; I got encouragement to continue with the study.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADB	African Development Bank
AET	Expected Annual Actual Evapotranspiration
BWB	Basin Water Board
BWO	Basin Water Office
CBNRM	Community Based Natural Resources Management
CIDA	Canadian International Development Agency
CWR	Crop Water Requirement
DALDO	District Agricultural and Livestock Development Officer
DANIDA	Danish International Development Agency
DAS	District Administrative Secretary
DED	District Executive Director
DEWRP	Department of Ecology's Water Resources Program
DSIA	Dry Season Irrigated Agriculture
EIA	Environmental Impact Assessment
EPA	United States Environmental Protection Agency
FAO	Food and Agriculture Organisation of the United Nations
GIS	Geographical Information System
GoT	Government of Tanzania
GoT	Governor of Tanganyika
GPS	Global Positioning System
GRR	Great Ruaha River
GRRC	Great Ruaha River Catchment
GWP	Global Water Partnership
HEP	Hydro Electric Power
ICWE	International Conference on Water and Environment
IFAD	International Fund for Agriculture Development
IHA	Indicators of Hydrologic Alteration
ILCA	International Livestock Centre for Africa
IMS	Information Management System
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
IUCN	The World Conservation Union
MATI	Ministry of Agriculture Training Institute

Mm^3	Million cubic meter
MoW	Ministry of Water
MSC	Mkoji sub-catchment
NORAD	Norwegian International Development Agency
NORPLAN	Norwegian Consulting Engineers and Planners
OAU	Organisation of African Union
PET	Potential Evapotranspiration
PRA	Participatory Rural Appraisal
PRC	Peoples Republic of China
RBG	River Basin Game
RBMSIIP	River Basin Management and Smallholder Irrigation Improvement
RBWB	Rufiji Basin Water Board
RBWO	Rufiji Basin Water Office
RIPARWIN	Raising Irrigation Productivity and Releasing Water for
TANESCO	Tanzania Electric Supply Company Limited
TMA	Tanzania Meteorological Agency
RWE	Regional Water Engineer
SMUWC	Sustainable Management of Usangu Wetlands and its Catchments
SWMRG	Soil-Water Management Research Group
ToT	Training of Trainers
TLU	Tropical Livestock Unit
TNC	The Nature Conservancy
Tshs.	Tanzania Shilling
TNW	Tanzania National Website
UGRRC	Upper Great Ruaha River Catchment
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Program
URT	United Republic of Tanzania
USACE	United States Army Corps of Engineers
USD	United States of America Dollar
WMO	World Meteorological Organisation
WWF	World Wildlife Fund for Nature
WWF-TPO	WWF Tanzania Programme Office
ZIO	Zonal Irrigation and Technical Services Unit

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Water is a basic natural resource, which sustains life and provides for various social and economic needs. Over the past 15 years, these demands have intensified. Major driving factors have been a growing population, economic development, improved living standards and increasing demands. Water scarcity is perceived at many places due to unreliable rainfall, multiplicity of competing uses, degradation of sources and catchments. Increasing demand for water is exerting severe pressure on our environment. Freshwater ecosystems are in crisis globally, with many rivers already severely degraded as a result of diminishing natural ecosystems. In poor nations, degradation of water resources is generally caused by poverty, as short-term survival supersedes long-term resource protection. In more developed countries, degradation of water ecosystems is more often the result of unsustainable consumption patterns. The number of river basins in the world where water demand cannot be met by available water resources is growing. The Great Ruaha River Basin in Tanzania belongs to this group and faces perceived (and sometimes real) water scarcity problems at local levels despite the fact that on average Tanzania has abundant water resources (estimated at about 2700 m^3/capita/year) (Norwegian Consulting Engineers and Planners (NORPLAN), 2000; Mutayoba *et al*, 2001).

In his struggle for a better life, man has expended great efforts to tame the rivers for transportation, water supply, agriculture, and power generation. However, a wide range of these human uses and transformations of freshwater have substantially altered, sometimes irreversibly, the natural flow and hydrologic regimes of a majority of the world's rivers (Naiman *et al.*, 1993; Madsen, 1996; Richter *et al.*, 1996, 1997). According to the World Conservation Union (IUCN) (2000), human activities that pose great threats to ecosystems include, among others: (a) population and consumption growth; (b) infrastructure development (dams, reservoirs, diversions etc) - alters timing and quantity of river flows, water temperature, nutrient and sediment transport; (c) land conversion - alters runoff patterns, inhibits natural recharge and fills water bodies with silt; (d) over-abstraction of water - depletes living resources, and biodiversity (groundwater depletion); and (e) release of pollutants to land, air or water – pollutes water bodies, alters chemistry and ecology of rivers, lakes and wetlands.

Various water withdrawal/diversion projects and impoundments alter stream flows in a variety of ways, but the greatest adverse impacts occur during periods of naturally low flows, when usable habitat can be especially vulnerable to flow reductions or other modifications. Water diversions/impoundments create wide-ranging hydrological and environmental consequences with impacts extending well beyond the initial planning area. The Great Ruaha River Catchment (GRRC) in Tanzania has not escaped this trend. The Great Ruaha River (GRR) is normally a perennial river. Although the river dried up in 1954 due to an extreme drought in south western Tanzania (Sustainable Management of Usangu Wetlands and its Catchments

(SMUWC), 2001b), the recent succession of cessation of dry season flows is unprecedented. These reduced flows in the GRR have been recorded since the early 1990s when complete drying of sections of the river was first observed. From 1993, initially for periods of a few weeks, but later for increasing lengths of time, periods of zero flows in long stretches of the river between the perennial swamp (*Ihefu*) and the Ruaha National Park were recorded (SMUWC, 2001b). The impacts of these changes have already been observed in the Usangu Game Reserve, Usangu wetlands, Ruaha National Park and Mtera Dam. It is suspected that regulation of the GRR through development of irrigated agriculture and other water diversions may have significantly altered its hydrologic regime.

Since the opening of the Kidatu Hydropower Plant in 1975, more water development projects have been undertaken. Irrigation projects including large irrigation schemes (developed area in brackets) such as Mbarali (3200 ha) Kimani (800 ha), Kapunga (3000 ha) and Madibira (3000 ha) were developed during the same period. Some smallholder irrigation schemes were also developed or improved and these include Kapunga Smallholder (800 ha), Chimala (3000 ha), Mswiswi (870 ha), Majengo (530 ha), Ipatagwa (542[1] ha), Moto Mbaya (600 ha), Luanda /Majenje (450[1] ha) and Igomelo (300[1] ha). This increased the area under irrigated rice in the Usangu Plains from 3000 ha in 1958 to 44 500 ha in 2001 (SMUWC, 2001c). Likewise dry season irrigation for maize, tomatoes and vegetables increased from zero ha in the 1930s to 3570 ha in 2003 (Raising Irrigation Productivity and Releasing Water for Intersectoral Needs (RIPARWIN), 2005). As a result of these developments, the

[1] Source: Smallholder Irrigation Improvement Program (SIIP)

water resources of the Great Ruaha River Catchment are becoming increasingly stressed and, downstream flows in some portions of the river have now been reduced to zero during the dry season. It is due to the above facts that this study was undertaken in the Upper Great Ruaha River Catchment (UGRRC) to investigate current levels and patterns of water abstraction and use, the driving factors of the observed patterns and the resulting impacts on the hydrologic regime of the Great Ruaha River. The ultimate aim is to propose ways of improving water management in the catchment in order to reverse the trend and ensure sustainability of the water resources.

1.2 Problem Statement and Justification

The drying of the GRR is not only a major social, economic and environmental problem in itself, but more importantly, it is flashing a warning that the level of use and management of water and other associated natural resources in the catchment is not sustainable and could ultimately result in irreparable damage to the environment and its biodiversity. Many changes have occurred in the UGRRC. These include: (a) decreased dry season flows in some tributary rivers - many rivers are now seasonal in their lower reaches but are said to have once been perennial (Rajabu *et al.*, 2005; Rajabu, 2006); (b) decreased seasonal flooding of the wetland, especially of the western wetland (SMUWC, 2001b; Kashaigili, 2006); and (c) cessation of dry season flows of the Great Ruaha River between the perennial swamp (*Ihefu*) and the Ruaha National Park (DANIDA/World Bank, 1995; SMUWC, 2001b; Kashaigili, 2006). These and other changes have given rise to numerous, and often conflicting, views on ‘the Usangu problem’. Deforestation, increased cattle numbers and increased human population have all been blamed for the changes (SMUWC, 2001a). However, the specific factors that are responsible for the observed changes as well as the linkages between them are not well known.

Water scarcity problems as well as conflicts associated with the dwindling water supplies of the river are currently the main concerns to the local population, the Rufiji Basin Water Office (RBWO) and to the nation at large. The local concerns arise from the fact the human population and their livestock depend on land, water and other natural resources available in the basin to sustain their livelihoods. Their long-term survival depends largely on the sustainable management of the resources of the basin, and on the maintenance of minimum flows in the rivers during the dry season. However, construction of intakes and diversions to abstract water from rivers for supplementary irrigation in order to minimize risks of crop failure has resulted into the Great Ruaha River and its tributaries being severely fragmented by increasing number of diversions and irrigation canals. Many of the rivers in the UGRRC, which once flowed perennially, no longer do so. However, the patterns and levels of water abstractions and use, the driving forces thereof as well as the resulting social, hydrologic and environmental impacts are not well known.

For the case of the Rufiji Basin Water Office, the concerns are due to the new challenges they are facing of regulating demand and supply to allocate efficiently a valuable and scarce water resource amongst competing users. One way that this has been done is through the granting of formal water rights. However, the administration of formal water rights is complicated when one takes into consideration multiple uses and users of the resource. These overlapping uses bring in different government and non-governmental institutions, as well as different sets of norms and rules related to water. Thus although the importance of formal water rights in controlling the amounts of water used is increasingly acknowledged, too little is known about how formal water rights systems work on the ground and can be improved in practice. This is so due to the fact that there have been enormous changes in the way human beings use water and formal statutory law may or may not be followed. Previous studies (e.g. Maganga, 2003; Maganga *et al*., 2004; van Koppen *et al*., 2004; Sokile, 2005) dealt mostly with the institutional part of water allocation; i.e. how to improve legal and institutional frameworks for intersectoral water allocation. However, no studies have been done to understand the relationship between water availability in rivers and formal water rights on one hand; and patterns of water abstraction and uses on the other hand.

The national concerns arise from the fact that the bulk of the water required for hydroelectric power (HEP) generation at Mtera and Kidatu hydropower plants (which account for about 50% of the total HEP in the country) has its source in the UGRRC. Dwindling water supplies from the UGRRC, especially during the dry season, affect negatively the existence of important ecosystems such as the Utengule swamp, Usangu Game Reserve and Ruaha National Park. These ecosystems are of both national and international importance as they are potential sources of foreign exchange generated through tourism and wildlife/game hunting. Inadequate water flows to the Mtera and Kidatu dams result into rationing of electricity leading into economic losses due reduced industrial production. Knowledge of which of the rivers in the UGRRC dry up during the dry season, where, when and why is required.

A number of studies, which focused on the hydrology of the GRR, have been carried out in the past. FAO (1960) conducted the first hydrological study of the Rufiji River Basin in order to established hydrometric network; Faraji and Masenza (1992) undertook a hydrological study of the Usangu Plains with particular reference to flow entering the Mtera Reservoir; DANIDA/World Bank (1995) studied demand driven management of land and water resources with local level participation at the GRRC; SMUWC, (2001d) developed the Usangu Hydrological Model; and Mwakalila (2001) modelled the hydrological response of the Great Ruaha River Basin as a function of physical characteristics. However, none of these studies undertook an in-depth investigation to understand the patterns of water abstraction and use, drivers (natural and human-induced) of the observed patterns and the resulting qualitative and quantitative impacts on the hydrologic regime of the GRR. This study therefore sought to investigate the dynamics of water availability and use and the resulting impacts on the sustainability of water resources management in the GRRC.

1.3 Objectives

1.3.1 Overall objective

The overall objective of the study was to provide information that would enhance understanding by river basin managers and other professionals of the variability of rainfall and river flows, current water use patterns and practices and their impacts on the hydrologic regime of rivers and sustainability of water resources management.

1.3.2 Specific objectives

The specific objectives were the following:

(i) To investigate spatial and temporal variability of rainfall and river flows in the UGRRC and quantify the available water resource

(ii) To investigate irrigated area and water use trends in the UGRRC and quantify the resulting changes in the hydrologic regime of the Great Ruaha River

(iii) To establish current water demands and uses in the UGRRC

(iv) To identify water abstraction and use patterns in relation to water availability and water rights and quantify the resulting impacts on flow downstream of irrigated areas

(v) To develop a methodology and apply it to assess sustainability of water resources management in the Great Ruaha River Catchment

1.4 Research Questions

The study attempted to answer the following research questions:

(i) What spatial and temporal changes (if any) have taken place in the time series of rainfall and stream flow variables in the UGRRC between 1955 and 2004 and how much water is currently available?

(ii) What water use changes have taken place in the UGRRC and what are the resulting impacts on the hydrologic regime of the Great Ruaha River?

(iii) What are the current water demands and uses by various water use sectors?

(iv) What are the prevailing water abstraction and use patterns in relation to water availability and water rights? What is the impact of the prevailing patterns on the flow on individual river tributaries downstream of irrigated areas?

(v) Are the current water resources management practices in the UGRRC sustainable?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Natural Resources Management Paradigms

2.1.1 Community based natural resources management

In the past decade, community based natural resources management (CBNRM) has emerged as the new paradigm for natural resources management. According to Boyer (2000), CBNRM can be defined as the local stewardship of ecosystem resources that promotes livelihood generation, coupled with the responsibility of ensuring future generations will have equal or better opportunity to benefit from the same resource. CBNRM framework provides an analytical approach that views local level resource users as the focal point for sustainable natural resources management (Boyer, 2000; Lyons, 2000; Stern *et al.*, 2004). It is widely acknowledged that local populations have a greater interest in the sustainable use of their resources than more distant organisations, and that they have the knowledge of local ecosystems, which allow them to manage the resources well (Boyer, 2000; Izac and Sanchez, 2001). Local level resource users thus have more reasons than anyone to manage a scarce resource wisely and play an important role in resource management and environmental sustainability. Proper management of natural resources requires understanding of the behaviour and status of the system in question to be able to make predictions of how the system will respond to changes in management. Thus, natural resources research requires the use of a wide variety of methods ranging from social surveys, Geographical Information System (GIS) techniques to long term resource monitoring (Stern *et al.*, 2004).

2.1.2 The concept of Integrated Water Resources Management (IWRM)

Water, as a common pool natural resource is a subject in which everyone is a stakeholder. Water related activities are not confined to the interests of limited groups of users, geographical boundaries, sectoral institutions, or national jurisdiction (Solanes and Gonzales-Villarreal, 1999), but to every stakeholder. While water is becoming increasingly a rare resource, the demand for it in all spheres of life is increasing rapidly. There are many users and uses of water in any one particular river basin. These range from irrigated agriculture, livestock production, hydroelectric power generation, industry, domestic uses, brick making, recreational activities and environmental requirements. There is therefore a need to develop sustainable management practices by a holistic approach based on the concept of integrated water resources management (IWRM) (International Conference on Water and the Environment (ICWE), 1992; FAO, 1995; GWP, 2000). The aim is to strike a balance between the use of resources for social and economic development and conservation of the resources to sustain their functions for future generations.

According to Global Water Partnership (GWP, 2003) integrated water resources management is a process, which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. IWRM focuses on integrating two major systems; the natural system with its critical importance for water resource availability and quality, and the human system which fundamentally determines the resource use, waste production and pollution of the resource and which must also set the development priorities (GWP, 2000). IWRM therefore, advocates for, among other things: (a) participatory development and management of water resources; (b) involvement of all users, planners and policy makers at all levels, and (c) cross-sectoral management. All these things are focused towards improving the lives of people while maintaining the quality of their environment. IWRM also seeks to shift water development and management systems from their currently unsustainable forms to more efficient, equitable and environmentally sustainable forms. In short, the IWRM concept embodies integration across sectors, integration of use, integration of demand, and integration with the environment as well as integration with the people (Cai *et al.*, 2001).

2.2 Dynamics of Water Availability and Use

Water availability varies in both space and time (GWP, 2000; Molden *et al.*, 2001). Investigation of water availability dynamics involves the study of rainfall distribution in time and space, high flows and their generation, low flows and their occurrence and the rainfall-runoff relationship from areas of different land use and cover. According to Rosegrant and Perez (1997) per capita water availability is highest in South and North America, while Africa, Asia and Europe have far less water per capita. Molden *et al.* (2001) reported that in 1995 Africa had very low per capita water supply of 119 m^3, constituting only one-fifth of the world average. The variations are explained by differences in topography, land use and the stochastic nature of rainfall, stream flow, evaporation and other variables pertinent to water availability determinations.

Water use and abstraction, just like water availability, are also very dynamic. For example, the amount of water used and/or withdrawn varies from one sector to another, varies with time (years, months) for the same sector, varies from different sources of water (rivers, reservoirs, lakes) and varies in space for various demand sites (International Water Management Institute (IWMI), 2000; Gleick, 1998). Agriculture is generally the largest user of freshwater, accounting for about 70% of all annual water withdrawals worldwide, though in Europe it ranks behind industry (Boberg, 2005). In Africa, irrigated agriculture is already responsible for more than 70% of all water withdrawals and more than 90% of all consumptive use of water (GWP, 2000). Most agricultural water use is for irrigation. Industry is the second largest consumer of water, responsible for 20% of annual worldwide withdrawals. Because many industries tend to cluster in urban areas, industrial water withdrawals are a significant component of urban water demand. Domestic sector generally demands the smallest share of water (about 10% worldwide), except in countries with little agriculture or industry. The domestic sector, although less demanding in terms of volume than the other sectors in most places, warrants special attention because of its implications for health and mortality. Safe drinking water is an important public health and political concern.

2.2.1 Water balance of catchments

Understanding the water balance in relation to climate and catchment characteristics provides insight into the complex processes operating over a range of spatial and temporal scales (Jothityangkoon *et al.*, 2001). According to Everson (2001), the water balance of a catchment is a deterministic relationship between the water balance components that are random variables in time and space, with usually unknown probability distributions. The independent input variable is rainfall, which is transformed in the hydrological system into the dependent output variables evaporation, streamflow and change in soil storage. A catchment water balance tracks inflows; outflows and change in storage. The water balance principle states that for any arbitrary volume during any period, the difference between the total input and output will be balanced by the change of water storage within the volume (Sankarasubramanian and Vogel, 2001; Everson, 2001). In order to develop a water balance model, the components of water balance that include evapotranspiration, precipitation, surface runoff and infiltration have to be determined. The water balance of a natural catchment over a given period is given by (Eagleson, 1978; Yin and Nicholson, 2002; Hickel and Zhang, 2003; Zhang *et al*., 2004):

$$P = E + Q + \Delta S \quad (1)$$

Where, P is the precipitation, E is the actual evapotranspiration, Q is the runoff, ΔS is a change in catchment soil water storage. All terms except P depend upon soil moisture level and distribution. If the integration interval is a full year and expected values are substituted, the change of storage is negligible and the average annual, “equilibrium”, or “steady state” water balance model becomes:

$$P - E = Q \quad \text{(mm/year)} \quad (2)$$

Various methods have been developed for analysing and estimating or measuring water balance components as discussed hereunder.

2.2.1.1 Precipitation in catchment areas

Precipitation and potential evapotranspiration are the major factors controlling the hydrology and water balances of a region (Alemaw and Chaoka, 2003). Rain falling on a catchment feeds both streamflow and evapotranspiration (Hickel and Zhang, 2003). Often it is necessary to estimate average areal rainfall over an area of interest. This can be done by averaging point observations from a number of rain gauges. The averaging may be done arithmetically or by some other methods such as drawing isohyets, Thiessen polygons and kriging. The arithmetic mean values that are based on spatial interpolation techniques do not address the variation in all climatic zones of the basin. For instance, the Thiessen polygon method provides spatial variation that depends only on distances between stations.

2.2.1.2 Evapotranspiration in catchments areas

The significance of evapotranspiration (ET) in catchment areas depends on the climate. The more arid the climate, the more extreme this effect becomes. Many methods exist for estimating evapotranspiration. Common methods of estimating potential evapotranspiration (PET) include empirical equations such as the Penman open water evaporation equation (Penman, 1948), the Priestley-Taylor equation (Priestley and Taylor, 1972), the Penman-Monteith potential evapotranspiration equation (Raes, 1996; Allen *et al.*, 1998) or the Thornthwaite method (Thornthwaite, 1948). Traditionally, actual evapotranspiration has been computed as a residual in water balance equations or from field measurements at meteorological stations. Turc (1955) and Pike (1964) derived an empirical formula for estimating the annual evaporation from the annual potential evaporation and the annual precipitation. They proposed that when precipitation increases, evaporation also, increases, but should not exceed a certain maximum. Instruments that measure evapotranspiration directly include lysimeters, evaporation pans and evapotranspirometers. Although evaporation pans are easy to operate and maintain, the reliability of the records and the definition of pan coefficients can be questionable. Recently, however, researchers have begun using scintilometers, remotely sensed data and hydrological models to estimate evapotranspiration (Kite and Droogers, 2000). Through use of common database, Kite and Droogers (2000) compared eight different methods of estimating actual evaporation. At the end of their study, they concluded that, there was no ideal method; all had their advantages and disadvantages. The Penman-Monteith equation (Raes, 1996; Allen *et al*., 1998) is currently the most widely recommended method for estimating evapotranspiration. However, it requires detailed measurements of the driving variables such as net radiation, wind speed and air temperature.

2.2.1.3 Surface runoff and groundwater flows

Another component of the catchment water balance is the surface runoff. Partitioning of rainfall into evapotranspiration and runoff is controlled by climate and catchment characteristics and hence surface runoff from a drainage basin into a catchment is difficult to estimate without a great deal of data. Surface inflows into catchments comprise a system of rivers that empty their water into the catchment. The inflow estimates are best obtained from point discharge measurements closest to the catchments periphery as these give the net balance from the catchment upstream. In such cases, stage measurements are converted into discharge readings using a rating curve. However, for some catchments formed within relatively flat surfaces of the floodplains, monitoring of the outflows is very difficult during the wet season as the water spread over the catchments and the neighbouring environment with no defined outlet channel.

Groundwater is one of the most important components of catchment hydrology. However, it is probably one of the most difficult components of catchment water balance to quantify (Kashaigili, 2006). Although groundwater behaviour is considered to be less variable than that of the hydrological systems (Hunt *et al.*, 1997), it may be difficult to collect all the data necessary for the calculation of groundwater inflow to and outflow from catchment. This is mainly because groundwater interacts with surface water in a wide variety of physiographic and climatic landscapes.

2.2.2 Spatial and temporal variability of rainfall

Assessing rainfall variability is a frequent practice in hydrology. An important application is the estimation of total rainfall over an area, e.g., a catchment, as an input for hydrological models (Buytaert *et al*., 2006). Most tropical and sub-tropical regions of the world are characterised by huge seasonal and annual variations in rainfall, often compounded by erratic short-term variations. For example, northern and southern Africa receives 9% and 12%, of the region’s rainfall respectively (Adeyemi, 2004). In contrast, the Congo River basin in the central humid zone, with 10% of Africa’s population, has over 35% of its annual runoff. However, in contrast, in the Sahara and Kalahari deserts, annual rainfall is less than 50 mm, and is exceeded by evaporation.

Various factors can influence the temporal variability of rainfall regime of an area. Most studies have associated the variability to the factors acting on regional and global scale. According to McGregor and Nieuwolt (1998), a number of factors, (some of which are active over very large areas, while others are effective over much smaller regions), control rainfall regimes in the tropics. Nyenzi *et al.* (1997) estimated that EL-Nino/Southern Oscillation (ENSO) might account for about 50% to 60% of rainfall variability in the tropics, particularly in eastern Africa. Other features linked with rainfall variability are the Monsoon winds and tropical cyclones.

In Tanzania, there are great disparities in rainfall characteristics between zones, which include northern coast, Lake Victoria basin, western, northeastern highlands, central areas, southwestern highlands and southern regions. In semi arid central Tanzania, which include Dodoma and Singida Regions, the rainfall is low, highly variable and of great uncertainty (Ngana, 1991). Mbilinyi (2000) found out that rainfall in Isimani Division, Iringa Region in Tanzania is characterised by high variability and uneven distribution. There was a considerable variation on the onset of rainfall as well as its distribution. Rajabu *et al.*, (2005) found out that in the Great Ruaha River Catchment, the highlands receive the highest annual rainfall as compared to the plains. According to Mushala (1993), the variation of annual rainfall in terms of total amount and distribution plays a significant role to the farmer than quasi-periodic rainfall variations. Rainfall variations can result into significant environmental consequences. For example, as a strategy to cope with uncertainty and poor distribution of rainfall during the crop-growing season, the local farming systems in the GRRC have constructed diversions to abstract water from rivers for supplementary irrigation in order to minimize risks of crop failure. This has resulted into the GRR being severely fragmented by increasing number of diversions, leading to the degradation of ecosystems.

2.2.3 Analysis of rainfall and river flow variability

2.2.3.1 Low flow frequency analysis

The study of low flows and their characteristics is important to determine the probability of the river system to provide adequate and assured water supply for meeting the expected demands. In the analysis of low flow, hydrologists are mainly concerned with the magnitude of flow, its duration and the frequency of occurrence of low flows (Pandey and Ramasastri, 2003). The magnitude of low flow is the quantity of water flowing through a given section of a stream for a specified period and it determines the amount of water available for use. The low flow duration depends on natural conditions as well as man-made effects and may reflect some specific water use practices. The frequency of occurrence of low flow reflects the risk of failure of a water supply scheme. In low flow studies, therefore, data are normally specified in terms of the magnitude of flow for a given period within a year or a season. The time-periods usually considered in flow duration analyses are 1 day, 7 days, 10 days or 30 days (The Nature Conservancy (TNC), 2005). Ordinarily, variations within periods less than 1 day are inconsequential, and the curves are therefore based on observed mean-daily flows (United States Army Corps of Engineers (USACE), 1997). For the purposes served by flow duration curves, the extreme rates of flow are not important.

2.2.3.2 Flow duration curve (FDC)

FDC is a relationship between any given discharge value and the percentage of time that this discharge is equalled or exceeded at a given location over some historic period. It is a plot of discharge (Q) versus the percent of time (t) during the period of the record in which the particular discharge is equalled or exceeded, without consideration for the chronology of the individual flows (USACE, 1997; Post, 2004). Thus, the curve is a graphical representation of the variability of stream flow at a site over an entire period of interest. It gives a summary of the flow variability at a site and represents perhaps the most informative method of displaying the complete range of river discharges from low flows to flood events (Smakhtin, 2000). The shape of the flow-duration curve is a function of the basin hydrological and physical characteristics. FDC may be constructed from either daily (1-day FDC) or monthly (1-month FDC) data. Both 1-day and 1-month FDCs may be calculated based on the completely available record period or based on all similar calendar months from the whole period (e.g. all Januaries). The former curves are sometimes referred to in the literature as “period of record FDC” (Vogel and Fennessey, 1994) and the latter as “long-term average monthly FDC” (Smakhtin and Watkins, 1997).

FDCs have long been used as means of summarising catchment hydrologic response, such as in low-flow studies to characterise the low flow regimes of a river. FDCs are also frequently used in water quality calculations, design of run-of-river abstraction schemes and estimation of required environmental flows. Significant land use change such as dam construction can have a significant impact on the FDCs, implying that FDCs may also be used as an indicator of land use change in a catchment. Recently, they have been used to validate the outputs of hydrologic models or compare observed and modelled hydrologic response (Hansen *et al.*, 1996; Ye *et al.* 1997). The procedure ordinarily used to prepare a flow duration curve consists of counting the number of mean-daily flows that occur within given ranges of magnitude (USACE, 1997; Smakhtin, 2000). The lower limit of magnitude in each range is then plotted against the percentage of days of record that mean-daily flows exceed that magnitude.

2.2.3.3 Rainfall and river flows trend detection methods

Many hydrologic systems such as river and wetland systems have experienced variation of climatic and hydrologic variables in both space and time as well as a gradual, long-term accumulation of human impacts. The detection and estimation of temporal or spatial trends are important for many hydrological and hydro-meteorological studies. Extreme spatial and temporal variability of climate and rainfall is one of the significant features of water resources in Africa and the world at large (Adeyemi, 2004). In cases where temporal or spatial patterns are strong, simple procedures such as time plots or linear regression over time can reveal trends. In more complex situations, sophisticated statistical models and procedures may be needed (United States Environmental Protection Agency (EPA), 2006). For example, the detection of trends may be made complicated by the overlaying of long-term and short-term trends, cyclical effects or autocorrelations. Most statistical tools focus on monotonic long-term trends (i.e., a trend that is exclusively increasing or decreasing), as well as other sources of systematic variation, such as seasonality. Furthermore, according to Yue *et al*. (2002b) the majority of studies regarding trend analyses have assumed that recorded hydro-meteorological time series are serially independent, even though annual mean and annual minimum hydro-meteorological time series may frequently display statistically significant serial correlation.

In many cases, parametric and non-parametric methods of hypothesis testing are used to detect trends. Parametric tests typically concern the population mean or quantile, use the actual data values, and assume data values follow a specific probability distribution. On the other hand, non-parametric tests typically concern the population mean or median, use data ranks, and do not assume a specific probability distribution. Parametric tests (e.g. the Student's **t-test**) require a tested series to be normally distributed. Its validity to assess the statistical significance of a linear trend or a shift in mean in a time series is on the basis of normality of a time series (EPA, 2006). Thus, whether or not sample data follow the normal distribution has to be examined prior to applying the *t*-test. The *t*-test also requires a time series to be serially independent. The existence of serial correlation in time series will affect the ability of the test to assess correctly the significance of trends (Yue *et al.,* 2002b).

When annual hydro-meteorological time series do not follow the normal distribution, nonparametric statistical tests, such as the Mann-Kendall test (Mann, 1945; Kendall, 1975) and the Mann-Whitney test (Mann and Whitney, 1947), are commonly applied to assess the statistical significance of trends. The former is for detecting a monotonic trend and the latter for identifying a shift in mean or median in a time series. The main reason for using non-parametric statistical tests is that they are distribution-free and thus more suitable for non-normal data and censored data (Hirsch and Slack, 1984; Helsel and Hirsch, 1988). The serial independence of a time series is still required in non-parametric tests (Yue *et al.*, 2002a).

The rank-based non-parametric Mann-Kendall (MK) statistical test (Helsel and Hirsch, 1992; Madsen 1996) has been widely used in hydrological studies to assess the significance of trends in hydro-meteorological time series such as water quality, streamflow, temperature and precipitation. Its advantages are that it is distribution-free and hence fewer assumptions about the data have to be made, it is robust against outliers, and has a higher power than many other commonly used tests (Hess *et al.*, 2001). However, the MK test should be applied to uncorrelated data (Helsel and Hirsch, 1992). Otherwise, the presence of serial correlation may lead to an erroneous rejection of the null hypothesis (Yue *et al.*, 2002a; Yue and Wang, 2002; Yue and Pilon, 2003).

Von Storch (1995) demonstrated that the existence of positive serial correlation within a time series increases the possibility that the Mann-Kendall test detects the significance of a trend. This may lead to rejection of the null hypothesis of no trend, while the null hypothesis is actually true. In order to eliminate the influence of serial correlation on the MK test, von Storch (1995) proposed to pre-whiten a series prior to applying the MK test. That is, the serial correlation component, such as a lag-one autoregressive process (AR (1)) is removed from a time series and the significance of a trend is then evaluated by using the MK test to the pre-whitened series. This method has been used in trend detection studies (e.g. Douglas *et al.*, 2000; Zhang *et al.*, 2000, 2001; Burn and Hag Elnur, 2002).

Both, the Mann-Kendall and parametric tests (e.g. the Student's t-test) have two parameters that are of importance to trend detection. The parameters are the significant level that indicates the trend's strength, and the slope that indicates the direction as well as the magnitude of the trend (Helsel and Hirsch, 1992; Madsen, 1996; Alemaw and Chaoka, 2002).

2.2.3.4 Previous studies on trend detection

Variability in rainfall and river flow and detection of underlying trends has been reported in literature (e.g. Kite, 1993). Past studies have identified a mixture of increasing and decreasing rainfall amounts in some parts of southern Africa (Mason and Joubert, 1997; Mkhandi and Ngana, 1999; Forestry and Beekeeping Division, 2005) while in others there was no strong evidence of declining or increasing trends. Ngana (1994) used spectral analysis and a 5-year moving average to determine if there were trends in the annual rainfall in various locations within the coastal forests in Tanzania. He found out that there has not been any increase or decrease of rainfall in the area; rather there has been fluctuating periods of high and low rainfall. Alemaw and Chaoka (2002) found a recent decrease in mean annual runoff in southern African catchments that occurred since 1975, particularly marked in Zambia, Angola, Mozambique and the South African High Veld. The decline is attributed mainly to declining and unreliable rainfall, population increase and changing land and water uses. Elkaduwa and Sakthivadivel (1999) investigated the long-term trends of variations in annual runoff, rainfall, and their ratios based on 5-year moving averages during the period 1940-1997 in the Upper Nilwala Basin in Sri Lanka. Linear regression models for the entire period showed an increasing trend of rainfall while runoff and runoff to rainfall ratio were decreasing. Alemaw and Chaoka (2002) used the parametric linear trend test to investigate the historical trend and variability of river flows in 502-river flow gauging stations in nine countries of the Southern African region. They assumed that the data were normally distributed and the trend to be tested was assumed linear.

2.2.3.5 Regime shift detection

The notion that climate variations often occur in the form of ‘‘regimes’’ began to become appreciated in the 1990s. Regime shifts are defined as rapid reorganizations of ecosystems from one relatively stable state to another (Rodionov and Overland, 2005). Shifts in the mean are the most common types considered in the literature. This definition is often based on “differing average levels over a multi-annual duration” (Rudnick and Davis, 2003). A number of methods have been developed to detect a regime shift, or discontinuity, in time series. Typically, these methods employ standard statistical techniques, such as the Student’s t-test or Mann-Kendall test, or their modifications. Easterling and Peterson (1995) provide a review of the methods. Lanzante (1996) discusses two difficult problems in regime shift detection caused by the existence of multiple shift points and trends in time series.

Studies of regime shifts typically involve some sort of confirmatory or hypothesis-driven analysis. Such an analysis requires a prior hypothesis that a regime shift has occurred at a certain time. Then using a statistical test this hypothesis is either rejected or confirmed. Although there are many methods for automatic detection of discontinuities in a time series, their performance drastically diminishes at the ends of the series and requires a substantial amount of data to be accumulated (Rodionov, 2006d). Consequently, the regime shifts are usually detected long after they actually occurred. In contrast, the sequential analysis (Rodionov, 2004; Rodionov and Overland, 2005) belongs to the category of exploratory or data-driven analysis that does not require a prior hypothesis on the timing of regime shifts. This greatly facilitates application of the algorithm for automatic computations with unlimited number of variables. The algorithm can also handle the incoming data.

2.3 Hydrologic Alteration of River Systems

A catchment or river basin ecosystem provides goods and services to users. To maintain these goods and services, ecosystems need to be protected and wisely managed. Protection of ecosystems requires a holistic approach, linking social and economic development. A wide range of human uses and transformations of freshwater have substantially altered, sometimes irreversibly, the natural flow of a majority of the world's rivers and the integrity of freshwater ecosystems (Richter *et al.*, 1996, 1997; IUCN, 2000; Maingi and Marsh, 2001). Development of reservoirs and diversions create wide-ranging hydrological and environmental consequences with impacts extending well beyond the initial planning area. For example, impacts due to the existence of dams and reservoirs include: (a) upstream change from river valley to reservoir, (b) changes in downstream morphology of riverbed and banks, (c) changes in downstream water quality, and (d) changes in downstream hydrology (Madsen, 1996; Maingi and Marsh, 2001). In downstream areas changes in flow regimes have been shown to lead to extensive ecological degradation and loss of biodiversity (Baxter, 1977; Kingsford, 2000; Jansson *et al.*, 2000).

Quantitative evaluations of human-induced hydrologic changes entail investigation of hydrologic parameters that are easily altered by man's action. According to Richter *et al.* (1996), hydrologic parameters that can quantitatively be evaluated are based upon five fundamental characteristics of hydrologic regimes. These are: (a) magnitude of monthly water conditions (b) magnitude and duration of annual extreme water conditions; (c) timing of annual extreme water conditions; (d) frequency and duration of high and low water pulses; and (e) rate (rise and fall) and frequency of water condition changes. In assessing the impact of perturbations on the hydrologic regime, the aim is to determine whether the state of an attribute of interest has been altered significantly (Stewart-Oaten *et al.*, 1986).

Hydrological conditions can vary in four dimensions within an ecosystem (three spatial dimensions and one time dimension). If the spatial domain is restricted to a specific point within a hydrologic system, however, (such as a measuring point in a river), the hydrologic regime can be defined in terms of one temporal and one spatial dimension i.e. changes in water conditions (e.g. levels, rates) at a single location over time (Richter *et al.*, 1996, 1997). The approach for assessing hydrologic alteration is based on the differences in stream flow regime characteristics between two defined time periods at a given stream gauge (Richter *et al.*, 1996, 1997, 1998). If the years of record at a stream gauge can be divided into a period of more natural or less altered (e.g. pre-development) stream flow conditions, and a period of more altered (e.g. post-development) conditions, then it is possible to measure the degree of alteration in streamflow regime that has taken place between these two periods (Richter *et al.*, 1996*).* Such hydrologic evaluations require application of methods for assessing the degree of hydrologic alteration. One of these methods is the Indicators of Hydrologic Alteration (IHA) method (Richter *et al.*, 1996; Koel, 2000; Maingi and Marsh, 2001).

The IHA method is based upon an analysis of hydrologic data available from existing measurement points within an ecosystem (such as at stream gauges) or model generated data. It uses 33 parameters, organised into groups to statistically characterise hydrologic variation within each year and results in the computation of a representative, multi-parameter suite of hydrologic characteristics-or indicators- for assessing hydrologic alteration. These parameters provide information on hydrologically and ecologically significant features of water regimes that influence aquatic, wetland and riparian ecosystems. Identifying the flow regime components that have been significantly altered by human actions permits decision makers and river managers to focus on the specific aspects of the flow regime that need to be restored or maintained.

The IHA can be used to compare two distinct time-periods or analyze trends over a single time period (TNC, 2005). If the hydrologic system one wishes to study has experienced an abrupt change such as construction of a dam, the IHA can be used to analyze how the flow regime was affected by computing the hydrologic parameters for two periods, before and after the impact. For hydrologic systems that have experienced a long-term accumulation of human modifications, the IHA can compute and graph linear regressions to evaluate the trend. When pre- or post-impact records are nonexistent, include data gaps, or are inadequate in length, various data reconstruction procedures can be employed. In order to eliminate the influence of climatic differences between the pre- and post-impact time-periods on the outcome of the IHA analysis, a reference site or set of sites uninfluenced by the human alterations being examined can be used as climatic controls (Alley and Burns, 1983).

2.4 River Basin Management

Many of the worlds' river basins-including those under humid conditions such as in Sri Lanka are faced with physical water shortages (Bastiaanssen and Chandrapala, 2003). With growing scarcity, the need for efficient, equitable, and sustainable water allocation policies has increased in importance in water resources management. These policies can best be examined at the river basin level, which link essential hydrologic, economic, agronomic, and institutional relationships as well as water uses and users and their allocation decisions (Rosegrant *et al*, 2000). The primary goal of river basin management is to enable rivers and watersheds to perform their many vital ecological functions and to benefit people who depend on them for the maintenance of their livelihoods.

The river basin planning as a concept is many centuries old (Saha, 1981; Cai *et al.*, 2001). Over the years, the concept has undergone a number of refinements. The concept is centred on the use of the basin as a natural unit for planning (Saha, 1981; Moeti, 1999). As the river basin progresses from an “open” to a “closed” condition, three phases can be identified: development, utilisation and allocation (Keller *et al.*, 1998; Molden *et al.*, 2001). In the first phase, water use is limited to rain-fed agriculture and run-of-river- water utilization. The amount of water effectively used for agriculture and other beneficial uses are less than what is available, much of which simply flows to the sea or to the next downstream basin. Water management tends to be based on demand, and conflicts, therefore, rarely arise. In the second phase, shortages of water begin to appear in the driest years and during unusually dry seasonal spells. In the third phase, the basin nears closure and sectoral allocation becomes a point of tension. The normal responses to water scarcity in the above phases are water-resources development, in the first phase; followed by improvements in efficiency and sectoral management in the second phase; and culminating with modernization and inter-sectoral allocation in the third phase.

A key feature of any effective river basin management organisation is the ability to adapt to changing needs. River basin organizations are a central component of the most recent evolution of the institutional framework that defines how water is managed at the river basin level, generally referred to as water governance. The form and functions of river basin management organizations are now changing whereby integrated management of river basins is replacing sector-based management, and in many cases new water laws and regulations are being developed and implemented. Government agencies are devolving activities to new organizations, which include active participation of stakeholders from multiple sectors. According to Gooch and Stålnacke (2003), there is need now for the basin organizations to change from the mainstream, traditional development model, which is typically sector-oriented to real integrated planning and management model, which attempts to take a cross-sectoral approach and focus more on water resources management.

2.4.1 Management of water rights in river basins

Freshwater is a finite resource and is imperative for sustainable development, economic growth, food production, human health, local livelihoods, and the well-being of ecosystems. Yet with increasing populations, industrialization, environmental degradation, agricultural intensification, rising per capita water use and other social and economic transformations, there is scarcity and competition for water, even in countries and regions where water may seem abundant (Bruns et al., 2005). As water becomes scarcer and access more often contested, societies pursue better rules for coordinating water use and settling conflicts. In most countries where water is scarce or costly to access, systems of rights for water use have evolved through customary norms and practices or though bodies of law and regulations (or both) (Sampath, 1992). Internationally, there is growing understanding that formal water rights are important and that lack of effective formal water rights systems creates major problems for the management of increasingly scarce water supplies. As such, in many countries around the world, increasing attention is being directed to the need to improve formal water rights systems.

Water rights, which concern who should be able to take how much water, when, where and for what purpose, are generally based on a variant or combination of the following three systems: prior (appropriative) rights, riparian rights, and public allocation (Sampath 1992; Holden and Thobani, 1996; Rajabu and Mahoo, 2007). Whereas prior rights are based on the appropriation doctrine, under which the water right is acquired by actual use over time, the location of one's land determines water rights under the riparian doctrine. Under this approach whoever owns land next to a flowing river may take its water as long as enough is left for downstream uses. Under public allocation, public authorities decide how to allocate water using guidelines or laws establishing priorities and often specify the uses to which the water can be put. Most developing countries, Tanzania inclusive, follow variants of this approach.

Water rights may be informal - based on customary patterns; embedded in local practice; or formally framed in water permits (Bruns and Meinzen-Dick, 2000; Juma and Maganga, 2005; Bruns, 2005; Rajabu and Mahoo, 2007). However, for the purpose of this study, water right is defined as "formal authorisation to use a certain amount of water for a designated purpose, including certain privileges, restrictions, and obligations" (Beccar et al., 2002; Department of Ecology's Water Resources Program (DEWRP), 2005).

As is the case with other areas in Sub-Saharan Africa, formal water rights were established in Tanzania during the colonial period in order to regulate and control the use of water. The 1923 Water Ordinance marked the start of the statutory water law in Tanzania (then Tanganyika) (van Koppen *et al.*, 2004). Registration to obtain a water right was stipulated in this Ordinance and every revision thereafter. With each subsequent revision, registered rights under any previous Water Ordinance were continued in one form or another. Thereafter, several ordinances, including the Water Ordinance, Cap 410 of 1959 (The Governor of Tanganyika (GoT), 1959) were adopted. After independence in 1961, the government of Tanganyika inherited this Ordinance and its provisions and sustained the water right system. The Water Utilization (Control and Regulation) Act No. 42 of 1974, with its subsequent amendments in 1981, 1989, 1997 and 1999 and regulations issued in 1975, 1994, 1997 and 2002 further intensified the water right system. The Act declares all water to be the property of the United Republic of Tanzania and the Ministry responsible for water manages the country’s water resources, in order to meet all the varied demands. The Act gives the right of access to all the citizens of Tanzania, and in order to safeguard and regulate this access, it requires any person who intends to divert, dam, store, abstract or use water or for any such purpose construct or maintain any works, to obtain a formal water right. Under the legislation, the Ministry of Water grants formal water rights for each withdrawal of water for use in domestic, industrial, hydropower, livestock, irrigation and mining activities.

In order to realize the objectives of water resources management, the principal Act also includes a set of "economic water users’ fees”. The fees were set forth-in

Subsidiary Legislation introduced vide Government Notice No. 347 of 1994. According to the principal Act water users fees are divided as: a) domestic/livestock, b) fish farming, c) irrigation, d) power royalty, e) industrial, f) mining and g) commercial. Ideally, charging of water users' fees was expected to deter overuse and hence avoid wastage of water. It was also thought that payment of water users' fees, coupled with formal water rights would help Basin Water Offices to reduce water related conflicts and would generate income to sustain water regulation, catchment conservation, and water resources monitoring activities. The economic water users' fees were lastly revised through the Water Utilization (General) (Amendment) Regulations of 2002 (URT, 2002b).

The growing attention to water rights in recent years reflects the increasing scarcity and competition for this vital resource. However, the administration of water rights is complicated when one takes into consideration multiple uses (irrigation, domestic, environmental maintenance, fishing, livestock, industries) as well as multiple users (different villages, groups of farmers in the head and tail, fishermen, cattle owners, etc.) of the resource. These overlapping uses bring in different government and non-governmental institutions, as well as different sets of norms and rules related to water. Thus although the importance of water rights in controlling and reducing over-abstraction of water is increasingly acknowledged, too little is known about how water rights systems work on the ground and can be improved in practice. The reason is that there have been enormous changes in the way human beings use water (Bruns *et al.*, 2005; Rajabu, 2006a) and formal statutory law may or may not be followed.

The complex nature of water rights management is also evident in the Upper Great Ruaha River Catchment (UGRRC) in Tanzania. Formally, majority of people's access to water in the UGRRC (like other areas in Tanzania) was regulated mainly according to customary laws and norms and to some extent by village by-laws (SMUWC, 2001a; Maganga, 2003; Maganga *et al*., 2004). Customary water laws refer to set of rules and norms practiced by a community over a long period of time and most often are not codified. These laws provide for a set of rights and duties to be observed by certain community and against outsiders. Various communities in Tanzania have a long history of practicing certain customary laws for management of water resources. Even in the advent of colonial invasion, customary water law continued to exist in parallel with statutory law. Traditional/customary water rights practiced by rural communities ensured sustainability of water resources although some communities have customary laws that bestowed them with ownership rights that exclude outsiders.

Both formal and customary (or informal) water rights are currently in use in Tanzania. At the national level, water management is predominantly governed by formal institutions, mainly policies, acts, legislations and related organizations that are judiciously established in accordance with the formal provisions. At the basin level, there is a mix of formal and informal arrangements, but the formal predominates, partly due to the fact that informal arrangements are often still quite localized and do not encompass the whole basin as yet. At the catchment and sub catchment levels, informal institutions and arrangements gain more strength.

However, this scenario is fast changing. Since the 1990s, the Tanzanian Government intensified the formal water right system with the aim of improving basin-level water management. Formal legislation is becoming increasingly important and water users are trying to get formal water rights because current water resources laws do not have provisions for recognition of customary laws and practices. Consequently, in 2001, Rufiji River Basin, which was established in 1993, opened a sub-office at Rujewa to deal with water resources management in the UGRRC. Although irrigated agriculture was widely practised during that time, most of the traditional irrigation schemes had no formal water rights. Therefore, the Rufiji Basin Water Office (RBWO), through its sub-office at Rujewa carried out awareness creation and sensitizations campaigns in order to enhance understanding of water users and other stakeholders on various aspects of water resources management, including granting of formal water rights. Existing water users were obliged to register and formalise their customary water abstraction rights into formal water rights and pay economic water users' fees. Consequently, an informal 'grace period' of five years was given to existing water users to register and 'formalise' their water abstractions. New water users were also required to apply for formal water rights to be allowed to abstract water.

However, despite widespread use of formal water rights to control and regulate water use, downstream water users continue to suffer from water shortages, especially during the dry season (Rajabu and Mahoo, 2007).

2.4.2 Effective river basin monitoring

Integrated Water Resources Management requires assembly, management and analysis of large amounts of information in relation to environments, resource uses, pollution and ambient conditions within given frames. Thus, a sound information and knowledge base is needed to provide timely and correct information on the quantity, quality, extent and dependability of water resources. However, there is lack of important water resources data in developing countries, which has led to unsustainable planning and development of water resources. According to Adeyemi (2004), a key limitation in Africa to improving water management at national, sub-regional and continental level is the paucity of data on water resources. This limitation is linked to inadequate resources for the collection, assessment and dissemination of data on water resources. These weaknesses not withstanding and in order to obtain correct and timely data and information, the National Water Policy of Tanzania (URT, 2002a) proposes to strengthen the existing system of data collection, processing, storage and dissemination on the basis of simplified, practical and cost effective solutions. However, how this will be achieved, is not stated.

Monitoring is very important in water resources management as it provides the informational basis of adaptive management. This is often the most effective strategy for managing natural systems characterized by high levels of human use and natural fluctuations. Effective monitoring thus requires involvement of all key actors and interested groups in water resources management. However, in Tanzania, there is inadequate participatory monitoring and evaluation of water resources, exacerbated by a weak Management Information Systems (MIS). Communities lack information about conditions elsewhere in a basin, as most river basin organizations tend to develop information systems that serve their internal purposes. An up to date MIS that addresses and defines performance targets and with a comprehensive information sharing, reporting and feedback mechanism from each level needs to be established (URT, 2002a).

It is also important to emphasise that data on the technical dimensions of resource change (such as reduced flows, or variations in forest area) only yield information on the outcomes of trends and processes occurring elsewhere. If the causes of the natural resource change have social and economic origins, it is necessary to develop dynamic systems of monitoring social and economic changes and the underlying causes, in addition to the technical parameters of resource change. Monitoring does not only comprise the collection of data. The translation of such data into a regulatory system is worthwhile to ensure that these data play a managerially significant task. For example, the development of an automated hydrological data collection system makes no sense if illegal water abstractions cannot be prevented.

The noted shortcomings in data and information systems in Tanzania are not caused by inadequate financial resources alone, but mainly due to lack of a fully articulated framework for assessing monitoring needs, designing data management systems and sequencing appropriate interventions, and disseminating information packages. For example, between 1996 and 2004, Tanzania implemented a USD 30.7 million-River Basin Management and Smallholder Irrigation Improvement Project, targeting among other areas, the GRRC. However, the state of data and information systems in the GRRC did not improve much. This is an issue that demands urgent and priority attention. Developing conceptual frameworks for processes such as monitoring and data management serves a variety of purposes. A framework can help focus dialogue on a problem, because the underlying trends, factors, and causative relationships are visible and understood (Lyons, 2000). A framework can also serve as a diagnostic tool, suggesting a logical sequence of examination questions and explanations for the behaviour of different parts of the system. Conceptual frameworks are neither static entities, nor is there necessarily a single best framework for a particular process. On the contrary, our knowledge of systems can be significantly advanced when alternative frameworks for the same process are applied to the same system.

2.4.3 Sustainability of water resources management

For centuries, water resources management has involved the alteration of the flows of water to the benefit of humans. Unfortunately, many of the alterations of the flows of water have had long-run consequences that are unintended, unanticipated, and undesirable. The gains in some uses have been accompanied by losses in other uses. Because water resources have such a great influence on the vitality of our society, ecosystems and economy, understanding sustainability of water resources management is a priority (Roy *et al.*, 2005). Defining exactly what sustainability means is very important to any discussion on resource management, although it is highly debated. In the global debate, sustainability is considered primarily in terms of continuing to improve human well being, whilst not undermining the natural resource base on which future generations will have to depend (Loucks, 2000).

According to Theodore (2004), sustainability is a concept that describes a dynamic condition of complex systems, particularly the biosphere of earth and the human socio-economic systems within it. The meaning of sustainability in the context of water resources management has changed through the time (Hermanowicz, 2005). Initially meeting water demand was the dominant concern. Later on quality issues became more important followed by wider water reuse. Today sustainability must include a whole range of aspects (e.g., energy, pollution and persistent chemicals), spatial and time scales. However, the underlying meaning of sustainability was still quite simple: Supply should be at least equal to the demand. As water demand continued to grow and water resources became scarcer, the simple sustainability paradigm underwent a change. Thus, the modified sustainability framework was to match water demand with available supplies in terms of both quantity and quality.

The evolution of sustainability for water resources took a new turn when water reclamation and direct water reuse were introduced as options to satisfy the demand (Hermanowicz, 2005). Sustainability therefore, acquired a broader meaning. It no longer means simply matching the quantity and quality of supplies and demands for domestic, industrial or agricultural uses. Concerns for the aquatic environment led to establishing the so-called “environmental flows” with water shared among a broader range of stakeholders. Concepts of demand and supply management provide one way of exploring sustainability. Demand management means reducing demand to meet levels of supply, in contrast to supply management which means boosting supply to meet increasing demands. Thus, the resource is sustainably delivered when supply matches or is greater than demand. However, from the perspective of sustainability, we need to go beyond quantity and quality. We need to assess all water resources management systems, in terms of their broader environmental and social impacts. Unfortunately, there is currently a lack of framework for assessment of sustainability in its broader sense (Hermanowicz, 2005).

Common definitions of sustainability argue for ‘‘the management of natural resources to ensure their continued capacity to be productive in both agricultural and environmental capacities’’ (Lankford and Beale, 2006). Sustainable water resources management is the management that meets the needs of the current generation without compromising the ability of future generations to meet their own needs (Cai *et al.*, 2001; Theodore, 2004; Roy *et al.*, 2005; Khan *et al.*, 2006). In light of sustainability, water resources management should simultaneously achieve two objectives: sustaining water use for agricultural, industrial and municipal and preserving the associated natural environment. However, how can we determine the extent to which the patterns of interaction among human social and economic systems and the environment are contributing to sustainability? To answer this question, substantial efforts should be made to develop the means to measure sustainability, particularly using statistical indicators. Ideally, countries should develop a linked set of indicators at multiple spatial and temporal scales that encompass the ecological, economic and social conditions and processes that are relevant to sustainable management of water resources. Indicators of water resource sustainability tell us “where we are” in meeting short-term and long-term social, economic and ecological needs. Indicators highlight trends, help evaluate causes and effects, and give a common language and understanding of issues.

2.5 Synthesis of the Literature Review

Water availability and use

From the literature review, water availability is very dynamic and varies both spatially and in time, the major driving factors being topography, land use and the stochastic nature of rainfall, stream flow and evaporation. Therefore, understanding the water balance in relation to climate and catchment characteristics provides insight into the complex processes operating over a range of spatial and temporal scales. In order to develop a water balance model, the components of water balance have to be determined. However, these components are random variables in time and space, with usually unknown probability distributions. Consequently, researchers have developed various simplified methods for analysing and estimating or measuring water balance components. The review has also shown that water use behaves the same way as water availability. However, despite variation of water usage across sectors, regions and over time, agriculture is generally the largest user of freshwater. Much of the agricultural water demand is for irrigation, whose demand is met in unsustainable way, thereby providing a potential intervention area for water saving.

Variability of rainfall and river flows

Most studies have associated the variability of rainfall to the factors acting on regional and global scale. Spatial and temporal variability of rainfall and river flows at the local scale have great impact on agricultural production and can result into significant environmental and socio-economic consequences. Consequently, hydrologists have developed many methods to understand and predict the behaviour of rainfall and river flow variables. The methods include low flow frequency analysis, flow duration curves and rainfall and river flow trend analysis. The review has shown that the detection of trends may be made complicated by the overlaying of long-term and short-term trends, cyclical effects or autocorrelations. In many cases regression, parametric and non-parametric methods are used to detect trends. Whereas parametric tests such as the Student's t-test assume that data values follow a specific probability distribution, non-parametric tests, such as the Mann-Kendall test are distribution-free and thus more suitable for non-normal data. However, the choice of the method to use depends on the type and characteristics of the data.

Hydrological alteration of river systems

The review has shown that a wide range of human uses and transformations of freshwater have substantially altered the natural flow of a majority of the world's rivers and the integrity of freshwater ecosystems. Methods have thus been developed to quantitatively evaluate hydrologic parameters that have been altered by human-induced hydrologic change. One of these is the Indicators of Hydrologic Alteration method. Identifying the flow regime components that have been significantly altered by human actions permits decision makers and river managers to focus on the specific aspects of the flow regime that need to be restored or maintained.

Sustainable water resources management

Attaining sustainable water resources management is a challenging undertaking. The review has highlighted different models and the phases that river basin management has undergone. Scholars agree that there is need for river basin organisations to adapt to the changing needs. However, how this should be done is not clear. Previous studies have set out broad guidelines for ensuring sustainable water resources management. Unfortunately, there is currently a lack of framework for assessment of sustainability in its broader sense. There are neither clear-cut methods of assessing sustainability nor an agreed set of indicators for the same. Formal water rights, which were expected to regulate water use have been shown to be very complex and too little is known about how they actually work on the ground and can be improved in practice. There is therefore a need of conducting more research on operationability of water right systems and assessment of sustainability of water resources.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Conceptual Framework of the Study

The conceptual framework of this study draws mainly on the ecosystem approach to water management and the integrated water resources management (IWRM) framework. The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way (IUCN, 2000). It essentially requires taking into consideration the effects of actions on every element of an ecosystem, based on the recognition that all elements of an ecosystem are linked. IWRM, on the other hand focuses on integrating two major systems; the natural system with its critical importance for water resource availability and quality, and the human system which fundamentally determines the resource use, waste production and pollution of the resource and which must also set the development priorities (GWP, 2000).

Under these concepts, sustainability of water resources management encompasses three major systems. The three systems are: 1) The Social System which includes all the human elements of the Biosphere; 2) The Economic System which includes capital and infrastructure required for an economic undertaking, markets and labour; and 3) The Natural Systems (or the ecosystems) which are the non-human elements of the Biosphere. All the three systems are contained within the Biophysical

Environment, which includes all living things on earth and the non-living systems with which they interact and on which they depend. Each of the three systems must fulfil some important functions to ensure sustainability of water resources.

The ecological system is required to have the capacity to make water of appropriate quality and quantity available to support ecosystems and ensure integrity of ecosystems. The social system, on the other hand has to ensure social well being resulting from the use of water resources and water related ecological resources; and that legal, institutional, community and technical capacities for the management of water and related land resources are in place. The function of the economic system is to provide capacity to make water of appropriate quality and quantity available for human uses and to ensure economic well being resulting from the use of water and water related land and ecological resources.

For the analysis of the natural system, a catchment or sub catchment is generally considered to provide the logical unit of analysis (GWP, 2000), whereas the analysis of the human system is better served by taking a farming system as the main unit of analysis. A farming systems approach is typically used to analyse human systems that are organised around agricultural systems (Dixon *et al.*, 2001). Thus, sub catchments have been selected as main study areas for the analysis of water resources, and within the sub catchments, households and irrigation schemes are identified and sampled to enable the analysis of human systems. The farming systems approach is useful to understand what drives water management decisions (i.e. perceptions, attitudes, behaviours and practices on the use of water). However, in order to evaluate their effects and impacts, these water management decisions need to be linked to environmental sustainability. Integrative system approach usually generates multiple variables that if studied independently, make it very difficult to draw meaningful conclusions. Therefore, in this research, patterns and relationships between various variables were investigated and data from varied sources were integrated in order to assist in drawing meaningful conclusions. For example, households and irrigation schemes were analysed with specific focus on the links between water availability, formal water rights, patterns of water abstraction and uses on one hand, and the resulting effects and impacts on the environment, on the other hand. The impacts of upstream abstractions were studied on individual tributary river systems and on the Great Ruaha River. The outcomes of the analyses were then used to assess sustainability of water resources management in the GRRC.

3.2 The Great Ruaha River Catchment (GRRC)

The Great Ruaha River (GRR) is one of the three major river systems of the Rufiji River Basin. The other rivers are Kilombero and Luwegu. The Rufiji River Basin is the largest basin in Tanzania, draining an area of 177 000 km^2. The Great Ruaha River Catchment (GRRC) (Fig. 1) covers an area of 83 970 km^2 or 47% of the Rufiji River Basin. The GRRC supports a range of important economic activities as well as valuable natural heritages. Livestock keeping, fishing, brick making and several irrigation schemes, which support the lives of thousands of Tanzanians, are found in this catchment. In addition, important ecosystems such as the Utengule swamp, Selous and Usangu Game Reserves and Ruaha National Park depend on the waters of the Great Ruaha River. These ecosystems are of both national and international importance as they are sources of foreign exchange generated through tourism and sport hunting while some of the swamps fall under the Ramsar Convention. Furthermore, the country's major hydropower plants of Mtera and Kidatu (representing over 50% of the hydro-electricity generation capacity in Tanzania) depend on waters of the GRR.

The GRR originates from a number of large and small streams at the Northern slopes of the Poroto and Kipengere mountains, from where the bulk of the flow is generated. From there, it flows into the Usangu Plains; a critically important region in Tanzania for irrigated agriculture (mostly rice) and livestock. There are two major wetlands in the Usangu Plains, namely the Western (Utengule) and Eastern wetland systems. The wetland system of the plains is important for the livelihoods of the communities in the area and for the adjacent Usangu Game Reserve. The GRR then flows through the Ruaha National Park, providing the main water source to the park, before being joined by the Little Ruaha River. It then continues to join the Rufiji River, supplying en route the Mtera reservoir and the associated power plants at Mtera and Kidatu. The GRRC can therefore be divided into four main hydrological areas (Fig. 2) i.e. (a) upstream of the perennial swamp (*Ihefu*), referred to as the Upper Great Ruaha River Catchment (UGRRC), (b) the area between the *Ihefu* and Mtera Reservoir, (c) the area between Mtera and Kidatu hydropower plants and (d) the area downstream of Kidatu hydropower plant.

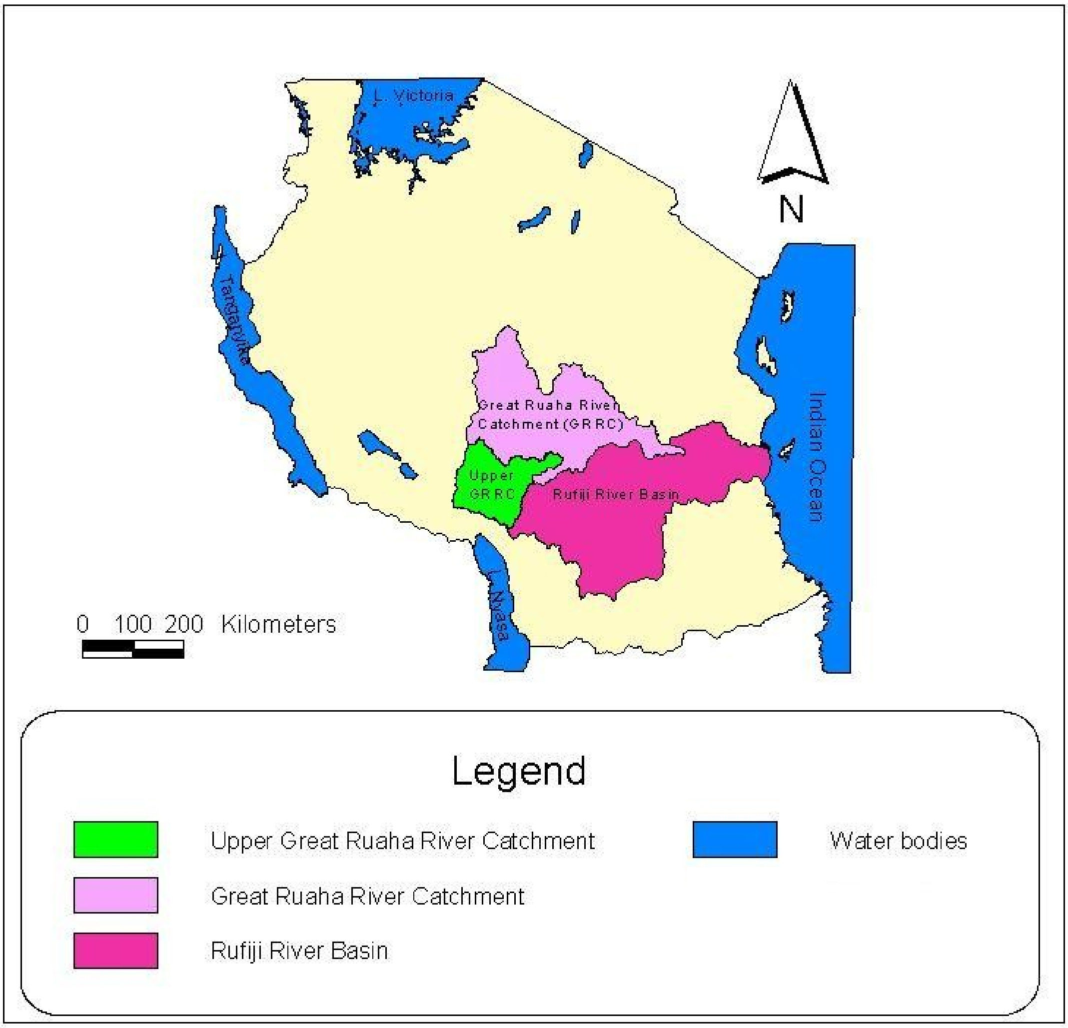


Figure 1: Location of the GRRC within the Rufiji River Basin in Tanzania

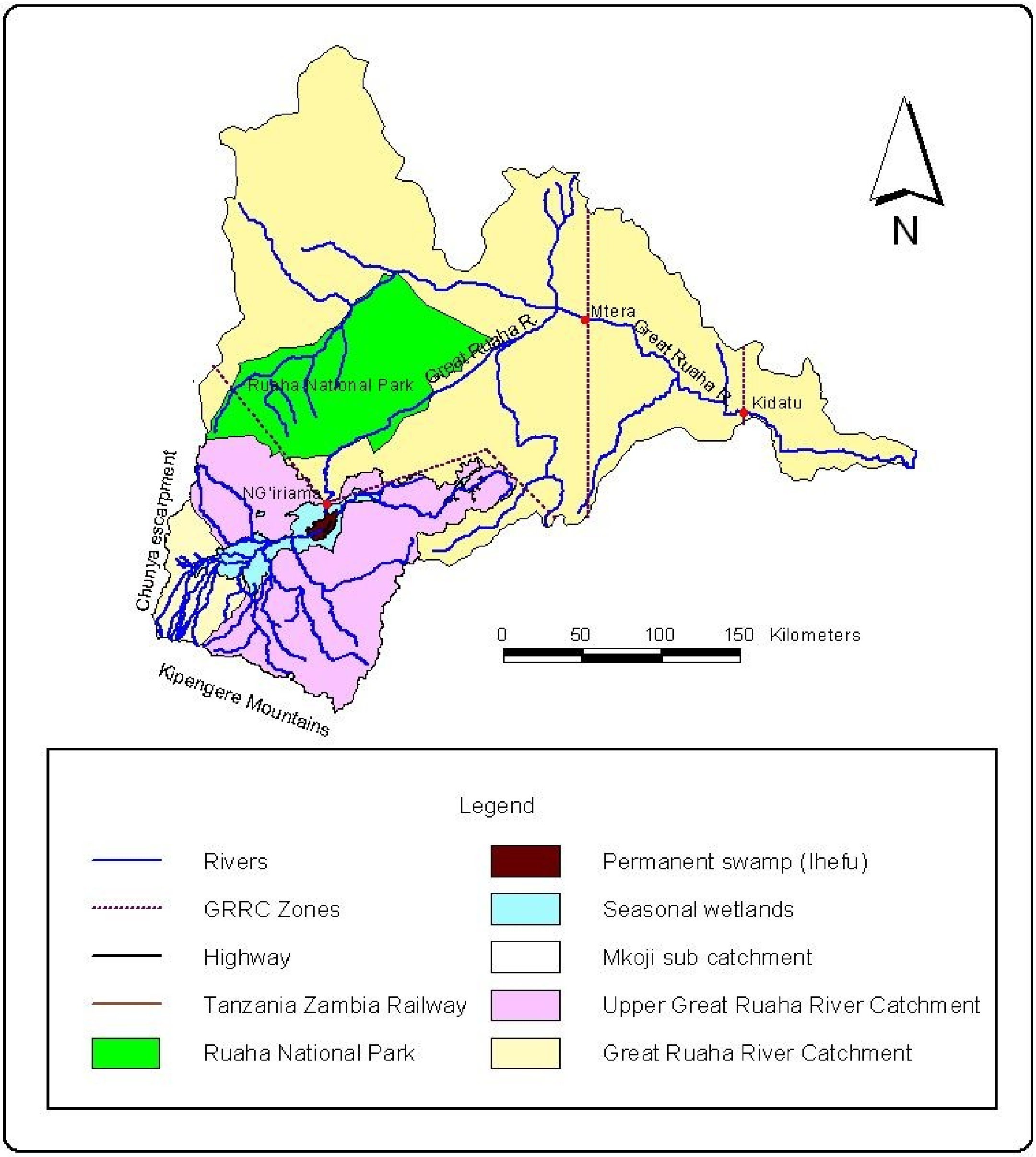


Figure 2: Important zones of the Great Ruaha River Catchment

3.3 Scope of the Study

This study was limited to the Upper Great Ruaha River Catchment (UGRRC) due to limitations on the available resources (time, financial, manpower and accessibility). However, since impacts of upstream water use extend very far beyond the initial planning area, the flows as recorded in the Great Ruaha River at Hausman's Bridge (1KA27) and Msembe (1KA59) gauging stations located immediately downstream of the UGRRC were also analysed. The UGRRC was chosen as the case study area because it generates the bulk of the flow of the GRR (about 56% of runoff to Mtera Dam (SMUWC, 2001b)) with many small rivers and streams flowing from the highlands to the plains and hence many irrigation abstractions. However, the studies on current water uses, water demands and water abstraction patterns were mainly concentrated in the Mkoji sub-catchment (MSC) (Fig. 3), although other sub catchments such as Mbarali and Kimani were also included to get good representation of the GRRC. MSC was chosen because there are: (a) more canal intakes than in any other sub catchment in the UGRRC; (b) significant water resources impacting activities, including dry season irrigated agriculture and livestock keeping; (c) many small seasonal rivers and streams; and (d) serious water shortages, especially during the dry season. Overall, 3 large perennial rivers, 25 seasonal rivers and 13 irrigation schemes were covered in this study.

3.4 Description of the Study Area

3.4.1 Location

The UGRRC is located in southwest Tanzania between latitudes $7^0$41’ and $9^0$25’ South and longitudes $33^0$40’ and $35^0$40’ East (Fig. 1). It has an area of 17 168 km^2 and a population of 480 000 people, according to the 2002 national population census (Tanzania National Website (TNW), 2003). The UGRRC consists of all the land from which water drains into the Usangu plains. A rock (granite) outcrop at NG’iriama defines the northern limit, where water exits the UGRRC as the Great Ruaha River.

The Mkoji sub-catchment (MSC) of the UGRRC is located in the southwest of Tanzania, between latitudes $7^0$48’ and $9^0$25’ South, and longitudes $33^0$40’ and $34^0$09’ East (Fig. 3). It covers an area of about 3400 km^2 with a population of about 146,000 people. The sub-catchment can be divided into three major agro-ecological zones as shown in Figures 4 and 5, which have the following important characteristics:

Zone A: Upper zone (the highlands)

This zone is highly populated and has high rainfall, deep soils and intensive agricultural production. In this zone, both rain-fed and irrigated agriculture is practised. The rainfall pattern and the type of soils allow for crop cultivation all year around.

Zone B: Intermediate (middle) zone

This zone is engaged in intensive, rain fed and irrigated agriculture. It is characterized by a high concentration of traditional irrigation systems as well as improved irrigation systems. Dry season irrigated agriculture is an important means of livelihood. Therefore, this is an area of high competitive water demand and hence persistent water conflicts.

Zone C: Lower zone (the plains)

This zone is under intensive rainfed agriculture. The area is semi-arid with alluvial and *mbuga* soils; and a high concentration of livestock particularly cattle. There are acute water shortages for domestic uses, especially during the dry season.

Figure 3: Location of MSC within the Rufiji River Basin in Tanzania

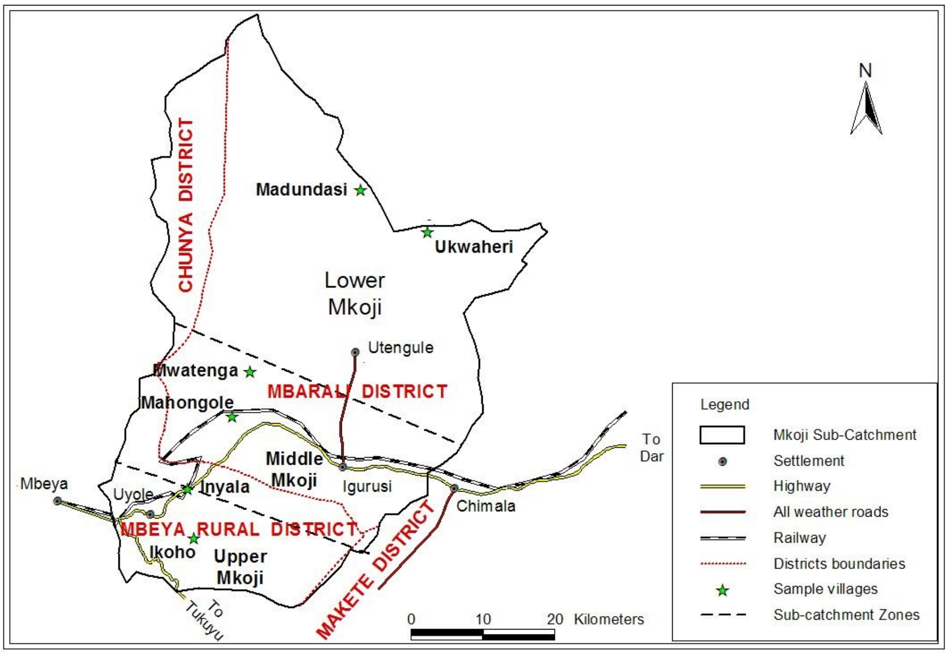


Figure 4: The Mkoji sub-catchment zones

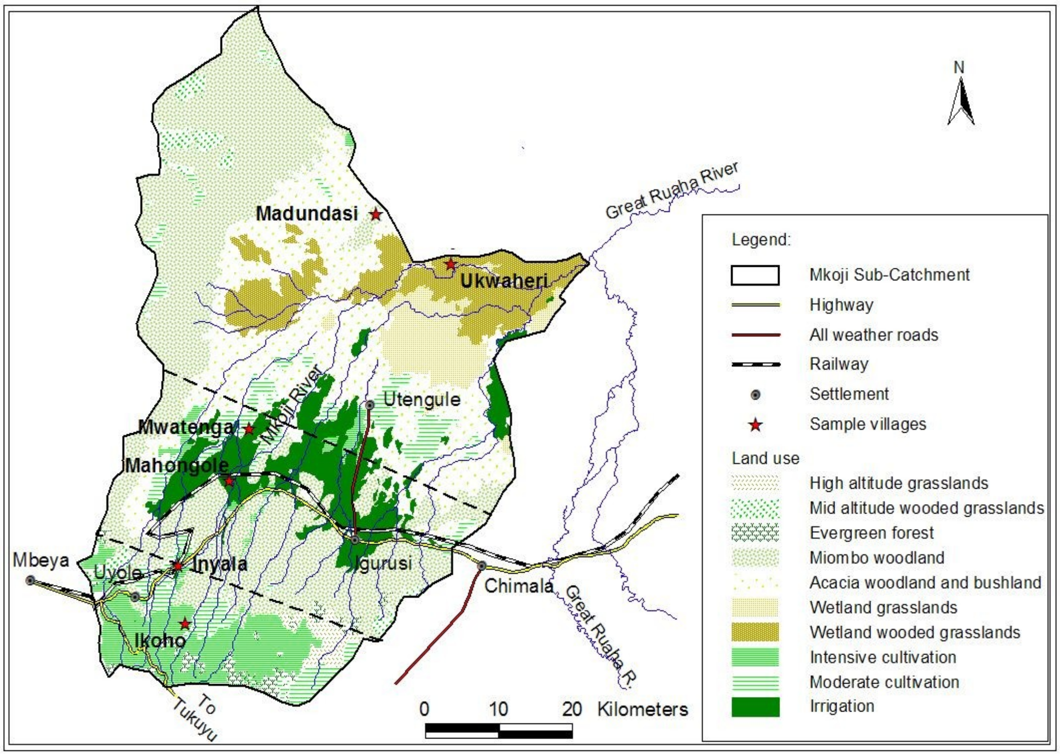


Figure 5: Mkoji sub-catchment – Land use patterns

3.4.2 Topography

The UGRRC lies within the eastern arm of the Rift Valley and is characterised by two distinct landscapes: a central plain (the Usangu Plains), and the highlands. The Usangu Plains are fairly flat and have an average elevation of 1100 m above mean sea level. The highlands are composed of the Chunya escarpment to the West and the Kipengere range and Poroto Mountains to the South, and rise from about 1100 m to over 2400 m above mean sea level. The Mkoji sub-catchment has the same topographical characteristics as the UGRRC.

3.4.3 Climate

(i) Temperature

The annual mean temperature for the UGRRC and MSC varies from about 18^0C at the higher altitudes to about 22^0C at Igurusi and Kapunga (in the plains). Most of the lower zone of the UGRRC and MSC, comprising the Usangu Plains, is semi-arid, whereas the highlands are semi-humid to humid.

(ii) Evaporation

Potential evaporation varies considerably within UGRRC and MSC. There is a tendency for decreasing evaporation with increasing rainfall and altitude. The pan evaporation is 2430 mm/year at Igurusi (middle zone) and decreases to 1890 mm/year in Mbeya (the upper zone). The yearly variation is smaller and steady (coefficient of variation is 7% at Igurusi).

(iii) Rainfall

The rainfall regime in the UGRRC and MSC is unimodal with a single rainy season starting from the third dekad of November and ending in the first dekad of April in the plains and third dekad of April in the highlands. In the high rainfall areas, the dry season is shorter as the rainy season tends to continue up to May. The heaviest rainfall generally occurs in December to March. The driest months are June to September. The mean annual areal rainfall over the UGRRC is 959 mm while that of MSC is 938 mm. The rainfall amounts as well as the onset of the rainy season vary considerably from year to year (annual coefficient of variation is about 24%). This variation often has a detrimental effect on crop production and other activities that depend on the reliable availability of water, especially in the drier areas.

3.4.4 Geology and soils

A basement complex of Precambrian rocks dominated by gneiss and granite under lays the major part of the UGRRC and MSC. However, the Usangu Plains are partly lacustrine and partly alluvial deposits. The south western part of MSC in the Poroto Mountains is composed of the volcanic parent material and ash deposit originating from the Rungwe-Mbozi volcanic complex. Mudstones, siltstones, quartz sandstones and quartzitic sandstones are found outcropping around Igurusi. The western part of MSC is characterised by quaternary alluvial, colluvial and terrestrial deposits that had been formed by the vegetation surrounding the plains and the rivers.

3.4.5 Water uses

Surface water is the main source of water for both agricultural and domestic purposes. Ground water use is confined to domestic use only (including brick making). Demand for water in the UGRRC and MSC is driven by a number of competing uses. These include domestic needs, irrigated agriculture, livestock, fishing, brick making, and environment maintenance. Of these, water for irrigation is the major use, since it is the largest anthropogenic consumptive use. There are three types of irrigation schemes in UGRRC.

These are:

a) Traditional irrigation systems, which comprise village irrigation, based on the diversion of perennial or seasonal flows, used mainly for the production of paddy, vegetables, and other relatively high value crops. These are self-sustaining systems, which are an important means of livelihood-generation for a large number of people in UGRRC. The most important feature of these schemes is that they have been initiated, financed and developed by the farmers themselves, without any external assistance. They are both farmer-managed; and farmer-owned.

b) Improved traditional irrigation systems, which comprise of schemes that have received government or donor interventions to improve the water control structures. There are claims that these systems have enhanced differences between upstream users who have benefited from improvements and downstream users who have lost a certain measure of water reliability and supply.

c) Modern irrigation schemes that comprise of large-scale farms (such as Kapunga, Mbarali and Madibira Rice Farms).

The same types of irrigation schemes exist in MSC with the exception of large-scale irrigation schemes. The Mkoji River is the main river draining the whole of MSC. It originates from the northern slopes of the Poroto Mountains from where it flows to the Usangu Plains to join the Great Ruaha River. Other important rivers that drain the MSC are as shown in Figure 6.

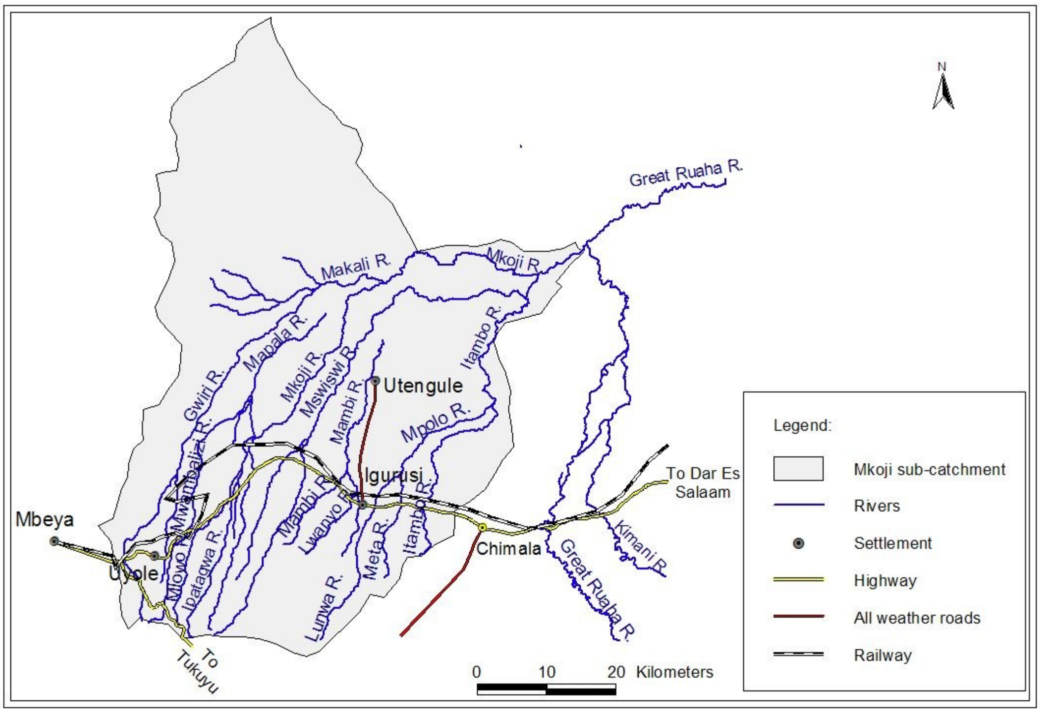


Figure 6: Mkoji sub-catchment - Water resources

3.5 Trend and Variability of Rainfall and River Flows

3.5.1 Data collection

i) Rainfall and evaporation

Historical rainfall and evaporation data from representative rainfall stations were collected from the Rufiji Basin Water Office (RBWO), Sustainable Management of Usangu Wetland and its Catchments (SMUWC) and Tanzania Meteorological Agency databases. In this study, geographic proximity was used for selecting the stations, both on the lower and upper catchments (Table 1). The available historical rainfall data for stations located within and just outside of the boundary of UGRRC had gaps of missing data. Therefore, the selection criteria of record length, missing data and period of interest were applied to preliminarily screen out unsuitable records. The overall requirements of analysing long continuous records therefore resulted into retaining 20 rainfall stations and 11 river flow stations. The rainfall stations used in the trend analysis were selected based on the criteria that the stations had at least 30 years of continuous records. For the case of areal rainfall, rainfall months were used if data for at least 25 days out of 30 are available whereas rainfall years were used if at least 11 out of 12 months had complete data. The distribution of some of the stations selected for the analysis is shown in Figure 7. Historical evaporation data were obtained from Ministry of Agriculture Training Institute (MATI) Igurusi, Kapunga Rice Farms, Mbeya, Dodoma and Madibira meteorological stations.

ii) River flow data

Historical river flow data from gauging stations located in the Great Ruaha River Catchment were collected from the Rufiji Basin Water Office and Directorate of Water Resources databases. There are 11 gauged sub catchments in UGRRC. Most of the gauging stations are located in the middle zone. Despite the presence of gaps in time series records, there is a substantial number of daily water level data in each gauging station to undertake runoff analysis. Table 2 presents details of the stations selected for runoff analysis. Figure 8 shows the spatial distribution of river flow stations used in the analysis of runoff. The available flow records were extended by recording water levels for two more consecutive years from the same gauging stations.

Table 1: Rainfall stations in and around UGRRC used in the analysis

Station Code	Station name	Easting	Northing	Period of Records Used	Years of Records used	Remark
09833020	Mbeya Maji	551343	9015065	1961-2004	43	A and T MSC & UGRRC
09833001	Mbeya Met	551340	9012854	1937-1999	63	A and T MSC & UGRRC
09834008	Mbarali Irrigation Scheme	642035	9042584	1957-2003	47	A and T MSC & UGRRC
09834010	Kimani	628299	9023374	1962-2003	42	A and T MSC & UGRRC
09833025	Uyole Agromet	571468	9017984	1971-2003	33	A and T MSC & UGRRC
09833002	Chunya Agriculture	545892	9057084	1934-2000	67	Areal MSC only
09833015	Kawetere Forestry	554980	9021694	1951-1992	42	Areal MSC only
09833003	Allsa Farm	571468	9018020	1971-1998	28	Areal MSC only
09933004	Rungwe Tea Estate	564051	8986632	1934-1998	65	Areal MSC only
09833000	Mbeya Boma	549475	9016173	1928-1989	62	Areal MSC only
09934024	Ichenga Agriculture	695767	8949366	1958-2001	44	A and T UGRRC only
09834006	Igawa Maji	652158	9030664	1964-2003	40	A and T UGRRC only
09934018	Tanganyika Wattle Co. Ltd.	695204	8972077	1928-2003	76	A and T UGRRC only
09834000	Madibira Maji	701500	9091900	1954-1991	38	Areal UGRRC only
09833031	MATI Igurusi	593485	9029364	1984-2004	21	Areal MSC only
09933013	Rungwe Sec. School	565919	8986629	1949-1971	23	Areal MSC only
09933028	Igembe Pr. School	549453	8998483	1962-1988	27	Areal MSC only
09834003	Rujewa Mission	646690	9039900	1943-1981	39	Areal UGRRC only
09834013	Matamba Pr. School	611772	9012364	2000-2003	4	Areal UGRRC only
09934049	Makete Bomani	635444	8968060	1985-2000	16	Areal UGRRC only

Note: A = Areal; T = Trend; UGRRC = Upper Great Ruaha River Catchment; MSC = Mkoji sub-catchment

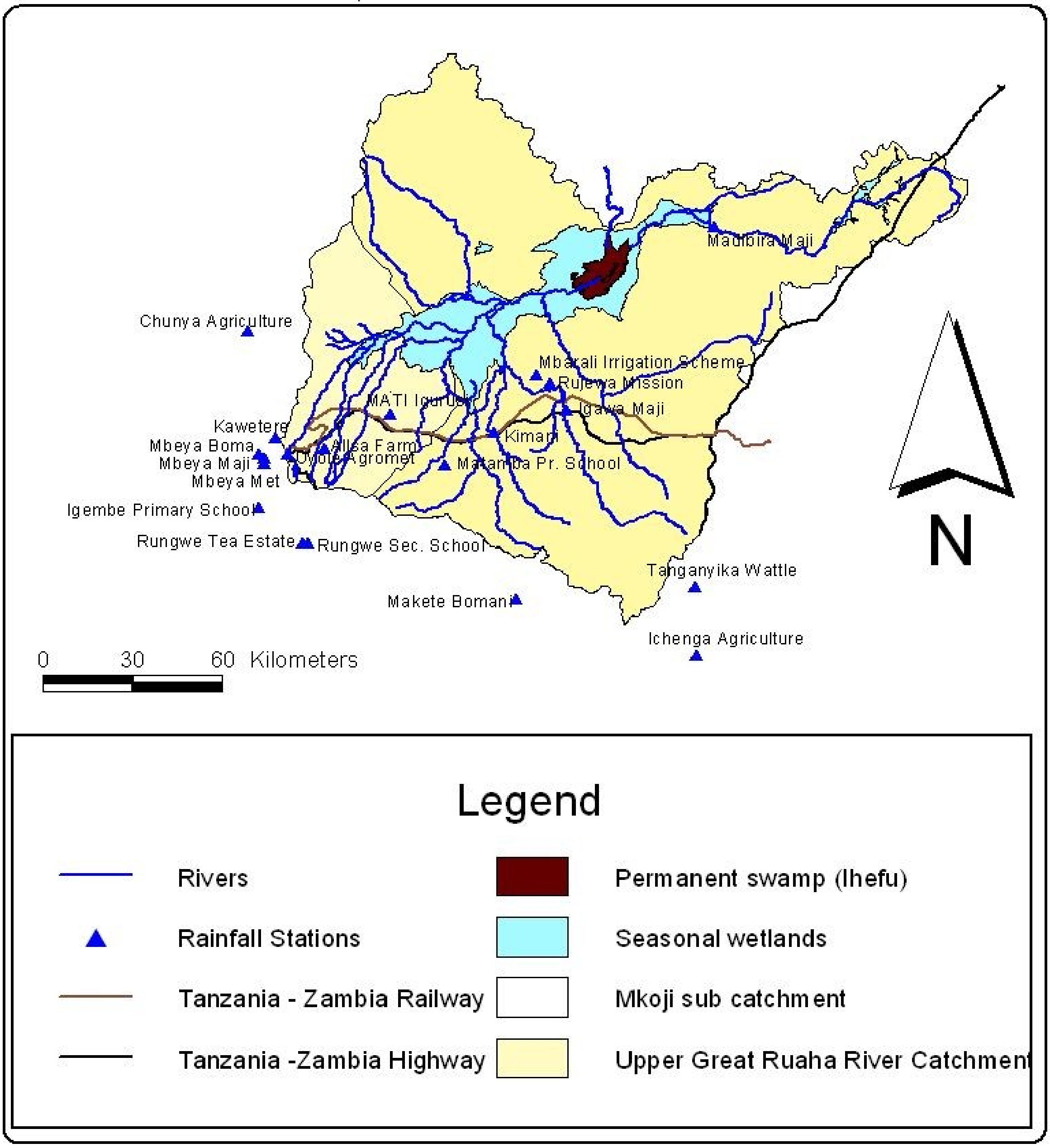


Figure 7: Spatial distribution of stations used for rainfall analysis

In order to facilitate assessment of water resources, additional gauging points were established in rivers to collect daily flow data for two consecutive years. Spot discharge measurements were also undertaken in un-gauged rivers in Mkoji sub-catchment at least twice a month during the dry season for two consecutive years. The aim was to estimate available dry season surface water resources.

iii) Hydrological survey data

Further investigations were conducted in the study area to supplement data obtained from hydrological analyses and identify other relevant indicators of hydrologic change other than differences in stream flow regime characteristics between two defined time periods at a given stream gauge. The methodology involved focus group discussions with key informants, survey of various stretches of the Great Ruaha River and its tributaries and administration of a structured questionnaire. Key informants were asked about their observation of flow changes in the Great Ruaha River and its tributaries over the years. Structured questionnaires were used to assist in identifying other relevant IHA, which are simple and can easily be understood by local people, who are the primary stakeholders and key players in case restoration plans are instituted. The IHA questionnaire is included in Appendix 2.

3.5.2 Data analysis

3.5.2.1 Reconstruction of missing rainfall and streamflow records

The generation of missing rainfall and stream flow data was by segment or date averages at the given station. Segment or date averages were computed from six values on either side of the gap (whenever possible), excluding outliers. In some instances, cross correlation method was used to fill the missing runoff data so that full-length records for the period of record were available for a particular station.

A time series of flow data at station number 1KA27 (Great Ruaha at Hausman's Bridge) was extended by using data from Msembe Ferry gauging station (1KA59), located about 50 km downstream of Hausman's Bridge. Hausman's Bridge station is located downstream of the exit from UGRRC (about 35 km). There are neither major tributaries nor water withdrawal points between the Hausman's Bridge and the exit from the UGRRC. Therefore, the flow at Hausman's Bridge can be assumed to be equivalent to that leaving the UGRRC. Whereas Hausman's Bridge station has operated from 1957 to 1988, Msembe Ferry station has been in operation from 1963 to date. The intervening catchment between the two stations is small (4200 km^2) and there are no water withdrawal points between them. In order to extend the flow records at Hausman's Bridge, a regression relationship developed by SMUWC (2001d) between the flows measured at the two stations by using data from the period when both stations were operational (i.e. 1963 to 1988) was used. The equation is:

$$Q_{Msembe}(t) = A * Q_{Hausman}(t - b) \qquad (3)$$

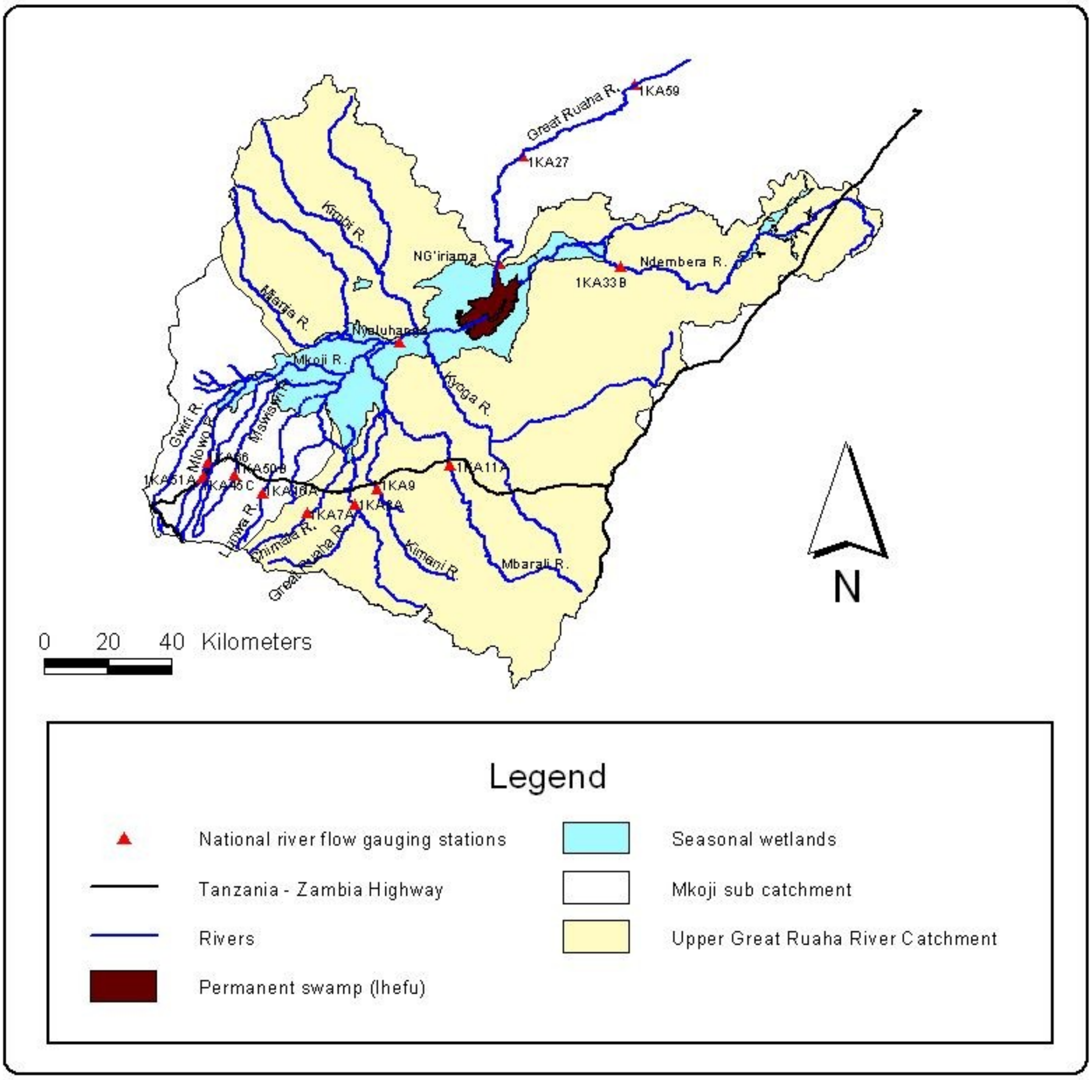
Where:	Q_{Msembe} (t)	=	daily flow at Msembe Ferry
	$Q_{Haussman}$ (t)	=	daily flow at Hausman's Bridge
	A	=	constant derived by linear regression
	b	=	lag time in days
	t	=	time interval (days)

The regression was done separately for the low flow season and for the high flow season. In both cases, the constant "b" was found to be zero; implying that the flow at Hausman's Bridge reaches Msembe Ferry on the same day. The constant "A" was found to be 0.9217 and 1.0046 in the low flow and high flow seasons respectively. The regression equation was used to fill missing data and to extend the records at Hausman's Bridge to 31 December 2004.

Table 2: River flow gauging stations used in the analysis of runoff

Station code	River Name	Physical location	Grid location		Duration of records
			Easting	Northing	
1KA7A	Chimala	Chimala at Chitekelo	607306	9014062	1962-2004
1KA 8A	Great Ruaha	Great Ruaha at Salimwani	622243	9016503	1954-2004
1KA9	Kimani	Kimani at Great North Road	629292	9021393	1954-2004
1KA11A	Mbarali	Mbarali at Igawa	651576	9028530	1955-2004
1KA16A	Lunwa	Lunwa at Igurusi	593600	9019900	1956-2004
1KA27	Great Ruaha	Great Ruaha at Hausman's Bridge	674414	9124776	1956-1988
1KA33B	Ndembera	Ndembera at Madibira	704750	9090250	1957-2004
1KA45C	Ipatagwa	Ipatagwa at Great North Road	575438	9025171	1958-2003
1KA51A	Mlowo	Umrobo at Great North Road	574955	9024770	1958-2004
1KA50B	Mswiswi	Mswiswi at Wilima	584800	9025800	1959-2004
1KA59	Great Ruaha	Great Ruaha at Msembe	709328	9146923	1963-2004

Figure 8: Spatial distribution of stations used in the analysis of runoff



3.5.2.2 Methods for rainfall and streamflow analysis

(a) Timescale for statistical variability analysis

In this study, the rainfall and streamflow analyses were performed at both the annual and seasonal timescales. The seasons are i) October-November-December (OND) early rainy season, ii) January-February-March (JFM) main rainy season, iii) April-May (AM) late rainy season, and iv) June-July-August-September (JJAS) dry season. These seasons have been deduced from the analysis of rainfall and river flow patterns and variations in the study area. Therefore, inter-annual variability analysis was performed in these four seasons.

(b) Methods for inter-annual variability analysis

i) Trend detection test

Several tests for trends are available. In this study, the time series of rainfall and streamflow variables from the selected stations were analysed using the Mann–Kendall (MK) non-parametric test for trend (Helsel and Hirsch, 1992). This test has been widely used in hydrological studies by several researchers (Hirsch *et al.*, 1982; Lins and Slack, 1999; Zhang *et al.*, 2001).

Procedure of the Mann-Kendall trend test

The Man-Kendall (MK) test is a non-parametric or distribution free test. It does not depend on the underlying distribution of the data. Assume that a sequence of data x_1, x_2, ….x_n is available. The test compares x_i, i=1,2,…,n-1 with all subsequent values, and if x_i tends to be smaller or larger than $x_{i+1}, x_{i+2}, \ldots, x_n$ an increasing or decreasing trend, respectively, may be present. The MK test is based on the test statistic S defined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(X_j - X_i) \tag{4}$$

Where the X_i and X_j are the sequential data values, n is the data set record length, and

$$\operatorname{sgn}(X_j - X_i) = \begin{cases} +1 & X_j > X_i \\ 0 \quad if & X_j = X_i \\ -1 & X_j < X_i \end{cases} \tag{5}$$

S = (sum of +ve signs)-(sum of –ve signs)

A positive value of S indicates an upward trend, whereas a negative value of S indicates a downward trend. Mann (1945) and Kendall (1975) have documented that for large sample sizes (n≥10), the statistic S is approximately normally distributed. If the data set is identically, independently distributed, then the mean (E) of S is zero and the variance Var(S) is computed as follows:

E(S) = 0,

$$Var(S) = \frac{[n(n-1)(2n+5) - \sum_{i=1}^{p} k(k-1)(2k+5)]}{18} \tag{6}$$

Where n is the length of the data set, p is the number of groups in the data set with identical x values (ties), k is the number of data points in any given tie, and Σ denotes the summation over all ties. This equation gives the variance of S with a correction for ties in data (EPA), 2006). A tie is a subset of the ordered data that comprises a sequence of the same values (i.e. observations with the same values).

The standardized normal variate is then used for hypothesis testing, and is called the test statistic Z. The standardized test statistic Z is computed by:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{var}(S)}} & \\ 0 & if \quad S = 0 \\ \dfrac{S+1}{\sqrt{\mathrm{var}(S)}} & \end{cases} \quad \begin{matrix} S > 0 \\ \\ S < 0 \end{matrix} \tag{7}$$

Z is then evaluated against the quantiles of a standard normal distribution. In a two-tailed test for trend, the null hypothesis H_o is accepted if $|z| \leq Z_{1-\alpha/2}$ at the α level of significance. In this study, the significance of the standardized statistic Z was assessed at 5% significance level and values of Z outside the limits at 5% significance level were considered statistically significant.

Slope estimator

When Y is linearly related to X, a robust non-parametric line, which is related to Kendall's rank correlation coefficient tau can be fitted. The magnitude of the slope of trend (β) is estimated using the non-parametric approach by Theil (1950) and Sen (1968). The approach is suitable for a nearly linear trend in the variable x and is less affected by non-normal data and outliers (Helsel and Hirsch, 1992).

The Theil slope estimate β is computed by comparing each data pair to all others in a pair-wise fashion. A data set of n (X,Y) pairs will result in n(n−1)/2 pair-wise comparisons. For each of these comparisons a slope ΔY/ΔX is computed. The median of all possible pair-wise slopes is taken as the non-parametric slope estimate β. A positive value of β_i indicates an ‘upward trend’, and a negative value of β indicates a ‘downward trend’. The slope β, was determined according to the equation by Hirsch *et al.* (1982), and is given by:

$$\beta = Median\left[\frac{(Xj - Xi)}{(j - i)}\right] \quad (8)$$

between all pairs i of the variable x, with i<j

The slope determined by the above equation is a robust estimate of the magnitude of a monotonic trend.

ii) Regime shift detection

Inter-annual variability of flow indices was investigated using the change-point analysis method, which identify discontinuities (shifts) in the mean values of a time series. The method is based on sequential t-test analysis of regime shifts. It treats all incoming data in real time, signals the possibility of a regime shift as soon as possible, then monitors how perception of the magnitude of the shift changes over time. The sequential analysis (Rodionov, 2004) belongs to the category of exploratory or data-driven analysis that does not require a prior hypothesis on the timing of regime shifts. This greatly facilitates an application of the algorithm for automatic computations, when the number of variables processed can be practically unlimited. Another advantage of the algorithm is that it can handle the incoming data. This study therefore used a sequential algorithm (Rodionov, 2004; Rodionov and Overland, 2005), which allows for early detection of a regime shift and subsequent monitoring of changes in its magnitude over time. The methodology is described in detail in Rodionov (2004; 2006c; 2006d) and Rodionov and Overland (2005). The detections were done by using the Sequential Regime Shift Detection Software (Rodionov, 2006c).

Procedure of the sequential method for detecting regime shifts in the mean

The method is based on the sequential application of the Student's t-test, which is used in the spirit of exploratory, rather than confirmatory, data analysis. Let x_1, x_2, …, x_t, …. be a time-series with new data arriving regularly. When a new observation arrives, a check is performed to determine whether it represents a statistically significant deviation from the mean value of the "current" regime ($\overline{X}_{cur}$). According to the t-test, for the difference between the mean value of the current regime ($\overline{X}_{cur}$) and the mean value of the new regime ($\overline{X}_{new}$) to be statistically significant at the level *p*, it should satisfy the conditions:

$$diff = \left|\overline{X}_{new} - \overline{X}_{cur}\right| = t\sqrt{2\overline{S_l}^2 / l} \qquad (9)$$

where *t* is the value of the *t*-distribution with 2*l* – 2 degrees of freedom at the given probability level *p*. It is assumed here that the variances for both regimes are the same and equal to the average variance for running *l*-year intervals in the time series $\{x_t\}$. It means that *diff* remains constant for the entire session with the given time series.

At the "current" time t_{cur}, the mean value of the new regime $\overline{X}_{new}$ is unknown, but it is known that it should be equal or greater than the critical level $\overline{X}^{\uparrow}_{crit}$, if the shift is upward, or equal or less than $\overline{X}^{\downarrow}_{crit}$, if the shift is downward, where

$$\overline{X}^{\uparrow}_{crit} = \overline{X}_{cur} + diff, \qquad (10)$$

$$\overline{X}^{\downarrow}_{crit} = \overline{X}_{cur} - diff \qquad (11)$$

If the current value $\overline{X}_{cur}$ is greater than $\overline{x}^{\uparrow}_{crit}$ or less than $\overline{x}^{\downarrow}_{crit}$, the time t_{cur} is marked as a potential change point *c*, and subsequent data are used to reject or accept this hypothesis. The testing consists of calculating the so-called regime shift index (**RSI**) that represents a cumulative sum of normalized anomalies relative to the critical level $\overline{X}_{crit}$:

$$RSI = \frac{1}{l\overline{S}_l}\sum_{i=t_{curt}}^{m}(X_l - X_{crit}), \quad m = t_{cur}, t_{cur+1}, \ldots, t_{cur} + l - 1 \qquad (12)$$

If at any time during the testing period from t_{cur} to t_{cur} + l the index turns negative, in the case of $\overline{X}_{crit} = \overline{x}^{\uparrow}_{crit}$, or positive, in the case of $\overline{X}_{crit} = \overline{x}^{\downarrow}_{crit}$, the null hypothesis about the existence of a shift in the mean at time t_{cur} is rejected, and the value x_{cur} is included in the current regime. Otherwise, the time t_{cur} is declared a change point *c*.

The magnitude and scale of the regimes to be detected are controlled by the significance level (the level at which the null hypothesis that the mean values of the two regimes are equal is rejected by the two-tailed Student t-test) and the cut-off length. In the analysis, a significance level of 5% and a cut-off length of 10 years were used, implying that regimes that are longer than 10 years will all be detected. For shorter regimes, the probability for them to be detected reduces proportionally to their length. Some of them, however, may still be selected if the magnitude of the shift is significant enough. Due to outliers, the average is not representative for the mean value of the regimes. The Huber's weight function (Huber, 2005) was employed to handle the outliers, and the weight parameter of 6 was used. Red noise (or serial correlation) was modelled by the first order autoregressive model (AR1). ARI was estimated by the Ordinary Least Square Method (Rodionov, 2006b; 2006c) using the entire time series. The time series were pre-whitened to remove the red noise component before the regime shifts were detected for the filtered time series.

iii) Modelling river flow changes using the split sample technique

In hydrologic time series shifts may be present in one or more of the statistical characteristics of the series. Split sample techniques can be used to show that there is significant difference between means of split samples in a time series that could support the hypothesis of trends in the data and quantify the magnitude of the changes. The procedure of the split-sample testing is as follows:

Consider a series x_i, i = 1,2,….,n which is divided into two sub-series of length N_1 and N_2, respectively, where $N_1+N_2=N$. The two sub-series are assumed to be independent, normally distributed with mean values μ_1 and μ_2 and variances σ_1^2 and σ_2^2. If the variances are identical, i.e. $\sigma_1^2=\sigma_2^2$, the simple t-test can be used for testing the null hypothesis H_o: $\mu_1=\mu_2$, against the two sided alternative H_1: $\mu_1\neq\mu_2$.

Suppose that two random samples of sizes N_1 and N_2; means $\overline{X}_1$ and $\overline{X}_2$; and standard deviations given by s_1 and s_2 are drawn from normal populations whose standard deviations are equal. To test the hypothesis H_o that the samples come from the same population, we use the t score given by:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sigma \sqrt{\frac{1}{N_1} + \frac{1}{N_2}}} \qquad (13)$$

with N_1+N_2-2 degrees of freedom, where, σ is given by:

$$\sigma = \sqrt{\frac{N_1 s_1{}^2 + N_2 s_2{}^2}{N_1 + N_2 - 2}} \qquad (14)$$

The null hypothesis is rejected at significance level α if the absolute value of the t-statistic is greater than the critical value of the student t-distribution denoted by $t_{1-\alpha/2,n-2}$. This corresponds to 1- α/2 quartile of the student's t-distribution with n-2 degrees of freedom.

iv) Time Series Transformation

Several of the time series tests included in this study, such as the split sample trend test assume that the variable under consideration is normally distributed. Unfortunately, many real data sets are in fact not approximately normal. Therefore, it is a usual practice to test the data for normality before further analysis. Some of the tests used include the chi-square test, the Kolmogrov-Smirnov test and procedures based on testing hypothesis that the skewness coefficient is equal to zero or the kurtosis coefficient is equal to three (Madsen, 1996). Appropriate transformation of a data set can often yield a data set that does follow approximately a normal distribution. This increases the applicability and usefulness of statistical techniques based on the normality assumption. The most widely used method for transforming data to normal is based on logarithmic transformation. Likewise, power transformation such as the Box-Cox (BC) (Box and Cox, 1964; Orlich, and

Delozier 2001) transformation is an alternative. In this study, the Box-Cox transformation was used to transform the data prior to split sample trend tests. The BC transformation is given by (Box and Cox, 1964; Peltier *et al.*, 1998; Orlich, and Delozier 2001):

$$X_t = \begin{cases} \dfrac{\left(y_t{}^{\lambda} - 1\right)}{\lambda} & \lambda \neq 0 \\ \ln(y_t) & \lambda = 0 \end{cases} \tag{15}$$

This transformation is a complex power transformation that takes the original data and raises each data observation to the power lambda (λ). The rationale is to find λ such that the skewness of the y_t becomes zero. It uses an iterative procedure for estimating the best transformation to normality within the family of power transformations. In this study the model form given by Equation 15 is used in which the parameter λ is determined by optimisation. For λ = 0, the natural log of the data is taken. The Rundom BC 1.0 software (Jadwiszczak, 2004) was used to assist to perform the Box-Cox data transformation in several settings. A λ range of -0.5 to 0.5 was specified for the transformations.

3.5.2.3 Study indices for rainfall and streamflow analysis

Annual rainfall is related to average annual discharges and seasonal rainfall amounts are also related to average seasonal discharges. Therefore seasonal and annual rainfall amounts were extracted from available rainfall records and analysed to highlight the probable influences of the changes of rainfall amounts, if any, on stream flow. Seasonal rainfall values were computed only from complete months that form a particular season. For the case of stream flows, various indices were extracted from the available stream flow records. Average annual discharges were considered appropriate to highlight the flow increases or decreases over the years. Moreover, seasonal average discharges are appropriate in relation to the effects of land use change. Monthly discharges were determined only for months with at least 90% of the daily observations available while seasonal flows were computed only from complete months that constitute that particular season. The seasons, as defined for rainfall, were used in stream flow analysis.

i) Rainfall analysis

First, the historical series of rainfall records from the selected stations were examined for within the year and inter-annual variations. This was followed by trend analysis using the Mann-Kendall procedure. Then the change-point analysis was performed to detect significant regime shift(s) in rainfall records.

ii) Runoff analysis

Runoff analysis was carried out in order to get a better understanding of the river flow characteristics in the Upper Great Ruaha River Catchment.

(a) Computation of discharge

Discharge data were computed from continuous stage records using an established rating curve at a gauging station on a river. To check for the reliability of the rating curves and computed discharges, measured discharge data sets were superimposed on the rating curves to see how the curves fit the data.

(b) River flow trend analysis

Trends in river flow characteristics of the selected stations were also investigated from historical time series data, as they tend to reflect an integrated response of the catchment area as a whole. First, the historical series of river flow records from the selected stations were examined for within the year and inter-annual variations. This was followed by trend analysis using the Mann-Kendall procedure. Then the change-point analysis was performed to detect significant regime shift(s) in river flow records. Thereafter (basing on the results of regime shift detection; irrigated land use trends and observed streamflow changes), river flow records were divided into two periods: 1960-1980 and from 1981 to 2000. The Students t-test was used to determine whether there was a statistically significant difference in means of streamflow between the two periods (1960-1980 and 1981-2000). The Box-Cox method was used to transform the data prior to split sample analysis.

(c) Generation of indicators of hydrologic alteration

River flow records from the Great Ruaha River at Hausman's Bridge gauging station (1KA27) and Msembe station (1KA59) located just downstream of the UGRRC were used to generate indicators of hydrologic alteration using the IHA software (TNC, 2005). The years of record at the gauging stations were split into two periods: the pre-impact (1957-1980) and post-impact (1981-2004) periods. The same cut-off year (1980) as for streamflow split sample analysis was adopted. Mean annual runoff; mean monthly runoff; number of zero-flow days; annual 1-day minimum flow; and Julian date of each annual 1-day minimum flow constituted the parameters that were investigated. The values of each of the hydrologic parameters was calculated for each year in each data series, that is one set of values for the pre-impact data series and one for the impact data series.

Quantification of hydrologic alteration was done by comparing inter-annual statistics between the pre and impact data series. Each result was presented as percent deviation of one time period (the impact condition) relative to the other (the pre-impact condition).

3.6 Irrigated Area Trends in the Upper Great Ruaha River Catchment

To understand the current and historical development of irrigated area in the UGRRC, it was necessary to examine the dynamics of irrigation seasons, to quantify the area under irrigation and to chart the development of irrigation over time. As well as the steady increase in maximum rice area and area under dry season irrigated agriculture for the last 40 years, the actual area of rice fluctuates from year to year. The irrigated rice area and area under dry season irrigated agriculture are subject to dynamic changes from year to year depending on many factors. The factors include:

a) Rainfall and river flows. During wet years, a relatively large area is put under rice production. The converse is true for a dry year. When the wet season receives poor rains, like the 2002/03 season, both irrigated and rain-fed agriculture suffer. Many farmers resort to irrigated agriculture during the dry season to cushion the threat of famine, thereby increasing the area under dry season irrigated agriculture.

b) Market prices. The higher the market price of the produce, the larger the area will be under cultivation the following year, other factors being constant; and

c) Construction of new modern irrigation schemes, which increases the reliability and availability of water for irrigation.

From the above observations, it is evident that no single methodology can be used to determine irrigated area trends in the UGRRC. Therefore, in order to determine irrigated area trends, a number of methodologies were used. They included: (a) review of past reports and studies to extract maximum and core irrigated areas; (b) analysis and on-screen digitisation of paddy areas from remotely sensed (RS) images of 1973, 1984, 1991, 1994, 1995 and 2000; (c) mapping some of the irrigated areas using Global Positioning System (GPS) receivers; and (d) studying the historical development of irrigated agriculture, more significantly, the increase in area over time; and the increase in the number of 'improved intakes' over time. Irrigated area data from irrigation furrow survey done by SMUWC in 1999 were updated, analysed and used in the study. Data from RS images and GPS receivers were processed using ESRI's ArcView 3.2 Geographical Information System (GIS) software.

In consideration of cloud cover and seasonality, the targeted images were those acquired during the months April-August when paddy fields could be clearly identified. The images selected for the analysis are shown in Table 3.

Table 3: Images used in the analysis of paddy areas

Image Type	Month of acquisition	Cloud cover (%)
Landsat MSS[+]	September 1973	0
Landsat TM*	June 1984	11
Landsat TM	August 1991	0
Landsat TM	August 1994	1
Landsat TM	June 1995	-
Landsat ETM+	May 2000	8

[+] MSS = Multi spectral scanner
* TM = thematic mapper
ETM+ = Enhanced thematic mapper plus

Analysis of paddy areas (from RS images) was done by using visual image interpretation. Visual interpretation involved use of image characteristics such as pattern, texture, and colours to delineate paddy areas. Visual image interpretation was considered to be feasible in this study because the knowledge of local experts could be integrated during interpretation. During ground truthing, it was found that agricultural land use pattern in the Usangu plains was very heterogeneous as a non-uniform mixture of crops and field sizes characterized cultivation. This made identification of smallholder paddy areas using digital image classification very unreliable, resulting in mixed pixels. Thus, visual interpretation was considered to be a more reliable technique to discern paddy areas.

3.7 Current Water Demands and Uses

For the purpose of this study, water use was defined as the amount of water that was actually used for a specific purpose, such as for domestic, livestock or irrigation. Field research on determining current water uses and demands was carried out in three main stages and involved both formal and informal survey methods (Chambers, 1992). The first stage involved discussion with key informants and groups of people with the aim of obtaining information and views concerning water demands and uses. The second stage consisted of a formal household water use survey using a structured questionnaire. This survey was conducted to collect specific and quantitative information from the representative households. The third stage concerned transects walks across the catchment to obtain physical information and verify the information collected during the formal and informal surveys. Secondary data from scientific reports, previous studies and hydrometric stations were also used as additional sources of information.

3.7.1 Household water use questionnaire surveys

Sampling techniques

Mkoji sub-catchment (MSC) was chosen as the case study area for a thorough investigation of current water uses and demands during the 2002/03 season. MSC was divided into three agro-ecological zones, namely, the upper, middle and lower zone. For the household surveys, a two-stage hierarchical or multistage sampling was used. The sampling strategy involved both deliberate (purposive) selection of samples and random selection of the samples to ensure proper representation and coverage of the full range of water uses and demands. Villages were selected, two from each agro-ecological zone. The sampled villages were Ikhoho and Inyala in the Upper Zone, Mwatenga and Mahongole in the Middle Zone and Madundasi and Ukwaheri in the Lower Zone. Then, five percent of the household heads were randomly selected from each of the sub-villages within the selected villages for questionnaire administration.

A follow-up survey was done in the 2004/05 season to scale-up and verify results found in the 2002/03 study and address other issues, which were not covered in the first survey, but were found to be important and impacting on the observed characteristics and patterns of water uses. The same three MSC agro-ecological zones were used. Six different villages from MSC were purposively and randomly sampled, two from each zone. The sampled villages were Imezu (bordering Inyala) and Iyawaya (bordering Ikhoho) in the Upper Zone, Igurusi and Majenje (with semi-urban type of livelihoods) in the Middle Zone and Mwatenga and Luhanga located in between the lower part of the Middle Zone and the upper part of the Lower Zone. Mwatenga village was retained because it is easily accessible during the wet season and one-half of the village falls in the lower zone. In order for the results so obtained to be representative for other areas in the UGRRC, two other villages (Uturo and Ihahi) were purposively chosen to represent the Kimani/Great Ruaha and Chimala Rivers sub catchments respectively. The follow-up study contained all the questions that were used in the previous survey plus additional questions added to address characteristics, attitudes and perceptions of people on various water issues. The latter questionnaire is included in Appendix 1. In total, the 2002/03 household survey covered a stratified sample of 246 respondents from six villages whereas 331 respondents from eight villages were covered in the 2004/05 follow-up survey. The locations of the surveyed and other important villages covered in this study are shown in Figure 9.

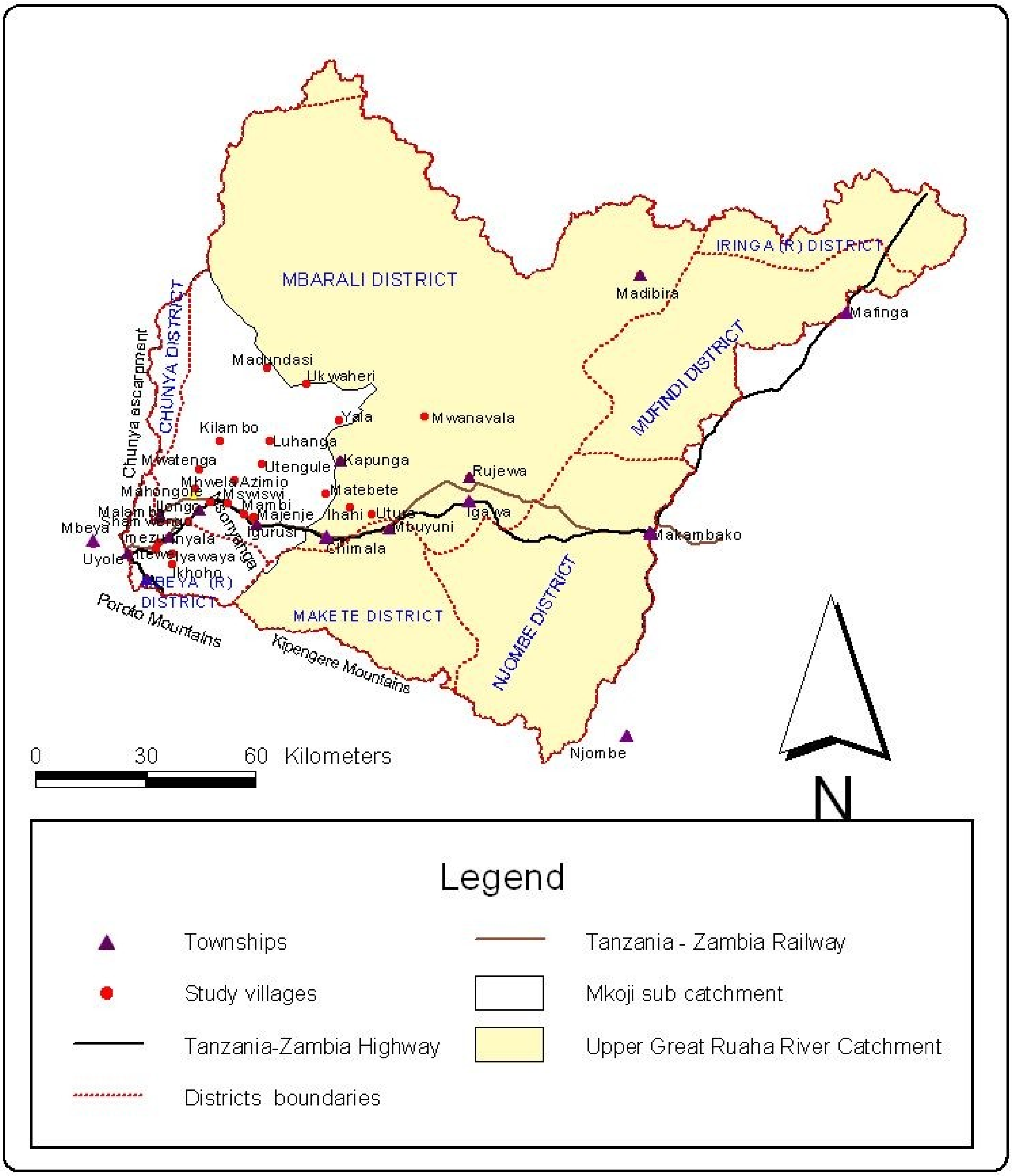


Figure 9: Location of surveyed and other important villages

Questionnaire design, pre-testing and administration

The questionnaires were designed in such a way as to make it possible to collect data on (a) household characteristics; (b) livelihood activities; (c) water sources, consumption and storage structures; (d) demand preferences and supply priorities; (e) perceptions on water sharing; and (f) coping mechanism/remedial measures in case of water shortages. The questionnaires were pre-tested in the respective areas before being administered to respondents in order to ensure that respondents understood the questions and the questions did not adversely affect survey cooperation. Thereafter, necessary adjustments were made to improve the questionnaire. Four field staff were recruited, trained and debriefed to ensure a consistency of approach by the enumerators, as well as freedom of expression by the respondents. The field staff, together with the researcher, then collected the information by visiting the respective villages and sub-villages and interviewing the respondents at the village offices or at their homes.

Data Processing and analysis

Data from the questionnaires were coded and entered into the computer. Analysis was accomplished using the Statistical Package for Social Sciences (SPSS/PC^{+}) computer program. Descriptive statistical parameters (means, percentages, multiple responses and cross-tabulations) were the main outputs of the analysis. The results were summarised in tables and graphs.

3.7.2 Determination of crop water use

SWMRG (2003) determined crop water requirements for various crops grown in the Mkoji sub-catchment. The crops included paddy, maize, wheat, millet, sorghum, beans, onions, tomatoes, potatoes and groundnuts. Reference evapotranspiration (ETo) was estimated by using the available data from Igurusi climatic station located in the Middle MSC zone and was supplemented by data from Kapunga station (representing Lower MSC zone) and Mbeya meteorological station (representing Upper MSC zone). The data were processed using the FAO CropWat 4 Windows version 4.3 model and ETo was modelled using Penman-Monteith equation (Raes, 1996). The ETo together with crop parameters (crop types, crop coefficients, crop growth stages, crop heights and planting dates) were then used to calculate crop water requirement (CWR). The CWR values and cultivated areas found during the survey were used to determine crop water use under both rainfed and supplementary irrigation.

3.8 Investigation of Water Abstraction Patterns in Relation to Water Availability and Water Rights and their Impacts on Downstream Flows

3.8.1 Water abstraction patterns

Data on types of diversions and water use were collected through site visits and informal discussions with key informants. Secondary data and information were obtained from various databases, reports, and other publications. Irrigated areas were obtained by mapping the areas using GPS receivers. Additional gauging points were established in rivers (upstream and downstream of irrigation schemes) and in water abstraction canals to collect daily flow data for two consecutive years. The aim of establishing these stations were to generate data: (a) on flow patterns in the rivers before and after they had been altered by various upstream human activities; and (b) on water abstractions of the canals that would facilitate assessment of whether conditions spelt in the formal water rights are being followed. Figure 10 shows the location of the additional gauging points installed on rivers. Locations of upstream and downstream gauging/metering stations are shown in Figure 11. In general, procedures used for the selection and installation of gauging stations and manual water level gauges, followed the guidelines of the World Meteorological Organisation (World Meteorological Organisation (WMO), 1994) and the Draft Guide to Hydrological Practices in Tanzania (Ministry of Water (MoW), 2002).

Water level data recording

Standard staff gauges were used in all gauging points. They consisted of one or more 1-m sections of enamelled steel plate accurately graduated to 10 cm. Each 10 cm was numbered and intermediate 5 cm graduation marks were wedge shaped. In areas, which were less secure, graduated sectional galvanised steel pipes with a diameter 62.5 mm were used. The gauges were set so that a reading of zero is below the lowest anticipated stage to avoid negative readings. Temporary benchmarks were established and these were made of a red point on top of a permanent structure (e.g. culvert, bridge, and immovable rock) or a 19 mm bolt embedded in concrete. The datum of these gauges were checked annually, in order to maintain the same gauge datum throughout the period of record. All manually read gauges, no matter how stable, will not produce an accurate reading, particularly on irrigation canals and small streams. This is mainly due to fluctuations in the rate of water flow or short storm events. Because of this, two systematic readings of water levels were therefore taken during the day at 0900 h and 1700 h. These were supplemented by more closely spaced readings during floods. Trained gauge readers, undertook daily recording of water level data.

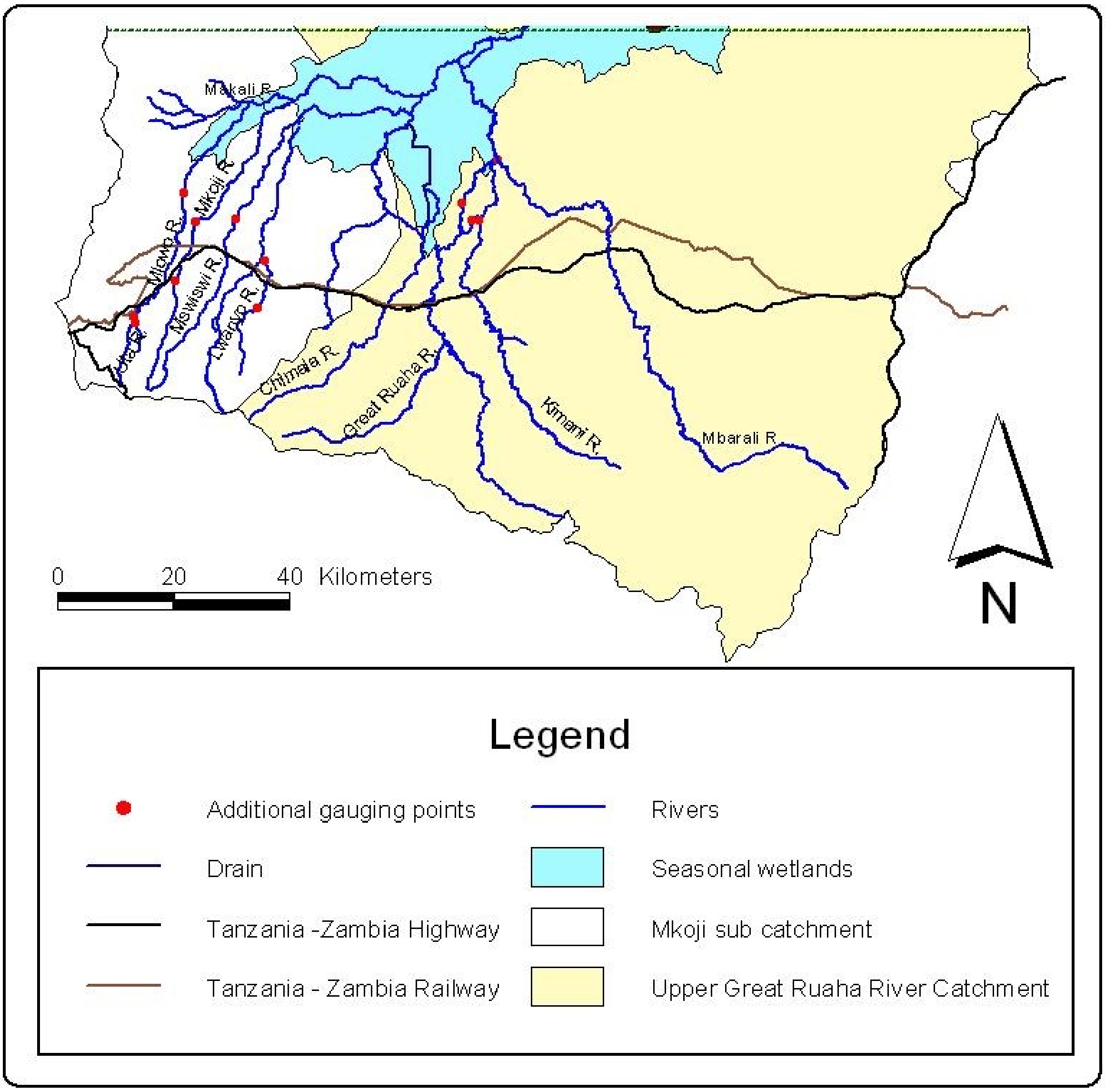


Figure 10: Additional gauging stations installed on rivers

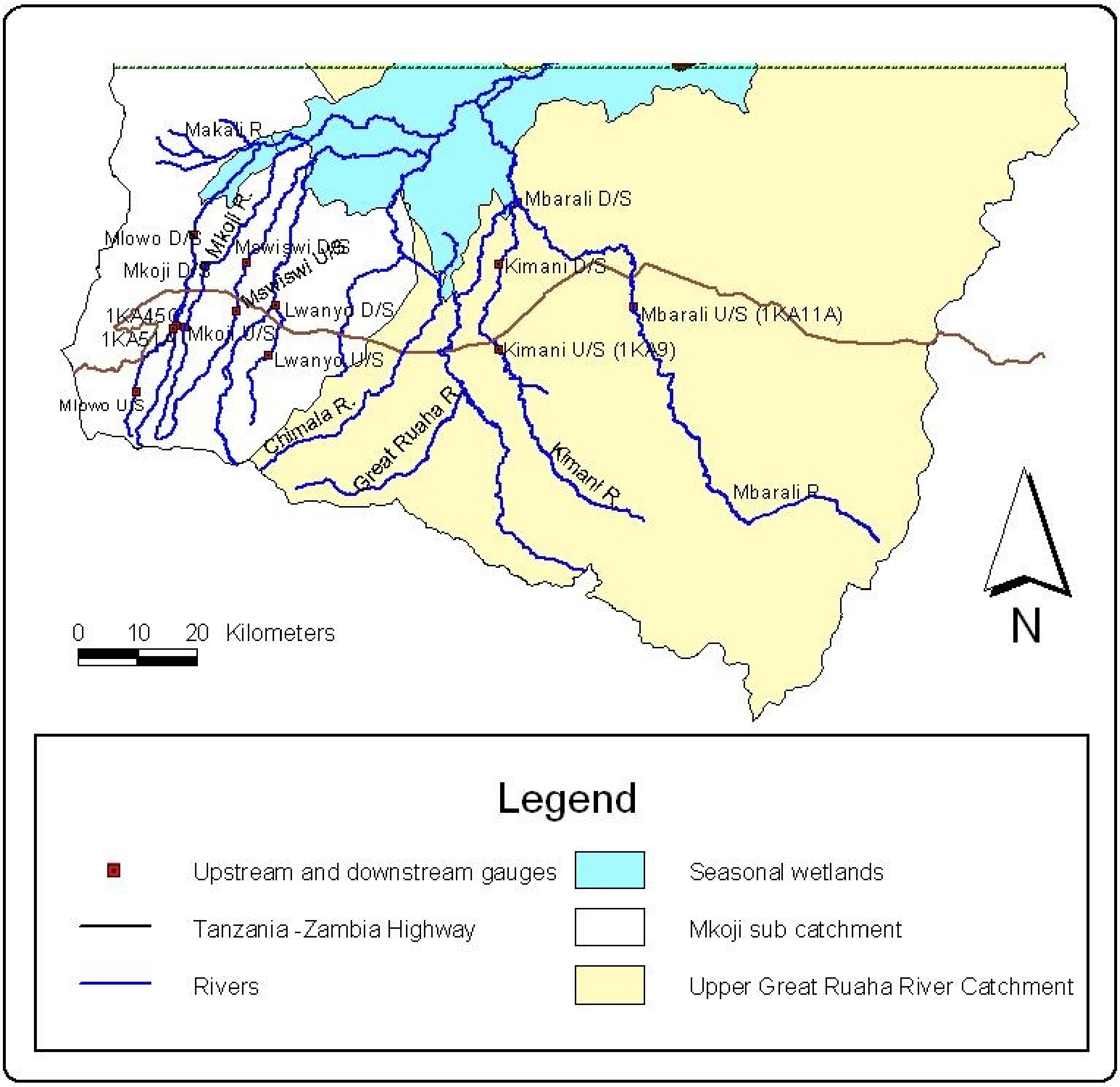


Figure 11: Location of upstream and downstream gauging/metering stations

Discharge measurements and rating equation

The derivation of flows from water levels requires development of a relationship between measured water levels and discharge (i.e., rating equation). This was done by undertaking discharge measurements in rivers and canals using current meters at different water levels to obtain enough data points for the derivation of the rating equation. However, during high flows, direct flow measurements by wading using a current meter was not possible. As such, the surface velocity approach was used. A relatively straight stretch of between 30-50 meter (whichever was possible) close to the gauging stations, identified by poles at one side of the bank was selected. Dry stick floats were thrown at the centre of the river just upstream of the initial observation point, and using a stop watch, the time taken by the float to travel the distance between the two poles was recorded. The surface velocity was computed as distance of travel divided by the time taken by the float to cover the distance. The procedure was repeated three times and the average surface velocity computed. This was then multiplied by a correction factor of 0.8 to obtain the mean velocity (V) for the river section. The cross-sectional area (A) corresponding to the depth of water at the gauge was determined from cross-sectional surveys done on the gauging stations. The discharge was then computed as:

$$Q = V \times A \quad (m^3/s) \tag{16}$$

It is worth noting that discharge measurements made by using floats are not as good as those done using current meters. However, since the target was mainly dry season flows, which were measured by wading using a current meter, the resulting flows were computed with greater certainty. The observed discharge and stage points were fitted with power function to develop the rating equation. This is the standard function used in Tanzania. The power function is given as:

$$Q_r = k(h - h_o)^x \quad (17)$$

Where: Q_r is the rating curve discharge (m^3/s); k is the coefficient; h is the water level (m); h_o is the gauge height corresponding to zero flow (m); and x is the power. The procedure is to find the values of k and x, which minimise the value
"sum $((Q_r-Q_m)^2)$", where Q_m is the measured discharge (m^3/s).

The rating curves were then used to convert the mean daily water levels to mean daily discharges. An example of derivation of rating curve for Lwanyo River at Majenje is given in Appendix 3. Other rating curves and equations used in the study are included in Appendix 3 (a-i). Spot discharge measurements were also undertaken in un-gauged rivers at least twice a month during the dry season for two consecutive years in order to estimate available surface water resources during the dry season.

The selection of irrigation schemes that were studied was based on the following criteria: (a) There is easy accessibility of the abstraction and gauged points throughout the year; (b) Both wet season and dry season irrigated agriculture are represented; (c) Traditional as well as improved traditional intakes are studied; and (d) Irrigation canals are selected from both the upstream and mid-stream of the respective rivers. The details pertaining to the irrigation schemes studied are as shown in Table 4. Three categories of irrigation canals were involved in the investigation of water abstraction patterns. In this context, water abstraction patterns imply the rate, duration, season and frequency of abstraction. The categories of the canals depended on seasons of abstraction, which are: (a) wet season (mainly for paddy cultivation); (b) dry season (mainly for dry season cultivation of vegetables, legumes and maize); and (c) throughout the year.

Table 4: Description of irrigation schemes studied

Sno	Scheme Name	Type of intake	Water source	Water rights (m^3/s)		Developed area[2] (ha)	Remarks/ Zone
				Wet season	Dry season		
1	Ipatagwa I Irrigation Project	Improved	Ipatagwa R.	1.000 (Nov-May)	0.100 (June-Oct)	542[3]	Irrigation[4] (Middle)
2	Ipatagwa II Irr. Project	Improved	Mkoji R.	0.300 (Nov-May)			Paddy irrigation (Middle)
3	Luanda Majenje	Improved	Lwanyo R.	0.180 (Dec-May)	0.040 (June-Nov)	371	Irrigation (Middle)
4	Kongolo Mswiswi	Traditional	Mswiswi R.	0.360 (Dec-June)		180	Irrigation (Middle)
5	Irrigation at Inyala (B)	Improved	Mlowo R.	0.180 (May-Aug)	0.025 (Sep-Nov)	60	Dry season (Upper)
6	Moto Mbaya Irr. Project	Improved	Mlowo R.	1.200	0.300	600	Irrigation (Middle)
7	Iyawaya Irr. Scheme	Improved	Uta R.	Not available	Not available	30	Dry season, domestic (Upper)
8	Habadaa Irrigation Scheme	Traditional	Habadaa Spring	Not available	Not available	22[5]	Dry season (Upper)
9	Kimani Irrigation Scheme	Improved	Kimani R.	7.998	0.093	500[1]	Irrigation (Upper)
10	Igomelo Irrigation Scheme	Improved	Mbarali R.	0.200	0.100	500[1]	Irrigation (Upper)
11	Hassan Mullar	Traditional	Mbarali R.	0.113	0.113		Irrigation, fishponds (Middle)

[2] Source: Mbeya Zonal Irrigation Unit – Master Plan, 2003
[3] Source: Smallholder Irrigation Improvement Project (SIIP)
[4] Obtained from GPS mapping
[5] Implies both paddy and dry season irrigation

3.8.2 Performance of formal water rights

This study utilised data collected from water abstraction and use pattern investigation as well as formal water rights data. Data on formal water rights were collected from the Rufiji Basin Water Office (RBWO) database. In order to obtain correct information on the particulars of the granted formal water rights in the UGRRC, the available hard copies of the water right grants were scrutinised and relevant information extracted. The information extracted included formal water right volumes and periods of abstractions, intended use of the water, location of the abstraction point, water source, and the irrigated area. Further information and data on formal water rights were collected using participatory approaches. The first approach involved informal discussions with key informants and groups of people. Key informants included, among others, village leaders, extension officers and people who are knowledgeable in water resource availability and use in their villages. Information on perceptions and attitudes concerning formal water rights and primary issues governing present water allocation and use were collected during the discussions.

The second approach entailed two River Basin Game (RBG) workshops conducted for the Mswiswi, Mambi and Mlowo river systems in the Mkoji sub-catchment. The first RBG workshop was conducted in November 2004 for the Mswiswi and Mambi river systems and 32 participants participated. Of these, 22 were local level water users and the remaining 10 were experts from the fields of agriculture, livestock, land use, irrigation, water resources and community development. These 10 assisted in giving experts' advice during the discussions. The second workshop was conducted in November 2005 for the Mlowo River and was attended by 44 participants. Out of these, 32 were local level water users and 12 were experts. The second workshop was conducted in November 2005 for the Mlowo River system and was attended by 44 participants. Out of these, 32 were local level water users and 12 were experts.

The RBG is a dialogue tool to aid the decision-making process in water management. It is a physical model representing the catchment in the form of a large wooden board with a river flowing centrally between the upper catchment and the lowlands. A complete description of the RBG is included in Appendix 4. In each of the two RBG workshops, participants contributed ideas on: (a) individual strategies to search for water; (b) community actions required to allocate water equitably; (c) the role, importance and shortcomings of formal water rights; and (d) required improvements or changes on the procedures being followed before granting formal water rights.

3.8.3 Water balance analysis

3.8.3.1 Annual water balances

A simple water balance of the UGRRC was undertaken in order to analyse the allocation of water among its components. The analysis was done for the 1KA27, Kimani, Mbarali and Mkoji sub-catchments.

Limited amounts of climatic data are available for estimation of potential evapotranspiration in the sub-catchments. Data on all parameters that are required in

Penman calculations are available from early 1970s for seven stations, namely, Dodoma, Iringa, Igawa, Madibira, Morogoro and Songea. However, large chunks of these data are missing. Of the seven stations, only Igawa and Madibira lie within the basin. The remaining five stations that lie outside the basin were included in the analysis because the data for the two stations within the basin are not of good quality. Like the rainfall regime, the Potential Evapotranspiration (PET) regime is different in the plains compared to that of the high catchment. For the high catchment, PET was assumed to be the same as that of Mbeya. PET of Dodoma is the same as that of Madibira and provides a reasonable estimate of PET for the Plains.

SMUWC (2001d) compared Penman potential evaporation at Madibira and that of Dodoma. It was found out that the PET regime at the two locations is similar. Therefore, for calculations of PET for the plains, data of the longer of the two series, from Dodoma climatic station, were used. Since the larger parts of the 1KA27 and Mkoji sub-catchments lie within the Usangu Plains, the Dodoma PET data were used for 1KA27 and MSC water balance analysis. For the case of the Kimani and Mbarali sub-catchments, the catchment area upstream of the gauges is located in the highlands while that of the area downstream of the gauges is located in the plains. Therefore, PET data from Mbeya meteorological station were used to represent the PET for the Kimani and Mbarali sub-catchments, upstream of the gauges. The FAO Penman-Monteith method (Allen *et al*., 1998) was used to calculate PET. Modified Thornthwaite models derived by SMUWC (2001d) were used to extend the time series of Penman potential evaporation to 1958 to coincide with available flow and rainfall data.

From the original Penman-Monteith equation and the equations of the aerodynamic and canopy resistance, the FAO Penman-Monteith equation gives Potential Evapotranspiration (ET_o) as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (18)$$

Where,

R_n is net radiation at the crop surface [MJ m^{-2} day^{-1}],

G is soil heat flux density [MJ m^{-2} day^{-1}],

T is mean daily air temperature at 2 m height [°C],

u_2 is wind speed at 2 m height [m s^{-1}],

e_s is saturation vapour pressure [kPa],

e_a is actual vapour pressure [kPa],

e_s - e_a is saturation vapour pressure deficit [kPa],

Δ is slope vapour pressure curve [kPa $°C^{-1}$],

γ is psychrometric constant [kPa $°C^{-1}$].

The modified Thornthwaite model for the estimation of potential evapotranspiration for Dodoma is given by:

$$E_i = \begin{cases} 0.126 * T_i + 2.274 & \text{for } T_i \leq 23 \\ 16 * a * \left(\frac{10 * T_i}{I} \right)^b & \text{for } T_i > 23 \end{cases} \qquad (19)$$

Where,

T_i is the monthly mean temperature in degrees centigrade,

E_i is the monthly evaporation in mm for month i,

a is a correction factor to account for the day length.

The Potential evapotranspiration is defined as the rate of evapotranspiration from a green grass cover of uniform height completely shading the ground and with adequate water.

A total of 17 rainfall stations were used for the estimation of areal rainfall for the 1KA27, 11 for MSC, seven stations for Mbarali and five stations for Kimani sub-catchments. It was assumed that the aerial rainfall over the sub-catchment is the same as that of the gauged area within the sub-catchment. The years of record used were 1958 to 2004 in order to coincide with availability of evapotranspiration and river flow data.

Since the runoff is known, the Turc and Pike method (Turk, 1955; Pike, 1964) as well as the simplified water balance equation (Equation 2) were used to estimate expected annual actual evaporation (AET) for Kimani, Mbarali and 1KA27 sub-catchments. The results from the two methodologies were later compared. The Turc and Pike formula is given as:

$$AET = \frac{P}{\sqrt{1 + (\frac{P}{PET})^2}} \qquad (20)$$

Where;

AET is expected annual actual evaporation, P is expected annual precipitation and PET is potential evaporation.

On a mean annual basis, actual evapotranspiration approaches precipitation under very dry conditions, while under very wet conditions; actual evapotranspiration asymptotically approaches the potential evapotranspiration.

Since, runoff data is not available for the MSC; expected annual actual evapotranspiration was calculated by using the Turc and Pike formula; and expected annual runoff was calculated as the balance after actual evapotranspiration is subtracted from precipitation. The "simplified" or "equilibrium" or "steady-state" water balance model (Zhang *et al*., 2004) (equation 2) was used to facilitate the calculation. The model is given as:

$$P = AET + Q \tag{21}$$

For the mean annual water balance, cumulative inter-annual storage change is zero. Thus, the water availability can be approximated by precipitation; and the atmospheric demand represents the maximum possible evapotranspiration and is often considered as potential evapotranspiration. In moving from mean annual to shorter time scale (e.g. monthly), one generally has to account for the effect of catchment water storage change on the water balance.

3.8.3.2 Dry season water balance

A simple dry season monthly water balance was undertaken for the Kimani, Mbarali and MSC in between upstream and downstream gauging points. In calculating water loss through evaporation in the river channels, some parameters were assumed. For Kimani River, the average channel width is 4 m (SMUWC, 2001d) and channel length is 17.45 km (own measurements). For Mbarali River, the average channel width is 5 m (SMUWC, 2001d) and channel length is 35.5 km (own measurements). Evaporation in the river channels was assumed to be at potential rates and rainfall on the catchment was negligible and was assumed to have been lost through infiltration and evaporation. The Class A Pan evaporation data measured in 2003 and 2004 at the nearby Ifushiro swamp were used to represent evaporation losses in the river channels. The pan values were reduced by 30% in order to obtain potential evaporation (Kashaigili, 2006).

3.9 Sustainability of Water Resources Management in the UGRRC

3.9.1 The ecosystems approach

The assessment of water resources sustainability was done by using the ecosystem approach to water management (ICWE, 1992; Kay *et al.*, 1999). The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way (IUCN, 2000). It essentially requires taking into consideration the effects of actions on every element of an ecosystem, based on the recognition that all elements of an ecosystem are linked. The ecosystem approach thus complements the current thinking on IWRM. Under the ecosystem approach, sustainability of water resources encompasses three major systems. The systems are i) The Social System, which includes all the human elements of the Biosphere ii) The Economic System which includes capital and infrastructure required for an economic undertaking iii) The

Natural Systems (or the ecosystems) which are the non-human elements of the Biosphere (Fig. 11). All the three systems are contained within the Biophysical Environment, which includes all living organisms on earth and the non-living systems with which they interact and on which they depend. Each of the three systems must fulfil some important functions to ensure sustainability of water resources.

The ecological system is required to have the capacity to make water of appropriate quality and quantity available to support ecosystems and ensure integrity of ecosystems. The social system, on the other hand has to ensure social well being resulting from the use of water and water-related ecological resources; and that legal, institutional, community and technical capacities for the management of water, and related land resources are in place. The function of the economic system is to provide capacity to make water of appropriate quality and quantity available for human uses and to ensure economic well being resulting from the use of water and water related land and ecological resources.

Previous studies have set out many guidelines for sustainable water resources management. However, such broad guidelines still need to be translated into operational concepts that can be applied to the planning and management of water resources systems at the basin level.

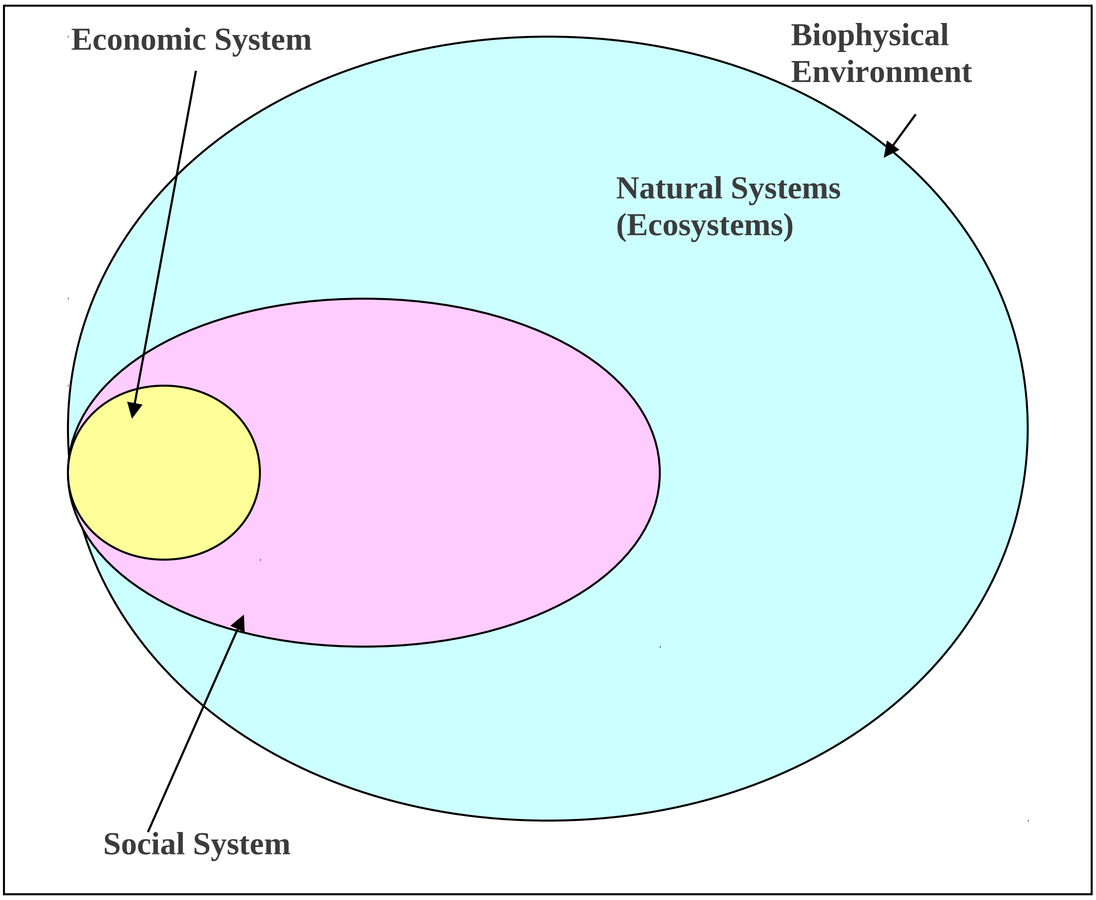


Figure 12: The General Systems Perspective

3.9.2 Development of the framework used to assess sustainability of water resources

3.9.2.1 Management decisions at the basin level

The river basin is taken as the main planning unit. Human activities are organized and coordinated within the river basin unit. In order to ensure sustainability of water resources, management decisions at the basin level should:

- Be based on physical processes (e.g. climate and river flow variability), and should take into account of the "hardware" (infrastructure) and "software" (management policies, laws, regulations, guidelines) components of water management;

- Take into account water allocation among different sectors and users, as well as the interaction between those sectors and users. Water can be used for in-stream purposes, including, recreation, fishing, domestic use, livestock watering, hydropower generation and wetlands; and for off-stream purposes such as agricultural (e.g. irrigated agriculture), municipal (e.g. domestic water use, waste water discharge) and industrial water uses (e.g. mining). Taking into account of in-stream water requirements for fishing, transport, recreation, hydropower generation, domestic water use and ecological uses involves setting aside sufficient water over space and time between in-stream and off-stream water uses;
- Consider the efficiency with which water is used at different places in the basin by different users and the degree to which different uses degrade the water quality (Batchelor, 1999; Rosegrant, 2003). For example, physical and economic efficiency can be improved at the irrigation scheme level through several ways such as a) Agronomic (e.g. improving crop husbandry and cropping strategies); b) Technical (e.g. installing an advanced irrigation system); c) Managerial (e.g. adopting demand-based irrigation scheduling systems and better maintaining equipment); and d) Institutional (e.g. introducing water pricing and improving the legal environment); and
- Consider the application of both, supply and demand management policies. Demand management means reducing demand to meet levels of supply, in contrast to supply management which means boosting supply to meet increasing

demands. A portion of the growing demand for water can be met by investing in water supply and utilization systems, despite the high economic and environmental costs that may be incurred as a result of developing new water resources. Demand management aims to better utilize existing water resources by curbing unnecessary, less-economical and wasteful water uses. In most cases, development of new water sources and improved demand management are both necessary and joint decisions for supply and demand should be made for sustainable water resources management.

These water management issues, policies, and decisions are complex and integrated. The interdisciplinary nature of water resources problems thus requires the integration of technical, economic, environmental, social, and legal aspects into a coherent analytical framework, so that social, economic and environmental consequences of policy choices can be examined. This decision support framework should be a dynamic system as it forms the basis for assessing the sustainability of water resources management at the basin level.

3.9.2.2 The developed framework

This study utilised an integrated decision-making framework for sustainable river basin management, which was adopted from the framework for sustainability analysis of irrigation water management by Cai *et al.*, 2001. However, it was modified to suit water resources management conditions in Tanzania. Further information that assisted in the development of the framework came through discussions on the new institutional and legal framework for water resources management in Tanzania and the new roles and responsibilities of river basin authorities. Some of the institutions that were consulted included the Rufiji Basin Water Office, the Directorate of Water Resources, Ministry of Water headquarters, NGOs dealing with water and natural resources management, District councils, WUAs and local level water users.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Trends and Variability of Rainfall and River Flows in the UGRRC

4.1.1 Rainfall variations

4.1.1.1 Within the year variations

Table 5 presents mean monthly variation of rainfall amounts at various stations in the UGRRC. The table shows that the highlands receive the highest rainfall. For example, the mean annual rainfall at Makete Bomani (in the highland) is about 1584 mm. The annual rainfall decreases towards the plains to about 762 mm at Kimani (in the middle zone) and 617 mm at Mbarali Irrigation Scheme (in the lower zone i.e. the plains). The mean annual areal rainfall over the UGRRC is about 959 mm equivalent to 16 464 Mm^3 of water. The heaviest rainfall generally occurs in December - March. The rainfall amounts as well as the onset of the rainy season can vary considerably from year to year (average annual coefficient of variation (CV) is about 24%). This variation often has a detrimental effect on crop production, especially in the drier areas.

Table 5: Rainfall characteristics of selected stations

Station Name	Month												Mean Annual Rainfall	CV (%)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Mbeya Maji	204.2	179.2	174.1	95.7	13.1	1.8	1.6	0.2	3.0	13.5	62.6	194.6	943.6	18.2
Tanganyika Wattle Co. Ltd.	221.7	190.9	252.8	135.9	27.5	3.7	1.4	1.8	5.3	12.0	59.5	191.0	1103.5	19.4
Uyole Agromet	203.9	165.5	206.4	153.4	34.6	0.7	0.4	0.1	1.9	21.3	63.5	187.2	1038.9	19.9
Kimani	178.0	140.5	159.8	62.3	6.0	0.3	0.1	0.1	0.3	5.2	46.6	163.1	762.3	21.3
Igawa Maji	154.1	132.1	139.7	53.9	5.7	0.1	0.0	0.1	0.6	1.9	33.5	149.8	671.6	21.5
Mbeya Met	213.8	182.8	179.5	102.7	18.1	0.7	0.3	0.1	2.4	15.7	58.6	198.3	973.1	22.3
Mbarali Irrigation Scheme	147.2	127.7	117.4	49.1	3.2	0.0	0.0	0.0	0.1	2.9	38.2	130.6	616.6	24.8
Madibira Maji	167.6	130.5	131.6	97.0	13.9	1.4	0.1	0.3	1.3	14.0	58.8	153.9	770.1	24.1
Ichenga Agriculture	233.7	231.1	315.7	188.0	42.0	5.9	3.7	2.7	3.9	14.8	84.5	217.1	1343.0	17.1
Makete Bomani	268.0	241.9	287.1	218.1	57.0	2.3	1.0	2.0	5.6	73.7	164.4	262.4	1583.5	32.4
Matamba Pr. School	342.7	235.0	298.9	164.6	20.2	0.0	1.7	0.0	6.8	45.7	199.1	328.3	1027.0	14.5
Rujewa Mission	145.6	158.4	136.4	50.2	4.1	0.1	0.0	0.1	0.2	4.0	33.0	144.3	676.4	46.3
Mean	206.7	176.3	200.0	114.2	20.4	1.4	0.9	0.6	2.6	18.7	75.2	193.4	959.1	23.5

Note: Rainfall in mm

The plots of monthly rainfall values are presented in Figures 13, 14, 15, 16 and 17. It can be observed from the plots that the UGRRC experiences unimodal type of rainfall. This rainfall regime has one main rainfall peak occurring in January-February-March (JFM) main rainy season. The periods October to December (OND) and April to May (AM) usually receive less rainfall and correspond to early and late rainfall seasons respectively. The seasonal variations further indicate the relatively dry period from June to September (JJAS) with monthly rainfall amounts predominantly below 20 mm. Maximum rainfall is recorded in the month of January for the Lower and Middle Zones; and March for the Upper Zone. July and August are the driest months in the catchment. The onset and duration of the rains vary from zone to zone. For example, whereas Fig. 13 shows that the rainy season for the Upper Zone (highlands) runs from October to

May, Figures 14 and 15 show that the rainy season for the Middle and Lower zones runs between November and April. Figure 16, which compares the amount of rainfall received in the upper, middle and lower zones of the UGRRC, clearly shows that the highlands receive the highest annual rainfall, followed by the Middle zone. The plains receive the lowest annual rainfall.

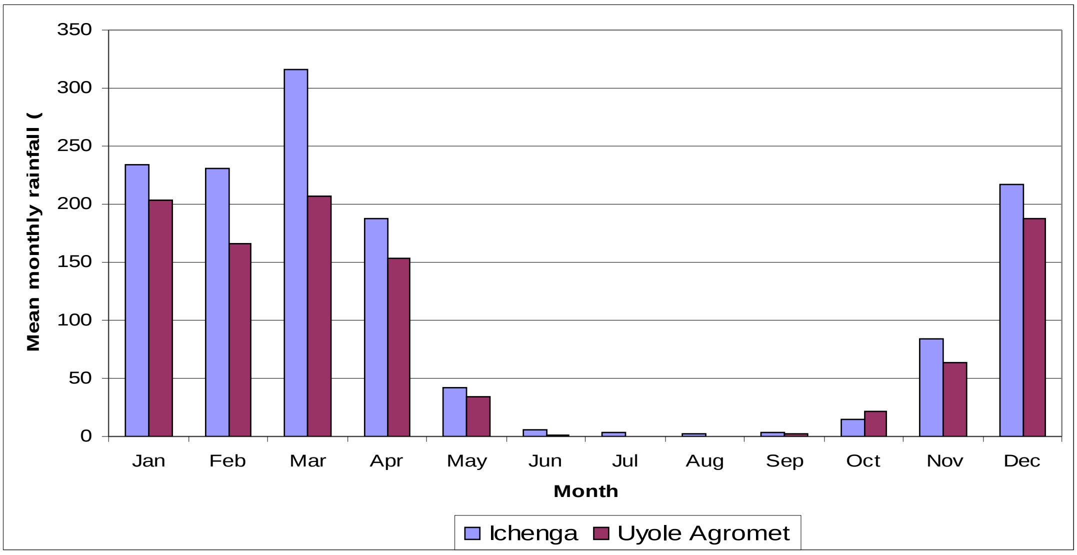


Figure 13: Mean monthly rainfall for upper zone UGRRC stations

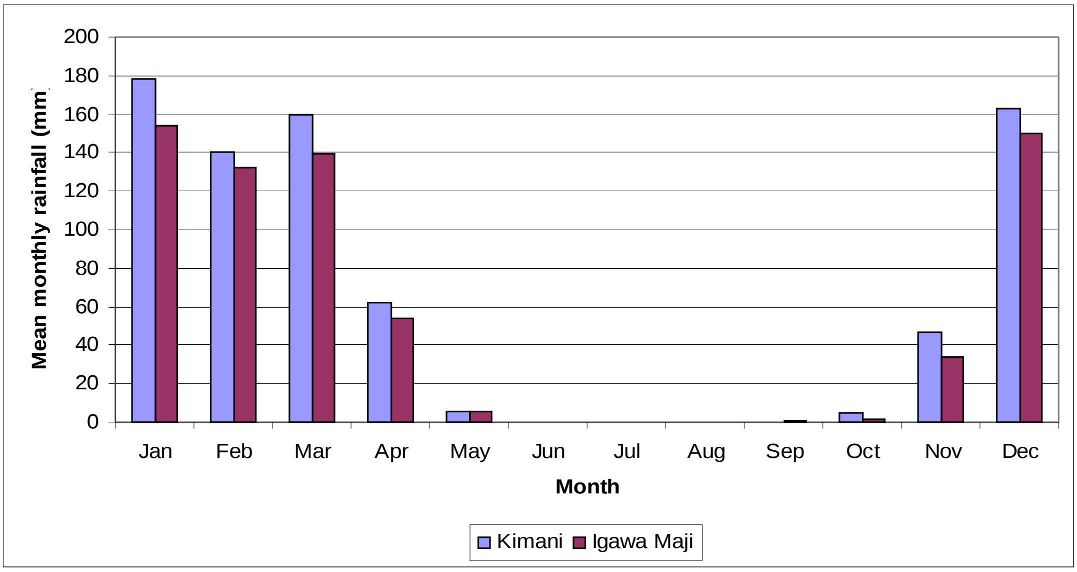


Figure 14: Mean monthly rainfall for middle zone UGRRC stations

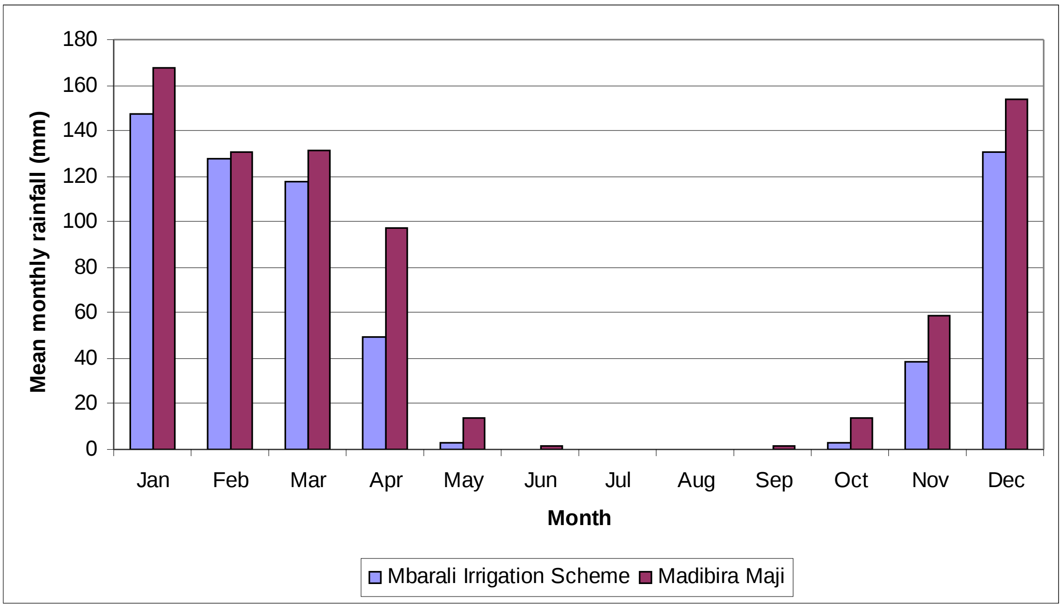


Figure 15: Mean monthly rainfall for lower zone (plains) UGRRC stations

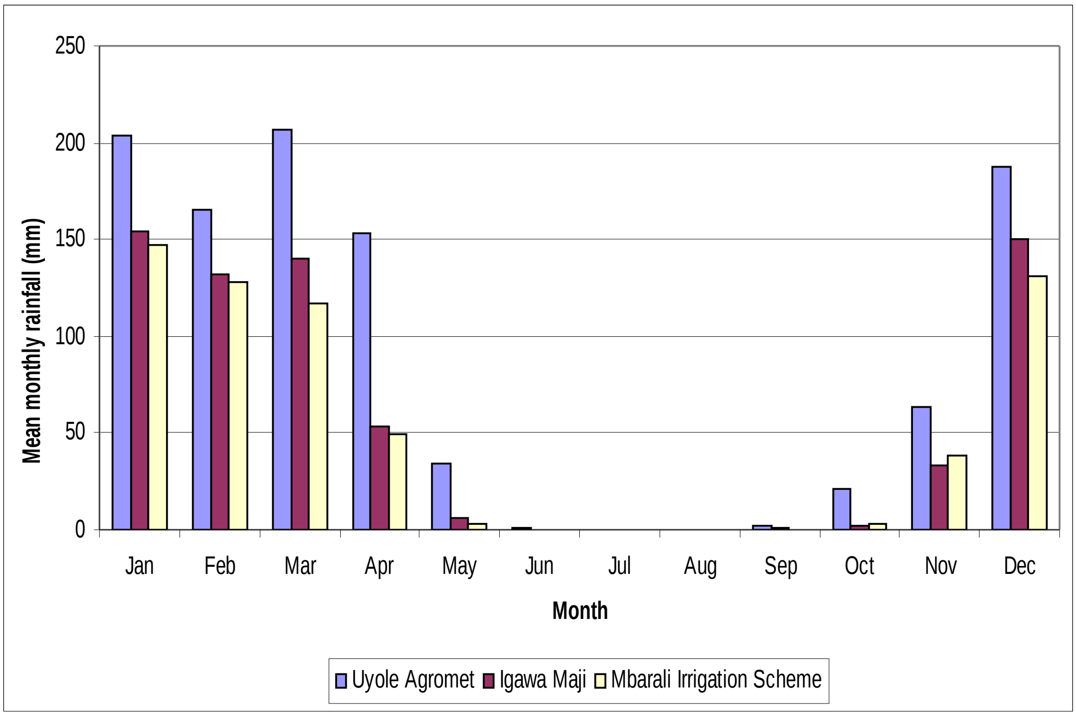


Figure 16: Rainfall comparison for the upper, middle and lower UGRRC

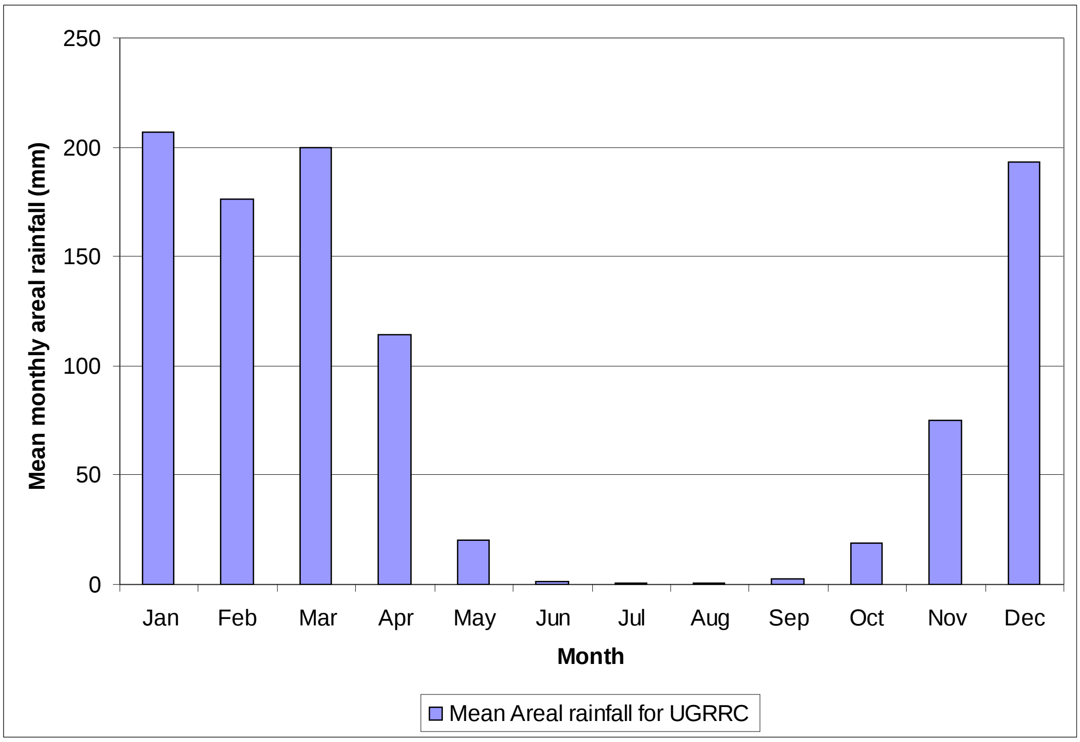


Figure 17: Mean areal rainfall for the UGRRC

Tables 6 and 7 show the mean seasonal rainfall amounts in the UGRRC. The uneven distribution of rainfall within the year indicate that the main rainfall period of January-February-March (JFM) contributes about 60% of annual rainfall amounts whereas the early rainfall season of October-November-December (OND) contributes about 27%. The late rainfall season of April to May (AM) provides only 12.5% of annual rainfall amounts, with the dry period of June to September contributing a meagre 0.5% of annual rainfall amounts. The period October-March therefore contributes close to 90% of the total annual rainfall. The implication of these results is that any changes of annual rainfall over the years could be attributed significantly to changes during this period.

Table 6: Mean seasonal rainfall amounts (mm)

Sno	Code	Station Name	Annual	Seasonal contribution to annual rainfall (mm)			
				JFM	AM	JJAS	OND
1	9833020	Mbeya Maji	935.7	553.8	109.8	6.5	265.7
2	-	Tanganyika Wattle Co.	1103.5	665.5	163.5	12.1	262.4
3	9834010	Kimani	764.0	476.2	68.1	0.8	218.8
4	9834006	Igawa Maji	674.9	425.2	59.6	0.8	189.3
5	9833001	Mbeya Met	973.1	576.1	120.8	3.6	272.6
6	9834008	Mbarali Irrigation	615.3	394.8	51.6	0.3	168.5
7	9934024	Ichenga Agriculture	1343.0	780.5	230.0	16.2	316.4
8	9833025	Uyole Agromet	1038.9	575.8	188.0	3.1	272.0
		MEAN	931.0	556.0	123.9	5.4	245.7

Table 7: Seasonal rainfall expressed as percentage of mean annual rainfall

Sno	Code	Station Name	Seasonal contribution to annual rainfall (%)			
			JFM	AM	JJAS	OND
1	9833020	Mbeya Maji	59.18	11.73	0.69	28.40
2	-	Tanganyika Wattle Co.	60.31	14.82	1.10	23.78
3	9834010	Kimani	62.33	8.92	0.10	28.64
4	9834006	Igawa Maji	63.00	8.83	0.12	28.05
5	9833001	Mbeya Met	59.20	12.41	0.37	28.01
6	9834008	Mbarali Irrigation	64.18	8.39	0.05	27.39
7	9934024	Ichenga Agriculture	58.11	17.12	1.20	23.56
8	9833025	Uyole Agromet	55.42	18.10	0.30	26.18
		MEAN	60.22	12.54	0.49	26.75

4.1.1.2 Inter-annual variations

Figures 18, 19 and 20 show the time series of annual rainfall for some stations in the UGRRC. The time series generally indicate a decline in annual rainfall amounts, with notable decrease appearing since the early 1980s. However, the trends observed were not strictly increasing or decreasing throughout the years. Thus, despite predominantly decreasing annual rainfall amounts for Mbarali Irrigation station since 1980s, they were abundant in several isolated years such as 1989, 1992 and 1996.

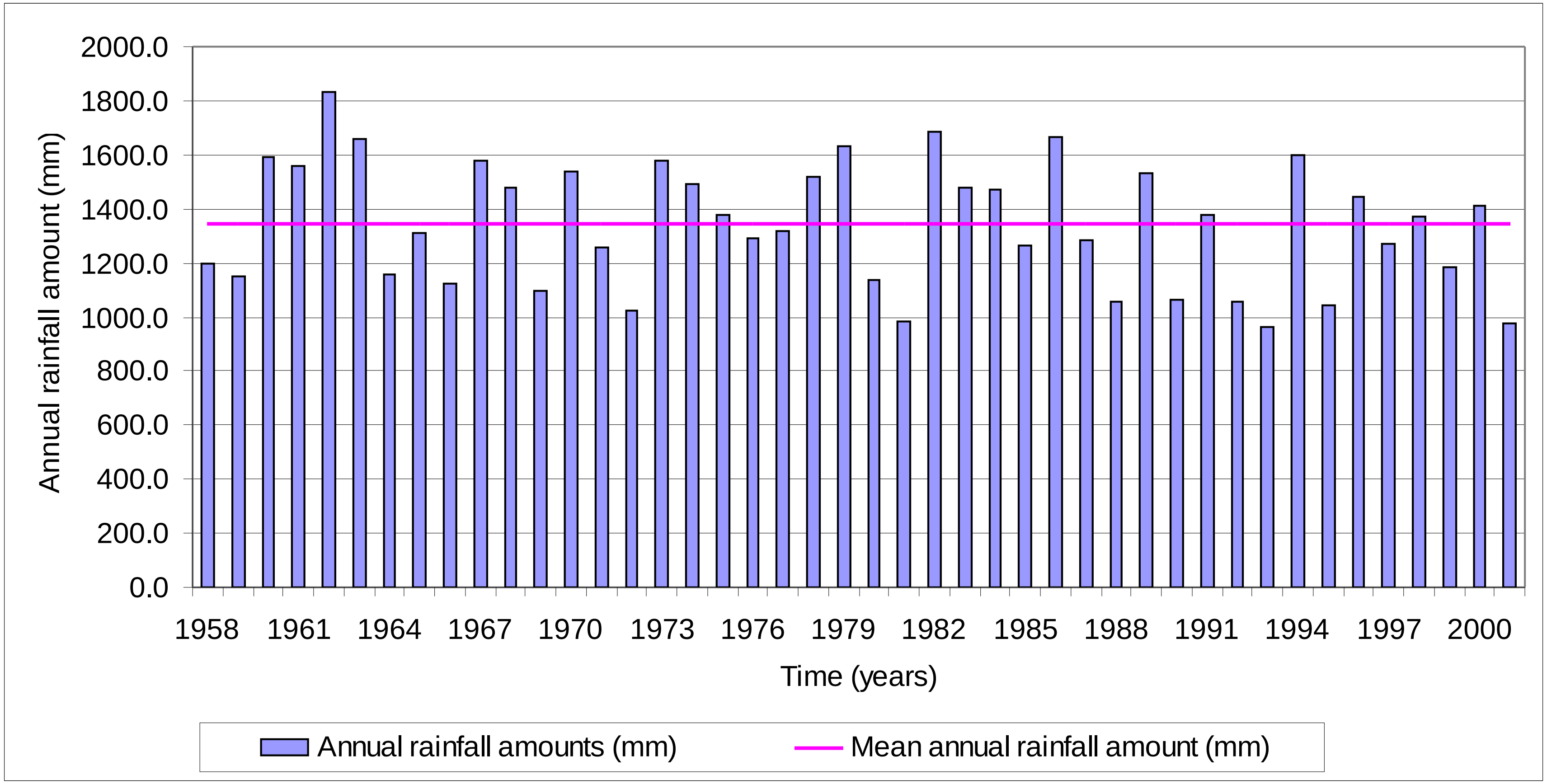


Figure 18: Time series of annual rainfall amounts at Ichenga Agriculture

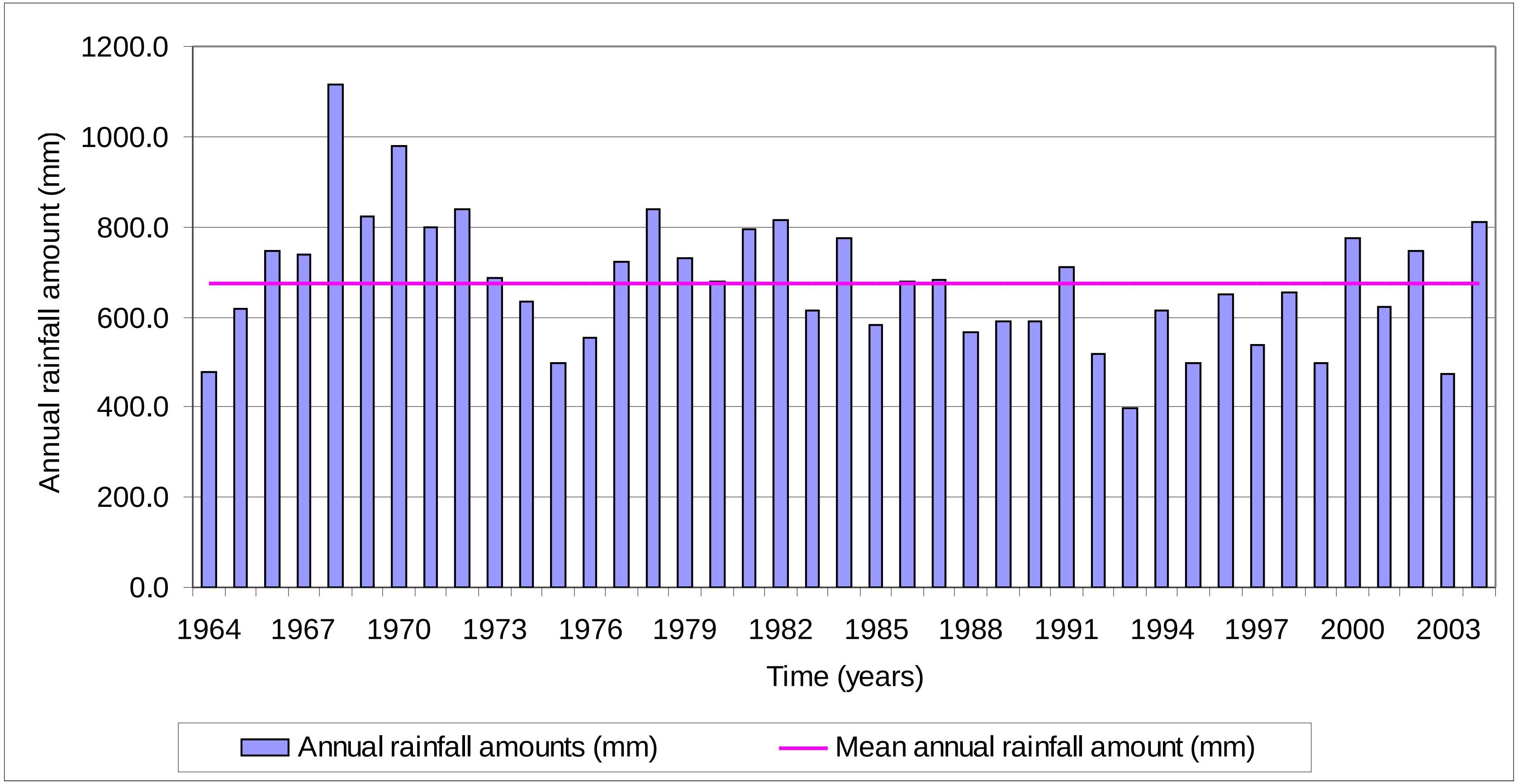


Figure 19: Time series of annual rainfall amounts at Igawa Maji

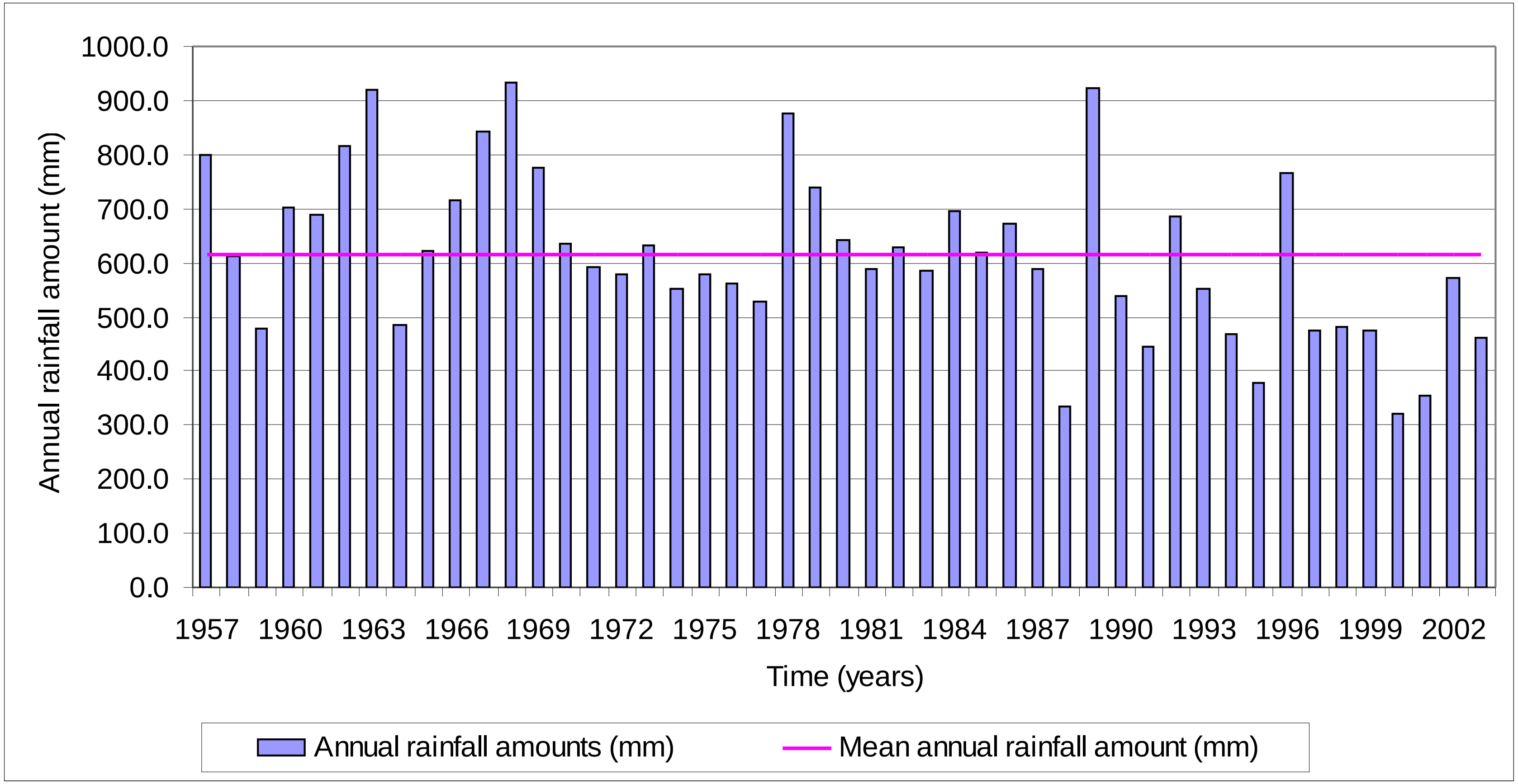


Figure 20: Time series of annual rainfall amounts at Mbarali Irrigation

(i) Rainfall trends

The results of trends on seasonal and annual rainfall amounts for the common period (1964-2001) and the whole periods are summarised in Table 8. During the period 1964-2001, all the stations generally indicated a decline in rainfall amounts in the annual, JFM (except Mbeya Maji), JJAS and the OND seasons. However, a mixture of increasing and decreasing trends in rainfall amounts characterized the AM season at 95% confidence level. Igawa Maji and Mbarali Irrigation showed significant decreasing trends of annual rainfall during the 1964-2001 period as well as during the whole periods (1964-2004 and 1957-2004 respectively); whereas Kimani showed significant decreasing trends in annual rainfall during the 1962-2004 period.

Spatially, the annual rainfall decreased significantly in the Lower Zone (the plains) over the years as compared to the other zones. Generally, in the dominant JFM and OND rainfall seasons, decreasing trends accounted for over 75% of all the studied stations during the 1964-2001 period as well as during the whole periods. Although this analysis failed to show conclusively the trend of rainfall over the UGRRC, it however showed that, in general the available water resource in the UGRRC has been decreasing over the period of records. Since the results of the trend analyses for the longer periods were, in some stations and seasons, not consistent (in terms of significance and direction) with those obtained from the shorter span of records, it implies that trends are affected by the period and length of record used in the analysis.

Table 8: Trends in seasonal and annual rainfall amounts at 5% significant level

Sno	Station name	Useful record	Parameter	Trend (whole period)					Trend (common period) 1964-2001				
				Annual	JFM	AM	JJAS	OND	Annual	JFM	AM	JJAS	OND
1	Mbeya Maji	1961-2004	Z	-1.35	-0.354	-0.79	-0.81	-1.91	-0.03	0.779	-0.64	-0.80	-1.43
			S	-2.73	-0.588	-0.40	0.00	-3.15	-0.08	1.894	-0.44	0.00	-2.92
2	Tanganyika Wattle	1928-2003	Z	1.41	0.892	0.48	0.21	1.61	-0.60	-0.050	0.21	-0.34	-0.98
			S	1.64	0.774	0.18	0.004	1.30	-1.47	-0.243	0.33	-0.04	-2.04
3	Kimani	1962-2004	Z	**-2.11**	**-2.198**	0.15	-1.382	-0.816	-1.71	-1.509	0.15	-0.662	-1.081
			S	-4.01	-3.076	0.08	0.00	-1.043	-4.20	-2.530	0.09	0.00	-1.916
4	Igawa Maji	1964-2004	Z	**-2.27**	-0.977	-0.74	-1.761	-1.516	**-2.65**	-1.056	-1.01	-1.489	-1.58
			S	-4.68	-1.514	-0.38	0.00	-2.233	-5.90	-1.595	-0.56	0.00	-2.905
5	Mbeya Met	1964-1999	Z	1.04	0.722	0.56	0.48	-0.75					
			S	2.62	1.695	0.59	0.00	-1.50					
6	Mbarali Irrigation	1957-2004	Z	**-3.70**	**-2.769**	-0.79	-0.477	-1.953	**-3.09**	**-2.263**	**-2.31**	-0.538	-1.38
			S	-5.95	-3.414	-0.31	0.00	-2.298	-6.85	-3.533	-1.36	0.00	-2.300
7	Ichenga Agriculture	1958-2001	Z	-1.75	-1.608	-1.10	-0.05	-0.52	-1.031	-0.63	-0.578	-0.24	-0.80
			S	-4.52	-2.831	-1.01	-0.02	-1.08	-3.272	-1.49	-0.656	-0.07	-2.35
8	Uyole Agromet	1971-2001	Z	-0.48	1.054	-0.61	-1.19	-0.71					
			S	-2.60	1.080	-1.30	-0.02	-2.36					
	Total number of stations			8	8	8	8	8	6	6	6	6	6
	Number of increasing trends			2	3	3	3	1	0	1	2	1	0
	Number of decreasing trends			6	5	5	2	7	6	5	4	2	6

Z = Test statistic
S = Slope
Significant trends are bolded

(ii) Rainfall regime change detection

Since rainfall in the UGRRC showed predominantly decreasing trends, regime shift analysis was performed to determine the timing of the first regime shift, the total number of shifts that had occurred for the period of record as well as the directions of the shifts. The Sequential Analysis of Regime Shifts (SARS) methodology was used, which automatically detected statistically significant shifts in the mean level and the magnitude of fluctuations in time series. A significance level of 5%, cut-off length of 10 years and a Huber weight parameter of 6 were used. The results are presented in Table 9 and Figures 21 and 22.

The results show that of the eight studied rainfall stations, six experienced significant regime shifts and all the shifts occurred starting from the 1980s. Igawa Maji experienced two rainfall regimes shifts in 1988 and 2004. The results also show that, in general rainfall regime in the UGRRC has been decreasing, as evidenced by the direction of regime changes. Only Mbeya Met station and the second regime shift at Igawa Maji (in 2004) show upward trends. All shifts that occurred after the 1990s are very strong, with percentage of change being 25% and above.

Table 9: Significant regime changes in annual rainfall amounts at 5% significant level

Sno	Station name	Useful record	Number of regimes	Change year	Mean of regime 1 (mm)	Mean of regime 2 (mm)	Mean of regime 3 (mm)	Change (%)	Change direction
1	Mbeya Maji	1961-2004	2	2002	951.47	720.63	-	-24.26	Downward
2	Tanganyika Wattle	1928-2003	2	2003	1108.39	734.9	-	-33.70	Downward
3	Kimani	1962-2004	1	-	763.95	763.95	-	0.00	-
4	Igawa Maji	1964-2004	3	1988; 2004	725.7	590.33	810.51	-18.65; 37.30	Downward; Upward
5	Mbeya Met	1956-1999	2	1994	933.74	1222.15	-	30.89	Upward
6	Mbarali Irrigation	1957-2004	2	1997	644.45	448.41	-	-30.42	Downward
7	Ichenga Agriculture	1958-2001	2	2001	1351.6	976.7	-	-27.74	Downward
8	Uyole Agromet	1971-2003	1	-	1038.89	1038.89	-	0.00	-

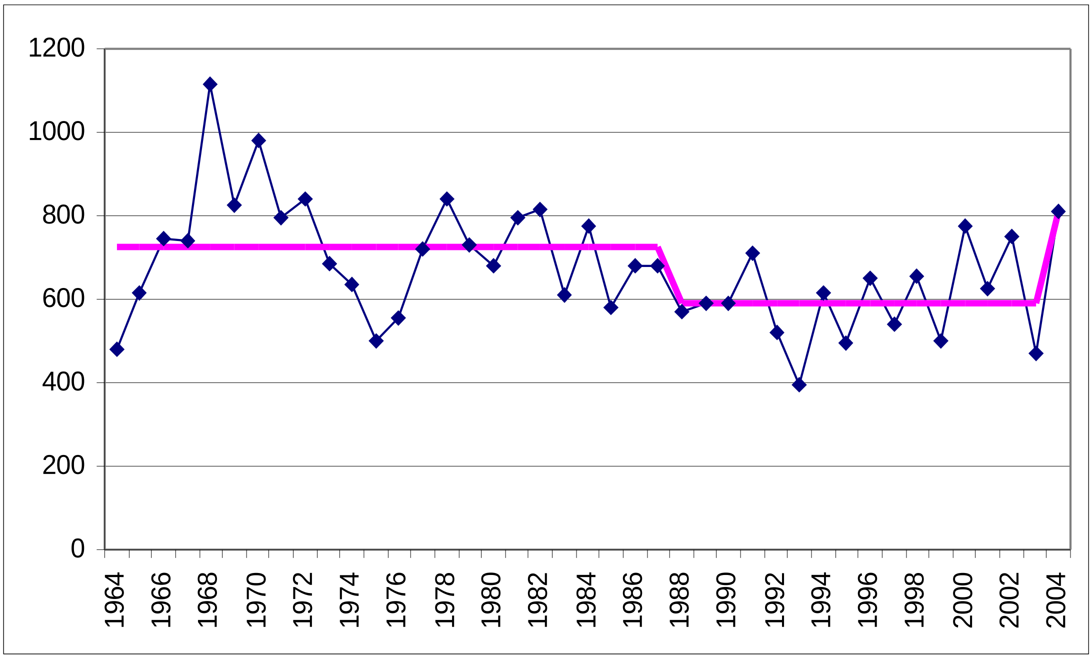


Figure 21: Shifts in the mean for Annual rainfall amounts (mm) at Igawa Maji
Cut-off length = 10 years; Huber parameter = 6
Shift detection: After pre-whitening;
Plot: Original data

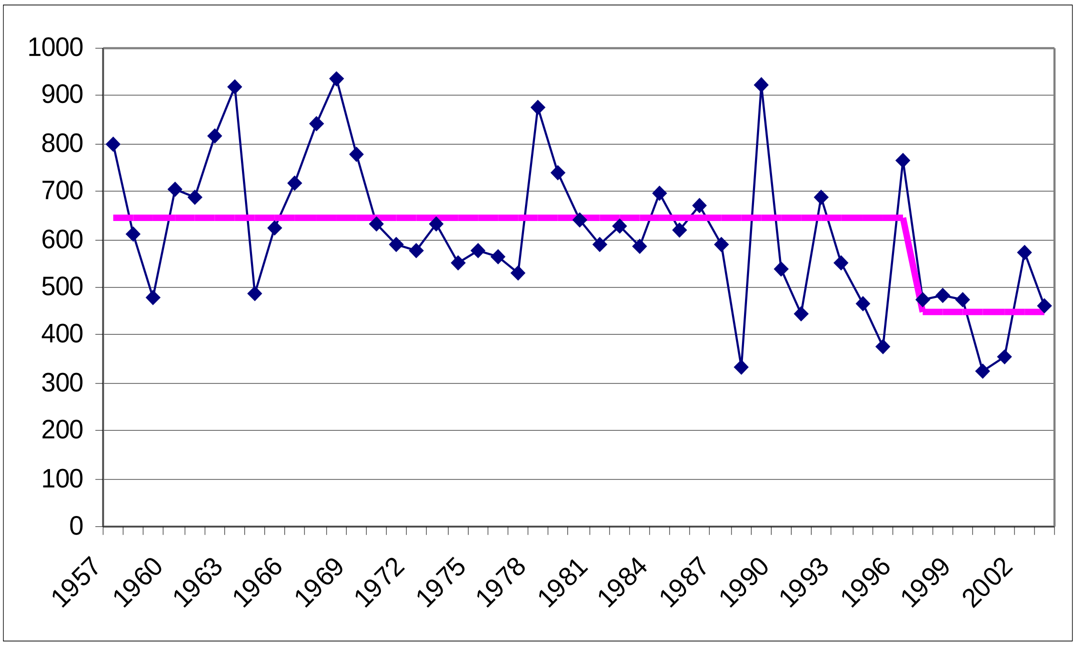


Figure 22: Shifts in the mean for annual rainfall (mm) at Mbarali Irrigation

4.1.2 River flow variations

4.1.2.1 Within the year variations

Figures 23 and 24 show monthly hydrographs for some rivers in UGRRC whereas daily flow hydrographs for the period 2002 to 2004 are shown in Figures 25 to 26. The hydrographs start to rise in December and peak flows are observed during the months of March and April, corresponding to the rainy season. The recession is very sharp and starts with the cessation of the wet season in April. Summary of monthly flows for some rivers in the UGRRC is shown in Table 10.

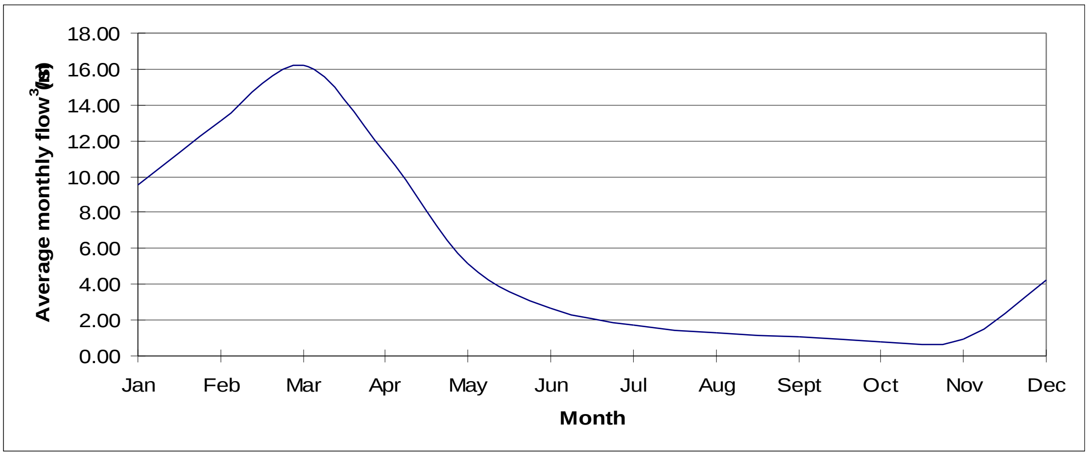


Figure 23: Monthly flow hydrograph for Kimani River at Great North Road

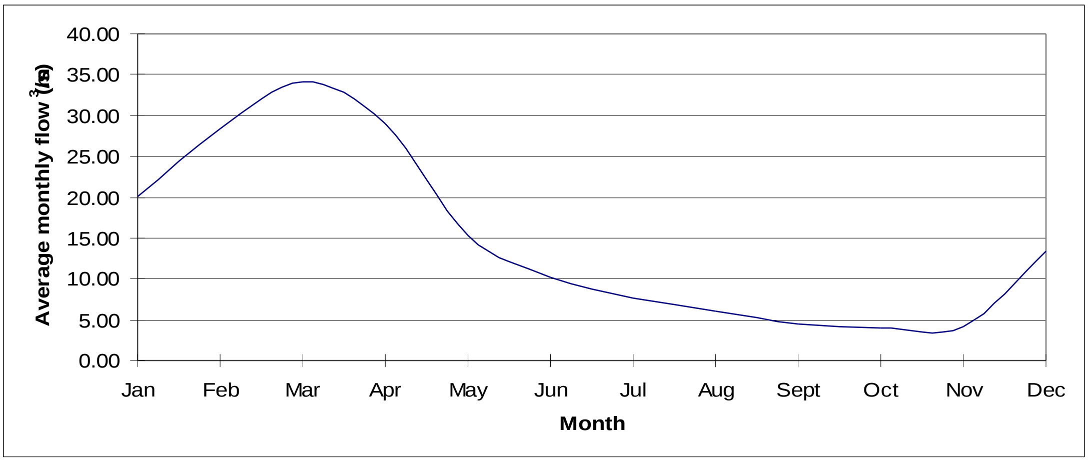


Figure 24: Monthly flow hydrograph for Mbarali River at Igawa

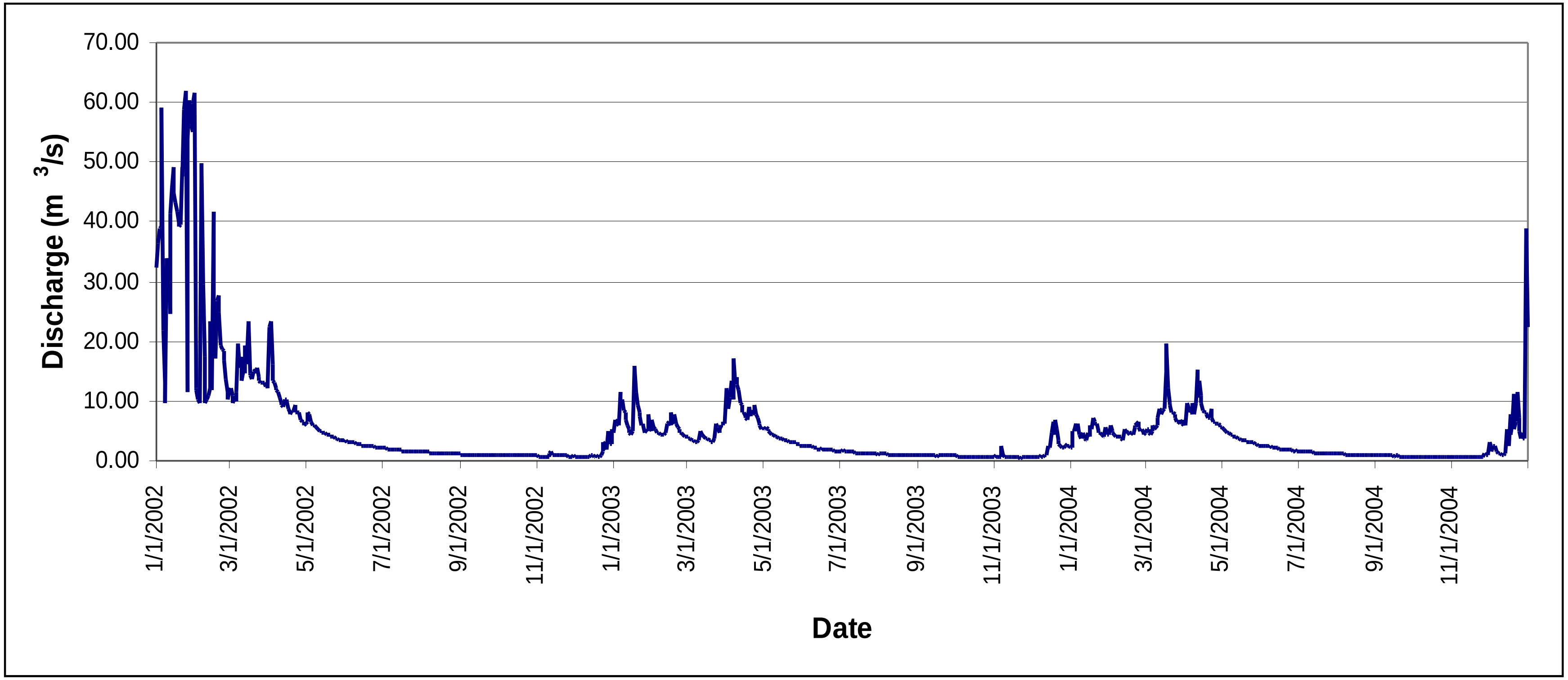


Figure 25: Daily stream flow hydrograph for Kimani River (1KA9) (2002-2004)

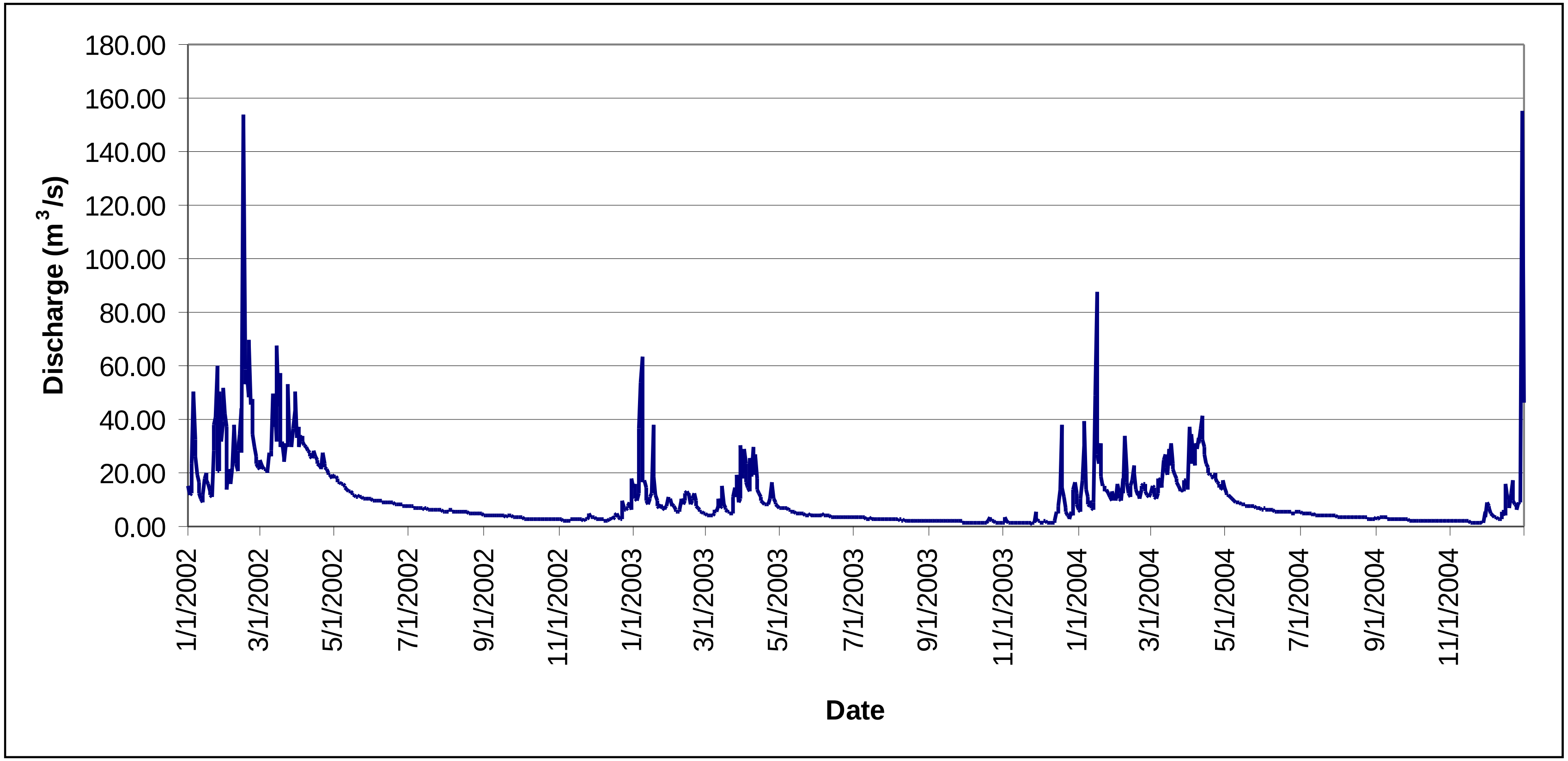


Figure 26: Daily stream flow hydrograph for Mbarali River (1KA11A) (2002-2004)

Table 10: Monthly flows for some UGRRC rivers

River Name	Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chimala (1KA7A)	m^3/s	4.16	5.63	7.95	8.06	3.80	1.79	1.23	0.90	0.73	0.67	0.80	2.18
	Mm^3	11.14	13.74	21.30	20.88	10.18	4.64	3.28	2.41	1.89	1.78	2.08	5.84
Great Ruaha (1KA8A)	m^3/s	26.26	40.26	46.24	38.39	13.62	5.66	4.40	3.35	2.70	2.20	2.40	10.93
	Mm^3	70.34	98.26	123.86	99.51	36.47	14.68	11.78	8.97	7.01	5.88	6.22	29.27
Kimani (1KA9)	m^3/s	9.55	13.14	16.21	11.34	5.18	2.67	1.70	1.27	1.05	0.79	0.94	4.26
	Mm^3	25.57	32.08	43.41	29.39	13.89	6.93	4.56	3.41	2.73	2.11	2.43	11.40
Mbarali (1KA11A)	m^3/s	20.08	28.32	34.04	29.02	15.29	10.13	7.66	6.00	4.44	3.93	4.13	13.41
	Mm^3	53.78	69.11	91.17	75.22	40.94	26.24	20.53	16.06	11.52	10.52	10.69	35.92
Lunwa (1KA16A)	m^3/s	2.00	2.87	4.28	4.41	1.59	0.69	0.46	0.24	0.14	0.13	0.40	1.05
	Mm^3	5.35	7.02	11.46	11.44	4.25	1.78	1.22	0.65	0.37	0.34	1.03	2.82
Great Ruaha (1KA27)	m^3/s	69.31	158.44	200.07	224.76	129.02	52.46	18.83	7.96	4.31	2.53	1.90	7.36
	Mm^3	185.65	386.71	535.87	582.57	345.58	135.98	50.44	21.33	11.16	6.77	4.92	19.70
Mswiswi (1KA50B)	m^3/s	1.02	1.95	3.25	3.92	1.89	0.50	0.22	0.11	0.06	0.04	0.07	0.32
	Mm^3	2.72	4.76	8.71	10.17	5.07	1.29	0.59	0.30	0.16	0.10	0.17	0.86
Umrobo (1KA51A)	m^3/s	0.64	0.93	1.37	1.67	0.91	0.42	0.35	0.33	0.31	0.27	0.24	0.41
	Mm^3	1.71	2.27	3.68	4.34	2.44	1.08	0.93	0.88	0.81	0.74	0.63	1.11
Great Ruaha (1KA59)	m^3/s	79.29	176.41	215.68	234.07	134.03	52.15	18.73	7.74	3.99	2.32	2.04	13.08
	Mm^3	212.36	430.59	577.67	606.72	358.98	135.18	50.18	20.74	10.33	6.22	5.29	35.03

Tables 11 and 12 show the mean seasonal flow volumes in the UGRRC. The results showed that about 49% of annual volumes in the Great Ruaha River (GRR) and its tributaries flow during the main (JFM) rainfall season, followed by the late (AM) rainfall season (33%). The JJAS dry season contributes about 11% whereas the early (OND) season accounts only for 7% of the annual flow volumes (Tables 11 and 12). Such high flow contributions by the JFM and AM rainfall seasons suggest that changes of annual flows over the years could be attributed significantly to changes during these two seasons. Table 11 shows that the average annual flow in the GRR at Msembe (1KA59) is 2459 Mm^3 (compare with the storage capacity of Mtera dam, which is estimated at 3600 Mm^3). Thus, the GRR could contribute 68% of the total volume of water required to be stored at Mtera dam.

Table 11: Mean seasonal flow volumes

Sno	Code	Station Name	Unit	Annual	Seasonal contribution to annual flow			
					JFM	AM	JJAS	OND
1	1KA7A	Chimala at Chitekelo	$m/^3s$	3.16	5.91	5.93	1.16	1.22
			Mm^3	99.26	46.11	31.25	12.23	9.67
2	1KA8A	GRR at Salimwani	$m/^3s$	16.37	37.59	26.00	4.03	5.17
			Mm^3	513.73	293.09	137.05	42.46	41.13
3	1KA9	Kimani at Great North Road	m^3/s	5.67	12.97	8.26	1.67	1.99
			Mm^3	178.14	101.10	43.54	17.65	15.85
4	1KA11A	Mbarali at Igawa	m^3/s	14.70	27.48	22.15	7.06	7.15
			Mm^3	462.28	214.26	116.76	74.39	56.87
5	1KA16A	Lunwa at Igurusi	m^3/s	1.52	3.05	3.00	0.38	0.52
			Mm^3	47.78	23.78	15.81	4.02	4.17
6	1KA27	GRR at Hausman's Bridge	$m/^3s$	73.08	142.61	176.89	20.89	3.93
			Mm^3	2295.70	1111.99	932.28	220.21	31.22
7	1KA5OB	Mswiswi at Wilima	$m/^3s$	1.11	2.07	2.91	0.22	0.14
			Mm^3	34.96	16.16	15.32	2.35	1.12
8	1KA51A	Umrobo at Great North Road	m^3/s	0.66	0.98	1.29	0.35	0.31
			Mm^3	20.63	7.65	6.81	3.70	2.47
9	1KA59	GRR at Msembe	m^3/s	78.29	157.13	184.05	20.65	5.81
			Mm^3	2459.14	1225.20	970.03	217.71	46.21

Table 12: Seasonal flows expressed as percentage of annual flow volumes

Sno	Code	Station Name	Seasonal contribution to annual flow volume (%)			
			JFM	AM	JJAS	OND
1	1KA7A	Chimala at Chitekelo	46.45	31.48	12.32	9.75
2	1KA8A	GRR at Salimwani	57.05	26.68	8.27	8.01
3	1KA9	Kimani at Great North Road	56.75	24.44	9.91	8.90
4	1KA11A	Mbarali at Igawa	46.35	25.26	16.09	12.30
5	1KA16A	Lunwa at Igurusi	49.77	33.09	8.42	8.73
6	1KA27	GRR at Hausman's Bridge	48.44	40.61	9.59	1.36
7	1KA5OB	Mswiswi at Wilima	46.23	43.83	6.73	3.21
8	1KA51A	Umrobo at Great North Road	37.08	33.01	17.94	11.96
9	1KA59	GRR at Msembe	49.82	39.45	8.85	1.88

GRR = Great Ruaha River

4.1.2.2 Inter-annual variations

Figures 27, 28 and 29 show the time series of flows for some rivers in the UGRRC. The time series generally indicate a decline in river flows, with notable decrease in river flows appearing since the mid 1980s. The exception is Lunwa River at Igurusi, which showed an increasing pattern. However, the river flow patterns were not strictly increasing or decreasing throughout the years. For example, Lunwa River recorded very low flows of about 10.5 Mm^3 in 1981, while the highest flow of 143.3 Mm^3 was recorded in 2001. For the case of Kimani River, the highest flow of 328.1 Mm^3 was observed in 1983 while since about 1988 the flows showed decreasing patterns. Mbarali River showed the same behaviour. These variations of the years in which UGRRC rivers recorded highest and lowest flows indicate that their respective sub-catchments had different rainfall patterns. The only exceptions were the years 1968, 1979 and 1983 when all the three stations recorded relatively high flows.

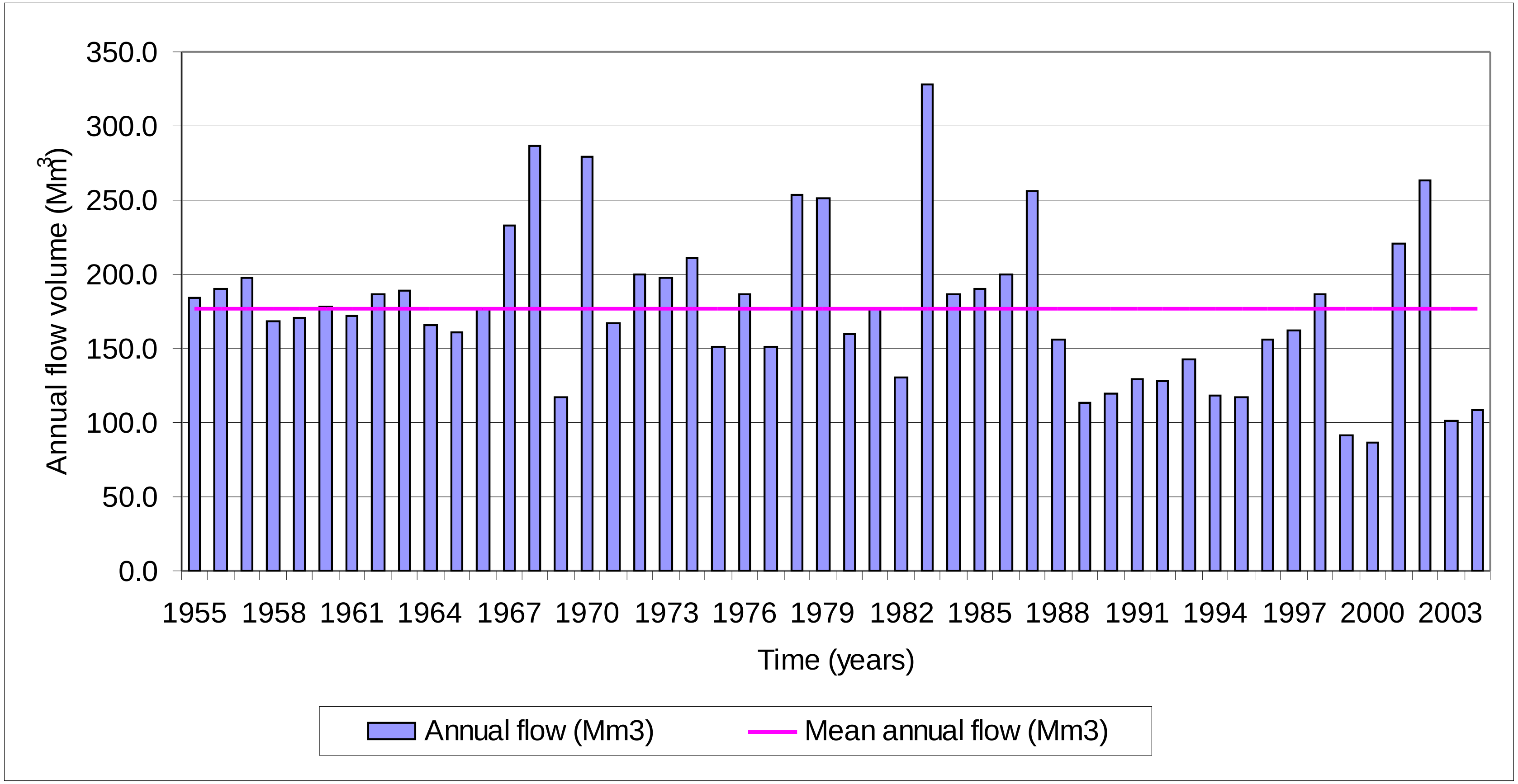


Figure 27: Time series of annual flow at Kimani River (1KA9)

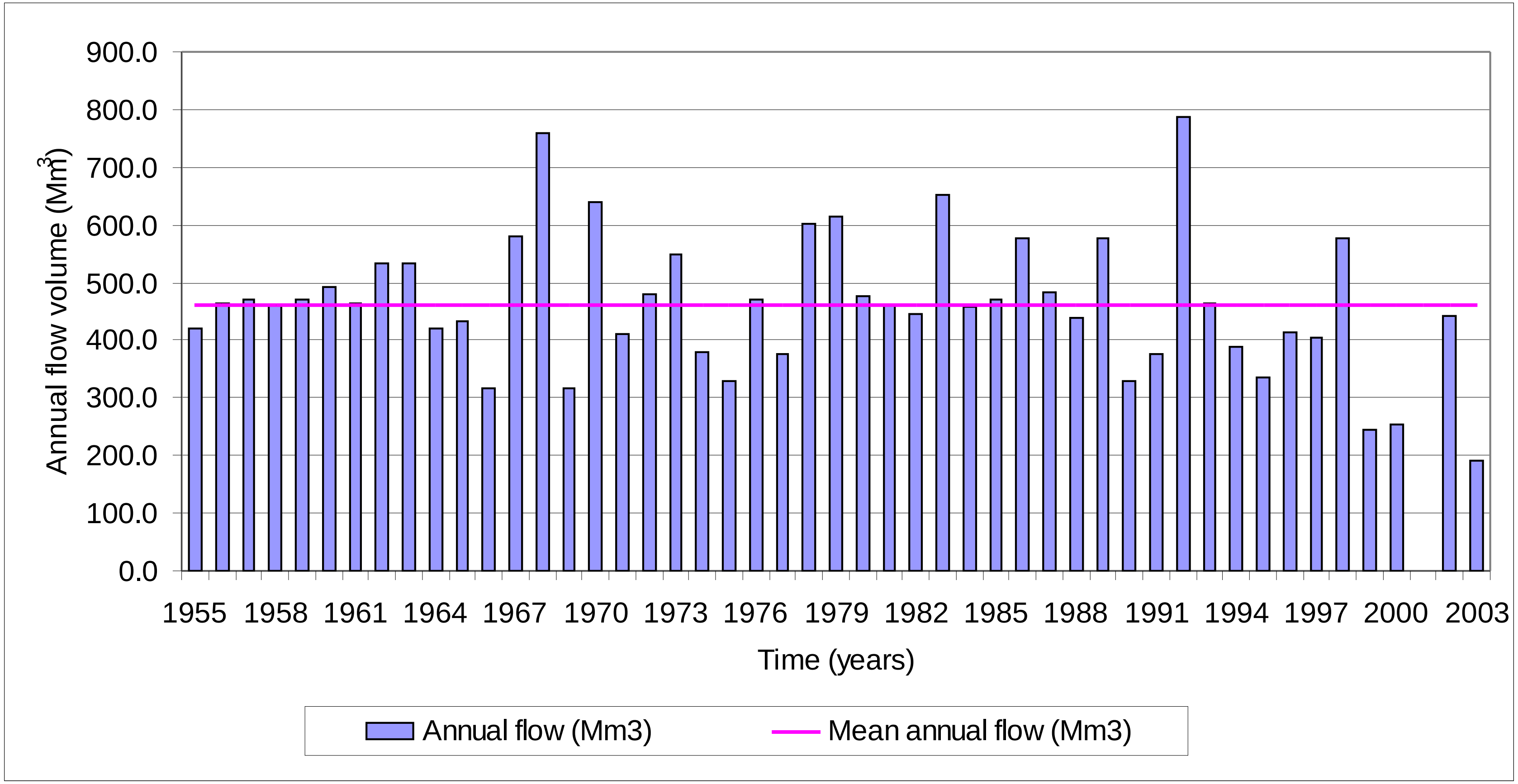


Figure 28: Time series of annual flow at Mbarali River (1KA11A)

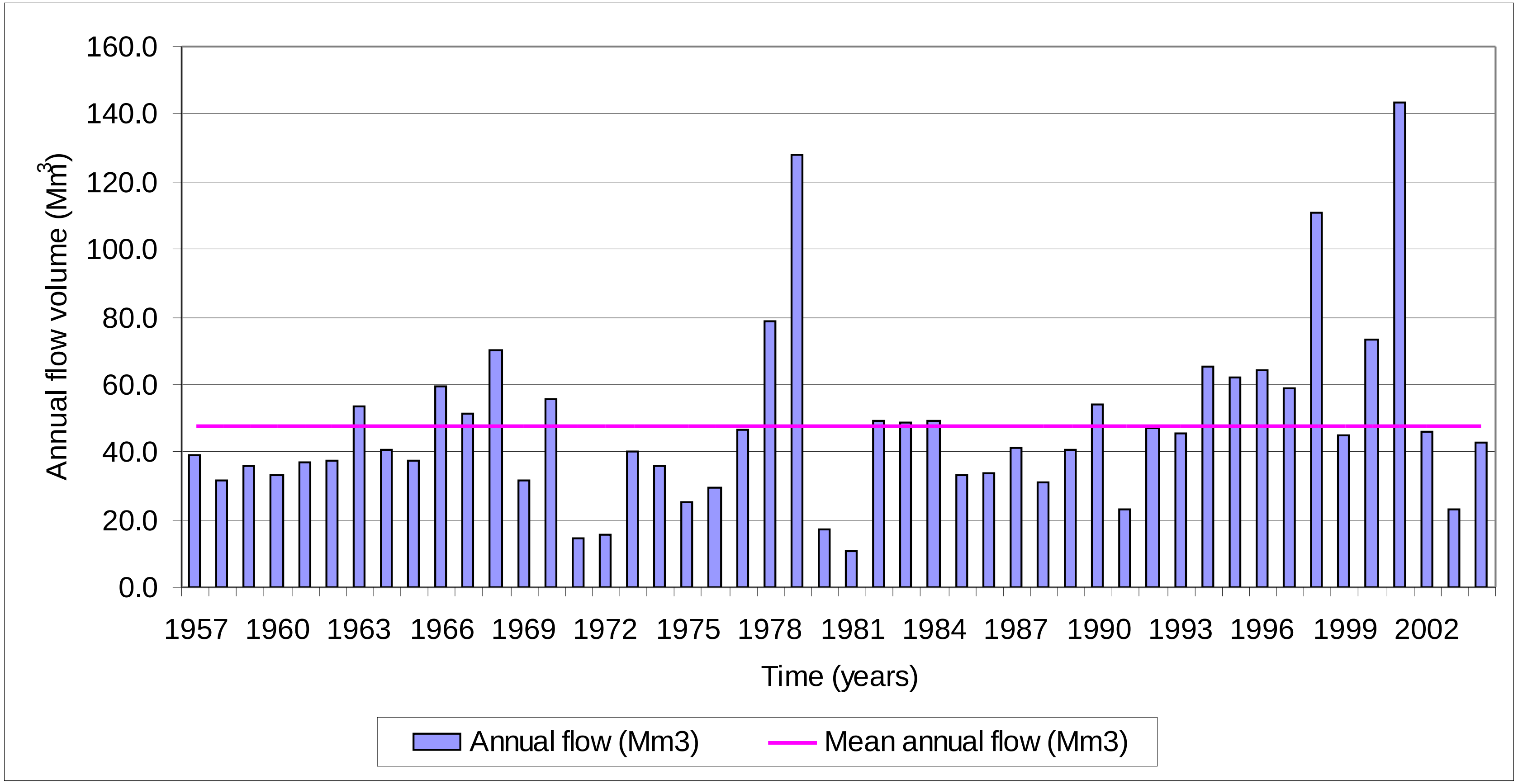


Figure 29: Time series of annual flow at Lunwa River (1KA16A)

(i) River flow trends

Table 13 shows results of trends on seasonal and annual river flows for the gauged rivers in the UGRRC at 5% significant level. The trends are presented for the common period (1960-1999) as well as for the whole periods of records. During the whole periods, all the stations showed a decline in river flows during the main JFM season, while 75% of the stations showed decreasing annual, AM and JJAS river flows. For the case of the 1960-1999 period, over 75% of the stations experienced decreasing river flows during the JFM, AM, JJAS and OND seasons. 1KA27 and 1KA59 stations, which are located downstream of the UGRRC showed significant decrease in the dry season flows in the JJAS and OND seasons during the 1960-1999 and the 1957-2004 periods. No significant decreases were observed for the JFM season. Generally, with the exception of few cases, the patterns of river flow trends were the same for the whole periods of records as well as for the 1960-1999 period.

Generally, the time series and trends analyses indicated: a) alternating periods of abundant and deficit annual flows; b) declining annual, JFM and AM flows; and c) how trends of flows in the dominant seasons influence annual flow trends. However, it is not always possible to relate the variations at the annual scale to those in the dominant season (e.g. 1KA16A and 1KA 51 for the whole season; and 1KA8A, 1KA16A and 1KA51A for the common period). Although this analysis failed to show conclusively the trend of river flows over the entire UGRRC, results for the Great Ruaha River at 1KA27 and 1KA59 stations, which are located just downstream of the UGRRC showed that in general, outflows from the UGRRC have been decreasing over the period of records.

Table 13: Trends in seasonal and annual river flows at 5% significant level

Sno	Station name	Useful record	Parameter	Trend (whole period)					Trend (common period): 1960-1999				
				Annual	JFM	AM	JJAS	OND	Annual	JFM	AM	JJAS	OND
1	1KA7A	1963-2004	Z	**-2.75**	**-2.384**	**-2.54**	-0.50	-0.09					
			S	-0.028	-0.072	-0.071	-0.001	0.000					
2	1KA8A	1955-2003	Z	-0.31	-0.684	-1.18	-1.70	-0.06	0.17	-0.151	-0.08	-1.90	-0.90
			S	-0.014	-0.069	-0.099	-0.010	-0.001	0.009	-0.012	-0.009	-0.015	-0.033
3	1KA9	1955-2004	Z	**-2.49**	-1.690	**-3.06**	**-4.75**	-0.62	**-2.32**	-1.503	**-1.97**	**-4.30**	-1.50
			S	-0.044	-0.101	-0.061	-0.012	-0.006	-0.050	-0.105	-0.058	-0.016	-0.018
4	1KA11A	1955-2004	Z	-1.77	-1.474	**-2.01**	**-2.32**	-0.75	-0.90	-0.874	-0.64	-1.15	-0.66
			S	-0.065	-0.154	-0.115	-0.032	-0.031	-0.057	-0.128	-0.050	-0.022	-0.037
5	1KA16A	1957-2004	Z	**2.11**	-0.382	0.97	**2.04**	1.86	1.64	-0.221	1.32	1.41	0.31
			S	0.013	-0.004	0.010	0.004	0.004	0.014	-0.003	0.022	0.004	0.001
6	1KA27	1957-2004	Z	-1.63	-0.755	-1.38	**-3.44**	**-4.35**	-0.97	-0.757	-0.06	**-2.02**	**-3.97**
			S	-0.546	-0.605	-1.246	-0.348	-0.113	-0.413	-1.052	-0.085	-0.309	-0.158
7	1KA50B	1960-2004	Z	-1.08	-1.409	-1.26	-1.08	0.38	-0.64	-0.804	-0.76	-1.48	-0.21
			S	-0.005	-0.015	-0.014	-0.001	0.000	-0.003	-0.010	-0.008	-0.002	0.000
8	1KA51A	1959-2004	Z	-0.30	-0.166	0.11	-0.88	-0.62	1.11	0.944	1.06	0.70	0.50
			S	0.000	-0.001	0.001	-0.001	-0.001	0.003	0.006	0.005	0.001	0.001
9	1KA59	1957-2004	Z	-1.45	-0.631	-1.61	**-2.94**	**-3.13**	-0.85	-0.548	-0.41	-1.57	**-2.63**
			S	-0.572	-0.543	-1.438	-0.328	-0.103	-0.503	-0.858	-0.645	-0.284	-0.139
	Total number of stations			9	9	9	9	9	8	8	8	8	8
	Number of increasing trends			2	0	2	1	1	3	1	2	2	1
	Number of decreasing trends			7	9	7	8	6	5	7	6	6	6

Z = Test statistic

S = Slope

Significant trends are bolded

(ii) River flow regime change detection

Since some rivers in the UGRRC showed significant decreasing trends, regime change analysis was done to determine the timing, total number of shifts that had occurred and the directions of the shifts. The same methodology as for rainfall was followed. The results are presented in Table 14 and Figures 30, 31, 32, 33 and 34.

The results show that all the studied rivers experienced significant regime shifts at 5% significance level. The dry season river flows at 1KA27 and 1KA59 (located downstream of UGRRC) experienced significant downward regime shifts of 61% and 57.2% respectively in 1975. NORPLAN (2000) also noted the apparent negative trend of the accumulated flow volumes at 1KA27 starting from 1975 (for the time series 1957-1996) during the months August-November. This could probably be due to paddy irrigation at the 3200 ha Mbarali Rice Farm established in 1973, which cultivated 1600 ha in 1975. Likewise, the OND flow at 1KA27 and the JASS flow at the two stations also underwent significant regime change. However, the annual flow at 1KA27 and 1KA59 and the OND flow at 1KA59 did not experience any regime change. The fact that the OND flow at 1KA27 (located 60 km upstream of 1KA59) underwent significant regime change while the OND flow of 1KA59 experienced no change implies that there are tributaries (e.g. Jongomero River) in between the two stations that contribute flow to 1KA59 during the OND season. The results also show that, in general, river flow regime, just like the rainfall regime in the UGRRC, has been decreasing with time, as evidenced by the direction of regime changes. Only Lunwa River (1KA16A) and the first regime shift at 1KA51A (in 1987) show upward trends.

Table 14: Significant regime changes in river flows at 5% significant level

Sno	Station name	Useful record	Number of regimes	Change year	Mean of regime 1 (m^3/s)	Mean of regime 2 (m^3/s)	Mean of regime 3 (m^3/s)	Change (%)	Change direction
1	1KA7A	1963-2004	2	2003	3.23	1.76		-45.51	Downward
2	1KA8A	1955-2003	2	1999	17.06	8.72		-48.89	Downward
3	1KA9	1955-2004	2	1989	6.23	4.49		-27.93	Downward
4	1KA11A	1955-2004	2	1999	15.33	9.20		-39.99	Downward
5	1KA16A	1957-2004	2	1998	1.40	2.21		57.86	Upward
6	1KA27	1957-2004	1	-	73.08	73.08	-	0.00	-
7	1KA50B	1960-2004	2	1980	1.29	0.95		-26.36	Downward
8	1KA51A	1959-2004	3	1987; 1997	0.63	0.87	0.47	38.10; -45.98	Upward; Downward
9	1KA59	1957-2004	1	-	78.29	78.29	-	0.00	-
10	1KA27_Dry	1957-2004	2	1975	11.44	4.47		-60.93	Downward
11	1KA27_OND	1957-2004	2	1969	8.37	2.45		-70.73	Downward
12	1KA27_JJAS	1957-2004	2	1999	22.81	7.45		-67.34	Downward
13	1KA59_Dry	1957-2004	2	1975	10.81	4.63		-57.17	Downward
14	1KA59_OND	1957-2004	1	-	5.81	5.81	-	0.00	-
15	1KA59_JJAS	1957-2004	2	1999	22.62	6.87		-69.63	Downward

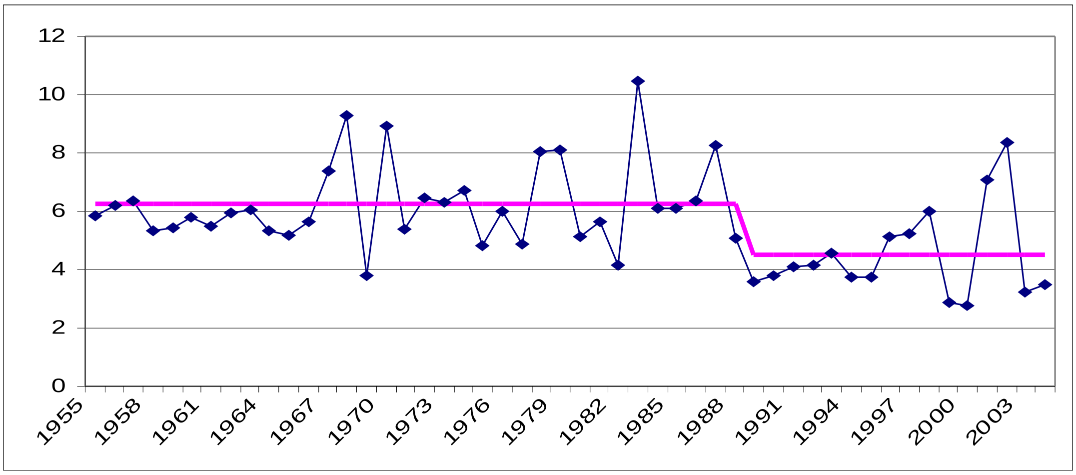


Figure 30: Shifts in the mean for annual river flow (m³/s) at Kimani River

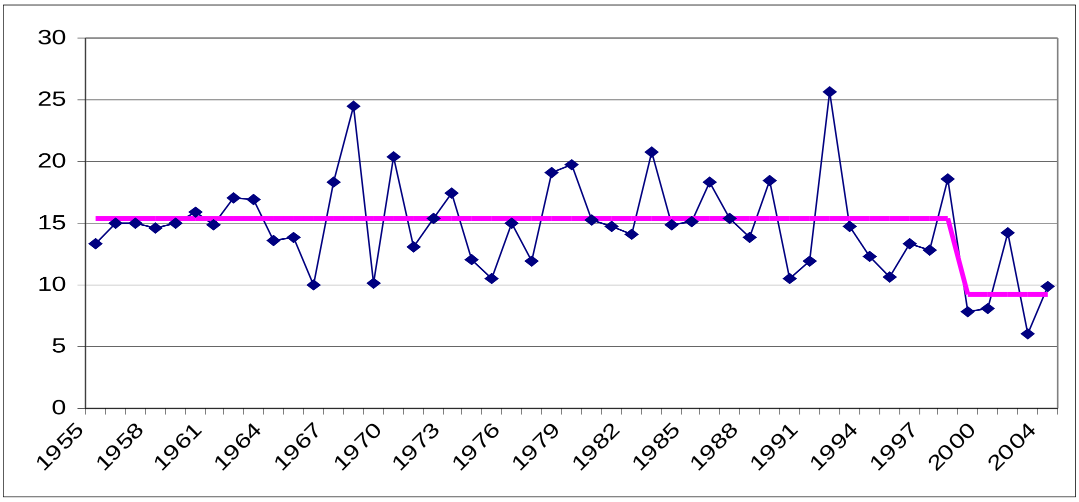


Figure 31: Shifts in the mean for annual river flow (m³/s) at Mbarali River

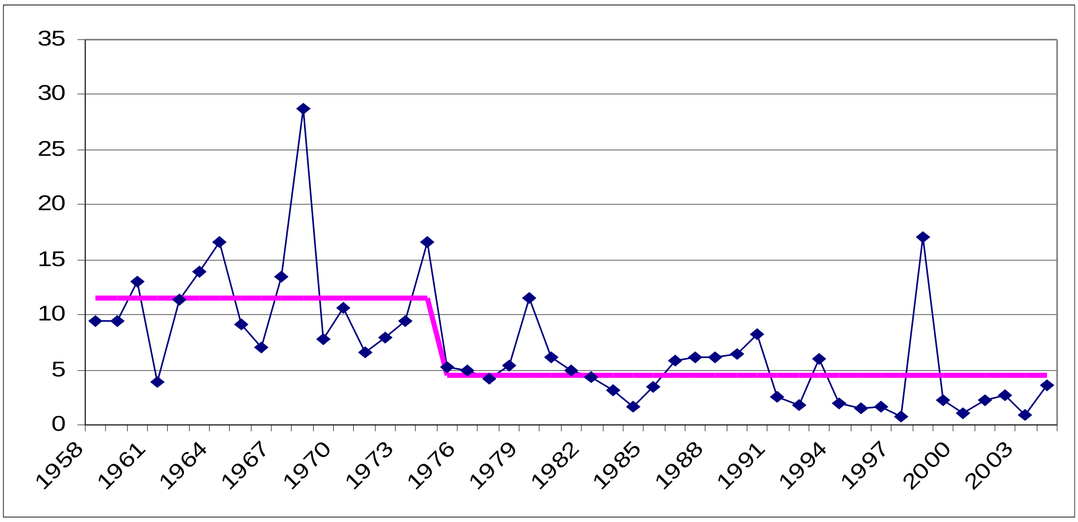


Figure 32: Shifts in the mean for dry season river flow (m³/s) at GRR (1KA27)

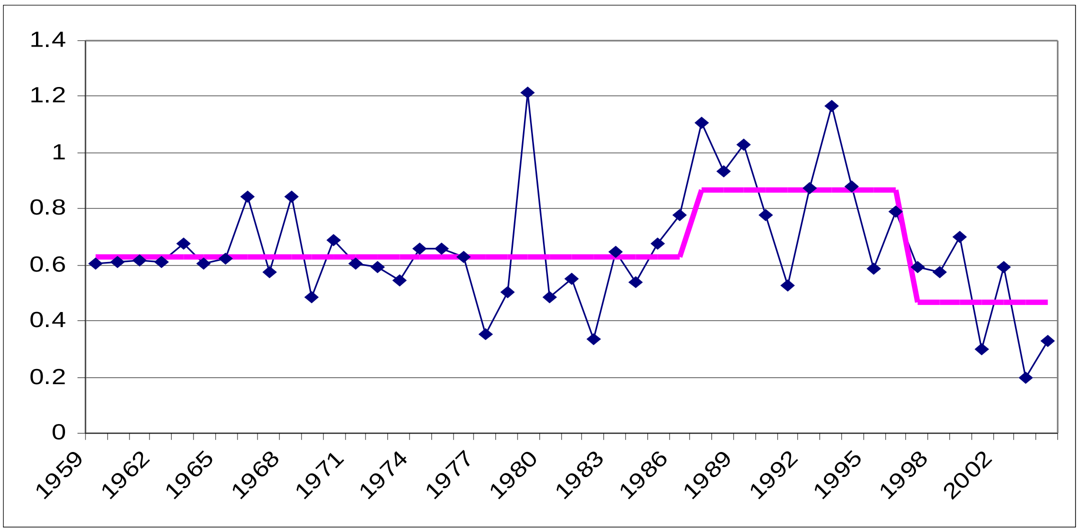


Figure 33: Shifts in the mean for annual river flow (m^3/s) at Umrobo River

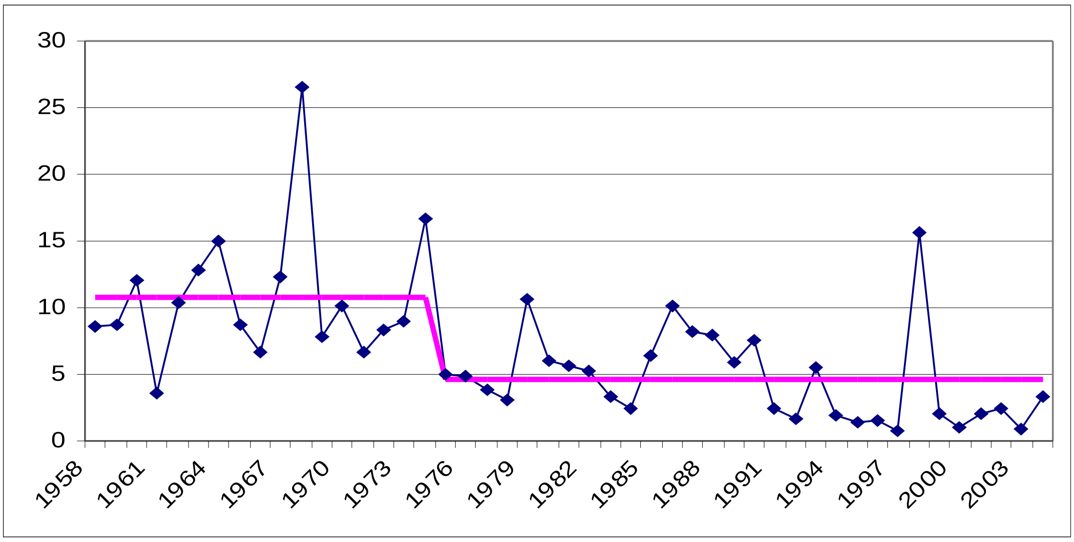


Figure 34: Shifts in the mean for dry season river flow (m^3/s) at GRR (1KA59)

4.1.2.3 Available surface water resources in the UGRRC

The foregone analysis of rainfall and river flows in the UGRRC has shown that the area is characterised by huge spatial and annual variations in rainfall, often compounded by poor distribution. There are thus great disparities in rainfall and hence water availability between agro-ecological zones of the UGRRC, with the highlands receiving the highest rainfall amounts. However, on average, the UGRRC receives 959 mm of rainfall annually, equivalent to 16 464 Mm^3 of water, whereas MSC receives 938 mm of rainfall or 3190 Mm^3 of water.

For the case of dry season, only surface water resources were analysed and quantified. This is due to the fact that there is very limited information on the groundwater resources in the UGRRC. Furthermore, there is also limited use of the same, with groundwater being mainly used for domestic purposes. The available ground water resources were therefore not investigated in this study. For the purpose of this analysis, dry season in the UGRRC was assumed to cover the period June to November. In the UGRRC, there are five perennial rivers, which are all gauged, and many small seasonal streams (mostly ungauged and located in MSC) that provide water to the catchment during the dry season. Since the gauging stations are located in the upper zone and there are no water abstractions upstream of the gauging stations, the flows as recorded by each station were the available surface water resources for use during the dry season. For the ungauged rivers, the available surface water was estimated from the bi-monthly spot discharge measurements undertaken during the dry seasons of 2003 and 2004 upstream of water abstraction points. Table 15 presents the available surface water resources in UGRRC during the dry season before any abstractions. The results show that the total available dry season surface water resource in UGRRC is about 257 Mm^3. Table 15 further shows that rivers in MSC (rivers number 6 to 21) have very low dry season flows and the total available dry season surface water resource in MSC is 37.47 Mm^3.

Table 15: Monthly dry season flow volumes (Mm^3) for UGRRC rivers

Sno	River gauging station name	Month					
		Jun	July	Aug	Sep	Oct	Nov
1	Chimala (1KA7A)	4.64	3.28	2.41	1.89	1.78	2.08
2	Great Ruaha (1KA8A)	14.75	11.86	8.97	7.05	6.08	6.49
3	Kimani (1KA9)	6.91	4.55	3.40	2.72	2.13	2.52
4	Mbarali (1KA11A)	26.14	20.51	16.01	11.53	10.60	11.01
5	Ndembera (1KA33B)	12.14	6.70	4.02	2.59	2.68	2.33
6	Lunwa (1KA16A)	1.78	1.22	0.65	0.37	0.34	1.03
7	Itambo at Itamboleo	0.04	0.03	0.02	0.02	0.02	0.01
8	Meta at Mapuga	0.28	0.29	0.21	0.23	0.32	0.27
9	Lwanyo at Igurusi	0.66	0.54	0.40	0.30	0.21	0.15
10	Mkoji at Shamwengo	0.45	0.26	0.18	0.13	0.14	0.08
11	Mswiswi at Wilima	1.68	1.10	0.81	0.80	0.53	0.69
12	Mambi at Kalanzi	1.40	0.81	0.77	0.55	0.44	0.32
13	Hayuya Spring at Inyala	0.07	0.06	0.03	0.03	0.03	0.01
14	Gwiri at Malamba	0.51	0.22	0.25	0.22	0.21	0.17
15	Ipatagwa (1KA45C)	1.67	1.40	1.21	1.14	1.12	1.04
16	Mwambalizi at Itewe	0.35	0.25	0.16	0.10	0.11	0.09
17	Sawa at Itewe	0.04	0.02	0.02	0.02	0.01	0.01
18	Mlowo at Idunda	0.62	0.48	0.36	0.29	0.24	0.18
19	Uta at Iyawaya	0.10	0.09	0.08	0.06	0.06	0.07
20	Abadaa Spring at Idunda	0.10	0.07	0.07	0.04	0.05	0.05
21	Other small rivers	0.92	0.71	0.57	0.43	0.40	0.36
	Total volume (Mm^3)	75.23	54.44	40.62	30.50	27.50	28.98
Total dry season volume (Mm^3)		257.26					

4.2 Irrigated Area Trends in the UGRRC and Changes in the Hydrologic Regime of the Great Ruaha River

4.2.1 Irrigated area and water use trends in the UGRRC

German missionaries first introduced irrigation to the Usangu Plains in the early 19^{th} century. They built small furrows to provide domestic water to the missions and to irrigate vegetable gardens. The *Baluchi* people (from Iran) developed a more extensive and sophisticated system of irrigated agriculture in the plains during the 1940s and 1950s. It is during this period that paddy cultivation by smallholder farmers spread rapidly in the Usangu plains. However, the most rapid expansion of the irrigated area probably occurred in the 1980s.

In addition, in the 1980s, there was also a proliferation of informal (unauthorised) irrigation, in particular in the upper and middle zones. Currently, both traditional and improved water diversion structures exist in the study area. For example, out of 150 operational water abstraction points, 37 have improved (concrete) head works. Traditional diversions are temporary in nature, needing to be re-built each year. They are built of wooden poles, rocks, gunny bags, clay soils and stones. Their principal disadvantage is that they are frequently damaged by large floods and need considerable input of labour for rebuilding. Although traditional diversions and water distribution structures may seem crude, they are effective in diverting water from ephemeral streams. Traditional schemes have neither drainage systems nor structures (e.g. gates) to control and regulate the amount of water being abstracted. Figures 35 and 36 show the trend of intake development in the UGRRC and MSC. Both figures show that there has been a steady increase in the cumulative number of intakes in both the UGRRC and MSC. However, the number of intakes developed in the 1990s is less than during the 1980s. This downward trend is probably due to dwindling water supplies in the rivers.

Furthermore, in the UGRRC farming communities, there has been a trend to modernize or develop new irrigation infrastructures and to increase the capacity to abstract stream flows for paddy as well as dry season irrigation. This has resulted in the construction of modern (concrete) intakes and diversion structures and lining of main canals. Developed irrigation projects included large irrigation schemes as well as smallholder irrigation schemes. For example (developed area in brackets), Majengo (530 ha), Mswiswi (870 ha) and Moto Mbaya (600 ha) schemes were built during the Usangu Village Irrigation Project in the mid 1980s and early 1990s. The construction of the schemes started in 1985 and by 1987 paddy cultivation started in the “pilot scheme”, the Majengo Irrigation Scheme. These schemes cultivated 1630 ha in 1992. In 1989/90 Kapunga Rice Irrigation Project (3000 ha) was established. In 1991/92, the Kapunga Project cultivated 2550 ha (Project records) and the figure rose to 3000 ha in 1992/93 season. During the same period, Kapunga smallholder scheme (800 ha) as well as Chimala smallholder scheme (3000 ha) were also developed. In 1997, infrastructure construction for Madibira Smallholder Rice Project (3000 ha) was completed. The production started in 1998/998 with the cultivation of 450 ha which rose to 2742 ha in 2003/04 season. Between 2000 and 2005, eleven other irrigation schemes were developed/ improved in UGRRC. They include Inyala A and B (120 ha), Iyawaya (30 ha), Imezu Mkombozi (160 ha), Itewe (60 ha), Isikaka, Shamwengo (40 ha), Luanda Majenje (450 ha), Ipatagwa I and II (542 ha) and Igomelo (300 ha) irrigation schemes.

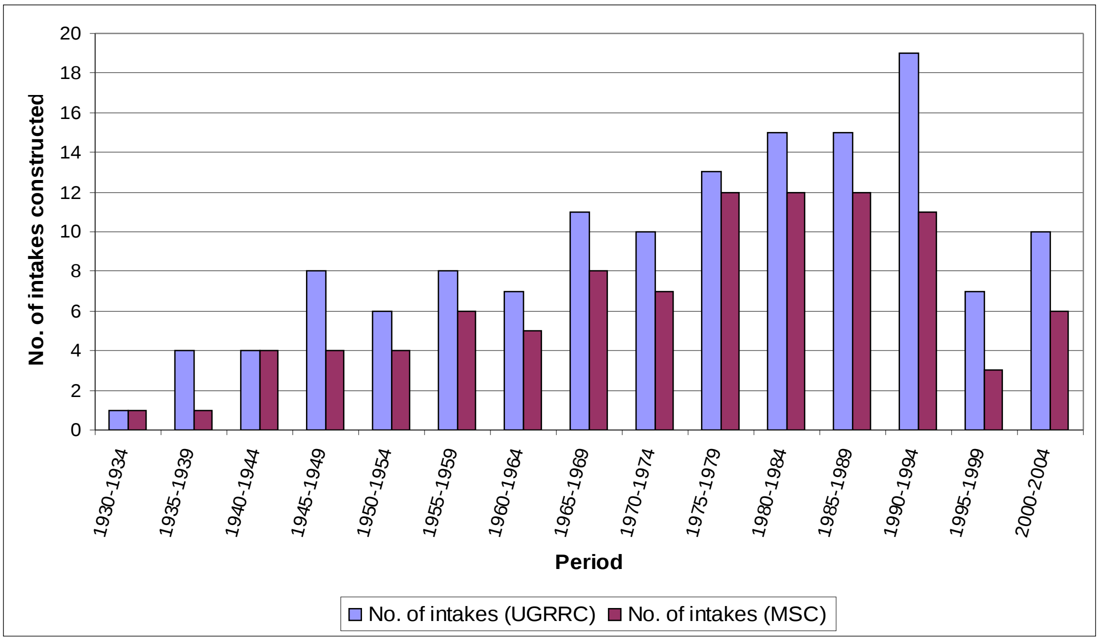


Figure 35: Development of intakes with time in UGRRC and MSC

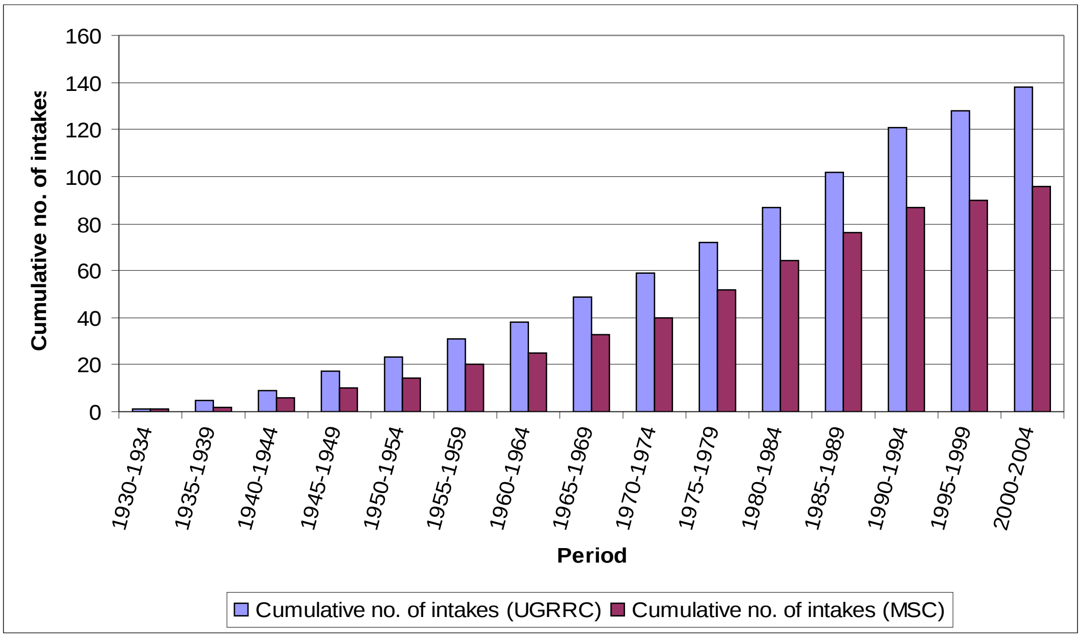


Figure 36: Cumulative number of intakes with time in UGRRC and MSC

The trend of improvement of traditional intakes and development of new modern intakes in the UGRRC and MSC is shown in Figures 37 and 38. Since the 1980s, there has been a steady increase in the number of intakes improved. Improvements of intakes improve their abstraction capacity. The improvement and construction of modern intakes normally allow water levels to be raised behind the weirs so that command of agricultural areas becomes possible during the dry season when rivers have very low flows. This practice is common at the Luanda Majenje and Shamwengo irrigation schemes. The raised levels lengthen the total duration of water abstraction. Consequently, dry season irrigated agriculture is now possible even during periods of very low flows and paddy cultivation now start earlier (October-November) and ends late in the season (July-August).

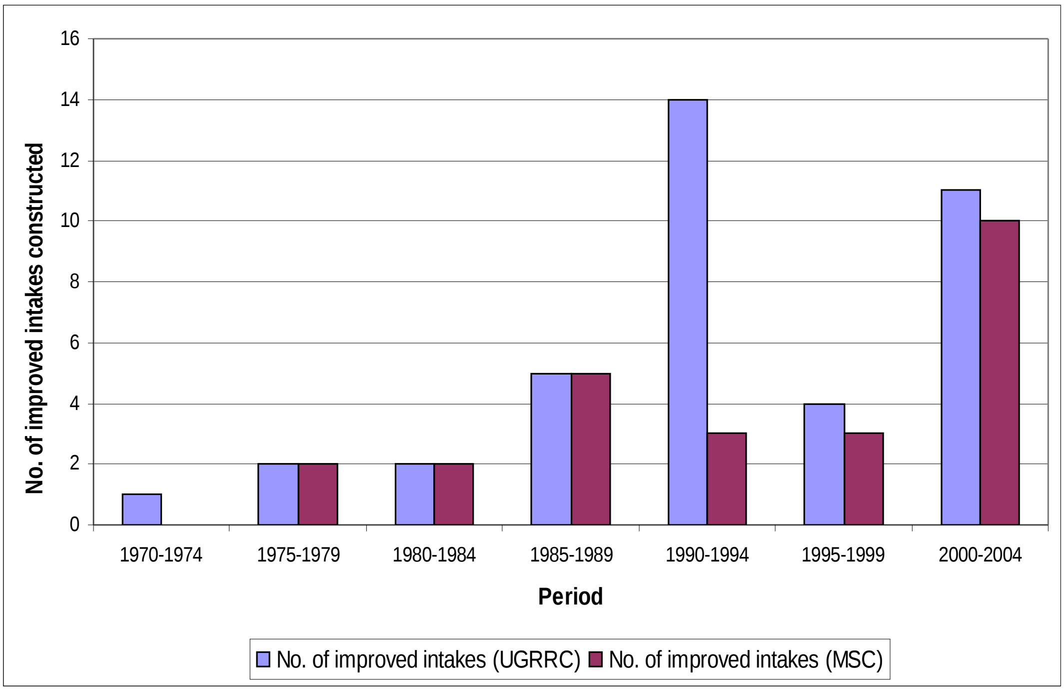


Figure 37: Development of improved intakes in UGRRC and MSC

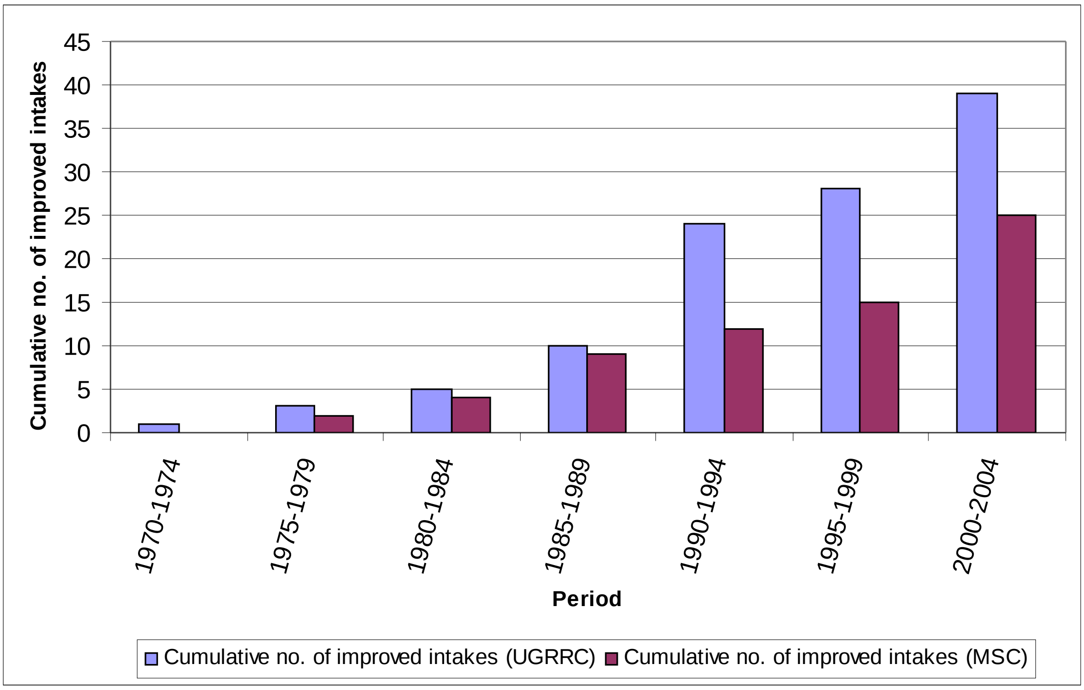


Figure 38: Cumulative number of improved intakes in UGRRC and MSC

The above-mentioned developments have contributed in increasing the area under irrigated rice in the UGRRC from about 4000 ha in 1950 to around 46 000 ha in 2005 (Figure 39). Between 1960 and 1980, paddy area increased by 12 380 ha whereas the increase rose sharply to 27 043 ha between 1981 and 2001 (an average of 1335 ha per year). Likewise, dry season irrigation for maize, tomatoes and vegetables increased from zero ha in the 1930s to about 3570 ha in 2003 (RIPARWIN, 2005). For the case of MSC, it was found out that 8038 ha was under irrigated agriculture in 2003, apportioned into 5266 ha in the wet season (mainly for paddy irrigation) and 2772 ha during the dry season. These findings are also supported by recent studies undertaken in the UGRRC (SMUWC, 2001a; DANIDA/World Bank, 1995), which have shown that irrigated paddy area has increased tremendously over the years.

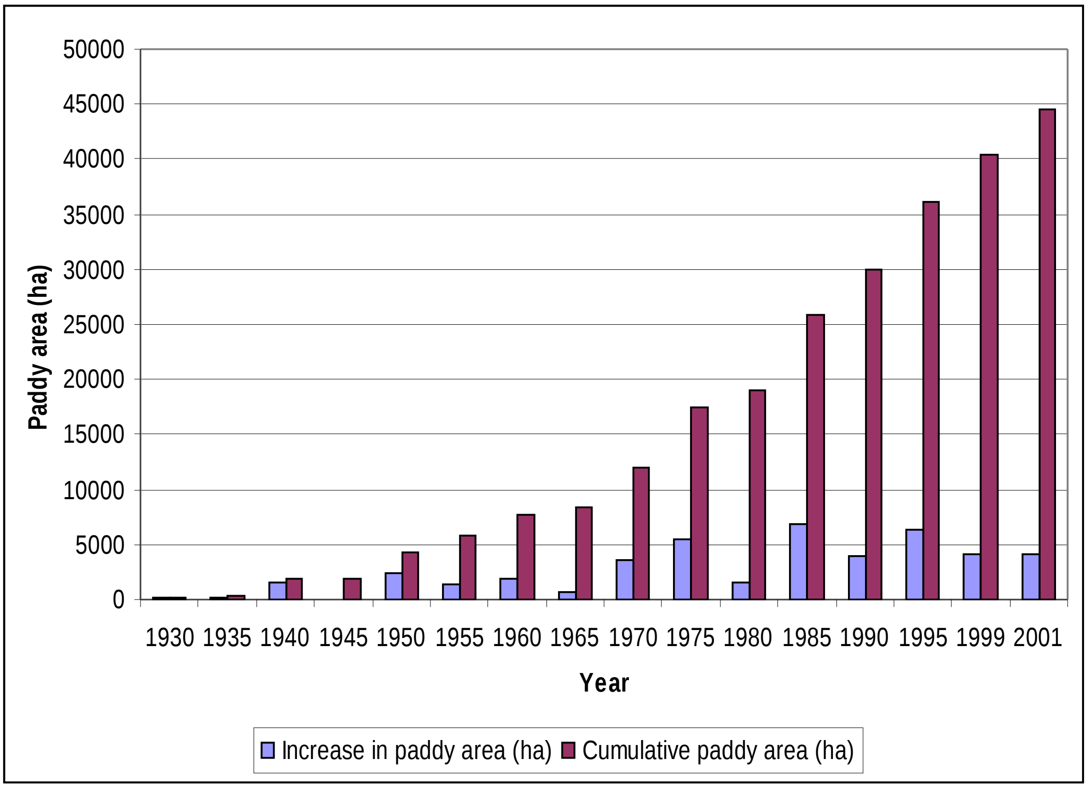


Figure 39: Development of area under paddy in UGRRC

From the above findings, it is clearly seen that since the 1980s there has been a substantial increase in the number of improved intakes in the UGRRC, the total abstraction capacity has steadily risen and more importantly, the ability to abstract water during the dry season has increased. While improved intakes are desired to control water abstractions and reduce unnecessary water losses through leakages at the intakes, selfish farmers can also abuse the intakes. Rivers in some sub catchments (e.g. MSC) have very small flows (less than 0.5 m^3/s) during the dry season. Consequently, most of the improved intakes are capable of diverting the whole flow of the river, which may have negative effects to downstream users. Thus, while farmers with improved intakes are pleased to have great control of water and use less time and labour to maintain their intakes, downstream farmers are deprived of water, particularly during the dry season. The overall consequences are that some rivers, which were once perennial, dry up in upstream areas now

4.2.2 Flow regime of the Great Ruaha River downstream of UGRRC

Results of regime shift detection showed that the GRR underwent significant regime shift in dry season flows at 1KA27 and 1KA59 in 1975. Kimani, Mswiswi and Umrobo rivers also experienced significant regime shifts in the annual river flows in the 1980s. Likewise, irrigated land use trends showed that the most rapid expansion of the irrigated area occurred in the 1980s (section 4.2.1). Thus, river flows split sampling analysis was performed in order to determine if the observed upstream regime shifts of river flows and land use changes had any significant impacts to the flows exiting the UGRRC. River flow records were divided into two common periods; 1960-1980 and 1981-2000. The Students t-test was used to determine whether there is a statistically significant difference in means of river flows between the two periods. The Box-Cox method was used to normalise the data prior to split sample analysis.

The results of the analysis are shown in Table 16. The results show that the analysis failed to show conclusively the trend of river flows as recorded by gauging stations located in the upper zone of the UGRRC between the two time windows. The table shows that the mean remained statistically unchanged in the five upstream-sub catchments analysed. Furthermore, considering the flows recorded at Great Ruaha River at Hausman’s Bridge, (the only outlet conveying water away from the

UGRRC), it can be seen that, although not statistically significant, the flows between the two windows decreased by about 20%. Further analysis of the flows at Great Ruaha River at Hausman’s Bridge shows that it is the dry season (July to November) flows, which have significantly changed. Table 16 (last row) shows that the dry season mean flow between the two time windows decreased by 57%, and the decrease is statistically significant at 5% significant level. When the dry season was further analysed, it was found out that it is the flows during the OND season that have decreased significantly (65% decrease) while the flows during the JJAS season experienced statistically non-significant decrease. The results of the split sampling analysis imply that the decrease in dry season flows as observed at 1KA27 was not caused by declining flows in the upper sub-catchments. It could rather be due to land uses changes taking place in the upstream areas.

4.2.3 Degree of alteration of river flow parameters downstream of UGRRC

The results of the split sampling and regime shifts analyses of the river flows in the UGRRC indicated significant changes in the flows exiting the UGRRC. It was therefore, necessary to undertake further analysis to assess and quantify the degree of alteration and identify river flow parameters (characteristics) that had changed over time. Flow records for the whole period of records (1957-2004) were used in the assessment and 1980 was used as the impact year. The river flow records were thus divided between two time windows (1957-1980 and 1981 to 2004). The assessment was done by using the Indicators of Hydrologic Alteration software (TNC, 2005).

Table 16: River flows split sampling tests at 5% significant level

Station Name	Starting year	End year	Years in Sample 1	Years in Sample 2	Percent increase in the mean	t-statistic	t-critical	Remarks (increase or decrease in mean)
Great Ruaha at Salimwani 1KA 8A	1960	2000	21	20	0.16	-0.02	2.03	Non significant increase
Kimani at Great North Road (GNR) 1KA 9	1960	2000	21	20	-14.56	1.72	2.03	Non significant decrease
Mbarali at Igawa 1KA11A	1960	2000	21	20	-2.31	0.28	2.03	Non significant decrease
Lunwa at Igurusi 1KA16A	1960	2000	21	20	10.54	-0.63	2.03	Non significant increase
Great Ruaha at Hausman’s Bridge 1KA27	1960	2000	21	20	-19.96	0.62	2.03	Non significant decrease
Umrobo at GNR 1KA51A	1960	2000	21	20	12.14	-1.19	2.03	Non significant increase
Great Ruaha at Hausman’s Bridge 1KA27 (Dry season - Jul to Nov)	1960	2000	21	20	-56.83	3.7	2.03	Significant decrease
Great Ruaha at Hausman’s Bridge 1KA27 – JJAS season	1960	2000	21	20	-20.55	0.98	2.03	Non significant decrease
Great Ruaha at Hausman’s Bridge 1KA27 – OND season	1960	2000	21	20	-64.86	2.95	2.03	Significant decrease

4.2.3.1 Mean annual runoff and mean monthly flows for GRR

Tables 17 and 19 show that mean annual runoff between pre impact and post impact periods decreased from 2537.55 Mm^3 to 2053.77 Mm^3 and from 2622.12 Mm^3 to 2308.75 Mm^3 at 1KA27 and 1KA59 respectively. The tables also show that it is the dry season flows, which decreased most. The corresponding monthly flow hydrographs at 1KA27 and 1KA59 between the two windows are shown in Figures 40, 41 and 42. The figures clearly show the declining dry season flows exiting the UGRRC.

4.2.3.2 Low flow indices

Tables 18 and 20 compare minimum flow parameters (m^3/s) between pre impact and post impact periods at 1KA27 and 1KA59. Table 18 shows that the number of zero flow days at 1KA27 increased from an average of 0.25 days per annum in the pre-impact window to 22 days in the post-impact period, with 1997 recording a maximum of 73 zero flow days. The same trend is evident for 1KA59 (Table 20). Further analysis revealed that, all the zero flow days at 1KA27 during the pre-impact window occurred only in one year (six days in 1979). Other low flow frequencies also showed the same trend. For example, 1-day minimum flow decreased from 2.572 m^3/s to 0.1221 m^3/s (Table 18) at 1KA27. For the case of 1KA59 (Table 20) the change is from 2.521 m^3/s to 0.015 m^3/s. The results also show that the timing of minimum flow at the two gauging stations changed. Recently, minimum flows at 1KA27 now start earlier (12^{th} November) instead of 26^{th} November, as was the case during the pre-impact window. For the case of 1KA59, the onset of minimum flows now is 5^{th} November instead of 27^{th} November. This shows that dry season flows from the UGRRC are depleted at a very faster rate now compared to the pre-impact window.

Table 17: Comparison of mean monthly flows (m^3/s) between pre impact and post impact periods at 1KA27

Month	Pre-impact period (1957-1980)	Post-impact period (1981-2004)	Magnitude of change	Percent change
January	79.50	58.69	-20.81	-26.18
February	146.20	163.00	16.80	11.49
March	214.70	185.40	-29.30	-13.65
April	264.70	184.80	-79.90	-30.19
May	144.80	113.40	-31.40	-21.69
June	54.16	50.76	-3.40	-6.28
July	23.05	14.61	-8.44	-36.62
August	12.59	3.34	-9.25	-73.45
September	7.45	1.17	-6.28	-84.34
October	4.57	0.49	-4.08	-89.37
November	3.27	0.53	-2.73	-83.69
December	9.95	4.76	-5.20	-52.20
Mean	80.41	65.08	-15.33	-19.06
Annual total (Mm^3)	2537.55	2053.77	-483.78	-19.06

Table 18: Comparison of minimum flow parameters (m^3/s) between pre impact and post impact periods at 1KA27

Parameter	Pre-impact period (1957-1980)	Post-impact period (1981-2004)	Magnitude of change	Percent change
1-day minimum flow	2.572	0.1221	-2.45	-95.25
7-day minimum flow	2.657	0.1366	-2.52	-94.86
30-day minimum flow	2.917	0.1705	-2.75	-94.15
Number of zero flow days	0.25	21.71	21.46	8584.00
Date of minimum flow	26-Nov	12-Nov	-14.00	

Table 19: Comparison of mean monthly flows (m^3/s) between pre impact and post impact periods at 1KA59

Month	Pre-impact period (1957-1980)	Post-impact period (1981-2004)	Magnitude of change	Percent change
January	77.77	80.68	2.91	3.74
February	156	186.6	30.60	19.62
March	228.4	204	-24.40	-10.68
April	273.7	197.6	-76.10	-27.80
May	146.2	122.8	-23.40	-16.01
June	51.51	52.74	1.23	2.39
July	21.4	16.28	-5.12	-23.93
August	12.01	3.816	-8.19	-68.23
September	7.181	1.045	-6.14	-85.45
October	4.55	0.2718	-4.28	-94.03
November	3.295	0.8836	-2.41	-73.18
December	15.11	11.21	-3.90	-25.81
Mean	83.09	73.16	-9.93	-11.95
Annual total (Mm^3)	2622.12	2308.75	-313.37	-11.95

Table 20: Comparison of minimum flow parameters (m^3/s) between pre impact and post impact periods at 1KA59

Parameter	Pre-impact period (1957-1980)	Post-impact period (1981-2004)	Magnitude of change	Percent change
1-day minimum flow	2.521	0.01536	-2.51	-99.39
7-day minimum flow	2.661	0.02459	-2.64	-99.08
30-day minimum flow	2.952	0.04867	-2.90	-98.35
Number of zero flow days	0.2609	23	22.74	8715.64
Date of minimum flow	27-Nov	05-Nov	-22.00	

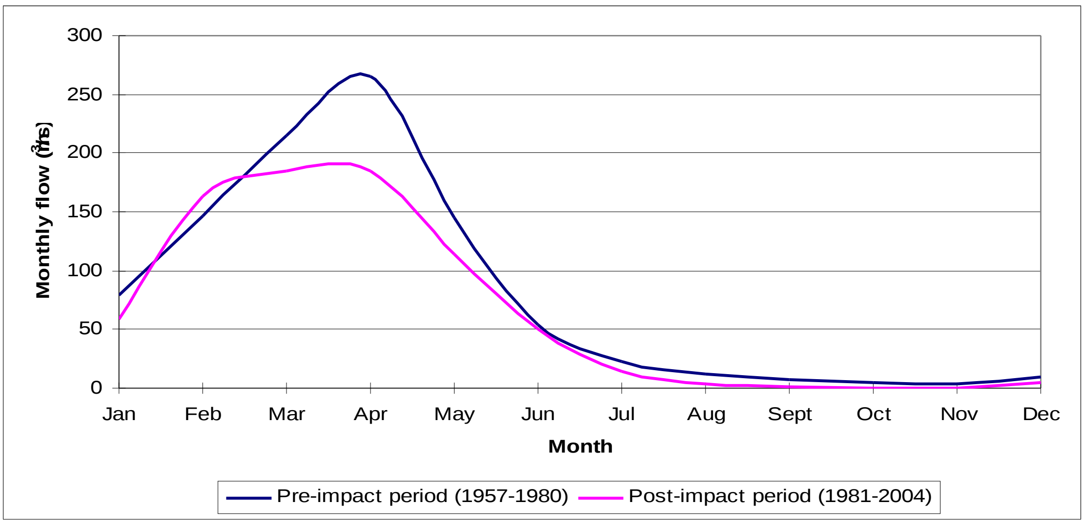


Figure 40: Monthly flow hydrograph for GRR at 1KA27

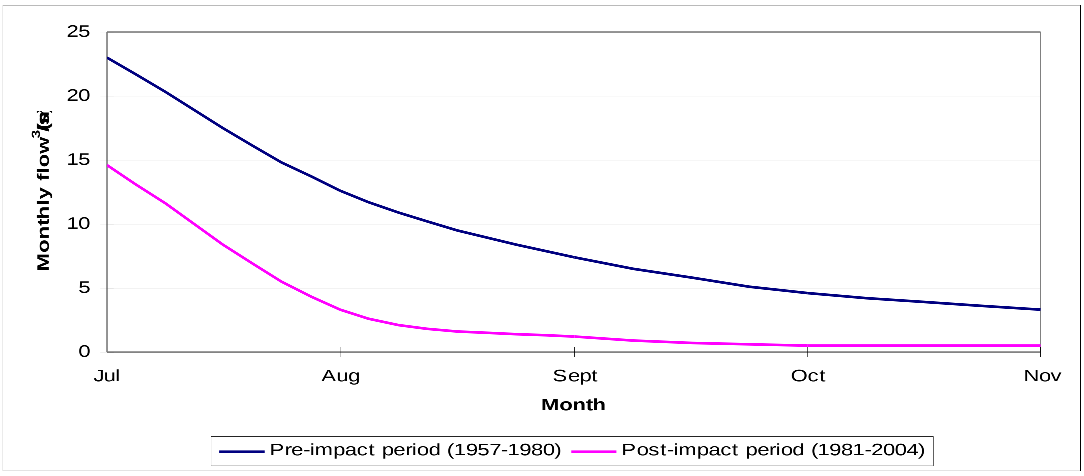


Figure 41: Dry season flow hydrograph for GRR at 1KA27

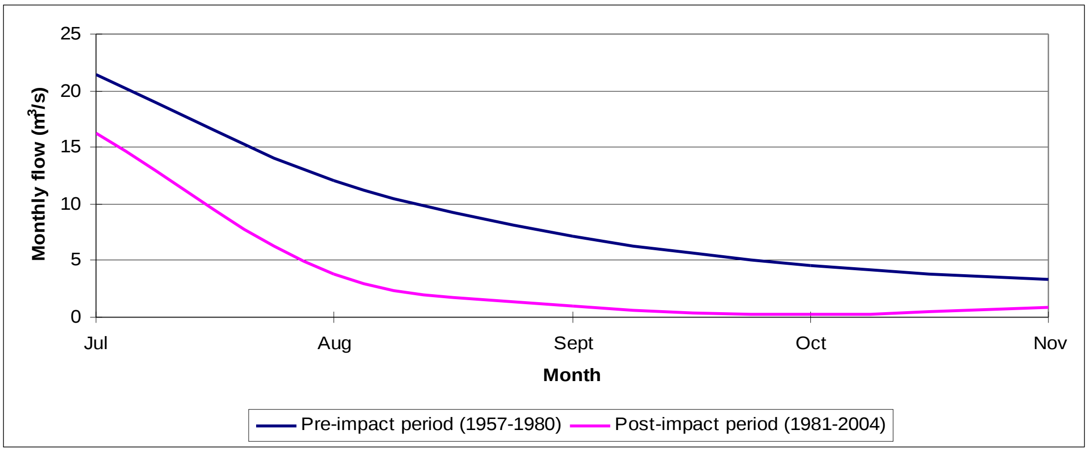


Figure 42: Dry season flow hydrograph for GRR at 1KA59

4.2.3.3 Flow duration curves (FDC)

Figure 43 shows the flow duration curves at 1KA27 for the two time windows (1957-1980 and 1981-2004). The one-day flow duration curves showed that there was a progressive decline in flows lower than Q_{30}. For example, between the 1957-1980 and 1981-2004 windows, Q_{90} decreased from 2.720 m^3/s to 0.266 m^3/s.

Low flow indices	1957-1980	1981-2004
Q_5	409.460	274.393
Q_{10}	193.050	176.970
Q_{25}	78.850	79.930
Q_{50}	19.460	10.710
Q_{75}	6.290	1.190
Q_{90}	2.720	0.266
Q_{95}	1.360	0.047

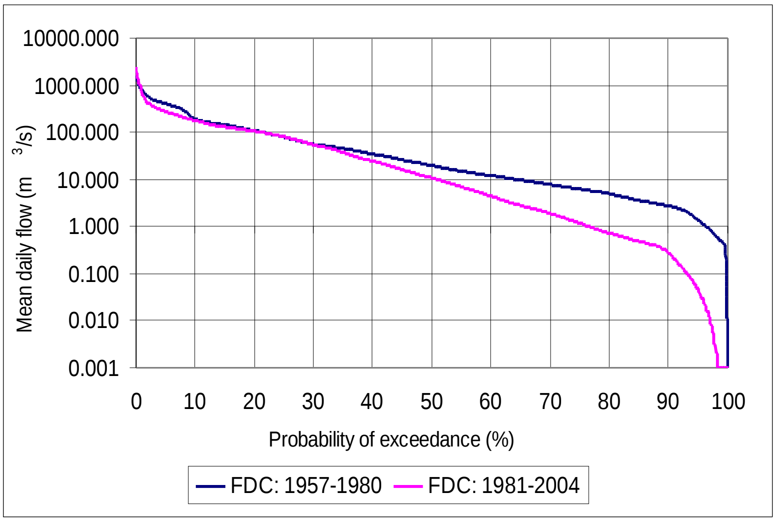


Figure 43: Flow duration curves (vertical log scale) for the GRR at 1KA27

4.2.3.4 Correlation between dry seasonal flows and paddy area

Figure 44 shows the relationship between dry seasonal flows exiting the UGRRC at 1KA27 and paddy area. The figure shows that there is a clear correlation between the two. As paddy area increases, the dry seasonal flows at 1KA27 decreased and the R-squared value is 67%. If the area under dry season irrigated agriculture had been taken into consideration, it is possible that the relationship would have been much stronger with an increase in the R-squared value. However, the time series of area under dry season irrigated agriculture at finer scales as that for paddy is not available.

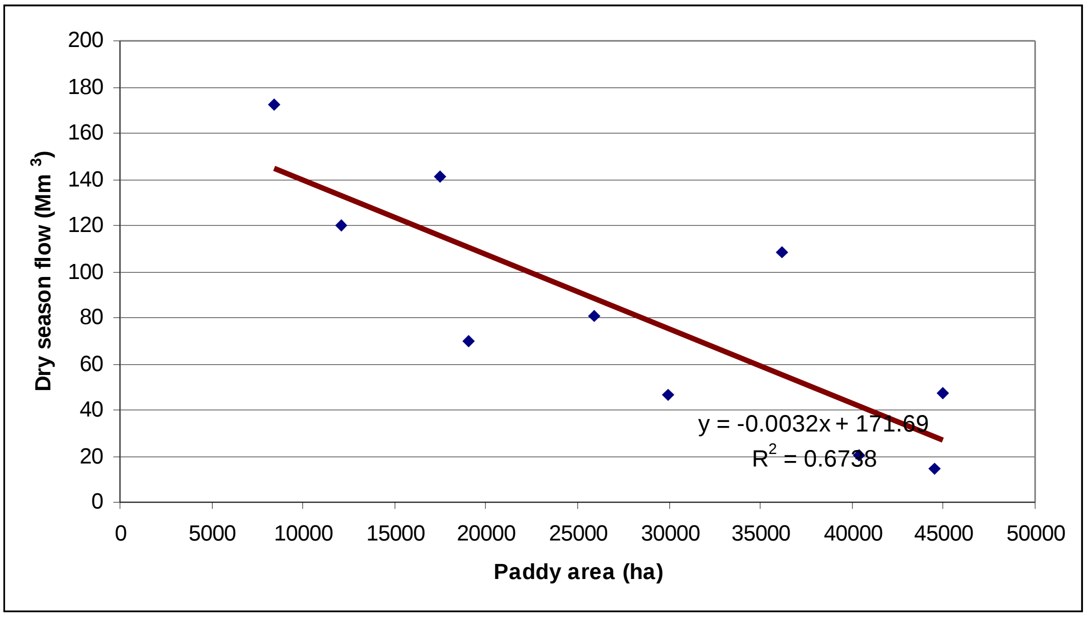


Figure 44: Relationship between paddy area and dry season flows at 1KA27

Analysis of rainfall has shown that there is no statistically significant change in rainfall amounts from stations located in the highlands (which generate the bulk of the flows). Likewise, split sample analysis has shown that there is no statistically significant change in the river flows entering the UGRRC. It can thus be concluded that river flows entering the UGRRC have not changed much over the time. Therefore, the observed decreasing flows, in particular dry season flows, leaving the UGRRC (as recorded at GRR at Hausman's Bridge) are not due to natural causes. They are rather due to increased human interventions, in particular irrigated agriculture (extended into the dry season), taking place between the gauging stations located in the upper zone and the Hausman's Bridge. These findings are in line with other studies (e.g. Elkaduwa and Sakthivadivel, 1999), which showed that the impacts of land use practices on surface water can be on the mean annual runoff or on the seasonal distribution of water availability.

4.2.3.5 Other relevant indicators of hydrologic change

Other indicators of hydrologic change, which were relevant to the conditions found in the UGRRC include the number of river relocations, change of size of wetlands (shrinking or expanding), drying of rivers, change of water table levels (increasing or decreasing) and number of boreholes, wells and springs that had dried. These indicators were simple and could easily be understood by local people. The simplicity of these indicators originated from the fact that they could physically be seen and the local people knew their consequences.

4.2.3.6 Channel changes (river relocations)

Field surveys and past research reports revealed that, about 19 river relocations affecting eight rivers had occurred in the UGRRC since 1950s. Table 21 shows historical channel changes that had occurred in the MSC. Both natural and man-made causes were responsible for causing channel changes. Although no in-depth scientific study had been carried out to determine the factors responsible for channel changes, site visits and discussions with key informants from the respective villages revealed that seven of the eight river relocations in MSC were reported to have been triggered by man’s action, notably river diversions through poorly designed and constructed intakes and associated irrigation canals. These river relocations changed the flow regimes of the rivers resulting into flooding of residential (e.g. Ndembera River at Madibira and Mambi River at Utengule) as well as agricultural areas.

Table 21: Historical channel changes of Mkoji sub-catchment Rivers

Year	River	Channel change	Cause(s)	Source(s)
Mid 1950s	Mlowo	Used to flow to join Mkoji River, but now changed course at Mhwela village to flow in North-western direction	Triggered by a traditional irrigation canal	Site visit and Mr. Jeremiah Mwakimbwa of Mhwela village (personal communication, September 2002)
1962	Mambi	Used to flow to Northeast direction to join Mswiswi river, but now changed course at Luhanga village to flow northwards.	Locally made irrigation diversion and canal	Site visit and Said Madeda of Utengule village (personal communication, July 2003)
Mid 1970s	Mswiswi	Used to flow north east, but now moved north west to flow through an irrigation canal to Azimio village	Poorly designed and constructed irrigation intake and furrow	Site visit and Mzee Meshack Panja of Mswiswi village (personal communication, September 2004)
Late 1980s	Mambi	Used to flow north west, but now moved north east to flow through an irrigation canal to Utengule village	Poorly designed and constructed irrigation intake and furrow	Site visit and Mzee Habibu Tajiri, & William Amani of Uhambule village (personal communication, September 2004)
Early 1990	Mambi	River rerouted further north west near Utengule village to flow through its former lower course	Man-made	Site visit and Said Madeda of Utengule village (personal communication, July 2003)
Late 1990s	Mapala	Channel completely silted near Mapala sub village	Poorly designed and constructed water abstraction canals to NARCO Ranch and Mapala sub village	Site visit and Tito Daudi Makanje of Mapala sub village (personal communication, August 2003)
1998	Gwiri	Used to flow north west, but now moved east to join with Mapala river near NARCO ranch at Kilambo village	Natural, due to excessive floods	Site visit and Said Juma of Kilambo village (personal communication, November 2005)
1998	Mambi	Used to flow North, but now moved east to flow through an irrigation canal near Uhambule Pr. School	Poorly designed and constructed irrigation intake and furrow	Site visit, November 2005

4.3 Current Water Demands and Uses in Mkoji Sub-Catchment

A thorough study on water demands and uses conducted in the Mkoji sub-catchment (MSC) for the 2002/03 season showed that a number of competing uses drive demand for water in the MSC. These include domestic needs, irrigated agriculture, livestock, fishing, brick making and environment maintenance. The amount of water consumed daily for domestic, livestock and brick making is the net volume used. Livestock water consumption considered only the amount of water used directly for drinking. The analysis did not include the amount of water contained in the forage or that used in dips or for cleanliness. For the case of rainfed and irrigated agriculture, it was assumed that the calculated crop water requirement (CWR), hence water demands of the crops grown in 2002/03 season was wholly met by the available water resources. This means that water demand of the crops was equal to water consumption. The results of the study, categorised into wet (2002/03) and dry (2003) seasons are discussed in this section.

4.3.1 The 2002/03 Wet season

4.3.1.1 Crop water use under rainfed and intermediate agriculture

Table 22 shows water utilization and the areas under different crops in MSC during the wet season. The crop water use was determined from the crop water requirements (CWR) within the crop growth period for each crop. The area under rainfed agriculture is distributed into 2680 ha for the upper, 2867 ha for the middle and 4407 ha for the lower MSC. Total crop water use under rainfed conditions is 10.76 Mm^3

for upper, 12.41 Mm^3 for middle and 19.45 Mm^3 for the lower MSC. The large rainfed area in the lower MSC is due to the reduced flooding, which make it possible to grow maize and beans in soils that were previously too wet to be cultivated due to seasonal flooding. The total water requirement to grow crops under rainfed conditions in MSC is 42.6 Mm^3 (compare with the available water resource of 3190 Mm^3 over the entire sub catchment during the rainy season).

Table 22: Crop water use under rainfed agriculture in MSC

Crop name	Upper Zone			Middle Zone			Lower Zone		
	Area (ha)	CWR (m)	Volume of water (Mm^3)	Area (ha)	CWR (m)	Volume of water (Mm^3)	Area (ha)	CWR (m)	Volume of water (Mm^3)
Maize	575	0.46	2.65	665	0.46	3.06	1056	0.47	4.96
Wheat	362	0.37	1.34						
Millet	728	0.39	2.84						
Sorghum				1274	0.40	5.10	1995	0.41	8.18
Beans	468	0.32	1.50	231	0.34	0.79	484	0.35	1.69
Onions				47	0.45	0.21			
Tomatoes	311	0.48	1.49	207	0.48	0.99			
Potatoes	236	0.40	0.94						
Ground nuts				444	0.51	2.26	871	0.53	4.62
TOTAL	2680		10.76	2867		12.41	4407		19.45

Source: Own survey data (2003) and 2002 national population census results (TNW, 2003)

Table 23 shows the crop water use for paddy under supplementary irrigation in the middle and lower parts of MSC. Crop water use was 14.48 Mm^3 and 20.89 Mm^3 for the middle and lower zones respectively. Thus, the total water requirement to grow paddy under supplementary irrigation in the MSC was estimated to be 35.37 Mm^3.

Table 23: Paddy water use under supplementary irrigation in MSC

MSC Zone	Total area (ha)	CWR (m)	Volume of water used (Mm^3)
Middle	2194	0.66	14.48
Lower	3072	0.68	20.89
TOTAL (MSC)	5265		35.37

Source: Own survey data (2003) and 2002 national population census results (TNW, 2003)

4.3.1.2 Domestic water use

During the wet season, domestic water uses were found to range from 0.11 to 0.37 Mm^3 (Table 24). The total domestic water uses for the whole of MSC was estimated at 0.8 Mm^3.

Table 24: The 2002/03 Wet season domestic water uses

MSC Zone	Total hh	Average hh size	Population	Daily water use per hh (litres)	Daily water use per person (litres)	Wet season days	Total water use (Mm^3)
Upper	14 870	4.0	59 480	151	37.8	165	0.37
Middle	12 695	3.9	49 511	143	36.7	165	0.30
Lower	4352	5.9	25 677	153	25.9	165	0.11
MSC	31 917	4.6	134 667	149	33.4		0.78

hh = household

Source: Own survey data (2003) and 2002 national population census results (TNW, 2003)

4.3.1.3 Livestock water uses

The average number of livestock owned per household was converted into Tropical Livestock Units (TLUs) by applying the TLUs conventionally used for Sub-Saharan Africa. According to ILCA (1990), Jahnke (1982) and Williamson and Payne (1978) the units are given as follows: an adult cow is equivalent to 0.7 TLU; a donkey to 0.5

TLU; a pig to 0.3 TLU; goats and sheep to 0.1 TLU; and poultry 0.01 TLU. The average numbers of livestock and their corresponding TLU for the sample villages are summarised in Table 25. The average TLUs increase as one moves from the highlands to the plains. The average TLUs per household owning livestock for the upper, middle, and lower MSC were estimated at 3.1; 6.7 and 55.9 respectively. However, livestock ownership in MSC is not uniformly distributed. Most of the households own none or few TLUs and few households own numerous units. For example, in the lower MSC only 4% of the total households own more than 250 cattle and the majority (about 70%) own none or less than five cattle.

Table 25: Wet season livestock numbers and their corresponding TLUs

MSC Zone	Description	Cattle	Shoats	Chicken	Pigs	Total TLUs
Upper	Average TLUs	0.7	0.1	0.01	0.3	
	Average livestock per hh owning livestock	2.5	5.4	27.6	1.7	
	TLU(s) per hh owning livestock	1.75	0.54	0.28	0.51	3.08
Middle	Average livestock per hh owning livestock	6.3	6.3	36.6	4.3	
	TLU(s) per hh owning livestock	4.41	0.63	0.37	1.29	6.70
Lower	Average livestock per hh owning livestock	74.4	29.6	66.4	0.6	
	TLU(s) per hh owning livestock	52.08	2.96	0.66	0.18	55.88

Source: Own survey data (2003) and 2002 national population census results (TNW, 2003)

In general, the average TLU per household owning livestock in MSC was 21.9 (Table 26). The total numbers of TLUs in the zones are as shown in Table 26. The table shows that lower MSC has the highest number of TLUs as compared to the other zones and that the total number of TLUs for MSC stands at 308 234.

Table 26: Wet season average numbers of TLUs in MSC zones

Description	MSC Zone			Total
	Upper	Middle	Lower	(MSC)
Total number of households	14 870	12 695	4352	31 917
Percentage of households owning livestock	77.5	78.2	84.8	80.2
TLU(s) per household owning livestock	3.08	6.70	55.88	21.89
Total number of TLUs in the zone	35 495	66 514	206 225	308 234

Source: Own survey data (2003) and 2002 national population census results (TNW, 2003)

The calculation of water use by livestock was mainly based on estimates given by King (1983) and SMUWC (2001b). King (1983) states that an African indigenous adult cattle with 350 kg live weight in semi arid area consumes about 25 litres of water per day. However, discussions with pastoralists and livestock keepers revealed that water consumption by cattle (250 kg) is about 40 litres/day in the dry season when forage has low moisture content and 20 litres/day during the rainy season. These latter estimates are in line with the estimates given by SMUWC (2001b). Since an adult cow (250 kg) is equivalent to 0.7 TLU and consumes 20 and 40 litres/day during the wet and dry seasons respectively, it follows that 1.0 TLU will consume 28.57 and 57.14 litres/day for the wet and dry seasons respectively. For the purpose of this study, it has been taken that 1.0 TLU consumes about 29 litres of water during the wet season and 57 litres of water during the dry season. In the study area, the wet season lasts about 165 days and the dry season lasts 200 days. Using the estimates of the total number of TLUs in the zones, the volumes of water consumed by livestock were therefore estimated at about 0.17 Mm^3 for the upper MSC; 0.32 Mm^3 for the middle MSC and 0.99 Mm^3 for the lower MSC. The total amount of water consumed for the whole MSC was put at 1.47 Mm^3 (Table 27).

Table 27: Wet season water consumption by livestock in MSC zones

Description	MSC Zone			Total (MSC)
	Upper	Middle	Lower	
Total number of TLUs in the zone	35 495	66 514	206 225	308 234
Number of days	165	165	165	165
Water consumed by one TLU per day (litres)	29	29	29	29
Total water consumption (Mm^3)	0.17	0.32	0.99	1.47

Source: Own survey data (2003) and 2002 national population census results (TNW, 2003)

4.3.1.4 Brick making

According to the respondents interviewed during the questionnaire survey, there are no brick making activities during the wet season. This is because brick making requires dry weather conditions to dry the muddy bricks before burning.

4.3.1.5 Fishing

Although all of the interviewed households responded that they are not engaged in fishing activities, discussions with key informants during the Participatory Rural Appraisal (PRA) surveys indicated that there are small-scale fishing activities going on. This is particularly done in irrigation canals or in streams mainly in the middle and lower MSC. Few fishing ponds were also observed around Igurusi, Majenje, Mambi and Mhwela villages, and these are mostly constructed next to irrigation canals and filled twice a year (with occasional topping-ups in between) by diverting water from irrigation canals. These results imply that while fishing is an important livelihood supporting activity in other parts of the UGRRC, it can be described as being insignificant in Mkoji sub-catchment.

4.3.2 The 2003 Dry season

4.3.2.1 Crop water use (dry season irrigated agriculture)

The crop water use during the dry season for the upper and middle MSC is shown in Table 28. There is no dry season irrigation in the lower MSC (Ukwaheri and Madundasi) because all the available water in the rivers in MSC is used up in upstream areas. The total area under dry season irrigation in MSC is 2771 ha, apportioned into 1774 ha for the upper MSC and 997 ha for the middle MSC. The total amount of water used under dry season irrigated agriculture in MSC is thus estimated at 12.4 Mm^3.

Table 28: Crop water use under irrigated agriculture in MSC zones

Crop	Upper Zone			Middle Zone			MSC
	Total area (ha)	CWR (m)	Volume used (Mm^3)	Total area (ha)	CWR (m)	Volume used (Mm^3)	Volume of water used (Mm^3)
Maize	902	0.43	3.879	402	0.52	2.090	5.969
Onions	214	0.52	1.113	47	0.56	0.263	1.376
Beans	413	0.33	1.363	313	0.38	1.189	2.552
Tomatoes	245	0.46	1.127	235	0.57	1.340	2.467
Total	1774		7.481	997		4.883	12.364

4.3.2.2 Domestic water use

The analysis of domestic water uses during the dry season was done using the same approach as for the wet season. As shown in Table 29, the average water used was estimated at 0.39; 0.44; and 0.13 Mm^3 for the upper, middle and lower MSC respectively. The total volume of water used for domestic purposes for the whole of MSC during the dry season was thus 0.96 Mm^3.

Table 29: 2003 Dry season domestic water uses in MSC

MSC zone	Total hh	Average hh size	Population	Water use per household (litres)	Water use per person (litres)	Dry season days	Total water consumption (Mm^3)
Upper	14 870	4.0	59 480	131	32.8	200	0.39
Middle	12 695	3.9	49 511	175	44.9	200	0.44
Lower	4352	5.9	25 677	143	24.2	200	0.13
Total (MSC)	31 917	4.6	134 667	150	34.0		0.96

Source: Own survey data (2003) and 2002 national population census results (TNW, 2003)

4.3.2.3 Livestock water use

During the dry season, there is shortage of good pasture and water resources in MSC to support big herds of livestock. Discussions with pastoralists and livestock keepers revealed that only those with less than 40 herds of cattle could stay with their herds within the MSC. Those with large cattle herds migrate to other areas outside MSC with their shoats (sheep and goats). Thus, the number of livestock found in MSC is normally very low during the dry season particularly in the lower MSC where the average TLUs per households were found to decline from 55.9 in the wet season to only 8.7 during the dry season (Table 30). This is a decline of about 84%. The total number of TLU present in the MSC declined from 308 234 to 98 839 (Table 31).

Table 30: Dry season livestock numbers and their corresponding TLUs

MSC Zone	Description	Cattle	Shoats	Chicken	Pigs	Total TLUs
	Average TLUs	0.7	0.1	0.01	0.3	
Upper	Average livestock per hh owning livestock	1.5	3.3	27.6	1.7	
	TLU(s) per hh owning livestock	1.05	0.33	0.28	0.51	2.17
Middle	Average livestock per hh owning livestock	3	4.4	36.6	4.3	
	TLU(s) per hh owning livestock	2.10	0.45	0.37	1.29	4.21
Lower	Average livestock per hh owning livestock	10.4	5.7	67.4	0.6	
	TLU(s) per hh owning livestock	7.28	0.57	0.67	0.18	8.70

Source: Own survey data (2003) and 2002 national population census results (TNW, 2003)

Table 31: Dry season average numbers of TLUs in MSC zones

Description	MSC Zone			Total (MSC)
	Upper	Middle	Lower	
Total number of households	14 870	12 695	4352	31 917
Percentage of households owning livestock	77.5	78.2	84.8	80.2
TLU(s) per household owning livestock	2.17	4.21	8.70	5.03
Total number of TLUs in the zone	24 962	41 755	32 122	98 839

Source: Own survey data (2003) and 2002 national population census results (TNW, 2003)

The quantities of water consumed by livestock during the dry season were estimated at 0.28 Mm^3 for the upper MSC; 0.48 Mm^3 for the middle MSC; and 0.37 Mm^3 for the lower MSC. The total amount of water used for livestock in the whole of MSC was 1.13 Mm^3 (Table 32).

Table 32: Dry season water consumption by livestock

Description	MSC zone			Total (MSC)
	Upper	Middle	Lower	
Total number of TLUs in the zone	24 962	41 755	32 122	98 839
Number of days	200	200	200	200
Water consumed by one TLU per day (litres)	57	57	57	57
Total water consumption (Mm^3)	0.28	0.48	0.37	1.13

Source: Own survey data (2003) and 2002 national population census results (TNW, 2003)

When livestock are grazing outside the MSC, they are in essence using water resources from other sub catchments (in UGRRC). In other words, this water can be accounted for in the livestock water balance equation as "imported virtual water" and was proportioned as 0.12 Mm^3 for the upper MSC; 0.28 Mm^3 for the middle MSC; and 1.98 Mm^3 for the lower MSC. The total livestock "virtual water" imports in MSC were estimated at 2.39 Mm^3 (Table 33), which is twice as much as the amount of water consumed by livestock staying within the MSC during the dry season.

Table 33: 2003 Dry season livestock "virtual water imports" in MSC

Description	MSC zone			Total (MSC)
	Upper	Middle	Lower	
Total number of TLUs out of the zone	10 533	24 759	174 103	209 395
Number of days	200	200	200	200
Water consumed by one TLU per day (litres)	57	57	57	57
Total "virtual water imports" (Mm^3)	0.12	0.28	1.98	2.39

Source: Own survey data (2003) and 2002 national population census results (TNW, 2003)

4.3.2.4 Brick making

Brick making is normally a dry season activity. The study has revealed that about 32.5% of the total households (hh) in the upper, 25.6% in the middle and 21.3% in the lower MSC are involved in brick making. The average numbers of bricks made per household were 2531; 2137; and 2031 for the upper; middle; and lower MSC respectively. According to survey results, the amount of water used to produce 400 bricks was put at about 1.0 m^3. Using this figure, water used for brick making in MSC was estimated at 0.053 Mm^3 with much of it being used in the upper and middle MSC (Table 34).

Table 34: Water uses for brick making in MSC

MSC zone	Number of hh	Average number of bricks produced per hh involved in brick making	Percentage of hh making bricks	Total number of bricks produced	Total water consumed per annum (Mm^3)
Upper	14870	2531	32.5	12231690	0.031
Middle	12695	2137	25.6	6945079	0.017
Lower	4352	2031	21.3	1882688	0.005
MSC	31917	2233	26.4	21059458	0.053

Source: Own survey data (2003) and 2002 national population census results (TNW, 2003)

4.3.2.5 Fishing

As was the case during the wet season, there are only small-scale fishing activities, (mainly in the few fishing ponds), going on in MSC. Therefore, fishing can be described as being insignificant in Mkoji sub-catchment during the dry season.

4.3.3 Comparison of available water resources and water uses

The available data do not allow for the determination of a complete water balance for the Mkoji sub-catchment. However, the data do allow for comparison of the available water resource and water uses. Therefore, water losses in the conveyance and distribution system (by seepage, evaporation and evapotranspiration of weeds), and water used to sustain the ecosystem are excluded in this comparison. Although far from sufficient, these figures can help to shed light on the water budget of MSC.

Table 35 shows that during the wet season, human activities used only a small proportion (2.52%) of the available water resource (3189 Mm^3). The remaining (about 97%) was available for natural vegetation use, groundwater recharge, evaporation and run off to downstream areas. Even if gross water abstraction for paddy supplementary irrigation (equivalent to 150 Mm^3 for the 165 wet season days) and water losses through evaporation, seepage and deep percolation were taken into account, there would still be enough water to meet every sector's needs. However, the main problem lies in the distribution of this rainwater, both in time and space. The result is that even during the wet season, there are regular conflicts due to shortage of water, especially for paddy irrigation. The problem is very critical during the period from December to January when farmers establish their paddy nurseries as well as transplanting early paddy.

During the dry season, the available water resource (39.36 Mm^3) was more than the total net water used by various sectors (estimated at 17 Mm^3). However, this water was distributed over 25 rivers and streams scattered all over the sub-catchment. If the 2771 ha available for dry season irrigated agriculture were to be utilised, they would have required 124.5 Mm^3 of water as per irrigation practices (average abstraction was about 2.6 l/s/ha and dry season lasts 200 days). Thus, the available water resource during the dry season was not enough to even, irrigate the 2771 ha available for dry season irrigated agriculture, let alone to satisfy other uses. The excess water abstracted was not returned into respective rivers because most of these schemes either had no drainage systems or had dirty drainage canals.

Table 35: Comparison of water availability and uses in MSC

Sno	Water use	Wet season (Mm^3)	% of total water use	Dry season (Mm^3)	% of total water use
1	Domestic	0.80	1.00	0.96	5.68
2	Rainfed agriculture	42.60	53.09	NA	
3	Irrigated agriculture	35.37	44.08	12.36	73.18
4	Livestock in MSC	1.47	1.83	1.13	6.69
5	Migrated livestock	NA		2.38	14.15
6	Brick making	NA		0.05	0.30
7	Fishing	Negligible		Negligible	
	Water withdrawn	37.64		14.5	
	Total water use	80.24		16.89	
	Total available surface water	3189.00		39.36	
	Water use as (%) of available water	2.52		42.91	

4.3.4 Comparison of the 2002/03 and 2004/05 surveys results

The follow-up survey aimed at verifying the results of 2002/03 household water use survey as well as identifying key households' characteristics, local practices, attitudes, behaviour and perceptions of the people on various water issues. These are the driving factors that govern and are behind the observed water use patterns.

4.3.4.1 Water consumption and water storage structures for domestic uses

Table 36 compares the average domestic water use (for drinking, cooking, bathing, washing clothes and sanitation) per person per day during the two surveys. The table shows that there is not much difference in the total per capita water use during the wet and dry seasons. However, the figures for the 2004/05 follow-up survey for MSC are lower than the 2002/03 survey. The reason is that during the surveys, determination of water consumption excluded in-stream and in-canal use of water for bathing, washing clothes and cooking utensils preferred by majority of people during periods when water is available in rivers and irrigation canals. Majority of people in Igurusi, Majenje, Iyawaya and Imezu villages (covered during the 2004/05 survey) prefer in-stream and in-canal use of water because of the presence of rivers and canals that have flowing water throughout the year. The trend is the same for Ihahi and Uturo villages located near perennial Chimala, Kimani and Great Ruaha rivers. The results also highlight the importance of quantifying and including the contribution of in-stream and in-canal use of water in future water use studies.

Table 36: Average water consumption (litres/person/day)

Area	2002/03 survey		Follow-up survey (2004/05)	
	Dry season	Wet season	Dry season	Wet season
MSC	33.4	33.9	21.28	20.57
Ihahi and Uturo			16.17	14.79

Table 37 shows the capacities of water storage structures. The majority of respondents depend on clay pots (with capacities ranging from 20 to 40 litres) and plastic buckets of 20 litres each for water storage. Only a few individuals (15.9%) have large metal drums of 200 litres capacity for storing water during both the wet and dry seasons. The combined capacities of water storage structures for the surveyed households range from 10 to 676 litres with a mean of 101.3 litres during the wet season and a mean of 107.8 litres during the dry season (Table 37). Likewise, the number of days that water can be stored for domestic use ranged from 1 day to 13 days, with a mean of 5 days during the wet season; and from 1 day to 11 days, with a mean of 4 days during the dry season. It is therefore necessary to ensure that water is available at least once after every four days if the water requirement for domestic use in the UGRRC is to be met.

Table 37: Capacities of water storage structures

Description	No. of respondents	Minimum	Maximum	Mean
Capacity of water storage structures (litres) during wet season	330	10	676	101.28
Capacity of water storage structures (litres) during dry season	330	10	676	107.76

4.3.4.2 Water use for livestock

Out of 331 respondents, only 117 or 35.3% are livestock keepers. The type and average numbers of livestock per household owning livestock in individual MSC Zones and Ihahi/Uturo villages are shown in Table 38. The percentage of livestock keepers in MSC in 2004/05 (40.6%) is lower as compared to that of 2002/03 survey (80.2%). The reason for this is that in the 2002/03 survey, households owning chicken were also included, while in the 2004/05 survey, chicken were excluded, as their water consumption is insignificant. Otherwise, the trend is the same. There is no difference in water consumption per TLU. Table 38 further shows that although the Lower Zone has the smallest percentage of respondents with livestock, those few people own large herds and hence the average number of livestock is the highest as compared to the Upper and Middle MSC Zones. These findings highlight the importance of providing enough water for livestock in the Lower MSC. Ihahi and Uturo villages (in the middle zone of the UGRRC) have more or less the same livestock characteristics as the Lower MSC.

Table 38: Average livestock numbers per household owning livestock

Description	Upper MSC	Middle MSC	Lower MSC	Ihahi and Uturo
No. of respondents	56	142	47	86
Percent of hh with livestock	58.9	33.1	29.8	26.7
Cattle	2.9	5.2	28.4	24.6
Goats	3.0	3.9	13.5	11.5
Sheep	1.0	1.5	21.8	12.8
Donkeys	0.0	0.0	3.0	9.0
Pigs	2.5	1.5	3.0	2.8

4.3.4.3 Brick making

Of the 330 respondents, 51.2% undertook brick making in the season 2003/04. This figure is higher than the 26.4% of respondents found during the 2002/03 survey. One of the reasons is that 2003 was a very dry year and so there was very little water for brick making. Another major reason could be the fact that many people (especially in peri-urban settings) are now replacing their mud houses with houses built using burnt bricks. Water consumption for brick making ranged from 100 to 2000 (with a mean of 600) bricks for every cubic metre of water used (compare with 400 bricks per one cubic metre of water in the 2002/03 survey). The standard deviation was 2.64. This high variability of the perceived water use for brick making is due to, among other things, different soil types being used, initial soil moisture content of the soil and variation of brick sizes (the predominant brick size in 2004/05 was 10*20*30 cm).

4.3.4.4 Fishing

The 2004/05 survey found out that the scale of fishing currently taking place in the UGRRC is still small as was the case during the 2002/03 survey. However, field visits and interviews with key informants conducted in the study area shows that fish farming is gaining importance in the study area. For example, by the end of 2005, there were about 90 fishponds at Mambi, Mswiswi, Igurusi, Majenje, Nsonyanga and Shamwengo villages.

4.3.5 Social and economic factors affecting sustainability of water resources

4.3.5.1 Heavy dependency on irrigated agriculture to sustain livelihoods

The 2004/05 survey results show that 99.4% of the respondents are farmers (Table 39), implying that almost every person in the surveyed villages, apart from doing other economic activities, is primarily engaged in agricultural activities. Agriculture is therefore the basic activity that sustains livelihoods of the majority of people in the Upper Great Ruaha River Catchment. Paddy is the major wet season crop followed by maize and beans. About one-half of these farmers (55.3%), are involved in dry season irrigated agriculture. Major crops grown are maize, beans and tomatoes.

Other economic activities undertaken in the surveyed villages include trading, livestock keeping, working in the fields as casual labourers and formal salaried employment. The major reasons that make some farmers to desist undertaking dry season irrigated agriculture are: a) shortage of water (70.5%); 2) Lack of funds to hire plots (40.4%) and lack of suitable farm plots to undertake dry season irrigated agriculture (34.2%). The implications of these results are that if more water is made available during the dry season by savings realised from the upstream areas and people manage to raise funds to hire field plots, then almost everybody will be engaged in dry season irrigated agriculture. The result would be that water to sustain the environment in the downstream reaches would continue to be elusive.

Table 39: Characteristics of agriculture

Sno	Description	Frequency	Percent
1	Farmers	329	99.4
2	Non farmers	2	0.6
3	Farming during both seasons	169	51.4
4	Farming during wet season only	147	44.7
5	Farming during dry season only	13	4.0
6	Engaging in other activities during the dry season (324 respondents)	203	62.7
7	Engaging in other activities during the wet season (304 respondents)	159	52.3

4.3.5.2 Increased trend of in-migration in the UGRRC

Table 40 shows the extent of in-migration in the surveyed villages, whereas Table 41 shows the areas that have contributed to the observed in-migration of people to the surveyed villages. The results show that about one-half of the household heads in the surveyed villages are in-migrants. Igurusi and Majenje villages (middle MSC zone), which have improved irrigation schemes and have a semi-urban type of set-up; (being located along the Tanzania-Zambia Highway), have more migrants (76.8%) than natives. This is due to economic opportunities created by the presence of irrigation schemes as well as other activities. It is also a sort of a trading centre, with many paddy-hulling machines. Therefore, many traders come to Igurusi to buy rice, which is exported to other regions in Tanzania. Likewise, there are also many in-migrants (43%) in Ihahi and Uturo villages, thanks again to thriving paddy cultivation. On the contrary, the majority of people (92.9%) living in Iyawaya and Imezu villages (upper MSC zone) are inhabitants of the two villages. The number of in-migrants is negligible as there are limited opportunities to engage in dry season irrigated agriculture or other economic activities.

Table 40: Extent of in-migration in the surveyed villages

Category of the village	Number of respondents	Number of in-migrants	Percent	Remarks
Imezu/Iyawaya (Upper MSC)	56	4	7.1	Upstream villages inhabited by the native *Safa* tribe
Igurusi/Majenje (Middle MSC)	142	109	76.8	Mid-stream villages with semi urban type of set-up and presence of improved smallholder irrigation schemes
Luhanga/Mwatenga (Lower MSC)	21	5	23.8	Downstream villages (All respondents are from Luhanga village)
Uturo/Ihahi (Great Ruaha, Kimani and Chimala sub catchments)	86	37	43.0	Mid-stream villages with extensive paddy cultivation
Total	305	155	50.8	

Table 41 shows that majority of the in-migrants originate from districts within Mbeya Region (58.7%). The nearby Southern Highlands regions of Iringa and

Rukwa contribute 27.7% of the in-migrants. Other in-migrants, apart from coming from other regions in the country, migrated to the study villages from neighbouring countries of Malawi and Zambia. Table 42 reveals that the trend of in-migration is increasing with time. The period 1985 to 1994, which coincide with the improvement and development of many irrigation schemes, has the highest percentage of immigrants (32.9%). The major reasons for in-migration include undertaking irrigated agriculture (54.8%), to join parents and other relatives (20.6%) and to look for formal employment (12.3%). Other minor reasons for in-migration are looking for water and good pasture for livestock, medical reasons and to engage in trading.

Table 41: Origin of in-migrants

Sno	Origin of in-migrants	Percent	Remarks
1	Mbarali and Mbeya Rural districts	19.35	
2	Other districts in Mbeya Region	39.35	
3	Lake Zone Regions	2.58	Tabora and Shinyanga regions
4	Southern Highlands regions	27.74	Iringa and Rukwa regions
5	Other regions	9.03	
6	Neighbouring countries	1.94	Zambia, Malawi
	Total	100	

Table 42: Trend of in-migration

Sno	Period	Percent	Remarks
1	1950-1974	19.35	Pre-irrigated agriculture development
2	1975-1984	20.65	Irrigated agriculture gaining importance
3	1985-1994	32.90	Many irrigation Projects improved and constructed
4	1995-2004	27.10	More Irrigation schemes improved
	Total	100.00	

4.3.5.3 Contradiction between the national and local peoples' prioritisation of water uses

Respondents in the surveyed villages were asked to prioritise water uses (i.e. mention water use sectors that should be accorded first, second and third priorities in being supplied with water). Supply priorities as perceived by various water users in the surveyed villages are as shown in the multiple responses Table 43. Results show that the respondents perceive satisfying domestic water demands as being the number one priority (95.2%) followed by agriculture (91.5%). By multiplying the frequencies as given for the priorities number one, two and three by weighting factors of 3,2 and 1 respectively and adding, livestock keeping became priority number three (48.6%), brick making and construction (41.8%), environment (13.4%), preparation of traditional brews (4.4%), fishing (3.4%) and hydropower generation (1.5%).

The results show that although reserving water for environmental sustenance is accorded second priority in the National Water Policy (URT, 2002a), people in the rural areas have different perceptions, and satisfying environmental water demands was accorded fifth priority. In fact, most of the respondents who accorded fifth priority to environmental water use were fishermen, who depend on the availability of water in rivers to undertake fishing activities! Things are worse for hydropower generation in that it was ranked lower than even the preparation of traditional brews! One interesting feature of the results is that, with the exception of domestic water use, almost every respondent accorded the highest priority to his/her own sectoral water use. The country thus faces an uphill task of educating the people on the importance of reserving water for the environment to protect the ecosystems that underpin our water resources, now and in the future. Otherwise, almost all the available water from various sources will be used to first satisfy their priority water use sectors, leading to the degradation of the environment.

Table 43: Supply priorities (multiple responses)

Sno	Water use sector	Percent scored (331 respondents)
1	Domestic	95.2
2	Agriculture	91.5
3	Livestock keeping	48.6
4	Brick making and construction	41.8
5	Environment	13.4
6	Traditional brews preparation	4.4
7	Fishing	3.4
8	Hydropower generation	1.5

4.3.5.4 Willingness to reduce water use during periods of water shortages

Respondents were asked whether they are willing to reduce water use for irrigated agriculture during periods of water shortages. The results, as presented in Table 44 show that 78.9% of the respondents are willing to reduce water use during periods of critical shortages. Majority of the farmers (70%) have indicated that they are ready to release one-half of the available water for downstream use during water shortages.

Table 44: Willingness to reduce water use

Sno	Response (313 respondents)	Percent
1	Willing	78.9
2	Unwilling	21.1
3	Fraction of water that could be willingly "freed"	
	One-quarter	28.2
	One-third	0.4
	One-half	69.8
	Three-quarters	1.6

Table 45 shows the trend of willingness to reduce water use in individual zones. From the table it is clear that different attitudes were shown by Imezu/Iyawaya (Upper MSC), Igurusi/Majenje (Middle MSC), Luhanga/Mwatenga (Lower MSC) and Ihahi/Uturo (Chimala, Kimani and GRR sub catchments) villages. The willingness varied according to the farming system being practiced, the social-economic setup and the location of the villages in relation to the river (upstream or downstream). Table 45 shows that, the majority of farmers in the Middle Zone villages are willing to reduce water use in periods of water shortages. For example 91.5% and 87.3% of respondents in Igurusi/Majenje and Uturo/Ihahi villages respectively, which are located in the Middle Zone, are willing to reduce water use.

Table 45: Willingness to reduce water use in individual zones (percentage)

Response	Imezu/Iyawaya n=56	Igurusi/Majenje n=141	Ihahi/Uturo n=85	Mwatenga/Luhanga n=47
Yes	32.6	91.5	87.3	72.3
No	67.4	8.5	12.7	27.7

On the other hand, 31 out of 46 or 67.4% of respondents from Imezu and Iyawaya villages indicated that they are not willing to reduce their water use during the dry season so that downstream users can also access the little available water. This is very alarming given the fact that the two villages are located in the Upper Zone of MSC and they are therefore expected to reduce their water consumption in order to release water for downstream use. One of the reasons for this shocking attitude could be the fact that 78.6% of the respondents depend on dry season irrigated agriculture to sustain their livelihoods, and so any amount of water "surrendered" means loss of income culminating into failure to provide basic human necessities to the family.

There are also three other reasons that were mentioned to be the driving force behind the unwillingness. The first one is the presence of rotational irrigation schedules (cited by 71% of respondents). The farmers therefore strictly comply with the shift roster. However, the rotational irrigation schedules as per the shift roster have considered only the upstream intakes at Imezu and Itewe villages, and not the whole sub catchment. The second reason is that the water available during the dry season is not enough even to meet the requirements of upstream villages. The third reason is that the farmers feel that by virtue of being located in upstream areas they have *prior rights* to satisfy their water requirements first, before releasing the excess water (which is not there!) for downstream use. This attitude is very bad and should not be left to continue and flourish as it defeats the main objective of integrated water resources management, which is "ensuring that water allocation takes into account the interests of all who are affected in order to have equitable access to water resources for basin dependants".

4.3.5.5 How local water users address and adapt to natural and man-made water resources problems (coping strategies)

Results from the survey show that the major coping strategies in case of water shortage for irrigated agriculture are frequent cleaning of irrigation canals (82.1%) and institution of rotational irrigation schedules (55.9%) (Table 46). These are followed by modification of excavated bund basins (*vijaruba*) to reduce water losses and increase water storage capacity, reduction of cropped areas and delayed establishment of paddy nurseries. Other coping mechanisms for irrigated agriculture include digging of wells in the fields to store water for irrigating paddy nurseries and dry season crops, planting crops that require less water to grow and “stealing” water during the night. This literally means cutting off or reducing the supply of water to fields being irrigated and re-directing the water to one’s field(s). This habit is very common and it usually results into physical confrontations among the irrigators.

Reduction of household water consumption, unclogging and cleaning of water conveyance systems and sealing of leaking points are some of the strategies employed to cope with water shortages for domestic use. For the case of livestock keeping, the leading coping strategies include use of ponded water in the river-beds during the early part of the dry season, fetching water from distant sources by using donkey-pulled carts and migrating to swampy areas at the peak of the dry season.

Table 46: Coping mechanisms and strategies in periods of water scarcity

Water use	Coping mechanism (313 respondents)	Percent
Domestic	Reduction of amount of water used for various household activities	100.0
	Unclogging and cleaning domestic water supply intakes	16.7
	Controlling and reducing water losses through leakages and (e.g. sealing leaking points)	10.8
	Utilising other distant sources of water e.g. springs, irrigation canals	8.9
	Digging traditional wells	1.3
Irrigation	Frequent cleaning of irrigation canals	82.1
	Institution of rotational irrigation schedules (irrigation shift roster)	55.9
	Completely filling to capacity and sealing all sources of water leakages from the excavated bund basins (vijaruba)	27.8
	Increasing the storage capacity of the excavated bund basins by increasing the height and size of the bunds	26.5
	Reduction of cultivated areas	15.7
	Delaying establishment of paddy nurseries until when the rain season starts	8.0
Livestock	Watering livestock using water found in surface ponds formed naturally in the river beds	43.0
	Fetching water from distant rivers by using oxen or donkey pulled carts	29.0
	Migrating to other distant areas where there is enough water	23.0
	Reducing livestock water consumption by feeding the livestock with only grass instead of also using maize husks	11.0
	Mixing drinking water with animal feed	3.0

4.4 Water Abstraction Patterns in UGRRC

4.4.1 Water abstraction by irrigation canals in UGRRC

Table 47 shows the pattern of water abstraction by the irrigation canals. These results show that all the canals studied, except Mbuyuni canal, abstract water throughout the year, provided there is water in the rivers, irrespective of the conditions spelt out in their formal water rights. In general, the abstraction pattern of irrigation canals is such that:

(i) Where the area is under paddy cultivation (e.g. Mbuyuni scheme), maximum abstraction occurs in March/April. The reason for this is that during this period water requirement by paddy is at the maximum and also water availability in rivers is at the maximum. Other months with relatively large abstractions are January and May;

(ii) When the area is under dry season irrigated agriculture (for example Habadaa and Inyala B schemes), relatively large abstractions occur in the months June through to November because the area is under intensive irrigated agriculture throughout this period;

(iii) When the scheme has a bigger area under dry season irrigated agriculture than that under paddy irrigation (for example Kongolo Mswiswi and Luanda Majenje), maximum abstractions occur in January/February (due to irrigation of maize crop planted in November and transplanting of paddy) and in June/July (the start of intensive dry season irrigated agriculture); and

(iv) Where there is multiple use of water such as domestic, livestock, and agriculture (e.g. Iyawaya scheme), maximum abstractions depend on the availability of water in rivers.

The significance of these findings is that they pinpoint the period when auditing, control, and regulation of the amount of water being abstracted will have greater positive effects in ensuring that as much water as possible flows to downstream areas. For example, March and April are the most appropriate months to undertake control and regulation of water abstractions for schemes engaged in paddy cultivation. Likewise, June and July are the most appropriate months for schemes undertaking dry season-irrigated agriculture. It is also worth noting that it is very crucial to monitor water abstractions in the month of November because this is the month in which river flows are at the minimum and water is required to establish paddy nurseries and to irrigate maize crop planted in October/early November. Otherwise, downstream areas will face critical water shortages. A map showing the location of studied water abstraction intakes is included in Appendix 6.

Table 47: Mean daily irrigation canal abstractions[6] (l/s)

Canal Name	Year	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ipatagwa	2003	333.7	324.2	364.7	381.8	361.7	328.4	224.7	188.3	150.8	122.8	116.7	139.6
	2004	231.5	249.2	378.3	920.8	552.5	306.5	160.7	138.4	71.0	59.2	56.1	245.4
Mkoji	2003	68.1	63.2	76.5	92.2	73.5	84.3	54.7	28.0	17.3	17.3	20.8	31.3
Moto Mbaya	2003	170.4	116.0	114.3	163.9	112.7	134.6	95.7	45.0	23.2	12.2	17.7	25.3
	2004	38.8	92.0	433.2	923.7	325.9	235.0	95.3	125.9	151.0	115.6	104.0	216.0
Kongolo Mswiswi	2003	120.2	150.7	90.2	98.8	102.8	133.1	94.6	84.9	64.5	58.6	53.4	49.0
	2004	100.9	93.0	95.8	133.5	177.7	121.0	118.8	94.8	92.9	71.9	45.5	65.5
Luanda Majenje	2003	109.7	126.5	101.3	151.5	89.8	45.3	62.3	40.9	45.8	43.0	15.7	40.3
	2004	105.4	203.7	210.9	180.3	190.0	152.2	89.8	82.8	66.9	48.2	28.5	86.0
Inyala B	2004	nd	nd	nd	35.1	38.0	38.0	48.0	79.3	65.5	38.2	32.2	30.0
Iyawaya	2004	nd	nd	nd	73.9	48.6	31.5	33.1	23.1	22.7	26.5	29.5	43.6
Mbuyuni	2003	1087.3	1258.7	1220.6	1897.3	954.3	247.2	187.3	203.7	124.4	173.8	284.1	824.3
	2004	2292.5	2469.1	2794.1	2424.7	934.6	0.0	0.0	0.0	0.0	0.0	219.3	692.3
Hassan Mullah	2003	233.4	191.0	190.7	321.0	112.5	87.9	69.6	76.7	50.9	99.7	224.5	412.2
	2004	658.6	763.5	510.3	706.1	516.3	337.8	141.2	152.3	131.5	136.9	230.4	426.8
Igomelo	2003	301.8	353.9	398.3	408.6	330.6	272.9	258.3	289.1	320.5	262.2	322.6	311.6
	2004	367.9	313.9	540.3	435.2	382.4	342.8	305.6	275.2	291.0	358.7	380.1	379.7
Habadaa	2004	10.9	8.6	8.6	7.7	16.8	18.9	19.8	18.5	18.7	18.5	18.8	9.4

nd = no data

[6] Obtained by summing mean daily discharges and dividing by the total number of days in the month

4.4.2 Formal water rights and water availability in rivers

Both formal and informal water rights are in use in the UGRRC. Formal water rights are embodied in official certificates and normally relate to access to water quantities measured volumetrically (in cubic metres) or by a flow rate (e.g. litres/second). Informal rights are based on customary arrangements and social norms and are embedded in local practice. Customary rights relate to access to water described by an approximate share (proportions) of the available water (e.g. "about one-half of what is present in the stream"), in terms of shifts or hours of water availability at an intake during rotational irrigation schedules. Customary rights are mostly used to allocate water within the irrigation canals or furrows (intra canal water rights).

4.4.2.1 Challenges of implementing formal water rights systems in Tanzania

Having a policy or a law is one thing and proper implementation of the same is something else. This is true for the implementation of formal water rights systems in Tanzania. Many people in Tanzania, like in other developing countries still believe that water is God-given and people who stay close to the water have the right to use it in any way they deem appropriate. As a result of this attitude and changes in the way human beings use water now, implementation of formal water rights system in Tanzania is not optimal due to the following challenges.

(i) A fairly lengthy procedure for obtaining formal water rights

The issue of granting formal water rights is dealt with in accordance of section 15 of the Water Utilization (Control and Regulation) Act No. 42 of 1974 and the regulations of 1997 made under section 38 (2) of the Act. The law has put in place a procedure that has to be followed before formal water rights are granted. The current procedure is as shown in Box 1. The first major problem facing formal water rights implementation in Tanzania is delays in granting the formal water rights. It takes a long time (sometimes more than three years) between submissions of application forms to the time when a decision on the application is made. The situation is clearly shown in Table 48. The delay in formal water right issuance is largely due to the long bureaucratic formal water right issuing procedure put in place by the Ministry of Water. The procedure was well intentioned (as it was intended to minimize power abuse by the Basin Water Office (BWO) by ensuring that other interested government institutions and the public at large are properly consulted before granting formal water rights). However, its implementation has resulted in delays in granting formal water rights. Three major factors are contributing to the delays.

The first factor is that the consulted government institutions do not respond and provide the required information within the 40 days. The BWO can not proceed with the process of granting formal water rights before receiving the required information. The second factor is that BWO do not have enough human and financial resources to timely ‘chase” and follow up responses from consulted government institutions. The third factor is that the frequency of Basin Water Boards (BWBs) meetings limits the number of formal water rights that can be granted annually. The BWBs meet twice a year, and for the case of Rufiji Basin Water Board, it can only approve 20 formal water right applications at a sitting or 40 formal water rights per year.

Box 1: Procedure for granting water rights in Tanzania

1. The person who requires to be a water user applies to the appropriate Basin Water Officer (BWO) through an application form filled in quadruplicate. The forms are then submitted to the Basin Water Officer together with an appropriate application fee (current fee is Tshs. 40,000/=). In most cases a letter will accompany the application from the village government where the project is supposed to be executed, to show the authenticity of both the applicant and the project;
2. When the application is received the BWO enters it in a register and opens a file of the application. The BWO acknowledges receipt of the application forms and the application fee in writing
3. The BWO requests for information on the said application from people and experts who can provide information regarding the matters pertaining to the nature of application. People who are most commonly contacted are: District Executive Director (DED) of the relevant district (on current and customary rights); District Administrative Secretary (DAS) of the relevant district (to report on any issues of concern, such as conflicts); the District Agricultural and Livestock Development Officer (DALDO), under whom the District Irrigation Officer works (for estimation of water requirements and technical agricultural report); and the Regional Water Engineer (RWE) (for submission of hydrological (water availability and quality) and hydraulics reports). The information is required to assist the Water Officer in issuing the grant. In most large water use projects the applicant is asked to submit an Environmental Impact Assessment (EIA) Study Report to the Basin Water Board;
4. The Water Officer then submits the application to the Principal Water Officer for information and for announcement in the Government Gazette. The application, after being published in the Government Gazette will also be made public at the respective District Commissioner's notice board. The process of publishing the application in order to receive objections (if any) from the wider public is scheduled to take 40 days;
5. After the Basin Water Officer has received the requested information, and if there are no objections from the relevant parties, the application will be taken to the Basin Water Board for discussion. The Board will advise the Basin Water Officer on steps to take.
6. The BWO then offers a Provisional Water Right Grant to last for a year. The Provisional Grant allows the applicant to start construction work (for new projects). In case of users who already have an intake that encompasses a “basic” structure, but is able (if operated properly) of allowing some water to flow down the river (avoids total abstraction) and drainage water to be safely returned to the river, the Provisional Grant allows the applicant to undertake improvements of the irrigation infrastructures. If the works are not completed in the prescribed time, the applicant will ask for an extension of time. After completion, the works are inspected by the relevant RWE. If he/she is satisfied that the required improvements have sufficiently been incorporated, the Basin Water Officer will be informed so that he/she can issue a Final Water Right Grant.
7. If any of the consulted institutions and people object, the applicant is asked to respond in writing. After evaluating the objections and the applicant responses, the BWO asks the parties to appear in person and make their case. If an agreement is reached, the application is forwarded to the Basin Water Board (BWB) for approval;
8. If the BWO fails to secure such an agreement, both the applicant and the objector(s) make their case to the BWB members under oath. The BWB makes a decision to grant/deny based on a majority rule;
9. If any of the parties are not satisfied by the Board’s decision, they have the right to appeal to the Minster for Water, whose decision is final and binding.

Table 48: Water rights application status in the UGRRC as of June 2005

Water right application number	Name of applicant	Application year	Granting year	Remarks
RBWO219	Chapakazi Irrigators Association	2000	Being processed	Abstracts water
RBWO260	Umoja wa Watumia Maji Inyala A	2001	2004	Provisional water right
RBWO261	Umoja wa Watumia Maji Inyala B	2001	2004	Provisional water right
RBWO271	Imezu village Irrigation Scheme	2001	Being processed	Abstracts water
RBWO287	Umoja wa Umwagiliaji Lyahamile	2002	Being processed	Abstracts water
RBWO322	Kikundi cha Umwagiliaji	2002	Being processed	Abstracts water
RBWO329	Nguvu Moja Isongwa	2002	Being processed	Abstracts water
RBWO349	Mfereji wa kati - Azimio	2003	Being processed	Abstracts water
RBWO350	Umwagiliaji mfereji wa Majojoro - Azimio	2003	Being processed	Abstracts water
RBWO359	Umwagiliaji Mkombozi - Igurusi	2003	Being processed	Abstracts water
RBWO364	Mkombozi Idunda	2003	Being processed	Abstracts water
RBWO453	Mfereji wa Muungano - Igurusi	2003	Being processed	Abstracts water

Source: RBWO Water right archives 2005 and site visits

Investigation of formal water rights application trends in the Rufiji River Basin shows that since 2002, the RBWO has been receiving about 46 formal water right applications annually (Table 49), which are above the maximum 40 formal water right applications the BWB can approve per year (if it manages to meet twice a year). Furthermore, there are also many formal water rights applications dating before 2002, which have not yet been decided. Therefore, the first challenge facing basin authorities is to ensure timely granting of formal water rights.

Table 49: Water rights application trends in Rufiji Basin as of June 2005

Sno	Year	Water rights applications
1.	2002	53
2.	2003	25
3.	2004	73
4.	2005	31
	Total	182

Source: RBWO water right archives

The consequences of these delays are that water right applicants hesitate to undertake improvements of their irrigation infrastructures, as they are not sure of the fate of their applications. It is also very difficult for the applicants to solicit funds from funding agencies to improve their infrastructures without having a Provisional Water Right Grant that specifies the kind of improvements that need to be undertaken. For example, development partners who provide funds for implementation of District Agricultural Development Plans require irrigation schemes to have formal water rights before they can be assisted to improve their irrigation infrastructures. Likewise, all the fifteen schemes improved during the World Bank funded River Basin Management and Smallholder Irrigation Improvement Project (RBMSIIP) were required to formalise their water rights during the implementation of the project. Thus in order to reduce the delays in granting formal water rights, and allow the applicants to undertake timely improvements of their irrigation infrastructures required for better water management, there is need to institute some “fast track” methods that could speed up the process. Currently, as an interim solution to those who have applied for and are waiting to be granted with formal water rights, the Rufiji Basin Water Office provides an “official letter” acknowledging receipt of the application forms and the application fee in writing. Therefore, although water right applications are not yet a right, based on this letter, the RBWO informally recognizes the concerned users as formal (to differentiate them with those who have not even applied for formal water rights) and charges them economic water users' fees.

(ii) Non-adherence to conditions spelt in the water rights

According to the law, applicants are only allowed to start abstracting water after having been granted with a Final Grant (under special circumstances, Provisional Grant holders can also be allowed to abstract water). However, the situation is different in practice. Because of the delays in obtaining a formal water right and taking into consideration the informal 'grace period' of five years given to traditional irrigation schemes to formalise their water uses, these schemes continue to abstract water just after submitting their application forms. The reason for this is that they still need to irrigate their fields while waiting for formalisation of their water abstraction intakes. However, even after obtaining Provisional Water Right Grants, traditional schemes rarely undertake and finish construction works and as such, most of these schemes continue to operate with 'expired' Provisional Water Right Grants for many years. For the case of new irrigation schemes, abstraction of water usually starts after they obtain Provisional Water Right Grants and have completed part of the construction works. However, these applicants rarely finish the construction works such that in most of these schemes water controlling, regulating and measuring structures that are necessary for proper water control are missing. Investigation of the formal water rights in the UGRRC (Mbarali and Mbeya (Rural) districts only) as of June 2005 (Table 50) showed that whereas Final Water Right Grants accounted for only 19% of all formal water rights issued or applied for, Provisional Water Right Grants and Applications accounted for 33.5% and 47% respectively. The second challenge facing basin authorities is thus to ensure that all Provisional Water Rights grant holders complete the required construction works.

The abstraction period and the amount of water allowed to be abstracted are clearly indicated in the formal water rights issued. However, the study of water abstraction patterns has shown that all the canals studied, except one, abstracted water throughout the year, provided there was water in the rivers. This was contrary to the conditions spelt out in their formal water rights, which require them to abstract water during certain specified months. Unfortunately, though, there are about 150 intake structures in the UGRRC, scattered over a large area, which makes it difficult for the under-staffed Basin Water Office to make timely and close follow-ups to ensure that water rights conditions are adhered to. Therefore, the third challenge facing basin authorities is to ensure that formal water rights holders comply with conditions spelt in their water rights.

Table 50: Status of water rights (WR) in the UGRRC

Sno	Source name	No. of WR issued or applied for	Type of grant			U	N	A
			Final	Prov.	App.			
1.	Habadaa spring	1	0	0	1	0	0	0
2.	Chimala River	17	7	6	4	5	0	2
3.	Dudumizi	1	1	0	0	0	0	0
4.	Gogo Spring	3	0	0	3	0	0	0
5.	Great Ruaha River	3	1	0	2	0	1	0
6.	Gwiri River	2	0	1	1	0	0	0
7.	Halinji Spring	2	0	0	2	0	0	0
8.	Haluya Spring	2	0	0	2	0	1	0
9.	Hamwenje Spring	2	0	0	2	0	0	0
10.	Hansiya Spring	1	0	0	1	0	1	0
11.	Hatete Spring	1	0	0	1	0	0	0
12.	Havulwa River	1	0	0	1	0	0	0
13.	Ilaji River	1	0	0	1	0	0	0
14.	Iwava Spring	1	0	0	1	0	1	0
15.	Ipatagwa River	2	0	1	1	0	0	0
16.	Kapyo River	1	0	1	0	0	0	0
17.	Kimani river	8	1	4	3	0	1	1
18.	Kioga River	16	0	11	5	0	0	0
19.	Lunwa River	7	1	4	2	0	1	0
20.	Lwanyo River	2	0	2	0	0	0	0
21.	Mambi River	12	0	8	4	2	0	0
22.	Mapo River	1	0	1	0	0	0	0
23.	Mbarali River	13	6	5	2	0	1	0
24.	Meta River	7	2	0	5	1	1	0
25.	Mgona Stream	1	0	1	0	0	0	0

Table 50: Continued

Sno	Source name	No. of WR issued or applied for	Type of grant			U	N	A
			Final	Prov.	App.			
26.	Mkoji River	4	0	1	3	3	2	0
27.	Mlowo River	21	9	5	7	3	2	1
28.	Mpolo River	7	0	0	7	0	0	0
29.	Mswiswi River	15	1	5	9	2	0	0
30.	Mwambalizi R.	16	3	3	10	1	1	0
31.	Mwandiya Spring	1	0	0	1	0	0	0
32.	Ndembera River	8	4	3	1	3	1	0
33.	Nkwanana Stream	2	0	1	1	0	0	0
34.	Nsalaga stream	7	1	2	4	0	4	0
35.	Nyamono Stream	1	0	1	0	0	0	0
36.	Nyenywa Spring	1	0	0	1	0	0	0
37.	Saawa River	3	0	0	3	0	0	0
38.	Uta River	3	0	0	3	0	0	0
Total		197	37	66	94	20	18	4
Percentage			18.78	33.50	47.21			

Note:

U = Unconfirmed (Status not known)

N = Non Operational (Not ready for use; still under construction)

A = Abandoned (Not being used)

WR = Water Right

Description of Grants

App. = Application: Applicant has applied for a Water Right

Prov. = Provisional: Applicant has been allowed to start construction activities

Final: Applicant is allowed to use water after completion of the works

(iii) Mismatch between granted water rights and actual water requirements

Formal water rights for irrigation use, which are required to be issued basing on long-term mean flows and irrigated areas, are in some cases, based on potential irrigation command areas (not developed irrigation areas). When just a portion of the potential area is developed due to financial limitations, the granted Provisional Water Right is not adjusted promptly to match with the developed area. Furthermore, not all the developed area is cultivated each year because of unreliable rainfall and hence river flows. Worse still, many formal water right applicants are content to have the Provisional Water Right grants and therefore do not complete the required works in order to get the final grant. Given the manpower shortages facing basin authorities, the Basin Water Officer as well as the Regional Water Engineer thus do not undertake final inspection of the works (because they are not yet completed!) and the water demand sites in order to adjust the Final Water Right Grant accordingly. As such, in most of the schemes, the volumes of water granted in the formal water rights are much higher than the actual water requirements. Therefore, the fourth challenge facing basin authorities is to ensure that formal water rights match with water requirements. Comparison of water righted and abstracted volumes (Figure 45) illustrates the challenge.

Figure 45 shows that with the exception of Igomelo and Hassan Mullar schemes (relatively small schemes located in a large perennial river – Mbarali River), all other schemes abstracted less annual volumes of water than permitted in the formal water rights. The under-utilisation of the formal water rights is due to a number of reasons such as higher granted water rights volumes than the actual water requirements (already discussed in section 4.4.2.1 (iii)) and/or low stream flows (discussed in section 4.4.2.1 (iv)).

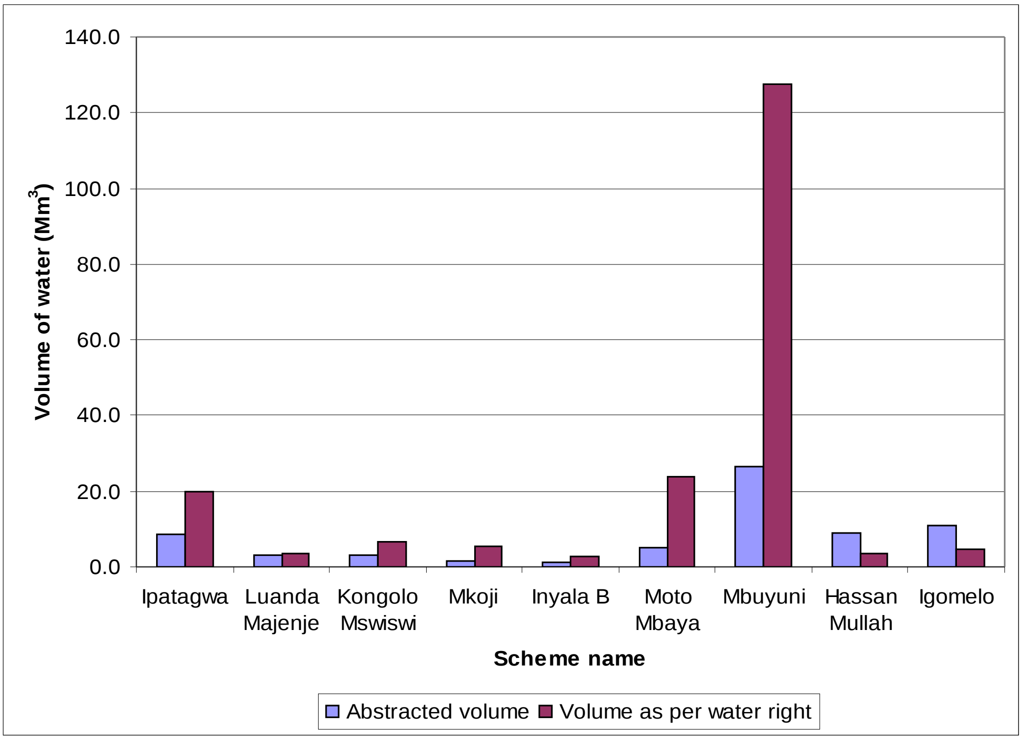


Figure 45: Comparison between abstracted and water righted volumes

The relationship between water rights, the amounts of water diverted from the sources and water requirements was investigated for Kongolo Mswiswi, Luanda Majenje and Habadaa irrigation schemes. The results (Table 51) showed that the abstraction rates were 0.9 l/s/ha for Habadaa (in the upper zone) and 1.8 and 4.3 l/s/ha (average of 2003 and 2004 dry seasons) for Kongolo Mswiswi and Luanda Majenje irrigation schemes respectively (in the middle zone). Considering maize as a representative crop (it is a major dry season crop grown extensively in all the schemes with an average growing period of 120 days), the above abstraction rates translate to 962, 1903 and 4419 mm of water respectively. These values are higher than the gross crop water requirements for maize, which have been estimated at 435 and 521mm for the upper and middle zones respectively (SWMRG, 2003). Thus, the upper zone irrigation scheme abstracted 962 mm of water instead of 435 mm (twice as much), whereas middle zone schemes abstracted an average of 3161 mm of water instead of 521 mm (6 times more) required to grow the same maize crop during the dry season. For the case of water abstraction for irrigated paddy, Kongolo Mswiswi and Luanda Majenje schemes abstracted an average of 3.35 l/s/ha instead of 1.68 (twice as much), which is normally taken as the gross water requirement for paddy in the UGRRC (SMUWC, 2001b; RIPARWIN, 2005). Therefore, although the annual volumes of water abstracted by Luanda Majenje and Kongolo Mswiswi schemes were less than the volumes spelt out in their formal water rights (Figure 45), there was still over-abstraction of water above what is needed for the size of areas and type of crops cultivated. In the absence of well functioning drainage systems, much of the excess water abstracted is lost through evapotranspiration.

The observed over-abstraction is due to the prevailing water use practices or low water users' fees. According to the Water Utilization (General) (Amendment) Regulations of 2002 (URT, 2002b), the annual water users' fees for small scale irrigation have been set at a flat rate of Tshs. 35 000.00 (USD 28) for all abstractions less than 3.7 l/s and Tshs. 35.00 (USD 0.028) per 1,000 m^3 for abstractions equal to or above 3.7 l/s.

Table 51: Relationship between amounts of water abstracted and water requirements

Scheme name	Year	Period of abstraction		Mean daily abstraction (l/s)[7]	Cropped area (ha)	Hydro[8] module (l/s/ha)	Depth used (mm)	Actual water requirement
		Wet season	Dry season					
Habada a	2004		July-Nov	18.87	20.34 (maize)	0.928	962	435 mm
Kongolo Mswiswi	2003		July-Nov	71.80	40.97 (maize)	1.835	1903	521 mm
	2004		July-Nov	84.73	44.20 (maize)			
Kongolo Mswiswi	2003/04	Dec-June		110.12	45.73 (paddy)	2.408	2497	1.68 l/s/ha
Luanda Majenje	2003		July-Nov	41.54	11.05 (maize)	4.262	4419	521 mm
	2004		July-Nov	63.18	13.26 (maize)			
Luanda Majenje	2003/04	Dec-June		154.68	36.00 (paddy)	4.297	4455	1.68 l/s/ha

Whereas individuals with traditional intakes pay an annual flat rate of USD 28, smallholder irrigation schemes are charged variable fees depending on the amount of water abstracted. However, due to the shortage of staff facing Basin Water Offices and absence of water measuring devices in traditional irrigation schemes, the actual amount of water abstracted is not measured. Water charges are thus based on the amount of water granted in the formal water right. Irrigators in traditional smallholder irrigation schemes usually pay an average of Tshs 1000.00 (USD 0.8) per person per annum as annual water users' fees. The schemes' Water Users

[7] Obtained by summing mean daily abstractions and dividing by the total number of days in the period

[8] Recommended hydro module for paddy is 1.68 l/s/ha and recommended depths of water for maize are 435 mm for Habadaa and 521 mm for Kongolo Mswiswi and Luanda Majenje schemes

Associations or Irrigation Committees, as the case may be, collect the fees on behalf of RBWO. In most of the traditional irrigation schemes in the UGRRC, all irrigators pay equal amounts of water use fees per annum, irrespective of the location of the field (at the head, middle or tail of the canal), or the actual amount of water consumed. The annual water use fees paid by irrigators are meant to service economic water users' fees charged to the scheme by Rufiji Basin Water Office as well as to cater for operational and maintenance costs of the irrigation system as determined during the members meeting. The average gross margin for a farmer who harvests 2 tons of rice per hectare is Tshs. 100 000.00 (USD 80) (Rajabu and Mahoo, 2006). Thus, the annual water use fee (USD 0.8) seems to be relatively low as compared to the income generated from the use of water.

(iv) Mismatch between granted water rights and water availability in rivers

In some river systems, the water quantities stipulated in the formal water rights are higher than the available water in the rivers, especially during the dry season and during dry years. This is clearly shown in Table 52 where the total granted wet season water amounts exceed the available river flows in Kimani, Ipatagwa, Mlowo, Mswiswi, and Lwanyo rivers. Likewise, the granted dry season water amounts also exceeded the available river flows for Mbarali, Kimani, Mswiswi, Mlowo, Lwanyo, Gwiri, and Mwambalizi rivers. It is worth noting that this analysis has been done by considering only the Final and Provisional Water Right Grants. If water right applications, which are yet to be decided by the basin authorities (but whose applicants also abstract water), were also considered, it is highly probable that the formal water rights would have exceeded the available river flows in almost all rivers. The river flows used in the analysis comprise the 2003 and 2004 daily flow data. The reason for this mismatch is that most of the water rights, which are supposed to be issued basing on long-term mean river flows, are actually issued basing on a few discharge measurements done on a particular river. These few discharge measurements, mostly done during the wet season, tend to overestimate the available water resources and do not represent the long-term mean flows, let alone the current river flows. Faraji and Masenza (1992) reported similar findings. They noted that under the prevailing formal water rights system, the amounts of water issued was more than the total available flow in the rivers, such that formal water right owners do not get authorised amounts during the dry season. The above situation is not fair as rights mean little unless there are ways to enforce them when they are infringed.

The overall consequences of these challenges are that formal water rights have failed to control and regulate water use such that some rivers, which were once perennial, dry up in upstream areas during the dry season, downstream water users suffer more from water shortages and some sub-catchments (e.g. Mkoji) are now seasonally closed contributing zero flows to the Great Ruaha River during the dry season. The fifth challenge facing optimal implementation of formal water rights systems in the UGRRC is thus to match formal water rights with available river flows.

Table 52: Relationship between granted water rights and river flows (m^3/s)

River Name	Wet season flows Dec-April (151 days)	Wet season WR Dec-April	Dry season flows May-Nov (214 days)	Dry season WR May-Nov	Daily flows 2003/04	Remarks
Mbarali	13.962	9.135	3.605	5.624	7.875	
Kimani	6.042	10.007	1.534	2.932	3.329	
Ipatagwa	0.631	1.000	0.405	0.357	0.499	
Mkoji	0.354	0.300	0.097	0.086	0.203	
Mswiswi	1.270	4.768	0.433	1.653	0.782	
Mlowo	1.141	1.630	0.509	0.695	0.766	
Lwanyo	0.741	1.580	0.205	0.460	0.436	
Lunwa	1.769	0.798	0.535	0.138	1.049	
Meta	No data	No data	0.101	0.005	No data	Jun-Nov
Gwiri	No data	No data	0.100	0.818	No data	Jun-Nov
Mambi	No data	No data	0.272	0.025	No data	Jun-Nov
Mwambalizi	No data	No data	0.067	0.072	No data	Jun-Nov

4.4.2.2 Opportunities for improving the management of water rights systems

Despite the aforementioned challenges, the current formal water rights management system in Tanzania has its strengths and there are opportunities for improving its implementation. Rights are at the heart of any water allocation system and are still needed to regulate water abstractions and reduce or halt over-abstraction of water. There seems to be eagerness among water users in Tanzania to obtain formal water rights, even though they very well understand that having a formal water right will make them pay water users' fees. Most local level water users in the UGRRC are aware now that given the dwindling supplies of water, they need to have formal water rights in order to: (a) provide them with a legal tool to safeguard their water resource against any infringement by big private investments; (b) enable them undergo training in proper water management and agronomic practices; (c) enable them seek and obtain financial and technical assistance to improve their irrigation infrastructures; and (d) be able to get help from formal government organs and institutions in solving water conflicts. On the other hand, Basin Water Offices need formal water rights to serve as a benchmark for better control and regulation of water utilization and collection of water users' fees. The willingness to acquire formal water right permits has undoubtedly positively contributed to the great strides made by the Rufiji Basin Water Office in registering water users (Figure 46). Since water rights are very important in water management, local level water users and Rufiji Basin Water Office have devised and are employing a number of strategies to respond to the challenges as discussed in the following sections.

(i) Introduction of rotational irrigation schedules

Rotational irrigation schedules provide an equitable way of sharing the available water in times of scarcity. In the UGRRC, both water users who have formal water rights and those who do not are increasingly realizing that the available water resource is not enough even for the water right holders, in some of the river systems. Therefore, when the available water in the respective rivers becomes low, representatives of irrigation canal committees or Water Users Associations, as the case may be, with technical backstopping from Rufiji Basin Water Office, come together and agree on how to share the available water through rotational arrangements. A weekly roster is set and agreed upon whereby intakes or villages take turns in abstracting water from the rivers. A committee is then set up to oversee the implementation of the roster. The most preferred rotational schedules are daily schedules whereby each intake is allocated day(s) in the week when it can abstract water. Daily rotations are preferred because they are easy to monitor as compared to hourly rotational schedules. Table 53 shows such rotation schedule between villages in the Mswiswi river systems. The irrigation schemes in turn prepare rotational irrigation schedules among irrigators (an intra canal or scheme rotation) basing on time schedules. The dates when these rotations are instituted vary from year to year, depending on the preceding season's rainfall situation. For example in the Mambi River system, the rotational schedules started in May in 2003 (it was a very dry year), August in 2004 and September in 2005 (it was a very good year with bumper paddy harvests). This arrangement ensures that every water user gets his/her share of the little available water and thus minimises conflicts over water.

Table 53: Irrigation water use rotational roster for Mswiswi River system - 2004

Village Name	Number of days	First phase		Second phase		Third phase		Fourth phase		Fifth phase		Sixth phase	
		Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
Kongolo Mswiswi	3	11 Sep	13 Sep	29 Sep	1 Oct	17 Oct	19 Oct	4 Nov	6 Nov	22 Nov	24 Nov	10 Dec	12 Dec
Nsonyanga and Kapyo	3	14 Sep	16 Sep	2 Oct	4 Oct	20 Oct	22 Oct	7 Nov	9 Nov	25 Nov	27 Nov	13 Dec	15 Dec
Mahango	3	17 Sep	19 Sep	5 Oct	7 Oct	23 Oct	25 Oct	10 Nov	12 Nov	28 Nov	30 Nov	16 Dec	18 Dec
Azimio Mswiswi	3	20 Sep	22 Sep	8 Oct	10 Oct	26 Oct	28 Oct	13 Nov	15 Nov	1 Dec	3 Dec	19 Dec	21 Dec
Simike	3	23 Sep	25 Sep	11 Oct	13 Oct	29 Oct	31 Oct	16 Nov	18 Nov	4 Dec	6 Dec	22 Dec	24 Dec
Luhanga	3	26 Sep	28 Sep	14 Oct	16 Oct	1 Nov	3 Nov	19 Nov	21 Nov	7 Dec	9 Dec	25 Dec	27 Dec

(ii) Irrigated area reduction and diversification to other activities

In times of water scarcity, irrigation schemes do not get their share of water as provided for in their water rights. This is because in some river systems the water quantities stipulated in the water rights are higher than the available water resource in the rivers during that particular season. As such, many irrigation schemes resort to reducing the area under irrigated agriculture to match with the available water. For example, in 2003, which was a very dry year, farmers in the Luanda Majenje Irrigation Scheme reduced and also concentrated the area under dry season irrigated agriculture in one core area located in the upstream areas of the scheme. This was done in order to reduce conveyance water losses.

For a very long time, farmers in the UGRRC believed that engagement in irrigated agriculture was the only way to sustain their livelihoods. This comprised of wet season supplementary irrigation for paddy as well as dry season irrigation of vegetables and other high value crops. However, things are changing now due to persistent water shortages. A substantial number of farmers have diversified and are now involved in fish farming. For example, by the end of 2004 there were only 10 fishponds (surface area ranging from 100 to 1200 m^2 with a depth of between 0.75 to 1 m) in Mkoji sub-catchment of the UGRRC. However, by August 2005 the number of fishponds had increased to 91 in 6 villages of MSC. The fishponds were established with assistance from the Heifer Project International (HPI). HPI trained extension officers and provided fish (free of charge) that were planted in the pilot ponds. Newly constructed ponds also obtain free fish for planting from the incumbent “fish-farmers.” Fish farming has become popular because it requires very low capital, has low operational costs, uses less labour and water and has shown to be profitable. For example, a fish-farmer can earn USD 300 after four months with a pond of 25*16*0.75 m (300 m^3) in size (compare with USD 30 for paddy or dry season irrigated maize for the same size of area).

(iii) Control and regulation of water abstractions

The Rufiji Basin Water Office has, since 2003 intensified regular auditing and assessment of water availability in rivers and uses in irrigation canals in the months of March/April and June/July, following the recommendations by Rajabu *et al.* (2005). The auditing is followed by the institution of temporary allocations, where necessary or complete closure of unauthorised abstractions. To compliment these efforts, the Rufiji Basin Water Office, in collaboration with other partners, has been conducting education and awareness campaigns to local level water users. The aim of the campaigns is to impart knowledge to local level water users on sustainable water use and conservation; laws, and regulations that govern water use. The results of these efforts are clearly seen in Figure 46, for Mbarali and Mbeya Rural districts. It can be observed that between 2000 and 2005, the Rufiji Basin Water Office received 93 applications from Mbarali and Mbeya Rural districts. However, downward trend is expected in the coming years due to the fact that over 90% of irrigation canals in the two districts already have water rights granted to them or are waiting decisions on their applications.

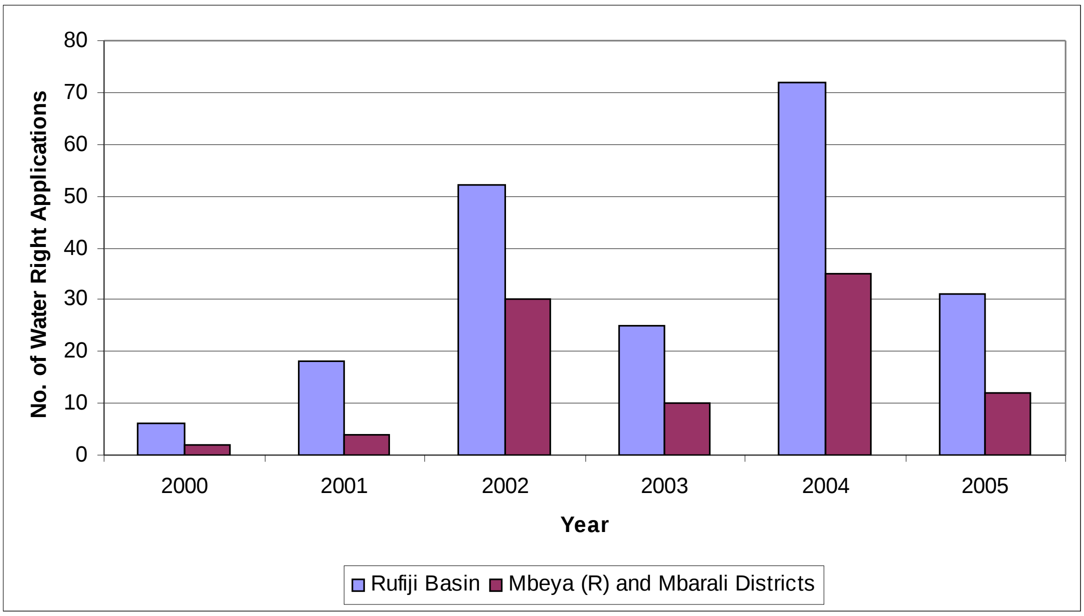


Figure 46: Water rights application trends in Rufiji Basin and UGRRC
Source: adopted and modified from RBWO water right archives (2005)

(iv) Formation of sub catchment water users' associations

In many parts of the UGRRC, water users are aware that the available water is not enough to meet all their requirements. One of the strategies that has been recommended by water users to ensure equitable water allocation is the formation of one apex organisation (sub-catchment WUA). The main function of such a body will be to oversee and manage water allocation from upstream to downstream within a river system. Thus, the Rufiji Basin Water Office, in collaboration with World Wide Fund for Nature, Tanzania Program Office (WWF-TPO) through its Ruaha Water Program; and the RIPARWIN Project assisted and facilitated the formation of sub catchment water users' associations for a number of river systems such as Mswiswi, Mkoji, Kimani and Mlowo rivers. It is hoped that once all the envisaged WUAs have been formed then the RBWO will be able to better support these fewer institutions rather than negotiating and dealing with representatives of the many intakes in the UGRRC.

4.4.2.3 Improving management of water rights systems in Tanzania

In order to address some of the challenges facing implementation of formal water rights in Tanzania, all existing water rights for irrigation should be reviewed to conform to the current irrigated areas, crop water requirements and downstream requirements. The whole concept of 'rights' is sometimes misleading to both right holders and non holders, as many people tend to equate water rights with "ownership" of water and the ability to do whatever one wants with it. It is therefore, recommended that water use licenses or permits should be introduced to replace the rights. The water use permits should be short-term, renewable (as, for example, in New Zealand and South Africa) and revocable once a holder fails to meet the conditions spelt in the licence or permit. This may create more opportunity for reallocation and reduce long-term problems due to speculative acquisition of rights. The duration of the short-term water use permits or licences should be sufficiently enough (for example 5 years) to give adequate security for users to invest in productive and efficient use of the resource.

During the review process, rules for the initial allocation of formal water use permits and how new permits would be allocated should be established in close collaboration with and involving local level water users. Since basin authorities lack more detailed local information (for example, how people use water, how farmers currently respond to water shortages, and how they adjust rules to fit local conditions and concepts of equity), there should be more involvement of the local water users in the day-to-day management of water resources. One way of doing this is for basin authorities to only allocate bulk volumes of water to each sub catchment. One water use permit could then be issued to each sub catchment water users' apex organisation. The sub catchment apex organisation should in turn be responsible for water allocation (with technical advice and assistance from basin authorities) among authorised intakes in the area under their jurisdiction. The apex organisations should be used as agents of Basin Water Offices and be responsible for collecting water users' fees from the authorised intakes on behalf of Basin Water Offices. A certain percentage of the collected fees should then be paid to apex organisations to enable them undertake their activities efficiently. Since the Ministry of Water in Tanzania is already thinking along these lines, it is hoped that the new water legislation will empower the sub catchment committees to undertake the recommended tasks.

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The legislation should also provide for introduction of "fast track" methods to clear backlog of water permit applications, whenever they occur. Empowering Basin Water Offices to issues water permits for applicants whose applications attracted no objections and the quantity of water applied for is small could be one way of speeding up the procedure of granting water use permits. There should also be regular auditing and assessment of water availability in rivers and uses in irrigation canals to back up the issued water use permits. Where necessary, basin authorities should implement temporary allocations to the sub catchments during critical periods in both, the dry and wet seasons. By so doing, the awareness of people towards water resource sharing would also be increased.

User charges are usually applicable for the use of collective goods in Tanzania. Ideally, the charge should match the cost of supplying the service consumed, so that consumers have an incentive not to over-use the service or abuse it (URT, 1997). Unfortunately, though, most environmental resources and services in Tanzania are either undervalued or considered as common property. The same facts apply to water users' fees in Tanzania, which were found to be relatively low. However, in view of the current methods of charging water users' fees (paid annually by irrigation scheme members) and the fact that actual amounts of water abstracted by irrigation schemes are rarely measured, it is highly improbable that increasing water users' fees will lead to "wise use" of water. Far from being deterred by increased fees, some upstream irrigators might expand their irrigated lands to generate maximum possible income to offset the increased water use costs. Consequently, upstream farmers may abstract more water thereby increasing upstream-downstream water use related conflicts.

Furthermore, many irrigators are just beginning to understand the rationale behind formal water use permits and institution of water users' fees. Increasing the fees now could result in negative attitudes towards their acceptance. Attempts to raise water users' fees to levels that reflect the true cost of water resources allocation, regulation and monitoring will thus be very unpopular and may attract stiff resistance. Efforts should therefore be intensified to introduce efficient water use technologies, as well as training water users on better water management practices and methods of enhancing productivity of water in agriculture. Increase in water users' fees should only be considered after these efforts have started to bear fruits.

Water rights in Tanzania are currently non-transferable. However, the National Water Policy (URT, 2002a) recommends that trading of water rights, among other measures, should be gradually built into the management system as a means or strategy for demand management and water conservation. However, it is strongly advised here that trading of water rights, if provided for by the new water legislation, should be implemented with great care and caution and after adequate preparations. The preparations should include establishment of strong and effective water management institutions, legislation and infrastructure. Even then, only transfer of formal water rights should initially be built into the management system so that those who under-utilise water could transfer part of their formal water rights to those who need more water. Leasing and other innovative institutional arrangements could provide attractive alternatives to trading of formal water rights. Otherwise, if developing countries (Tanzania inclusive) start by embracing trading of formal water rights, the majority of resource-poor farmers might end up trading all their formal water rights in order to solve pressing problems, as short-term survival (for poor people) usually supersedes long-term investments.

4.4.3 Impacts of water abstraction patterns on downstream river flows

The Great Ruaha River, upstream of the Nyaluhanga gauging station has three major tributaries (Kimani, Mbarali and Mkoji rivers). Kimani and Mbarali are all perennial rivers. However, Mkoji River is only perennial upstream of irrigated areas. In order to assess the effects of upstream abstractions on downstream flows on these tributaries, discharges as recorded at gauging stations located upstream and downstream of irrigated areas were compared. The coefficient of abstraction (CA) was calculated using Equation 21.

$$CA = \frac{\text{Upstream flow - downstream flow}}{\text{upstream flow}} \times 100 \qquad (21)$$

In calculating the coefficients of abstraction, it was assumed that other water losses occurring in rivers (e.g. seepage, evaporation and weed transpiration) were negligible due to the relatively short distances between the upstream and downstream gauging points (in many cases, about 6 kilometres).

Results in Tables 54 and 55 show that whereas Mbarali River recorded 13 days of zero flow in November 2003, the river never dried in 2004. Likewise, the amount of water abstracted in 2003 was more than 2004 despite the fact that more water was available in the river in 2004 as compared to 2003 and the area under paddy cultivation was more as compared to 2003. In fact, the coefficient of abstraction dropped from 52% in 2003 to only 19% in 2004. The reason for this is that during the dry season of 2004 the amount of water abstracted by Mbarali Rice Farms was closely regulated and monitored by the Rufiji Basin Water Office. The farms were restricted from abstracting water during the night for domestic uses as well as to meet livestock and fish ponds water requirements. This was clearly reflected by the downstream gauge readings taken in the mornings. On top of that, during the 2004/05 there was no early transplanting of paddy (in November) because of the delay by the Government of Tanzania to allow the management of Mbarali Rice Farm to lease the farms to individual farmers for paddy cultivation (Mbarali Rice

Farm was in the process of being sold to private investors). As a result, the average dry season abstractions from Mbarali River dropped from 1.227 m^3/s (52.3% of the river flow) in 2003 to 0.603 m^3/s (19.4% of the river flow) in 2004. The same trend was observed in Kimani River. Since June 2004, Mbuyuni intake, which is a major abstraction point supplying water to Kimani Irrigation Scheme with a water right of 7.998 m^3/s (wet season) and 0.093 m^3/s (dry season), was closed completely up to the end of October 2004. As such, the average dry season abstractions from Kimani River dropped from 0.670 m^3/s (63.2 % of the river flow) in 2003 to 0.394 m^3/s (42.9 % of the river flow) in 2004.

Table 54: Zero flow days at downstream gauges in UGRRC rivers

Sno	River name	Start of zero flow	Resumption of flow	Zero flow days	Remarks
1	Lwanyo	03/11/2003	14/12/2003	41	
		2004		None	The river never dried in 2004
2	Mswiswi	2003		3	The river never dried continuously due to rotational water abstraction schedules
		2004		2	
3	Mkoji	07/09/2003	18/12/2003	102	
		02/08/2004	01/12/2004	121	
4	Mlowo	06/06/2003	15/01/2004	198	
		18/07/2004	04/12/2004	136	
5	Kimani	19/11/2003	26/11/2003	7	Perennially large river
		22/11/2003	30/11/2003	8	
6	Mbarali	15/11/2003	28/11/2003	13	Perennially large river
		2004		None	The river never dried in 2004

Table 55: Comparison of dry season flows between upstream and downstream gauges in Mbarali and Kimani rivers

Month	Mean daily discharges[9] (m^3/s) Mbarali U/S	Mbarali D/S	Amount abstr.	CA (%)	Kimani U/S	Kimani D/S	Amount abstr.	CA (%)
Jun-03	3.737	1.488	2.248	60.17	2.022	0.840	1.182	58.47
Jul-03	2.987	1.516	1.471	49.26	1.349	0.603	0.746	55.30
Aug-03	2.215	1.180	1.035	46.71	1.000	0.319	0.681	68.14
Sep-03	1.840	0.882	0.959	52.09	0.841	0.339	0.503	59.73
Oct-03	1.627	1.285	0.342	21.02	0.673	0.313	0.360	53.51
Nov-03	1.551	0.243	1.308	84.36	0.652	0.105	0.547	83.84
Average	2.326	1.099	1.227	52.27	1.090	0.420	0.670	63.17
Jun-04	5.686	4.288	1.398	24.59	2.049	1.482	0.567	27.67
Jul-04	4.378	4.097	0.281	6.41	1.368	0.882	0.486	35.51
Aug-04	3.323	2.970	0.353	10.62	0.975	0.879	0.096	9.87
Sep-04	2.835	2.459	0.376	13.26	0.812	0.481	0.331	40.74
Oct-04	2.014	1.488	0.526	26.12	0.630	0.289	0.341	54.08
Nov-04	1.941	1.259	0.682	35.14	0.606	0.064	0.542	89.44
Average	3.363	2.760	0.603	19.36	1.073	0.680	0.394	42.88

abstr = abstracted

Table 56 shows that for the case of MSC, Mswiswi River recorded the lowest coefficients of abstractions (CA) as compared to the other rivers, which recorded CA of 90% and above. The reason for this is that at the peak of the dry season (August to November) there are rotational schedules among all irrigation intakes as well as other water users in Mswiswi. The rotation is on daily basis. There are, therefore, days of the week when irrigation abstractions are required to stop and all the available water in the river is left to flow to downstream villages. However, this amount of water does not flow very far beyond the downstream gauge and therefore, Mswiswi River also dries up from June, like other MSC rivers (Table 54). There are no rotational schedules that take into account downstream water requirements (e.g. for domestic use and environmental sustenance) in the other studied rivers.

[9] Obtained by summing mean daily discharges and dividing by the total number of days in the month

Table 56: Comparison of dry season flows between upstream and downstream gauges in MSC

Month	Mean daily discharges[10] (m^3/s)											
	Lwanyo U/S	Lwanyo D/S	CA[11] (%)	Mswiswi U/S	Mswiswi D/S	CA (%)	Mkoji U/S	Mkoji D/S	CA (%)	Mlowo U/S	Mlowo D/S	CA (%)
Jun-03	0.259	0.002	99.27	0.245	0.152	38.01	0.102	0.009	90.82	0.439	0.000	100.00
Jul-03	0.210	0.002	98.95	0.184	0.104	43.17	0.082	0.003	96.90	0.400	0.000	100.00
Aug-03	0.176	0.002	99.12	0.167	0.062	63.00	0.041	0.003	92.56	0.327	0.000	100.00
Sep-03	0.151	0.000	99.78	0.134	0.084	37.53	0.037	0.000	99.96	0.279	0.000	100.00
Oct-03	0.086	0.000	99.93	0.105	0.043	59.48	0.024	0.000	100.00	0.206	0.000	100.00
Nov-03	0.065	0.000	100.00	0.253	0.083	67.05	0.027	0.000	100.00	0.188	0.000	100.00
Average	0.158	0.001	99.51	0.181	0.088	51.37	0.052	0.002	96.71	0.306	0.000	100.00
Jun-04	0.358	0.014	96.20	0.730	0.223	69.40	0.170	0.040	76.43	0.823	0.009	98.85
Jul-04	0.196	0.001	99.30	0.580	0.121	79.07	0.100	0.005	95.38	0.624	0.002	99.64
Aug-04	0.151	0.007	95.49	0.469	0.081	82.65	0.073	0.000	100.00	0.522	0.000	100.00
Sep-04	0.091	0.007	92.05	0.415	0.084	79.88	0.060	0.000	100.00	0.503	0.000	100.00
Oct-04	0.068	0.007	89.90	0.347	0.056	83.86	0.037	0.000	100.00	0.485	0.000	100.00
Nov-04	0.043	0.007	84.14	0.307	0.054	82.41	0.043	0.000	100.00	0.455	0.000	100.00
Average	0.151	0.007	92.85	0.475	0.103	79.55	0.081	0.007	95.30	0.569	0.002	99.75

Note: U/S = Upstream; D/S = Downstream

[10] Obtained by summing mean daily discharges and dividing by the total number of days in the month
[11] Coefficient of Abstraction

The monthly flow hydrographs of gauged points upstream and downstream of irrigated areas are shown in Figures 47, 48 and 49. These figures indicate that the lower reach of Mkoji River dry up during much of the dry season. For the case of Kimani River, the amount of water abstracted during the wet season is more than the contribution from the intervening catchment. The situation is different for Mbarali River. During the months of January to April, the contribution from the intervening catchment exceeds the amount of water abstracted by the irrigation schemes. There is no contribution from the intervening catchment during the dry season. Monthly flow hydrographs for Lwanyo, Mswiswi and Mlowo rivers are shown in Appendix 5 (a-c).

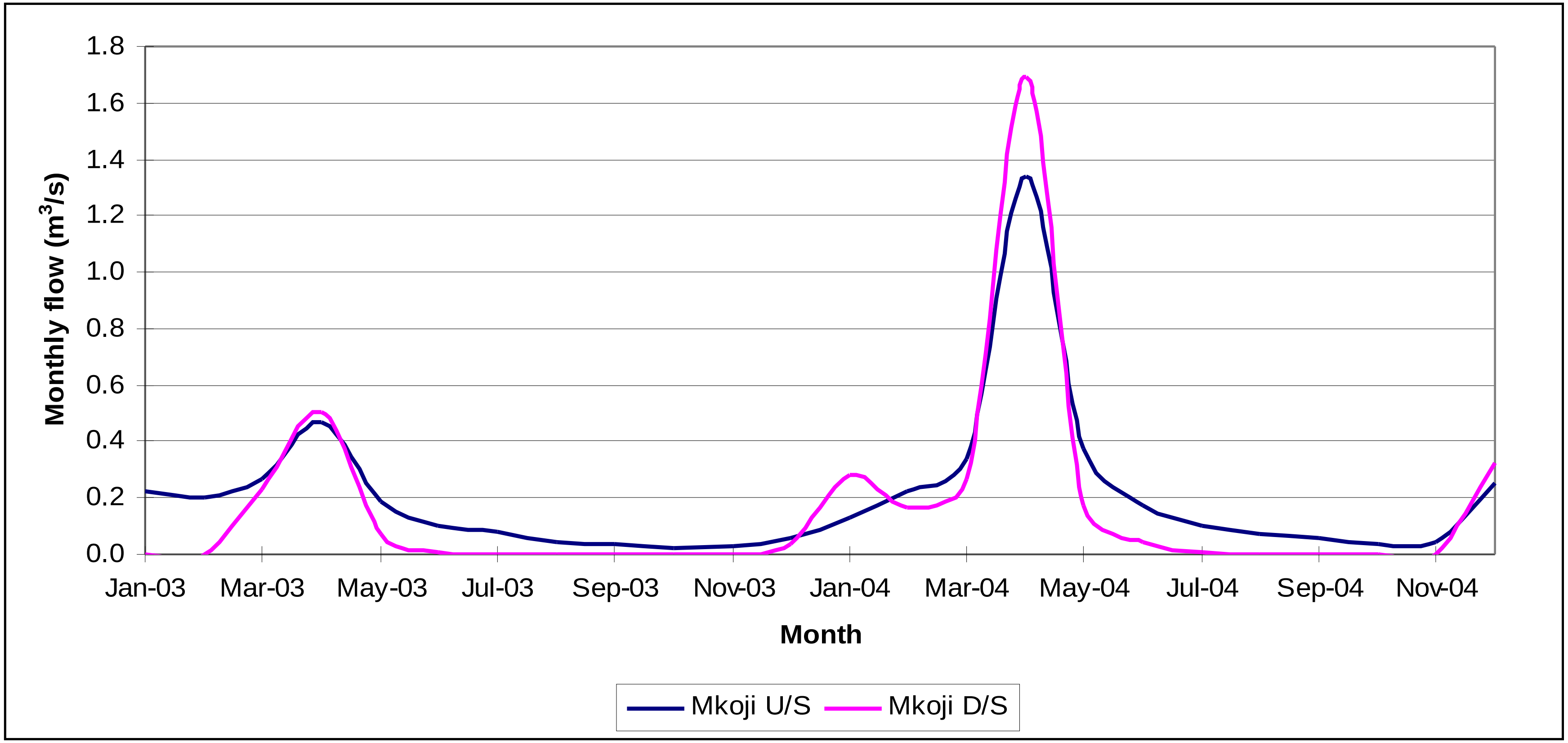


Figure 47: Monthly flow hydrograph for Mkoji River (2003-2004) at upstream and downstream gauges

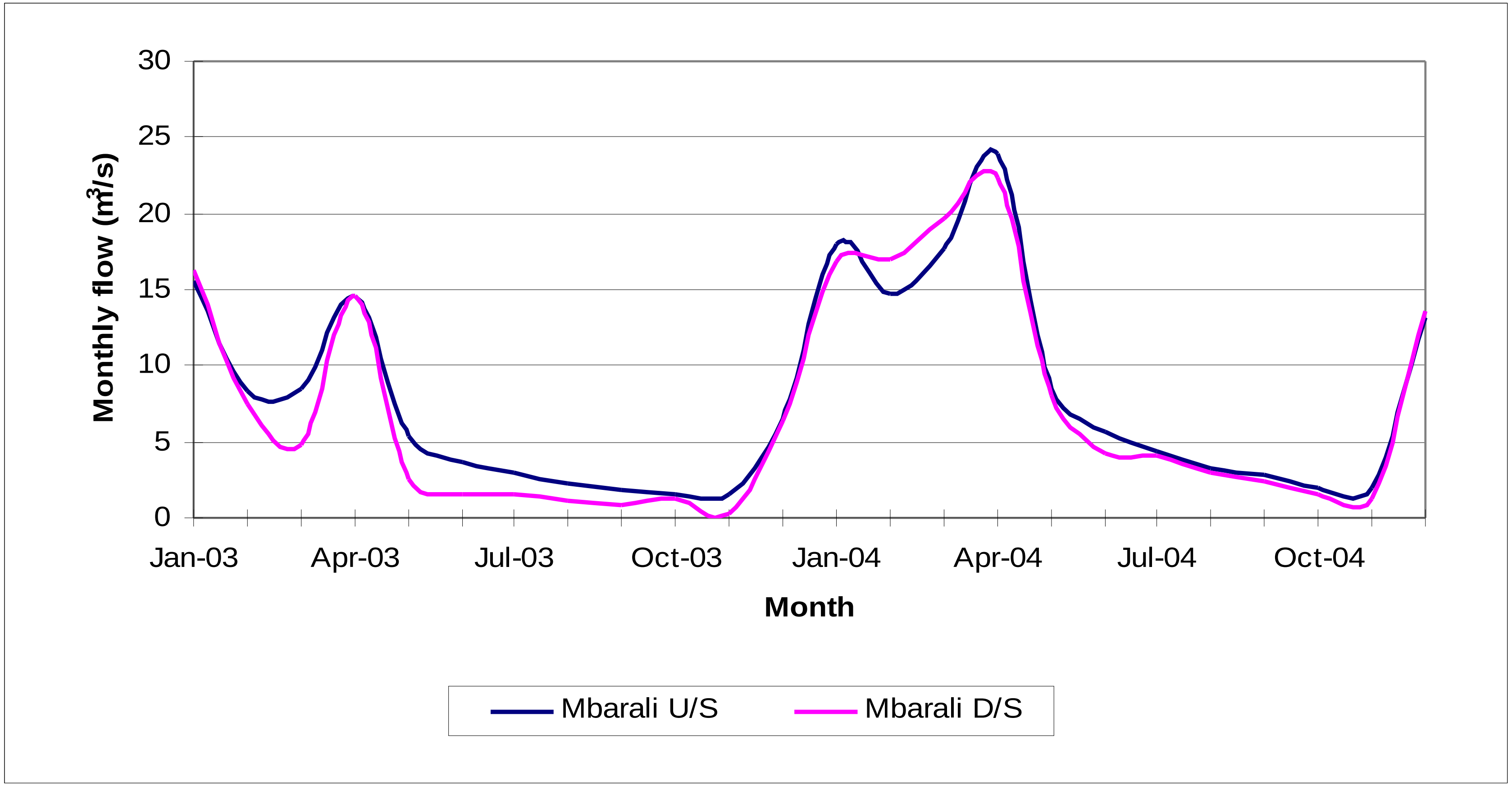


Figure 48: Monthly flow hydrograph for Mbarali River (2003-2004) at upstream and downstream gauges

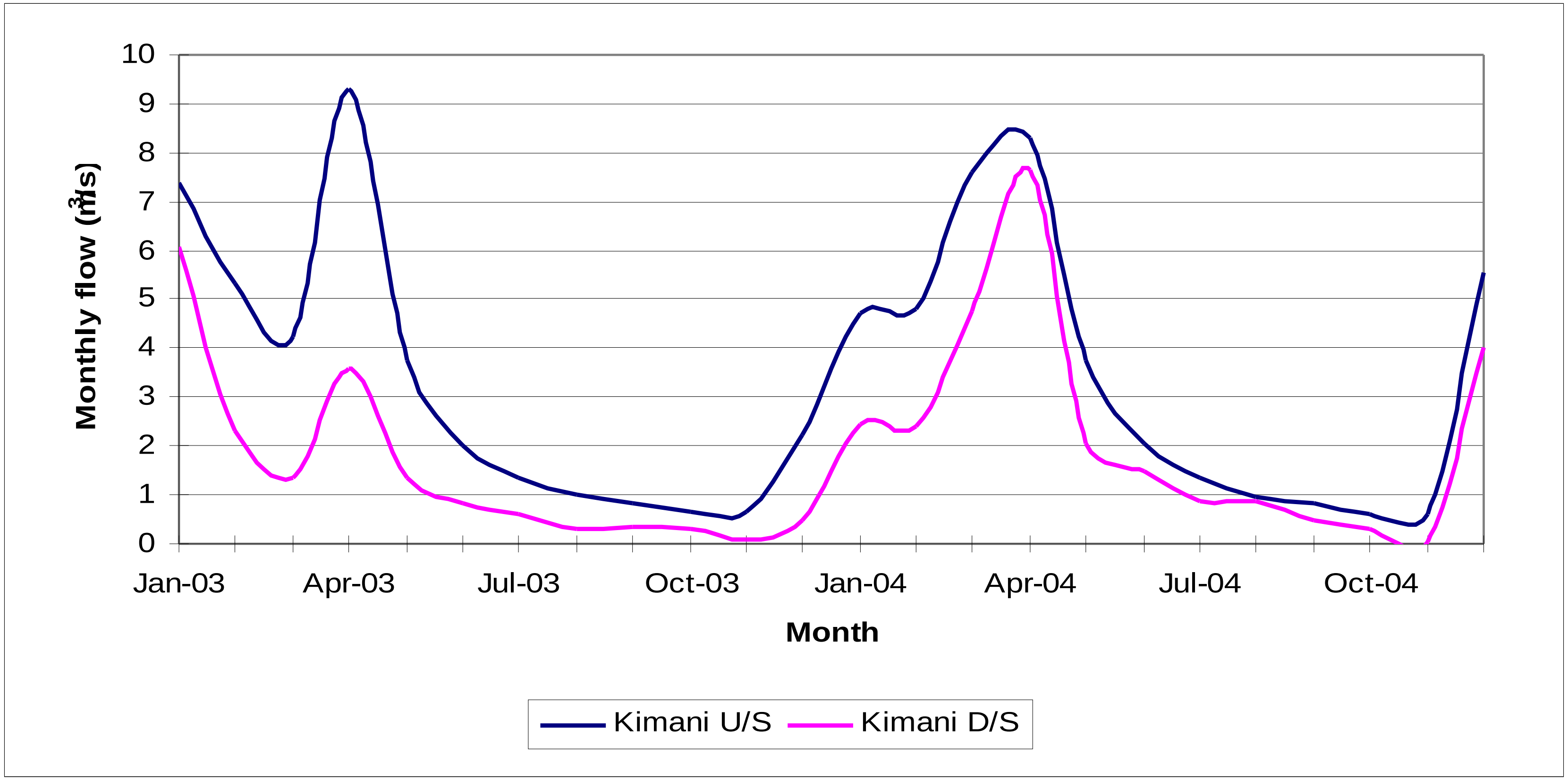


Figure 49: Monthly flow hydrograph for Kimani River (2003-2004) at upstream and downstream gauges

4.4.4 Catchment water balance

4.4.4.1 Annual water balance components

Table 57 shows the water balance components for various sub-catchments of the UGRRC. The table shows that the expected annual actual evapotranspiration is lower for the upper sub-catchments of Kimani and Mbarali as compared to the lower sub-catchments of MSC and 1KA27. Furthermore, the table shows that as rainfall increases, the expected annual actual evapotranspiration also increases. As far as partitioning of rainfall is concerned, AET constituted a higher proportion of annual rainfall in the Mbarali, MSC and 1KA27 sub-catchments (67.4%; 88.2% and 88.3% respectively). However, for the Kimani sub-catchment, AET constituted only about 42% of the expected annual rainfall. Table 57 also shows that the Turc and Pike method generally overestimated the AET as compared to the simplified water balance model. However, it should be understood that AET, whether estimated by using the water balance model or the Turc and Pike formula, depends very much on the accuracy of interpolation of aerial rainfall.

Table 57: Water balance components in the UGRRC sub-catchments

Sub-catchment	Area (km^2)	Water Balance (mm)					Turc and Pike AET (mm)
		Expected annual rainfall (mm)	Water balance AET		Runoff		
			Amount (mm)	Proportion of annual rainfall (%)	Amount (mm)	Proportion of annual rainfall (%)	
Kimani	448	676.7	283.5	41.89	393.2	58.11	619.0
Mbarali	1600	883.5	595.8	67.43	287.7	32.57	767.4
MSC (Turc and Pike)	3400	997.4	879.7	88.21	117.6	11.79	879.7
1KA27	20120	980.4	865.8	88.31	114.6	11.69	870.6

Notes:

1. In the 1KA27 sub-catchment, about 88% of rainfall is lost through evaporation, in seasonally inundated and permanent swamps and irrigation abstractions. The average outflow from UGRRC as recorded at 1KA27 is 114.6 mm or 73.1 m^3/s.
2. In the MSC, 12% of rainfall, equivalent to 117.6 mm (12.6 m^3/s) is available as runoff and could be used for irrigation purposes.
3. The runoff from Kimani and Mbarali sub-catchments as recorded at 1KA9 and 1KA11A are 393.2 mm (5.59 m^3/s) and 287.7 mm (14.58 m^3/s) respectively.

4.4.4.2 Dry season water balance

Table 58 presents the water budget of the Mbarali and Kimani River channels. Table 58 shows that irrigation abstraction and other losses (e.g. infiltration) account for 52.5% and 35.3% of the total inflow during the dry seasons of 2003-04 for Kimani and Mbarali river channels respectively. On the other hand, in-channel evaporation losses are very low and account for only 0.54% and 0.51% of the total inflow for Kimani and Mbarali river channels respectively. However, the table clearly shows a decline in irrigation abstraction and other losses in 2004 as compared to 2003. This is due to close monitoring and tight control of water abstractions undertaken by RBWO in 2004 in Kimani and Mbarali rivers. Table 58 further shows that the maximum water abstraction and other losses in Kimani and Mbarali rivers occur in the months of June and July, most probably due to lengthened paddy cultivation season. The other month with high losses is November, most probably due to early establishment of paddy nurseries. Spot discharge measurements undertaken between downstream gauges and Nyaluhanga gauging station showed that evaporation and infiltration losses increase (up to 20% of available flow) due to increased channel widths and decreased depths of the rivers, as the rivers pass through the sandy fans.

Table 58: Dry season water balance components

Month	(Inflow + rainfall) (m^3/s)	Actual evaporation (m^3/s)	Measured outflow (m^3/s)	Other Losses (m^3/s)	Evaporation losses as proportion of total inflow (%)	Irrigation and other losses as proportion of total inflow (%)
KIMANI RIVER (Total surface area of the river channel is 69800 m^2)						
Jun-03	2.022	0.0028	0.840	1.179	0.14	58.33
Jul-03	1.349	0.0032	0.603	0.743	0.24	55.07
Aug-03	1.000	0.0039	0.319	0.677	0.39	67.75
Sep-03	0.841	0.0051	0.339	0.498	0.61	59.13
Oct-03	0.673	0.0062	0.313	0.354	0.91	52.61
Nov-03	0.653	0.0060	0.105	0.541	0.92	82.93
Average					0.54	62.63
Jun-04	2.049	0.0022	1.482	0.565	0.11	27.56
Jul-04	1.368	0.0026	0.882	0.483	0.19	35.32
Aug-04	0.975	0.0036	0.879	0.093	0.37	9.50
Sep-04	0.812	0.0062	0.481	0.325	0.77	39.97
Oct-04	0.630	0.0057	0.289	0.335	0.90	53.20
Nov-04	0.608	0.0053	0.064	0.538	0.88	88.59
Average					0.54	42.36
Grand Average					0.54	52.50
MBARALI RIVER (Total surface area of the river channel is 177500 m^2)						
Jun-03	3.737	0.0072	1.488	2.241	0.19	59.98
Jul-03	2.987	0.0082	1.516	1.463	0.27	48.98
Aug-03	2.215	0.0098	1.180	1.025	0.44	46.27
Sep-03	1.840	0.0130	0.882	0.946	0.71	51.39
Oct-03	1.627	0.0157	1.285	0.327	0.96	20.06
Nov-03	1.553	0.0153	0.243	1.295	0.99	83.39
Average					0.59	51.68
Jun-04	5.686	0.0056	4.288	1.392	0.10	24.49
Jul-04	4.378	0.0065	4.097	0.274	0.15	6.26
Aug-04	3.323	0.0091	2.970	0.344	0.28	10.35
Sep-04	2.835	0.0159	2.459	0.360	0.56	12.70
Oct-04	2.015	0.0145	1.488	0.512	0.72	25.42
Nov-04	1.948	0.0136	1.259	0.675	0.70	34.66
Average					0.42	18.98
Grand Average					0.51	35.33

4.4.5 Maintaining continuous flows downstream of the UGRRC

Kashaigili (2006) found out that about 7.0 m^3/s is required to enter the perennial swamp (*Ihefu*) during the dry season in order to have an outflow of 0.5 m^3/s from the UGRRC into the Ruaha National Park. Investigation of water rights has shown that water is already over-allocated in most of the rivers in the UGRRC. The analysis has also revealed that dry season irrigated agriculture is widely practiced in Mkoji sub-catchment and to a very lesser extent in other sub-catchments. In order to be able to provide a flow of 7.0 m^3/s into the perennial swamp, upstream abstractions need to be reduced. The key question is whether it is possible to provide that flow during the dry season and how. To provide answers to that question, the following management alternatives were considered.

4.4.5.1 Outright banning of dry season irrigated agriculture (DSIA)

Dry season irrigated agriculture is an important livelihood activity in Mkoji sub-catchment as there are people who solely depend on it to sustain their livelihoods. Therefore, outright banning of DSIA is not possible given the fact that some smallholder irrigation schemes have even water rights to undertake DSIA and there are no ‘ready-made’ alternative livelihood sustaining activities to replace DSIA. However, even if it is possible to ban DSIA, the amount of water that can be saved is too little to make any difference in the base flow of Great Ruaha River. Table 59 shows the amount of available surface water before any abstractions. The table shows that the average dry season flow in the MSC is 2.37 m^3/s. However, this flow is distributed in over 25 rivers and streams scattered all over MSC. Moreover, the river with the highest flows has only an average flow of 0.48 m^3/s. In order to reach the Great Ruaha River, this water has to be conveyed a distance of about 100 km. From this observation, it is obvious that even if DSIA is banned, the water so saved from MSC will not add anything to the base flow of GRR as much of the water will be lost during conveyance. At most, the water will help to keep the channels healthy and reduce the sufferings of downstream water users from water shortages thereby leading into reduction of conflicts over water.

Table 59: Available surface water flows during the dry season (2000-2004)

Sub-catchment	2000-2004 monthly flows (m^3/s)						Mean
	Jun	Jul	Aug	Sep	Oct	Nov	
Chimala (1KA7A)	1.509	1.140	0.860	0.708	0.654	0.702	0.929
Great Ruaha (1KA8A)	4.842	3.447	2.786	2.435	2.492	2.599	3.100
Kimani (1KA9)	2.228	1.480	1.103	0.895	0.731	0.707	1.190
Mbarali (1KA11A)	5.738	4.497	3.452	2.768	2.075	2.522	3.509
Ndembera (1KA33B)	4.683	2.500	1.500	1.000	1.000	0.900	1.931
Mkoji (2003/04 flows)	4.112	2.815	2.169	1.813	1.576	1.753	2.373
Total flow upstream of all abstractions	23.112	15.878	11.870	9.618	8.528	9.183	13.032
Total flow excluding Chimala and Mkoji	17.491	11.923	8.841	7.098	6.298	6.728	9.730
Conveyance losses (10%)	1.749	1.192	0.884	0.710	0.630	0.673	0.973
Available flow for downstream use	15.742	10.731	7.957	6.388	5.668	6.055	8.757
Flow into the swamp	7.000	7.000	7.000	7.000	7.000	7.000	7.000
Available flow for upstream use	8.742	3.731	0.957	-0.612	-1.332	-0.945	1.757

4.4.5.2 Reduction of water abstractions from perennial rivers

The average dry season flows in the UGRRC before any abstractions for the past five years (2000-2004) is 13.032 m^3/s. Excluding the contribution of MSC and Chimala

River (the river has been relocated and fragmented into many channels during construction of Kapunga Rice Farms such that much of the water ends up in intermediate swamps), the remaining upstream flow is 9.73 m^3/s. If conveyance and other losses, estimated at 10% are subtracted from the available upstream flow, about 8.76 m^3/s will remain to be shared between upstream anthropogenic water requirements and the inflow into the perennial swamp. If the perennial swamp inflow requirements are to be satisfied first, it means that 79.9% (7.0 m^3/s) of the available dry season surface flows will have to be allocated to maintain the environment and only 20% or 1.6 m^3/s will be available for anthropogenic uses. Even then, there are months (September-November) when the available flow for downstream use is less than 7.0 m^3/s, implying that the outflow of 0.5 m^3/s may not be realised unless there is enough accumulated storage in the perennial swamp.

The above analysis has been done by considering dry season flows for the period 2000-2004. However, if the long-term mean flows are considered (Table 60), an average of 4.61 m^3/s will be available for upstream anthropogenic uses. Again, inadequate available flows for upstream uses are evident for the months October-November if the inflow to the swamp is satisfied first. In the dry season of 2004, a combined total of 0.997 m^3/s was abstracted in upstream areas of Mbarali and Kimani rivers, (including conveyance losses). This amount was enough to cater for all anthropogenic requirements in upstream areas. If the quantities of water abstracted are maintained to the 2004 levels, then Mbarali and Kimani rivers will contribute an average of 6.47 m^3/s or 102.4 Mm^3 to the inflow into the perennial swamp. This is possible if tight control and monitoring of levels of water abstraction during the dry season is maintained, as was the case in 2004. The deficit is therefore only about 0.5 m^3/s. This can easily be realised from Great Ruaha and Ndembera rivers, where there is no dry season irrigated agriculture taking place. The amount of water required and abstracted in 2004 for anthropogenic uses was 0.9 m^3/s for Great Ruaha River and 0.1 m^3/s for Ndembera River (Rajabu, 2005). The Great Ruaha and Ndembera rivers have average dry season flows of 3.49 and 1.93 m^3/s respectively.

Table 60: Available surface water flows during the dry season (long-term mean)

Sub-catchment	Long-term monthly flows (m^3/s)						Mean	U/S needs
	Jun	Jul	Aug	Sep	Oct	Nov		
Great Ruaha (1KA8A)	5.690	4.429	3.350	2.722	2.272	2.504	3.494	0.9
Kimani (1KA9)	2.667	1.697	1.268	1.051	0.796	0.971	1.408	0.2
Mbarali (1KA11A)	10.083	7.659	5.979	4.450	3.958	4.247	6.063	0.6
Ndembera (1KA33B)	4.683	2.500	1.500	1.000	1.000	0.900	1.931	0.1
Total flow upstream of all abstractions	23.123	16.285	12.097	9.222	8.025	8.623	12.896	
Conveyance losses (10%)	2.312	1.629	1.210	0.922	0.803	0.862	1.290	
Available flow for downstream use	20.811	14.657	10.888	8.300	7.223	7.760	11.606	
Flow into the swamp (m^3/s)	7.000	7.000	7.000	7.000	7.000	7.000	7.000	
Available flow for upstream use (m^3/s)	13.811	7.657	3.888	1.300	0.223	0.760	4.606	

U/S = Upstream

In order to ensure that there are adequate inflows into the swamp in the September to November period, some supply management measures have to be considered and implemented, wherever feasible. Construction of storage dams upstream of the perennial rivers, construction of small surface dams (or *charco dams*) and increased exploitation of groundwater for domestic as well as livestock use are some of the measures. Previous studies have shown that there are suitable areas for the construction of dams to store water during the rainy season. The water could be used during the dry season to supplement the required inflow into the perennial swamp.

From the foregone discussions, it is obvious that the drying up of Mbarali and Kimani rivers in November was due to increased early abstraction of water for paddy nurseries establishment and paddy transplanting (despite the fact that most rivers have very low flows in November). Likewise, the perennial rivers of Mbarali, Kimani, Ndembera and Great Ruaha are the ones to be accorded the highest priority if significant water savings during the dry season are to be realised. Efforts should thus be intensified to ensure that there is close monitoring and regulation of water abstractions during the dry season in all perennial rivers.

For the case of MSC, during the dry season, all the rivers draining the sub-catchment are perennial in the Upper Zone. However, a few kilometres downstream of this Zone, all these rivers dry up from June and are perceived as seasonal. This is mainly due to dry season irrigated agriculture, which uses all the water that would have kept them flowing otherwise during the dry season. The distance from the Upper Zone to the points, where the rivers dry up varies from river to river and is a function of the number, type, capacity and location of water abstraction intakes in a particular river. Mkoji River, therefore, does not contribute any water to the dry season flows of the Great Ruaha River.

4.5 Assessing Sustainability of Water Resources Management in the UGRRC

The conceptual framework to assess sustainability of water resources management is shown in Figure 50. It has been developed within the institutional framework of water resources management in Tanzania as described by the National Water Policy (URT, 2002a). In assessing the sustainability of water resources management in the UGRRC, the framework was used in three different scenarios. Firstly, it was used to assess whether management decisions being implemented at various levels could lead to sustainability of water resources. The decisions being taken are on:

At national level: Financing of water resources development, enforcement of water legislation, implementation of disaster mitigation plans, staff capacity and development.

At basin level: Water allocation; administration of water rights and conflict mitigation mechanisms; agricultural and hydropower production and other water-dependent economic activities; water resources monitoring; and protection and conservation of the environment.

At catchment and water users' level: Quality and reliability of domestic and livestock water supply; environmental flow reservation; irrigation infrastructure improvements and their performance; and development of water management institutions

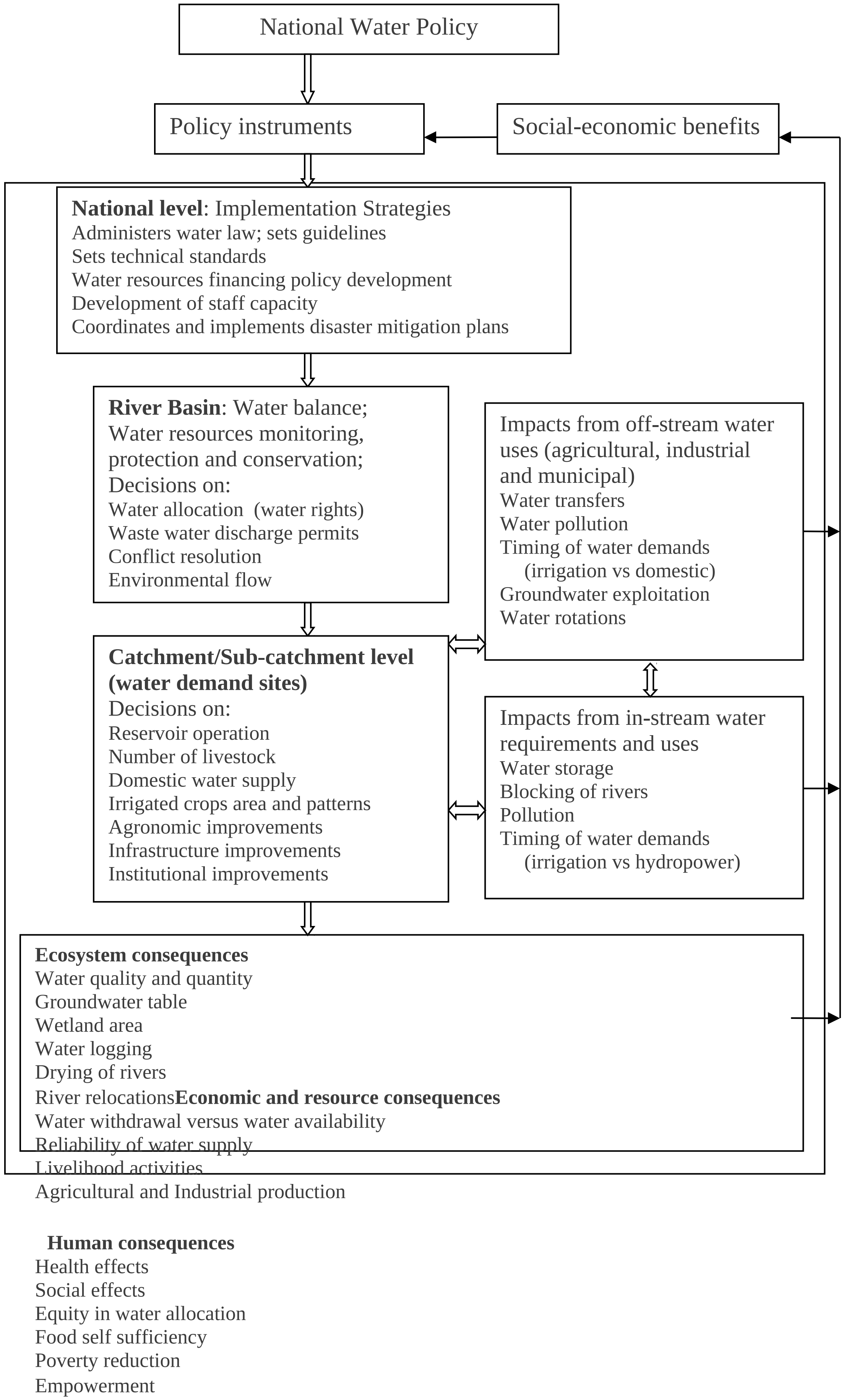

National Water Policy
Policy instruments
Social-economic benefits
National level: Implementation Strategies
Administers water law; sets guidelines
Sets technical standards
Water resources financing policy development
Development of staff capacity
Coordinates and implements disaster mitigation plans
River Basin: Water balance;
Water resources monitoring,
protection and conservation;
Decisions on:
Water allocation (water rights)
Waste water discharge permits
Conflict resolution
Environmental flow
Impacts from off-stream water uses (agricultural, industrial and municipal)
Water transfers
Water pollution
Timing of water demands
(irrigation vs domestic)
Groundwater exploitation
Water rotations
Catchment/Sub-catchment level (water demand sites)
Decisions on:
Reservoir operation
Number of livestock
Domestic water supply
Irrigated crops area and patterns
Agronomic improvements
Infrastructure improvements
Institutional improvements
Impacts from in-stream water requirements and uses
Water storage
Blocking of rivers
Pollution
Timing of water demands
(irrigation vs hydropower)
Ecosystem consequences
Water quality and quantity
Groundwater table
Wetland area
Water logging
Drying of rivers
River relocations
Economic and resource consequences
Water withdrawal versus water availability
Reliability of water supply
Livelihood activities
Agricultural and Industrial production
Human consequences
Health effects
Social effects
Equity in water allocation
Food self sufficiency
Poverty reduction
Empowerment

Figure 50: A conceptual framework for sustainable river basin management
Source: Adapted from Cai *et al.* (2001)

Secondly, the conceptual framework was used to assess sustainability of current water use patterns, practices, perceptions and attitudes; and

Thirdly, it was used to assess ecosystem consequences (quantity of water, drying of rivers, and wetland area), human consequences (equity of water allocation, food self-sufficiency and poverty reduction) and economic and resource consequences (reliability of water supply, agricultural and industrial production) of the prevailing water management practices and decisions. The assessment of sustainability drew heavily on the results and findings of the previous sections (section 4.1-4.4).

In all the three scenarios, the sustainability of water resources management in the UGRRC was assessed against nine sustainability criteria established in this study. The criteria were adopted and modified from Acreman (1997); URT (2002a) and Adeyemi (2004). Therefore, sustainability assessment was based on the criteria that:

1) Water is treated as an economic good and is appropriately priced;
2) Human actions do not compromise long-term water availability;
3) Water resources management is adequately financed;
4) Effective monitoring and data management system is established;
5) Water for basic human needs is guaranteed and water for environmental sustenance is reserved (i.e. taking an ecosystem approach);

6) Water is not a limiting factor for agricultural, energy production and other economic activities (equitable access by all sectors);
7) Efficient and environmentally sound technologies are in use;
8) Suitable and effective institutions are developed to manage water resources and adequate and appropriately trained staff are available at all levels; and
9) Effective and sustainable strategies are in place to address and adapt to climate change and human-induced water resources problems

4.5.1 Water is treated as an economic good and is appropriately priced

Water is the basis of life and provides great value. While water is abundant, people need to understand and appreciate that it is limited in many regions, there are environmental and economic costs of damaging water resources, and unbounded water and land use poses serious risks to people and ecosystems. The Tanzania Water Policy (URT, 2002a) treats water as a social, economic and environmental good. Recognizing the extent to which the water resource contributes to economic productivity on the one hand, and the financial investments required for water development on the other, the Tanzania Water Policy therefore treats development of water for productive purposes as an economic undertaking requiring efficient management of the resource and financed by water users themselves.

The Water Utilization (General) (Amendment) Regulations of 2002 (URT 2002b) have set forth a set of "economic water users’ fees" and as such all water uses for economic purposes are charged for. In addition, the entities supplying domestic water to the final consumer charge for this service, with dues payable in cash in urban areas, and often in terms of labour contribution to system maintenance in rural areas. Ideally, the charge should match the cost of supplying the service consumed, so that consumers have an incentive not to over-use the service or abuse it. However, the price of water does not at present reflect its true scarcity value. Neither the basin level "economic users' fees" nor the charges for delivery of water cover the true cost of the resource as these tariffs are still low. For example, the current levels of water user fees paid by irrigators in the UGRRC are about USD 2.0 per person per hectare per annum. Consequently, insufficient revenues are generated to cover operation and maintenance costs of irrigation schemes thereby undermining the quality of the service, and of the water received. These low tariffs encourage inefficient use of water by irrigators. As it has already been pointed out, there is over-abstraction and over-use of water above what is needed leading to high wastage levels in irrigation schemes.

However, increasing economic water users' charges to reflect the true cost of supplying water for irrigation purposes now could be counter-productive. The reason is that, currently irrigation schemes usually charge their members a 'flat rate' charge, irrespective of the location and the size of the irrigated field. Furthermore, the actual amounts of water abstracted by irrigation schemes are rarely measured. It is therefore highly improbable that increasing water user fees will lead to "wise use" of water. On the contrary, the increase may trigger irrigated area expansion in upstream areas thereby aggravating water scarcity problems in downstream areas. From social point of view, any attempts to raise water user fees to levels that reflect the true cost of water, will be very unpopular. Many people still believe that water is God-given, to be utilised freely by anyone who can access it in order to increase revenues collected by RBWO, which is required to finance some of its operations, efforts should be intensified to charge all water users who are currently not charged for water uses at all. For example, out of about 1514 abstractions in the Rufiji River Basin, only 1050 are billed, and of these, only 70% pay (The World Bank, 2004). Consequently, during the RBMSIIP Project, Rufiji River Basin managed to collect (excluding TANESCO Royalty fees) only USD 52 600 as water user fees (The World Bank, 2004). There is thus an enormous capacity to increase the revenues from user fees, due to the large degree of non-payment. According to NORPLAN (2000) cited by the World Bank, 2004, the royalty paid by TANESCO to Rufiji and Pangani Basin authorities could be increased without significantly affecting TANESCO's costing. For example, TANESCO is currently paying Royalty fees of Tshs 61 000 000.00 (USD 48 960) and Tshs 24 000 000.00 (USD 19 200) for Kidatu and Mtera hydropower generation plants respectively (RBWO records). This is equivalent to Tshs 300 000.00 (USD 240) per 1MW generation capacity per annum. In 1997, the royalty amounted to 0.1 percent of TANESCO's electric power sales and about 0.14 percent of the cost of sales (NORPLAN, 2000 cited by The World Bank, 2004). Efforts should also be intensified in introducing efficient water use technologies and training local level water users on better water management practices and methods of enhancing productivity of water in agriculture. This will provide a viable option of improving sustainability of water resources.

From sustainability point of view, current methods of determining water tariffs, levels of water charges, and revenue collection mechanisms are not effective and do not promote efficient and sustainable water use.

4.5.2 Human actions do not compromise long-term freshwater availability

Irrigated agriculture is the largest "consumptive" user of surface water. For example, in the Mkoji sub-catchment water for irrigation accounted for 94% of water withdrawn during the wet season and 73% of water withdrawal during the dry season. Results of rainfall and river flow analysis have shown that the UGRRC is characterised by huge spatial and annual variations in rainfall and that the catchment has experienced a considerable decrease in annual rainfall, especially in the plains. Results have further shown that despite the fact that available water resources are getting less and less with time, the area under irrigated agriculture has been steadily increasing since the 1980s and there is over-abstraction and misuse of water. The problem has been further exacerbated by the long dry season and several years of less than average rainfall and encroachment of people to water source areas. Increased in-migration of both pastoralists and farmers, new opportunities in agriculture following the liberalisation of the economy and greater demand for water for irrigation have contributed to dwindling water supplies in the UGRRC.

On top of the above observations, the results of this study have revealed that many river relocations have occurred in the GRRC since 1950s. It was shown that many river relocations have been triggered by man’s action, notably river diversions through poorly designed and constructed intakes, which caused rivers to flow through the associated irrigation canals and furrows. In some cases, the rivers were purposely completely blocked in order to change their courses. Channel changes caused by man's actions have had very negative effects on the hydrologic regime of the rivers. Usually the morphology of the river changes (sometimes becoming very shallow and narrow) and the bed slope becomes less and less. Consequently, much of the water, during the rainy season, just spreads and floods nearby areas and is lost through evapotranspiration.

The overall consequences are the degradation of water sources, drying of rivers and shrinking of wetland areas. Part of the problem is a reflection of poor planning where planning has often taken place by deciding first how much water is needed and then trying to find a source. In contrast, the opposite process is likely to lead to more sustainable water use, by first assessing the available water resource and then deciding how best it can be used.

From the foregone discussion, it can be concluded that if current human actions continue unabated they will impair long-term availability of fresh water resources. Thus, from sustainability point of view, the current water use practices in the UGRRC are unsustainable.

4.5.3 Water resources management is adequately financed

Water resources management entails a variety of technical, administrative and legal activities that cost money to implement. These activities include water resources exploration, assessment, water allocation, pollution control, monitoring and evaluation, regulation and enforcement, environmental protection, basin planning and development. Financing of water resources development in Tanzania is largely dependent on foreign aid. For example during the formulation and implementation of Water Master Plans in the 1980s, all the plans for the 17 different regions, with the exception of one, were financed and prepared by donor agencies.

Similarly, external donors funded many large irrigation projects that have been executed in Tanzania since the 1980s. Examples include 1) Lower Moshi Irrigation Project (Japanese Government); 2) Dakawa Rice Irrigation Project; 3) Participatory Agricultural Development and Empowerment Project (USD 69.99 million - The World Bank); 4) Madibira Smallholder Agricultural Development Project (USD 20 million - African Development Fund); 5) Kapunga Rice Irrigation Project (USD 60 million - African Development Bank); 6) River Basin Management and Smallholder Irrigation Improvement Project (USD 30.7 million - The World Bank); 7) Participatory Irrigation Development Program (USD 25.238 million - IFAD; World Food Program; Irish Aid); 8) The Smallholder Development Project for Marginal Areas (USD 18.09 million - IFAD; World Food Program) and The Usangu Village Irrigation Project Phase II (USD 2.7 million - UNDP) (IMAWESA, 2006). Likewise, most of the improved and modern irrigation schemes in the UGRRC have been constructed with assistance from external support agencies such as FAO, IFAD, UNDP, the World Bank, DANIDA, African Development Bank and others (Table 61). Even when projects are implemented in partnership between donor agencies and the Government, there is always the problem of late disbursement of the local funds leading to delayed implementation of the projects.

Table 61: Irrigation schemes constructed with donor support in the UGRRC

Sno	River name	Name of Irrigation Scheme	Year improved	Area (ha)	Financer
1	Mbarali	Mbarali Rice Farms	1972	3200	PRC; GoT
2	Mswiswi	Mahango Mswiswi	1982	607.3	FAO
3	Mswiswi	Nsonyanga B	1983	809.7	FAO
4	Mambi	Majengo	1985	750	GoT; FAO UNDP
5	Lunwa	Igurusi	1989	200	ZIO (GoT)
6	Mlowo	Abdulkader Mehrab	1989	4	Private
7	Chimala	Chosi	1991	607.3	ADB
8	Chimala	Njombe	1991	121.5	ADB
9	Chimala	Isitu	1991	81	ADB
10	Chimala	Herman	1991	900	ADB
11	Chimala	Igumbilo	1991	161.9	ADB
12	Chimala	Mgonakuvagogolo	1991	81	ADB
13	Kimani	Kimani	1991	1200	CIDA; GoT
14	Great Ruaha	Kapunga	1991	3800	ADB; GoT
15	Mlowo	Langwira Pasture Seed Farm	1992	18.2	Japanese; GoT
16	Chimala	Matebete	1993	161.9	ADB
17	Mlowo	Moto Mbaya	1994	550	GoT; FAO-UNDP
18	Mswiswi	Mswiswi	1995	1579	FAO
19	Ndembera	Madibira Smallholder Rice Project	1997	3000	ADB; GoT
20	Lunwa	Maendeleo Igurusi	1999	30.3	World Bank; GoT
21	Lunwa	Kilombero Njalalila	1999	113.2	RBWO (GoT)
22	Mbarali	Igomelo	2002	300	World Bank; GoT
23	Ipatagwa	Ipatagwa II	2002		World Bank; GoT
24	Mkoji	Ipatagwa I	2002	542	World Bank; GoT
25	Lwanyo	Luanda Majenje	2002	450	World Bank; GoT
26	Uta	Iyawaya	2002	30	OAU; GoT
27	Mlowo	Inyala A	2002		OAU; GoT
28	Mlowo	Inyala B	2002	120	OAU; GoT
29	Mwambalizi	Imezu Mkombozi	2002	160	RBWO (GoT)
30	Mlowo	Isikaka	2005		Private individuals
31	Mlowo	Shamwengo	2005	40	Tanzania Japanese Food Counterpart Fund

The government also has inadequate resources to finance water resources management and to fund operations of the regulatory agencies. Allocations of funds from the Government are too small to allow the Basin authorities to carry out their duties satisfactorily. In some years, actual releases from the government have been even smaller than the allocations (NORPLAN, 2000 cited by The World Bank, 2004). For example, a study of financing mechanisms in the Pangani Basin (The World Bank, 2004) showed that the main sources of funds over three years (2000/01 - 2002/03) were, on average, the water user fees (36%), Central Government (MoW) (29%), TANESCO royalties (20%), and funds from River Basin Management Project (12%). Support from stakeholders to address specific issues amounted to only one percent. The financial gap was, on average about 27-30%.

The same situation prevails in the Rufiji Basin. RBWO has limited capacity to mobilize social and economical resources to finance various activities and support the needs, interests and wishes of the heterogeneous groups and water users of the basin. Due to inadequate funding, the basin faces problems of carrying out its duties such as enforcement of water legislation, pollution control, conflict resolution, regulating water abstractions and use, monitoring, data collection and dissemination.

Financial sustainability of water resources management depends on improved financing mechanisms and funding at the basin level, including economic water user fees. Government funding is required to cover some of the general regulatory functions of Basin Water Offices as well as to finance water related development projects.

It can be concluded that the current levels of funding and dependency on foreign aid in Tanzania do not guarantee financial sustainability of water resources development and management.

4.5.4 Effective monitoring and data management system is established

Integrated management of river basins requires assembly, management and analysis of large amounts of information in relation to environments, resource uses, pollution and ambient conditions within given frames. Thus, an effective integrated water management system must be able to provide timely and correct information on the quality and quantity of surface and groundwater resources, socio and economic situation, establishment of basin water demands and the extent of resource use. This is necessary because sustainable management could only be achieved if decisions are based on sound information. Monitoring at a local, district, catchment, basin and national levels requires having objectives at each level. Monitoring should allow the actors at the various levels to have better knowledge of the water situation. It should also help them in their planning so that they can anticipate and correct any disparities in the existing water situation. It should finally allow them to have precise knowledge of the results of actions on the ground.

Since 1955, the operation of hydrological services in Tanzania was done according to guidelines developed during the Rufiji River Basin Research Work (FAO, 1960). In 1979, the Ministry of Water, Energy and Minerals in collaboration with the Norwegian Agency for International Development (NORAD) jointly prepared a

Manual on Procedures in Operational Hydrology to assist in field operations. In October 1987, another manual titled “Guide to Hydrological Practices for Regional Offices in Tanzania” was developed and since then the Hydrology Section of the Water Resources Directorate in the Ministry of Water has been using the manual. However, the current hydrometric networks in Tanzania were planned before the current era of integrated model of river basin management. The emphasis at that time was generally on ‘hydrological’ knowledge rather than on knowledge designed to support river basin management. The data on water use by particular users are scattered among different institutions, making estimation of the total water use and demand within the basin difficult. Indicators that were decided to be monitored were only those required to facilitate water resources assessment. Furthermore, current water resources management paradigms such as IWRM, the ecosystem-based approaches to basin management and the consideration of the basin, as the basic planning unit were not yet in place.

At the basin scale, data collection networks in the UGRRC are far from ideal to support integrated planning and management of water resources due to inadequate resources and tools. The results are that water managers are often unable to determine trends of supply and demand. Some of the rivers are not monitored effectively, which means that the true water resource is not known with certainty and effective planning and management are little more than shots in the dark. A study done during the Sustainable Management of the Usangu Wetlands and its Catchment (SMUWC) Project revealed that out of 177 rainfall stations that had operated in the UGRRC, data were available for only 100 stations in the archives of Tanzania

Meteorological Agency (TMA). The situation is particularly worse with river flow data. Out of 41 hydrometric stations that operated in the UGRRC, only 16 stations had processed river flow data; and the flow (current meter measurements) data were only available for 32 stations. Of these, computerised flow (current meter measurement) database comprised 23 stations. On top of that, most stations in the UGRRC have poor and old rating curves while cross sections at most of the gauging stations have changed over the years.

On the issue of water data and information sharing, the only notable achievements recorded by Tanzania in as far as hydrological data dissemination is concerned were the publication of Hydrological Year Books. These were published for the first time in 1963, covering the period 1950 to 1959. However, the publication stopped in 1980 due to financial difficulties. An effective monitoring system must present information in a format appropriate for the various stakeholders and data applications. Presentation formats can include oral presentations, small format tabular or graphic summaries, large format summaries or technical reports. Dissemination of analysed and summarised hydrological and water use data and information should be done promptly and timely to potential users.

Despite the fact that adequate funds were allocated for the improvements and rehabilitation of monitoring networks during the USD 30.7 million RBMSIIP (The World Bank, 2004), the situation of data availability has not improved much. About 43 hydrometric stations and 11 weather stations were rehabilitated during the project (The World Bank, 2004). However, there were data gaps even during the time (1996-

2004) when the project was operational. This implies that the problems facing monitoring and data management networks are not caused by inadequate funding alone. The current data monitoring system lacks a fully articulated framework for assessing monitoring needs, designing data management systems and sequencing appropriate interventions, and disseminating information packages. The implication of the above findings is that the current hydrometric service is only partly suited to the requirements of today. It is therefore proposed that the current monitoring and data management system be revisited and improved to fulfil the current mission, goals and objectives of water resources management in Tanzania. Development of a framework to assist designing of monitoring and data management system will go a long way in improving collection, analysis and dissemination of water data and information.

In view of the above observations, the current system of basin monitoring and data management is far from ideal and does not promote sustainable water resources management.

4.5.5 Water for basic human needs is guaranteed and water for environmental sustenance is reserved (i.e. taking an ecosystem approach)

The Dublin Statement (ICWE, 1992), states "since water sustains all life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems." Superimposed on this natural environment is the effect of human beings. An ecosystem approach, through integrated river basin management aims to make the sustainable use of resources within a river basin. Access to safe water is essential for addressing poverty and health problems. However, in Tanzania (UGRRC inclusive) the poor, most of whom live in rural areas, have limited access to clean water for domestic use and lack adequate sanitation services. Water resource statistics are often provided on a per capita basis. This represents an average across the entire population, giving the impression of equality in the availability of the resource. The contrast in access is strikingly evident in many developing countries, Tanzania inclusive. For example, according to the Ministry of Water (IRIN, 2006), water supply coverage in urban areas is 73%. However, much of the supply is unreliable and demand for water exceeds supply in most of the 19 urban centres served through the Urban Water Supply and Sanitation Authorities. With regard to sewerage services, many urban areas continue to be affected by poor sanitary services. Only about 7 percent of the urban dwellers are connected to the existing water piped sewerage system. The situation is worse for the rural areas where only about 53% of rural dwellers have access to clean safe water supply. The supply is however inadequate and unreliable. While these figures represent national averages, the situation varies a great deal between different geographical locations.

In Mkoji sub-catchment of the UGRRC, the access to dry season water resources has been reduced to such a level that Lower Zone households have to find other locations to access water resources, at far distances from their households. For the case of adequate water to sustain the environment, the results have shown that fragmentation of the rivers by increased diversions and irrigation canals has led to the shrinking of the seasonally inundated flood plains due to reduced flooding. As such the Lower Zone and some Middle Zone communities are now shifting towards charcoal making, thatch grass and firewood selling during the dry season as a way of sustaining their livelihoods, in the absence of dry season irrigated agriculture opportunities. However, this diversification results into further degradation of water ecosystems.

Furthermore, during the dry season, most of the rivers draining the UGRRC, which were once perennial, now dry up in upstream areas, making downstream water users to suffer more from water shortages. This is mainly due to dry season irrigated agriculture, over-abstraction and misuse of water in upstream areas, which uses all the water that would have kept the rivers flowing during the dry season. For example, since the early 1990s, initially for periods of a few weeks, but later for increasing lengths of time, periods of zero flows in long stretches of the Great Ruaha River between the perennial swamp (*Ihefu*) and the Ruaha National Park have been recorded. Thus dwindling water supplies from the UGRRC, and drying of rivers especially during the dry season, affect negatively the existence of important ecosystems such as the Utengule swamp, Usangu Game Reserve and the Ruaha National Park. All these ecosystems are of both national and international importance as they are potential sources of foreign exchange generated through tourism and wildlife/game hunting.

Therefore, from environmental point of view, it can be concluded that current water use practices in the UGRRC are unsustainable, have negative impacts on and degrade the environment.

4.5.6 Water is not a limiting factor for agricultural, energy production and other economic activities (equitable access by all sectors)

Water scarcity affects all social and economic sectors and threatens the sustainability of the natural resources base. According to URT (2007), water scarcity is defined as 'The point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully'. Current data shows that the per capita water is decreasing with time due to increasing population and water use activities. Water scarcity affects productivity in all aspects of economic life with greatest impacts felt by those living in the semi arid areas of Tanzania such as the Usangu Plains in the UGRRC. Growing scarcity and competition for water stand as the major threat to future advances in poverty reduction, especially in rural areas, which host 80% of the population in Tanzania.

It is recognized that ensuring food and energy security calls for a range of actions involving socio-economic development policies. In Tanzania, development of irrigation systems is an important aspect of an agricultural development strategy. In the first place, the variability inherent in Tanzania's rainfed production systems creates problems of shortages of the main food crops in years of inadequate or poorly timed rainfall. For this reason, agricultural policies have always sought to increase food production in irrigated areas, and to reduce this variation. Second, irrigation schemes if properly managed can provide sustainable increases in small farmer productivity and income, addressing rural poverty alleviation and environmental management objectives. Finally, irrigated agriculture provides an option in which high value crops (vegetables, flowers) can be produced under controlled conditions needed to meet market schedules in Europe and elsewhere.

However, water can be a limiting factor while implementing irrigated agriculture. For example, this study has shown that since the 1980s, there has been a steady and tremendous increase in the area under paddy cultivation (at a rate of 1335 ha per year) as well as the area under dry season irrigated agriculture. There has also been an increase in the number of improved intakes in the UGRRC, the total abstraction capacity has steadily risen and more importantly, the ability to abstract water during the dry season has increased. The result is that water is now a limiting production factor, especially during the dry season and dry years. Increased irrigation activities in the Upper Zone of MSC have aggravated water scarcity problems thereby forcing Middle and Lower Zone communities to change their farming systems and livelihood strategies. For example, livestock keepers are now forced to migrate to swampy areas during the dry season in search of pasture and water for their livestock. Likewise, the water users in Mkoji sub-catchment increasingly feel the constraints posed by the limited water resources. During the dry season, water resources are the limiting production factor. In parts of the Middle Zone, the dry season agricultural production is limited to a small proportion of the irrigable land, and is subjected increasingly to risks of failure and yield reductions due to intense competition for water.

According to the World Bank (2004), irrigation and hydropower account for 99% of all abstractions in the Rufiji and Pangani basins, with hydropower located downstream of irrigated areas and urban water abstraction points. This makes water availability for hydropower generation negatively impacted by other off-stream uses such as irrigation abstractions. It is vital that the national hydropower system, which is entirely located in the Rufiji and Pangani rivers, gets adequate water and is operated optimally. For example, hydroelectric power (HEP) generation at Mtera and Kidatu hydropower plants (which account for about 50% of the total HEP in the country) depends on water from the UGRRC. Inefficient water use and wastage in upstream irrigation schemes have contributed to inadequate water supply in both hydropower reservoirs. Inadequate water flows to the Mtera and Kidatu hydropower plants in the early 1990s and between 2003/04 to 2005/06 rainfall seasons resulted into rationing of electricity leading into economic losses due to reduced industrial production.

Thus, from food and energy production point of view, it can be concluded that current land and water management practices in the UGRRC are unsustainable and have contributed to reduced hydropower generation as well as reduced agricultural production in downstream areas.

The challenge is, therefore, how to manage Tanzania's water resources so that water does not become the limiting factor in the expansion and increased productivity of irrigated agriculture (to ensure food security and economic development) as well as energy production. There is thus a need to save water through efficiency improvements in the irrigation schemes and enhanced operating routines of the hydropower system.

4.5.7 Efficient and environmentally sound technologies are in use

Water use efficiency is a subject of concern to a large majority of countries and relates to all sectors, as it sets excessive demand on the resource itself. The problem is of particular significance in agriculture and more so in irrigation which has a heavy demand for water. Given its current economic situation, Tanzania cannot afford to spend its constrained resources on producing water that is allowed to go to waste. Yet, the results of this study have shown that much water is wasted. For example, direct conveyance of water from rivers using the extended and long irrigation canals conveying water for brick making in the UGRRC contributes to increased water losses. The practice increases the number of diversions and leads to more water losses through evaporation and seepage during conveyance, especially in the dry season.

Most traditional irrigation schemes in the UGRRC practice on-farm water management through traditional furrows and small-cultivated bunded basins locally called *vijaruba*. The intakes and furrows lose a lot of water during conveyance through seepage and water logging. Access to water is uneven within schemes, with tail-end farmers suffering from frequent water shortages. Irrigation efficiencies in some of these schemes are still low, estimated at 15-20% (the World Bank, 2004; Rajabu, 2006a). Irrigation efficiencies in the schemes, which were improved during the RBMSIIP Project have only increased to about 27% during the wet season (the World Bank, 2004), a figure which is still low. Over-abstractions of water above what is needed for crop production have been observed in most of the studied traditional and improved traditional irrigation schemes. The schemes abstracted as much as six times the recommended amounts. In the absence of appropriate and well functioning drainage systems, much of the excess water abstracted is lost through seepage and evapotranspiration through weeds.

The high levels of water wastage experienced in the studied irrigation schemes in the UGRRC are attributed to inadequate knowledge on proper water management techniques, sheer negligence among water users and the use of inefficient technologies. Incentives and technological improvements are needed to reduce such waste and improve the efficiency of investments in water resources. Simple and innovative technologies that have proved to be effective and efficiency in other countries (for example the use of drip irrigation in Botswana) are not yet being used in the UGRRC. Treadle pumps, which are cheap and efficient to use are not yet popular and are being used in very isolated cases.

However, the trend is different with smallholder schemes that were established alongside large state farms. The fields were levelled, the intakes are modern and the water conveyance canals were well constructed. While the large and capital intensive Mbarali and Kapunga Rice Farms collapsed and had to be sold to private investors, the smallholders' irrigation schemes of Kapunga, Madibira and Chimala have shown a certain degree of resilience and are still operating profitably. A comparison of yields of the smallholder schemes with those achieved in large-scale state farms over the same period reveals the better performance of smallholders. The Kapunga smallholders realized average yields of 2.9 metric tons per ha, while the Chimala smallholders realised average yields of 2.8 metric tons per ha over the four years 1990/91 to 1993/94. The Madibira Smallholders Scheme, which was implemented much later and started production in 1998/99, has achieved steady but increasing yields each year, averaging 5 metric tons per ha over the period 2000/01 to 2003/04. These yield figures point to the fact that the smallholder schemes that were established alongside large state farms use irrigation water more efficiently and productively than the large estate farms. In a study which compared water utilization efficiency between the smallholders and the large Kapunga Estate Farm (SMUWC, 2001b), it was found out that the latter's efficiency was 45% while the smallholders' efficiency was 65%.

From the efficiency point of view, the results were inconclusive. Kapunga and Madibira smallholder schemes performed well in terms of efficiency and productivity respectively. On the other hand, some of the traditional and improved traditional irrigation schemes and other water users in the UGRRC employ inefficient water use technologies and water management practices, which results into high levels of water wastage.

However, it can generally be said that water use technologies currently being employed in the UGRRC are contributing to unsustainable water resources management.

4.5.8 Suitable and effective institutions are developed to manage water resources and trained staff are available at all levels

Institutions at various levels are essential for sustainable management of water. The institutional framework for water resources management in Tanzania supports effective participation in all aspects of water resources management at all the five main levels (National, Basin, Catchment, District and Community/Water User level).

At the National level, the Ministry of Water is responsible for the overall management of water, on behalf of the Government. Basin-wise, Tanzania is divided into nine river basins (including the Rufiji River Basin). This is the level for data collection, processing and analysis, water allocation, pollution control, preparation of water utilization plans, collection of the various fees and charges, and resolution of various water related conflicts. However, the large size of river basins makes water management difficult at this level since basin staffs are distant from water users. In order to remedy this, the National Water Policy (URT, 2002a) provides for the establishment of Catchment Water Committees and Sub-catchment Water Committees composed of representatives from the public and private sector, and from the Water User Associations within the respective basin. The roles of Catchment Water Committees include preparation and implementation of catchment plans and resolution of conflicts within the catchment.

At the District level, District Councils participate fully in Basin Boards and Catchment Committees. Water Users Associations (WUAs) or Water Users Groups (WUGs) are the lowest level of management. These associations are responsible for local level management of allocated water resources, mediation of disputes among users and between groups within their areas of jurisdiction, collection of various data and information, participation in the preparation of water utilization plans and conservation and protection of water sources and catchment areas.

Establishment of lower levels of institutions is an area where the UGRRC is very strong. At the catchment level, there are two committees that deal with water management. The committees are: a) Water managers Committee which comprises of top management of the three big farms (Mbarali, Kapunga and Madibira Rice Farms) as well as chairpersons of the established Water User Associations in the area, Ward Secretaries, District Water Engineers, District Agricultural and Livestock Development Officers and RBWO; and b) the Great Ruaha Catchment Committee comprising of Regional Administrative Secretaries (Mbeya and Iringa regions), District Executive Directors (all districts in the UGRRC) and RBWO.

The catchment has about nine well performing Apex water users' organisations overseeing water management in six major river systems (Mkoji, Chimala, Kimani, Ndembera, Kyoga and Mbarali rivers). There are also three formal irrigators associations for the improved irrigation schemes of Luanda Majenje, Igomelo and Ipatagwa. There are also many informal irrigation canal committees or domestic water supply committees managing irrigation and water supply schemes in the UGRRC. District wise, all the districts that fall within the UGRRC, have established District Facilitation Teams (DFTs) that oversee capacity building as well as assisting in the development of water utilisation and other plans in their respective districts.

The effectiveness of water resource management, depends on the quality of water rights administration. However, during this study, it was evident that the management of water rights is problematic. It was found out that the water rights issued for irrigation use do not match with the developed area and irrigation schemes abstracted water throughout the year irrespective of the conditions spelt out in their water rights. Consequently, water rights have failed to control and reduce over-abstraction. All these point to lack of enforcements of the laws and regulations. Investigation of supply priorities has shown that people living in rural areas have different perceptions as compared to the priorities given in the National Water Policy (URT, 2002a). For example, whereas the water policy accords second priority to satisfying environmental water demands, people interviewed accorded it fifth priority. This implies that not very much effort has been spent in disseminating and educating people on various issues of the new water policy.

Capacity building and sustainability are closely related. Without adequate and appropriate capacity at different levels of government and at local level, water resources management will not be sustainable. The number of experts in the various fields of water management has continued to dwindle due to various reasons such as some leaving their jobs, retirement or death. For example, the Rufiji Basin Water Office, Rujewa sub office has only two trained staff (a water technician and a hydro-geologist). The two staff are supposed to cover an area of about 17 168 km^2 with a population of 480 000. Worse still, there are many intakes in the area (about 150) scattered over a wide area. Much of the area is inaccessible during the rainy season.

At the national level, Tanzania has inadequate number of personnel skilled in IWRM. A massive programme for manpower development is therefore needed to produce a cadre of water professionals who are highly skilled in IWRM principles and practices. At the local level, communities often suffer from lack of capacity to set up stronger, well organised and effective water management institutions. Therefore, capacity building[12], especially on issues related to water management, monitoring and data collection and conflict resolution must be intensified and rooted locally to facilitate sustainable water resources management and livelihood

[12] Capacity building is the process of strengthening the abilities of individuals, institutions, organizations and societies to make effective use of resources, in order to achieve desired results on a sustainable basis (Georgiadou, 2001; Whyte, 2004)

improvements. This will contribute to the empowerment[13] of local communities. Empowered people are better placed to influence the course of their lives and the decisions, which affect them.

It is encouraging to note that the focus of institutional capacity building and human resource development has been extended to the district and grassroots levels in the UGRRC. As such, the catchment has made great strides in imparting the necessary water management skills to staff and water users at different levels. Members of the District Facilitation Teams have received adequate training in order to perform their duties well. Likewise, water users associations committee members as well as local level water users have also attended capacity building workshops (e.g. through the River Basin Game (Rajabu, 2006b) and participatory planning workshops). Members of Luanda Majenje Irrigators Society also attended training on proper water management conducted by the Kilimanjaro Agricultural Training Centre (KATC). WUAs committee members and Farmer Field School members from Lower Chimala River sub-catchment also received training on water allocation, efficient use of irrigation water, conflict resolution, leadership skills, awareness on the new water policy, gender and HIV/AIDS. These trainings were facilitated by various partners (such as RIPARWIN and WWF) in collaboration with RBWO and District Councils.

[13] Empowerment refers to the expansion of assets and capabilities of poor people to participate in, negotiate with, influence, control, and hold accountable, institutions that affect their lives (World Bank, 2002)

In view of the above, it can be said that despite the weaknesses in enforcing the water legislation, there are promising indications that the UGRRC is in the right direction in establishing effective and sustainable water resources management institutions and good governance and this guarantees institutional sustainability of water resources management.

There is an urgent need to speed up the process of enacting the new water legislation so that the newly developed Water Policy (URT, 2002a) and the Water Sector Development Strategy could effectively be put into operation. A strong institutional set-up will help to curb the lapses and weaknesses in enforcements of the water legislation.

4.5.9 Effective and sustainable strategies are in place to address and adapt to climate change and human-induced water resources problems

In Tanzania, mitigation and handling of disasters is under the Prime Minister's Office (PMO). Therefore, although coordination and implementation of water related disaster mitigation is one of the responsibilities of the Ministry of Water, in actual sense it is the PMO, which drives the process. However, results of this study identified evidence of institutional capacity in the UGRRC to dynamically, adjust irrigation, domestic and livestock water use practices to variability in water supply. Actions taken include: 1) rotational irrigation schedules to distribute water more equitably across systems; 2) fines and temporary bye-laws to prevent water theft and water blocking; 3) use of the village organs to mediate and resolve conflicts; 4) collective canal cleaning; 5) alterations to in-field water control; 5) reduction of cultivated areas; 6) concentrating irrigated agriculture to core areas in the upstream of the schemes in dry years to prevent crop failure; 7) delayed establishment of paddy nurseries; 8) diversification to crops that require less water; 9) diversification to other economic activities apart from agriculture (e.g. fish farming); 10) digging wells in the fields to store water for irrigating paddy nurseries and dry season crops; 11) migrating to swampy areas in search of water for livestock use; and 12) digging wells in dry river-beds during the dry season.

Thus, farmers have a flexible and practical relationship with systems of water management. This evidence from the UGRRC suggests that rules and management practices and even entire irrigation systems are adopted and discarded, as required by irrigators, and according to the prevailing water availability conditions. The challenge is how to strengthen this institutional capacity to cope with, and adapt to, water variability and unpredictability. The potential for adaptation within farming systems and rural economies may significantly increase resilience to water variability.

It can be concluded that, although the Ministry of Water lacks effective disaster mitigation plans, local level water users have developed the capacity and techniques of dealing with adverse effects of water and therefore, from sustainable point of view, current local level disaster mitigation strategies are sustainable.

In summary, from the above assessment of sustainability using the decision-making framework for river basin management in the UGRRC, it is concluded here that water resources management cannot be sustainable without: 1) continued government commitment and donor support to finance water resources development; 2) substantially strengthening the institutional and human resources capacity; 3) adopting appropriate, effective, efficient and environmentally friendly water use technologies; and 4) enforcement of laws and regulations governing water use.

However, if the current water resources management practices are maintained, they will lead to worse social, environmental and economic consequences.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Variability of rainfall and river flows

The UGRRC is characterised by huge spatial and annual variations in rainfall, often compounded by poor distribution. This variation coupled with inadequate and decreasing rainfall trends in the plains make it necessary to undertake supplementary irrigation in order to meet crop water requirements for paddy and other crops.

Rainfall regime shift analysis showed that three quarters of the rainfall stations experienced significant regime shifts at 5% significance level. The downward direction of regime changes is a proof that in general rainfall regime in the UGRRC has been decreasing with time. River flow regime change analysis revealed that the annual river flow of 1KA27 did not experience any significant regime change. On the contrary, the dry season river flows at 1KA27 and 1KA59 experienced significant downward regime shifts of 61% and 57.2% respectively in 1975. Early detection of the shifts could have acted as a warning that something was wrong with the dry season flows exiting the UGRRC.

5.1.2 Irrigated area trends in the UGRRC and changes in the hydrologic regime of the Great Ruaha River

Since the 1980s, there has been a steady and rapid increase in the area under paddy cultivation (at a rate of 1335 ha per year) as well as the area under dry season irrigated agriculture in the UGRRC. This rapid increase in the irrigated area was accompanied by extended season of paddy cultivation (the season now runs from October to August) and increase in water abstractions in the Upper and Middle zones to such an extent that downstream water users suffer even more from water shortages.

Although river flows entering the UGRRC have not changed much between pre 1980 and post 1980 time windows, split sample analysis of the flows exiting the UGRRC showed that the dry season flows between the two time windows decreased by 57% and the decrease is statistically significance at 5% significance level.

Analysis of indicators of hydrologic alteration (IHA) at 1KA27 between the time windows (1957-1980 and 1981-2004) revealed a progressive decline in flows lower than Q_{30}. The analysis showed also that the minimum flows now, start two weeks earlier as compared to the pre-impact window. This shows that dry season flows from the UGRRC are depleted at a very faster rate now compared to the pre-impact period. The decrease is not due to natural causes. It is rather due to water use changes taking place between the gauging stations located in the upper zone and 1KA27.

5.1.3 Current water uses and demands in the Mkoji sub-catchment

Irrigated agriculture is the largest "consumptive" user of surface water in the UGRRC. In Mkoji sub-catchment water for irrigation accounted for 94% of water withdrawn during the wet season and 73% of water withdrawal during the dry season, whereas combined domestic and livestock water uses accounted for 6% and 14% of water withdrawn during the wet and dry season respectively.

Investigation of supply priorities has shown that people living in rural areas have different perceptions as compared to the priorities given in the National Water Policy (URT, 2002a). For example, whereas the water policy accords second priority to satisfying environmental water demands, people interviewed accorded it fifth priority. This implies that not very much effort has been spent in disseminating and educating people on various issues of the new water policy, including the importance of environment sustenance.

5.1.4 Upstream water abstraction patterns and use and their impacts to downstream flows

Although water rights and water users’ fees are meant to control and regulate the use of water, they are also subject to abuse by selfish farmers if not managed and monitored closely. Proper monitoring of water rights demands high levels of supervision that are not commensurate with resources currently available to most basin authorities in developing countries.

It is possible to maintain flow throughout the year in Kimani, Mbarali and Great Ruaha rivers if the levels of water abstractions are closely monitored and controlled. If interventions are not undertaken to control and regulate water abstraction during the dry season, water supply and demand in the UGRRC will be unbalanced, downstream areas will suffer more from water shortages, and thus more conflicts on water use will emerge.

5.1.5 Sustainability of water resources management

Data collection networks in the UGRRC are far from ideal to support integrated planning and management of water resources due to inadequate resources and tools. Some of the rivers are not monitored effectively and groundwater resources are not monitored adequately, which means that the true water resource is not known with certainty. Likewise, levels of water use, such as for irrigation, livestock and brick making are not known precisely. Under this situation, effective planning, development and management are little more than shots in the dark as water managers are often unable to determine trends of supply and demand.

Dwindling water supplies from the UGRRC, and drying of rivers, especially during the dry season, affect negatively the existence of important ecosystems such that wetlands and swamps are shrinking; and Usangu Game Reserve and Ruaha National Park suffer from lack of adequate water for the game and aquatic animals. Thus, it can be concluded that current water use practices in the UGRRC are unsustainable and have negative impacts on the environment.

Sustainable management of water resources characterised by highly variable supply and dynamic use should be governed by an understanding of the prevailing water use patterns; overall impacts across a river basin; be based on increasing resilience (to water shortages) of water users, livelihood activities and ecosystems; and continue to build the capacity of water management at all levels. This entails close collaboration with water users, while at the same time establishing strong financing mechanisms, institutional, legal and regulatory frameworks at the basin scale that recognize water variability, multiple uses and demands and the tricky management of water allocation between the transition periods (from wet to dry season and vice versa).

5.2 Recommendations

The current monitoring and data management system be revisited and improved to fulfil the mission, goals and objectives of water resources management in Tanzania. A fully articulated framework for assessing monitoring needs and designing data management systems should be developed.

People should be encouraged to diversify to other economic activities that use less water (e.g. fish farming as is the case in MSC) to reduce pressure on water resources. In order to regulate amounts of water abstracted during critical periods, there should be regular auditing and assessment of water availability in rivers and uses in irrigation canals, followed by implementation of temporary allocations.

Water rights for irrigation should be reviewed to conform to actual crop water requirements. The water rights should also be short-term, renewable, revocable once a holder violates the conditions, proportional to flows, provide for downstream requirements and preferably be held by water users' associations or other collective entities.

More research needs to be done to ascertain the major factors responsible for the observed hydrological change and to quantify their impacts to the hydrological regime of the Great Ruaha River as well as to the livelihoods of the people. An overall water balance study should be undertaken in order to reveal the relationship between water balance components and water abstraction.

This study has demonstrated the value of combining different research methods and analyses and the role of simple decision support tools to assist in reaching and evaluating decisions concerning sustainable water resources management. The integrated decision-making framework for sustainable river basin management is simple and could be used to assist decision-makers in evaluating social, economic and environment impacts of water management decisions. However, in order for the framework to be more effective and useful, assessment criteria should be refined, and more criteria should be investigated and added. Development of simple and measurable indicators to address the underlying ecosystem processes, stressors, investments, water quality and quantity, human effects (e.g. health) and environmental effects can go a long way to improve the decision-making framework.

REFERENCES

Acreman, M. (1997). Principles of water management for people and the environment. *IUCN Wetlands Programme Newsletter* 15:25-29.

Adeyemi, Y. (Ed.) (2004). *Outcomes and Recommendations*. Proceedings of the Pan-African Implementation and Partnership Conference on Water (PANAFCON), Addis Ababa, Ethiopia, 8-13 December, 2003. 77pp.

Alemaw, B. F., and Chaoka, T. R. (2003). A continental scale water balance model: a GIS-approach for Southern Africa. *Journal of Physics and Chemistry of the Earth* 28/20-2: 957-966.

Alemaw, B. F. and Chaoka, T. R. (2002). Investigation of Regional Trends and Seasonal Shifts in the River Flow Regimes of Southern Africa. *Botswana Journal of Technology* 11(1): 57-63.

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998). Crop evapotranspiration -Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56, Food and Agriculture Organization, Rome.

Alley, W. M. and Burns, A. W. (1983). Mixed-station extension of monthly streamflow records. *Journal of Hydraulic Engineering* 109: 1272-1284.

Bastiaanssen, W. G. M. and Chandrapala, L. (2003). Water balance variability across Sri Lanka for assessing agricultural and environmental water use. *Agricultural Water Management* 58: 171-192.

Batchelor, C. (1999). Improving water use efficiency as part of integrated catchment management. *Agricultural Water Management* 40(2): 249–263.

Baxter, R.M. (1977). Environmental effects of dams and impoundments. *Annual Review of Ecology and Systematics*, 8: 255–283.

Beccar, L., Boelens, R. and Hoogendam, P. (2002). Water rights and collective action in community irrigation. In: *Water right and empowerment*. (Edited by Boelens, R. and Hoogendam, P.) KONINKLIJKE VAN GORCUM. pp. 1-19.

Boberg, J. (2005). Liquid Assets: How Demographic Changes and Water Management Policies Affect Freshwater Resources. Rand Corporation. [www.rand.org] site visited on 14/4/2006.

Box, G. E. P., and Cox, D. R. (1964). An analysis of transformations. *J. R. Stat. Soc. B* 26: 211-252.

Boyer, D. (2000). Community-Based Resource Management: A Framework for Action. Program Planning and Learning Unit, Oxfam America. Working Paper No. 1. 26pp.

Bruns, B. (2005). Community-based principles for negotiating water rights: some conjectures on assumptions and priorities. Paper presented during the International workshop on '*African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa*', 26-28 January 2005, Johannesburg, South Africa

Bruns, B. R., Ringler, C., and Meinzen-Dick, R. (Eds.) (2005). Water Rights Reform: Lessons for Institutional Design. International Food Policy Research Institute. 336pp.

Bruns, B.R. and Meinzen-Dick, R., (Eds.) (2000). Negotiating Water Rights. International Food Policy Research Institute and Intermediate Technology Publications, London. 326pp.

Burn, D. H. and Hag Elnur, M. A. (2002). Detection of hydrologic trends and variability. *Journal of Hydrology* 255(1-4): 107-122.

Buytaert, W., Celleri, R. Willems, P., De Bie`vre, B. and Wyseure, G. (2006) (In Press). Spatial and temporal rainfall variability in mountainous areas: A case study from the south Ecuadorian Andes. *Journal of Hydrology*. doi:10.1016/j.jhydrol.2006.02.031.

Cai, X., McKinney, D. C. and Rosegrant, M. W. (2001). Sustainability Analysis for irrigation Water management: Concepts, Methodology, and Application to the Aral Sea Region. Environment and Production Technology Division (EPTD) Discussion Paper No. 86. International Food Policy Research Institute

Chambers, R. (1992). Rural appraisal: rapid, relaxed and participatory. *Discussion paper 311*, Institute of Development Studies, Brighton, Sussex.

DANIDA/World Bank (1995). Water Resources Management in the Great Ruaha Basin: A Study of Demand Driven Management of Land and Water Resources with Local Level Participation. A Report prepared for Rufiji Basin Water Office, Ministry of Water, Energy and Minerals, Dar es Salaam.

Department of Ecology's Water Resources Program (DEWRP) (2005). Frequently asked questions. Washington State. [http://www.ecy.wa.gov/biblio/wr.html] site visited on 1/12/2005.

Dixon, J., Gulliver, A. and Gibbon, D. (2001). Farming Systems and Poverty. Improving farmers' livelihoods in a changing world. FAO and World Bank, Rome and Washington D. C.

Douglas, E. M., Vogel, R. M. & Kroll, C. N. (2000). Trends in floods and low flows in the United States: impact of spatial correlation. *Journal of Hydrology* 240: 90–105.

Eagleson, P.S. (1978). Climate, soil and vegetation. *Water Resources Research* 14 (5): 705–776.

Easterling, D. R., and Peterson, T. C. (1995). A new method for detecting undocumented discontinuities in climatological time series. *International Journal of Climatology* 15: 369 -377.

Elkaduwa, W. K. B. and Sakthivadivel, R. (1999). Use of Historical Data as a Decision Support Tool in Watershed Management: A Case Study of the Upper Nilwala Basin in Sri Lanka. Research Report 26. Colombo, Sri Lanka: International Water Management Institute. 44pp.

Everson, C. S. (2001). The water balance of a first order catchment in the montane grasslands of South Africa. *Journal of Hydrology* 241: 110–123

FAO (1960). The Rufiji Basin Tanganyika. FAO Report No. 1269 to the Government of Tanganyika on the Preliminary Reconnaissance Survey of the Rufiji Basin. Volume II, Hydrology and Water Resources. Part I, General Report on Hydrology, Computations and Analyses. FAO, Rome.

FAO (1995). Reforming Water Resources Policy - A guide to methods, processes and practices, Rome, FAO Irrigation and drainage paper 52.

Faraji, S. A. S; and Masenza, I. A. (1992). Hydrological study for the Usangu Plains with particular reference to flow entering the Mtera Reservoir and water abstractions for irrigation. Ministry of Agriculture and Livestock Development, Dar es Salaam, Tanzania (unpublished.).

Forestry and Beekeeping Division (2005). Hydrological analysis of the Eastern Arc Mountain forests. Conservation and Management of the Eastern Arc Mountain Forests, Forestry and Beekeeping Division, Dar es Salaam. 89 pp.

Georgiadou, Y. (2001). Capacity Building Aspects for a Geospatial Data Infrastructure (GDI). Proceedings of 5th Global Spatial Data Infrastructure Conference, 21-25 May, Cartagena de Indias Colombia.

Gleick, P. H. (1998). *The world's water 1998-1999*. The Biennial Report on Freshwater Resources. Washington, D. C.: Island Press.

Global Water Partnership (GWP) (1998). Water as a Social and Economic Good: How to Put the Principle into Practice. GWP Technical Advisory Committee (TAC) Background Paper No. 2. GWP, Stockholm, Sweden.

Global Water Partnership (GWP) (2000). Integrated Water Resources Management. GWP Technical Advisory Committee. TAC Background Paper No. 4. GWP, Stockholm, Sweden. 67pp.

Global Water Partnership (GWP) (2003). IWRM Tool Box Version 2: Sharing knowledge for equitable, efficient and sustainable water resources management, The Press Works, United Kingdom.

Gooch, G. D. and Stålnacke, P. (2003). Integrated Scenarios - The Key for Successful Water and River Basin Management? Diffuse Pollution Conference, Dublin. pp 20-24.

Hansen, D. P., Ye, W., Jakeman A. J., Cooke, R. and Sharma, P. (1996). Analysis of the effect of rainfall and streamflow data quality and catchment dynamics on streamflow prediction using the rainfall-runoff model IHACRES. *Environmental Software*. 11(1-3): 193-202.

Helsel, D. R. and Hirsch, R. M. (1992). Statistical Methods in Water Resources. Elsevier, Amsterdam. 522 pp.

Helsel, D. R. and Hirsch, R. M. (1988). Discussion of Applicability of the t-test for detecting trends in water quality variables: *Water Resources Bulletin* 24: 201-204.

Hermanowicz, S. W. (2005). Sustainability in Water Resources Management: Changes in Meaning and Perception. Water Resources Centre Archives, University of California. Working Paper swr v3. [http://repositories.cdlib.org/wrca/wp/swr v3] site visited on 10/2/2007.

Hess, A., Iyer, H., Malm, W. (2001). Linear trend analysis: a comparison of methods. *Atmos. Environ*. 35: 5211–5222.

Hickel, K. and Zhang, L. (2003). The Impact of Rainfall Seasonality on Mean Annual Water Balance in Catchments with Different Land Cover. Technical Report 03/11. Cooperative Research Centre for Catchment Hydrology. pp 37

Hirsch, R. M. and Slack, J. R. (1984) Non-parametric trend test for seasonal data with serial dependence. *Water Resources Research* 20(6): 727–732.

Hirsch, R. M., Slack, J. R., and Smith, R. A. (1982). Techniques of trend analysis for monthly water quality data. *Water Resources Research* 18: 107-121.

Holden, P. and Thobani, M. (1996). Tradable Water Rights: A Property Rights Approach to Resolving Water Shortages and Promoting Investment. Policy Research Working Paper Series 1627, the World Bank.

Huber, P. J. (2005). Robust estimation of a location parameter, *Annals Mathematical Statistics* 35: 73-101

Hunt, R. J., Krabbenhoft, D. P. and Anderson, M. P. (1997). Assessing hydrogeochemical heterogeneity in natural constructed wetlands. *Biogeochemistry* 34:271-293.

International Livestock Centre for Africa (ILCA) (1990). Livestock system research manual. Working Paper 1, Vol. I. ILCA, Addis Ababa, Ethiopia.

Improved Management of Agricultural Water in Eastern and Southern Africa (IMAWESA) Project (2006). Rapid Appraisal of Policies and Institutional Frameworks for Agricultural Water Management: Tanzania Country Report (unpublished).

International Conference on Water and the Environment (ICWE) (1992). The Dublin Statement and Record of the Conference. Geneva: World Meteorological Organization.

International Water Management Institute (IWMI) (2000). Research contributions to the World Water Vision. Colombo, Sri Lanka.

IRIN (2006). TANZANIA: Water Week marked but "water for all" remains a distant dream [http://www.irinnews.org/report.aspx] site visited on 1/11/2007.

Izac, A. M. and Sanchez, P. A. (2001). Towards a natural resource management paradigm for international agriculture: the example of agroforestry research. *Agricultural Systems* 69: 5-25.

Jadwiszczak, P. (2004). Rundom BC 1.0 software. [http://pjadw.tripod.com] site visited on 10/2/2007.

Jahnke, H. E. (1982). *Livestock production systems and livestock development in Tropical Africa.* Kieler Wissenschaftsverlag, VAUK.

Jansson, R., Nilsson, C., Dynesius, M. and Andersson, E. (2000). Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. *Ecological Applications* 10: 203–224.

Jothityangkoon, C., Sivapalan, M. and Farmer, D. L. (2001). Process control of water balance variability in a large semi-arid catchment: downward approach to hydrological model development. *Journal of Hydrology* 254: 174-198.

Juma, I. H. and Maganga, F. P. (2005). Current reforms and their implications for rural water management in Tanzania. Paper presented during the International workshop on '*African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa*', 26-28 January 2005, Johannesburg, South Africa. [http://www.nri.org/waterlaw/AWLworkshop/papers.htm] site visited on 10/1/2007.

Kashaigili, J. J. (2006). Land cover Dynamics and Hydrological Functioning of Wetlands in the Usangu Plains in Tanzania. Thesis for Award of PhD Degree at the Sokoine University of Agriculture, Morogoro, Tanzania, 266pp.

Kay, J. J., Regier, H. A., Boyle, M. and Francis, G. (1999). An Ecosystem Approach for Sustainability: Addressing the Challenge of Complexity. *Futures* 31(7): 721-742.

Keller, J., Keller, A. and Davids, G. (1998). River basin development phases and implications of closure. *Journal of Applied Irrigation Science* 33(2):145-164.

Kendall, M. G. (1975) *Rank Correlation Methods*. Griffin, London, UK.

Khan, S., Tariq, R., Yuanlai, C. and Blackwell, J. (2006). Can irrigation be sustainable? *Agricultural Water Management* 80: 87–99.

King J. (1983). *Livestock Water Needs in Pastoral Africa in Relation to Climate and Forage*. International Livestock Centre for Africa.

Kingsford, R.T. (2000). Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Australia Ecology* 25: 109–127.

Kite, G. W. (1993). Analysing hydro-meteorological time series for evidence of climate change. *Journal of Hydrology* 24: 135-150.

Kite, G. and Droogers, P. (2000). Comparing Estimates of Actual Evapotranspiration from Satellites, Hydrological Models, and Field Data: *Journal of Hydrology* 229: 3-18.

Koel, T. M. (2000). Eco-hydrology and Development of Ecological Criteria for Operation of Dams. [http://www.umesc.usgs.gov/reports_publications/psrs/psr_2000_02.html] site visited on 4/8/2002.

Lankford, B. and Beale, T. (2006). Equilibrium and non-equilibrium theories of sustainable water resources management: Dynamic river basin and irrigation behaviour in Tanzania. *Global Environmental Change*. doi:10.1016/j.gloenvcha.2006.05.003

Lanzante, J. R. (1996). Resistant, robust and non-parametric techniques for the analysis of climate data: theory and examples, including applications to historical radiosonde station data. *International Journal of Climatology* 16: 1197 -1226.

Lins, H. F. and Slack, J. R. (1999) Streamflow trends in the United States. *Geophysical Research Letters* 26(2): 227–230.

Loucks, D. P. (2000). Sustainable water resources management. *Water International* 25(1): 3–11.

Lyons, A. (2000). An Effective Monitoring Framework for Community Based Natural Resource Management: A Case Study of The ADMADE Program in Zambia. Thesis for Award of MSc Degree at the Graduate School of the University of Florida, Florida, USA. pp 1-8.

Madsen, H. (1996). *Analysis of Hydrologic Time Series*. Technical University of Denmark. 74pp.

Maganga, F.P. (2003). Incorporating customary laws in implementation of IWRM: some insights from Rufiji River Basin, Tanzania. *Physics and Chemistry of the Earth*, Parts A/B/C, 28: 995-1000.

Maganga, F., Kiwasila, H., Juma, I. and Butterworth, J. (2004). Implications of customary norms and laws for implementing IWRM: Finding from Pangani and Rufiji basins, Tanzania. *Physics and Chemistry of the Earth*, Parts A/B/C, 29: 1335-1342.

Maingi, J. K. and Marsh, S. E. (2001). Quantifying hydrologic impacts following dam construction along the Tana River, Kenya. *Journal of Arid Environments* 50: 53-79.

Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica* 13: 245–259.

Mann, H. B. and Whitney, D. R. (1947). On a test of whether one of two random variables is stochastically larger than the other. *Ann. Math. Statist*. 18: 50–60.

Mason, S. J. and Joubert, A. M. (1997). Simulated changes in extreme rainfall over southern Africa. *International Journal of Climatology* 17: 291 – 301

Mbilinyi, B. P. (2000). Assessment of Land Degradation and its Consequences: Use of Remote Sensing and Geographical Information System Techniques: A Case Study in the Isimani Division, Iringa Region, Tanzania. PhD Thesis. ISBN 3-89820-091-4. 139pp.

McGregor, G. R. and Nieuwolt, S. (1998). *An Introduction to the Climates of the Low Latitudes*, **2nd Edition.** John Wiley & Sons, London, New York, Sydney, Toronto. 352pp.

Ministry of Water (MoW) (2002). Guide to Hydrological Practices in Tanzania (Revision). Unpublished.

Mkhandi, S. H. and Ngana, J. O. (1999). Trend analysis and spatial variability of annual rainfall in Pangani river basin. *In Water management in Pangani river basin, Challenges and opportunities. (*Edited by Ngana, J. O.) Dar Es Salaam University Press. pp 11 – 20.

Moeti, L. D. (1999). Paradox of water resource development: Lesotho Highlands Water Project. *South-South Journal of Culture and Development* 1 (2): 1-20.

Molden, D., Amarasinghe, U. and Intizar, H. (2001). Water for rural development: Background paper on water for rural development prepared for the World Bank. Working Paper 32. Colombo, Sri Lanka: International Water Management Institute. 89pp.

Mushala, H. M. (1993). Rainfall Variability and its Implications on Agriculture. In: *Proceedings of the Third Annual Scientific Conference of the SADC-Land and Water Management Research Programme*. (Edited by Kronen, M.). 5-7 April 1992, Harare, Zimbabwe. pp 12-18.

Mutayoba, W., Saidi, F. and Hirji, R. (2001). The development of river basin management in Tanzania: Early experiences and lessons. [http://wbln0018.worldbank.org] site visited on 23/5/2002.

Mwakalila, S. (2001). Modelling Hydrological Response of Semi-arid Catchments in Function of Physical Characteristics, with Application to the Great Ruaha Basin in Tanzania. Dissertation for Award of PhD Degree at K.U.Leuven, Belgium.

Naiman, R.J., Decamps, H. and Pollock, M. (1993). The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3: 209–212.

Ngana, J. O. (1991). Selection of a Probability Distribution for Estimating Reliably Seasonal Rainfall in Semi-Arid Central Tanzania. Research Report No. 79. Institute of Resource Assessment, University of Dar es Salaam. 23pp.

Ngana, J. O. (1994). The Climatology and Hydrology of Pugu and Kazimzumbwi Coastal Forests. Research Report No. 94 (New Series). Institute of Resource Assessment, University of Dar es Salaam. 28pp.

Norwegian Consulting Engineers and Planners (NORPLAN) (2000). Review of water resources management policy, legislation and institutional framework. River basin modelling. Ministry of Water, United Republic of Tanzania.

Nyenzi, B. S., Kavishe, M. M., Tibaijuka, P. F., Kululetera, V., Nassib, I. R. and Tilya, F. F. (1997). A Study on Long Range Weather Forecasting in Tanzania. Research Report No. 1/97. Directorate of Meteorology, Dar es Salaam.

Orlich, S. and Delozier, M. (2001). Box-Cox Transformation Analysis Macro. Minitab Inc. 7pp.

Peltier, M. R., Wilcox, C. J. and Sharp, D. C. (1998). Application of the Box-Cox Data Transformation to Animal Science Experiments. *Journal of Animal Science* 76: 847–849.

Penman, H. L. (1948). Evaporation in Nature. *Rep Prog Phys* XI: 366-388.

Pike, J. G. (1964). Estimation of annual run-off from meteorological data in tropical climate. *Journal of Hydrology* 2(2): 116-123.

Post, D. A. (2004). A New Method for Estimating Flow Duration Curves: An Application to the Burdekin River Catchment, North Queensland, Australia. [http://www.iemss.org/iemss2004] site visited on 15/1/2006.

Priestley, C.H.B. and Taylor, R.J. (1972). On the assessment of the surface heat flux and evaporation using large-scale parameters. *Mon. Weather Rev*. 100: 81-92.

Pandey, R. P. and Ramasastri, K. S. (2003). Estimation of Lean Season Water Availability in Streams with Limited Data. *IE (I) Journal* 84:149-152. [www.ieindia.org/publish/cv/1103/] site visited on 14/4/2006.

Raes, D. (1996). Irrigation Agronomy. Lecture notes – Interuniversity Programme in Water Resources Engineering, Katholieke Universiteit Leuven. 145pp.

Raising Irrigation Productivity and Releasing Water for Intersectoral Needs (RIPARWIN) Project (2005). *Water Productivity Table for Great Ruaha River*. (unpublished).

Rajabu, K. R. M. (2006a). The dynamics of water availability and use and their impacts to the ecosystems and livelihood of the people in Mkoji sub-catchment in Tanzania. Paper presented during the International Conference on Ecosystems Changes and Implications on Livelihoods of Rural Communities in Africa, 18-20 October 2006, Dar Es salaam Tanzania.

Rajabu, K. R. M. (2006b). Impacts of the River Basin Game in Implementation of Integrated Water Resources Management in Mkoji Sub-Catchment in Tanzania. Submitted to *Agricultural Water Management Journal.*

Rajabu, K. R. M. (2005). Jinsi kilimo cha mpunga kinavyoathiri upatikanaji na kiasi cha maji katika Mto Ruaha Mkuu na matawi yake. Paper presented during Mbarali District Paddy Stakeholders Alliance Meeting, Rujewa, Mbeya -Tanzania. Unpublished.

Rajabu, K. R. M. and Mahoo, H. F. (2007). Towards Optimal Administration of Water Rights for Irrigation in the Great Ruaha River Catchment in Tanzania: Challenges and Opportunities. Submitted to *Agricultural Water Management Journal.*

Rajabu, K. R. M., Mahoo, H. F., Sally H. and Mashauri, D. A. (2005). Water Abstraction and Use Patterns and Their Implications on Downstream River Flows: A case study of Mkoji Sub-catchment in Tanzania. In: *Proceedings of the East Africa Integrated River Basin Management Conference.* (Edited by Lankford, B. and Mahoo, H.F.) 7 - 9 March 2005, Morogoro, Tanzania. 233-245pp.

Richter, B.D., Baumgartner, J. V., Powell, J. and Braun, D. P. (1998). A Spatial Assessment of Hydrologic Alteration within a River Network. *Regulated Rivers: Research and Management* 14: 329-340.

Richter, B.D., Baumgartner, J. V., Wigington, R. and Braun, D. P. (1997). How Much Water Does a River Need? *Freshwater Biology* 37: 231-249.

Richter, B.D., Baumgartner, J. V., Powell, J. and Braun, D. P. (1996). A Method for Assessing Hydrologic Alteration within Ecosystems. *Conservation Biology* 10(4): 1163-1174.

Rodionov, S. (2006a). The Problem of red noise in climate shift determination. *Geophysical Research Letters* (submitted).

Rodionov, S. N. (2006b). Use of prewhitening in climate regime shift detection, *Geophysical Research Letters* 33: L12707, doi:10.1029/2006GL025904.

Rodionov, S. (2006c). Sequential Regime Shift Detection Software. [http://www.beringclimate.noaa.gov] site visited on 10/2/2007.

Rodionov, S. N. (2006d). A Sequential Method for Detecting Regime Shifts in the Mean and Variance. [www.beringclimate.noaa.gov/regimes/rodionov_var.pdf] site visited on 7/3/2007.

Rodionov, S. N. (2004). A sequential algorithm for testing climate regime shifts. *Geophysical Research Letters* 31, L09204, doi:10.1029/2004GL019448.

Rodionov, S., and Overland, J. E. (2005). Application of a sequential regime shift detection method to the Bering Sea ecosystem. ICES *Journal of Marine Science* 62: 328 - 332.

Rosegrant, M. W. (2003). Policies and Institutions for Sustainable Water Resource Management: A Research Agenda. Challenge Program on Water and Food. Background Paper 5: 160-195. [www.iwmi.cgiar.org/challenge-program/pdf/paper5.pdf] site visited on 10/2/2007.

Rosegrant, M. W. and Perez, N. D. (1997). Water Resources Development in Africa: A Review and Synthesis of Issues, Potentials and Strategies for the future. Environment and Production Technology Division Discussion Paper No. 28. International Food Policy Research Institute. Washington, D.C., U.S.A. 85pp.

Rosegrant, M. W., Ringler, C., McKinney, D. C., Cai, X., Keller, A. and Donoso, G. (2000). Integrated Economic-Hydrologic Water Modelling at the Basin Scale: The Maipo River Basin. Environment and Production Technology Division (EPTD), Discussion Paper No. 63. International Food Policy Research Institute, Washington, D.C., U.S.A. 36pp.

Roy, S. B., Ricci, P. F., Summers, K. V., Chung, C.F. and Goldstein, R.A. (2005). Evaluation of the Sustainability of Water Withdrawals in the United States, 1995-2025; *Journal of the American Water Resources Association* 41(5):1091-1108.

Rudnick, D. I. and Davis, R. E. (2003). Red noise and regime shifts, *Deep-Sea Research* 50: 691-699.

Saha, S. K. (1981). River basin planning as a field study: Design of a course structure for practitioners. In: *Rivet basin planning: Theory and practice*. (Edited by Saha, S. K. and Barrow, C. J.) John Wiley and Sons, Chichester. pp 9-40.

Sampath, R. K. (1992). Issues in Irrigation Pricing in Developing Countries. *World Development* 20(7): 967-977.

Sankarasubramanian, A. and Vogel, R. M. (2001). Climate elasticity of streamflow in the United States. *Water Resources Research* 37(6):1771 -1781.

Sen, P.K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association* 63:1379-1389.

Smakhtin, V. U. (2000). Estimating daily flow duration curves from monthly stream flow data. *Water SA* 26(1):13-18. [http://www.wrc.org.za] site visited on 13/4/2006.

Smakhtin, V. U. and Watkins, D. A. (1997). Low Flow Estimation in South Africa. Water Research Commission Report No 494/1/97, Pretoria, South Africa.

Soil Water Management Research Group (SWMRG) (2003). Comprehensive assessment of water resources of Mkoji sub-catchment, its current use and productivity (unpublished). 115 pp.

Sokile, C. S. (2005). Improvement of Institutional Frameworks for Intersectoral Water Management: The Case of Mkoji sub-catchment of the Great Ruaha River in the Rufiji Basin, Tanzania. Thesis for Award of PhD Degree at the University of Dar es Salaam, Tanzania.

Sokile, C. S. and van Koppen, B. (2003). Local Water Rights and Local Water User Entities: The Unsung Heroines to Water Resource Management in Tanzania. A paper presented at the WATERNET/WARFSA 4th[d] Symposium. Gaborone, Botswana, October 2003.

Sokile, C. S., Kashaigili, J. J. and Kadigi, R. M. J. (2003). Towards An Integrated Water Resource Management In Tanzania: The Role of Appropriate Institutional Framework in Rufiji Basin. Elsevier Journal, Special Edition of *Physics and Chemistry of the Earth*, Part A/B/C, Volume 28, Issues 20-27.

Solanes, M. and Gonzales-Villarreal, F. (1999). The Dublin Principles for Water as Reflected in a Comparative Assessment of Institutional and Legal Arrangements for Integrated Water Resources Management. TAC Background Paper No.3. GWP, Stockholm, Sweden.

Stern, R., Coe, R., Allan, E. and Dale, I. (2004). Good Statistical Practice for Natural Resources Research. CABI Publishing, CABI international, Wallingford, Oxfordshire, UK. 388pp.

Stewart-Oaten, A., Murdoch, W. W. and Parker, K. R. (1986). Environmental impact assessment: “pseudoreplication” in time? *Ecology* 73: 1396-1404.

Sustainable Management of the Usangu Wetland and its Catchments (SMUWC) (2001a). Baseline 2001. [http://www.usangu.org/] site visited on 23/5/2002.

Sustainable Management of the Usangu Wetland and its Catchments (SMUWC) (2001b). Water Resources. Supporting Report 7. [http://www.usangu.org/reports/] site visited on 23/5/2002.

Sustainable Management of the Usangu Wetland and its Catchments (SMUWC) (2001c). Irrigation water management and efficiency. Supporting Report 8. [http://www.usangu.org/reports/] site visited on 23/5/2002

Sustainable Management of the Usangu Wetland and its Catchments (SMUWC) (2001d). Usangu Basin modelling study. Supporting Report 11. [http://www.usangu.org/repors/] site visited on 23/5/2002.

Tanzania National Website (TNW) (2003). 2002 Population and Housing Census. [http://www.tanzania.go.tz/census/districts] site visited 24/7/2005.

Theil, H. (1950). A rank-invariant method of linear and polynomial regression analysis, 1 and 2. *Ned. Akad. Wentsch Proc,* 53: 386-392 and 521-525.

The Governor of Tanganyika (GoT) (1959). The Water Ordinance 1959 (Cap. 410).

The Nature Conservancy (TNC) (2005). *Indicators of Hydrologic Alteration Version 7 User's Manual*. 50pp.

The World Bank (2004). Implementation Completion Report: Tanzania River Basin Management and Smallholder Irrigation Improvement Project. Report No. 30929.

The World Bank (2002). Empowerment and Poverty Reduction: A Sourcebook

The World Bank (1996). Staff Appraisal Report: Tanzania River Basin Management and Smallholder Irrigation Improvement Project. Report No. 15122-TA

The World Conservation Union (IUCN) (2000). Vision for Water and Nature. *A World Strategy for Conservation and Sustainable Management of Water Resources in the 21st Century - Compilation of All Project Documents*. Cambridge.

Theodore, H. H. (2004). Applying the Concept of Sustainability to Water Resources Management. *Water Resources Update* 127: 6-10.

Turc, L. (1955). Water balance of soils: relationship between precipitation, evapotranspiration and runoff (in French). *Ann. Agron* 6: 5-131.

Thornthwaite, C. W. (1948). An approach toward a rational classification of climate. *Geographical Review* 38: 55-94.

United States Environmental Protection Agency (EPA) (2006). Data Quality Assessment: Statistical Methods for Practitioners. EPA QA/G-9S. Office of Environmental Information. 190pp.

United States Army Corps of Engineers (USACE) (1997). Engineering and Design - Hydrologic Engineering Requirements for Reservoirs (Manual No. 1110-2-1420) [www.usace.army.mil/usace-docs/eng-manuals/em1110-2-1420/] site visited on 10/04/2006.

United Republic of Tanzania (URT) (2007). Coping With water Scarcity. Statement from the Minister for Water at the Climax of Maji Week. The Guardian, Issue No. 3840. p. 10.

United Republic of Tanzania (URT) (2002a). National Water Policy. Ministry of Water and Livestock Development, Dar es Salaam, Tanzania.

United Republic of Tanzania (URT) (2002b). The Water Utilization (General) (Amendment) Regulations, of 2002. Ministry of Water and Livestock Development, Dar es Salaam, Tanzania.

United Republic of Tanzania (URT) (1997). National Environmental Policy. Vice President’s Office, Dar es Salaam, Tanzania.

United Republic of Tanzania (URT)/Ministry of Water (1995). Rapid Water Resources Assessment, Volumes I and II, DANIDA/World Bank.

United Republic of Tanzania (1974). The Water Utilization (Control and Regulation) Act No. 42. of 1974.

Van Koppen, B., Sokile, C. S., Hatibu, N., Lankford, B. A., Mahoo, H. F. and Yanda, P. Z. (2004). Formal water rights in rural Tanzania: Deepening the dichotomy? International Water Management Institute, Working paper 71.

Vogel, R. M. and Fennessey, N. M. (1994). Flow duration curves I: A new interpretation and confidence intervals. *Journal of Water Resources Planning and Management* 120(4): 485 -504.

von Storch, H. (1995). Misuses of statistical analysis in climate research. In: *Analysis of Climate Variability: Applications of Statistical Techniques.* (Edited by von Storch, H. and Navarra, A.), Springer-Verlag, Berlin, Germany. pp. 21-26.

Whyte, A. (2004). Human and Institutional Capacity Building: Landscape Analysis of Donor Trends in International Development. Report to the Rockefeller Foundation. New York.

Williamson, G. and Payne, W. J. A. (1978). *Animal husbandry in the Tropics*. (3rd Ed.). Longman Group Limited, UK.

World Meteorological Organisation (WMO) (1994). *Guide to Hydrological Practices. Data acquisition and processing, analysis, forecasting and other applications* (WMO-No. 168). Fifth Edition, World meteorological Organisation. 738pp.

www.consecol.org/journal/vol5/iss2/art21/ site visited on 15/4/2003.

Ye, W., Hansen, D. P., Jakeman A. J., Sharma, P. and Cooke, R. (1997). Assessing the natural variability of runoff: Clarence Basin catchments, NSW, Australia. *Mathematics and computers in Simulation*. 43(3-6): 251-260.

Yin, X. and Nicholson, S. E. (2002). Interpreting Annual Rainfall from the Levels of Lake Victoria. *Journal of Hydrometeorology* 3: 406-416.

Yue, S. and Pilon, P (2003). Canadian streamflow trend detection: impacts of serial and cross-correlation. *Hydrological Sciences Journal* 48(1): 51-63**.**

Yue, S. and Wang, C. Y. (2002). Applicability of pre-whitening to eliminate the influence of serial correlation on the Mann-Kendall test. *Water Resources Research* 38 (6). doi:10.1029/2001WR000861.

Yue, S., Pilon, P. and Cavadias, G. (2002a). Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *Journal of Hydrology* 259: 254–271.

Yue, S., Pilon, P., Phinney, B. and Cavadias, G. (2002b). The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrological Processes* 16(9): 1807–1829.

Zhang, L., Hickel, K., Dawes, W. R. Chiew, F. H. S., Western, A. W. and Briggs, P. R. (2004). A rational function approach for estimating mean annual evapotranspiration. *Water Resources Research,* 40: W02502, doi:10.1029/2003WR002710.

Zhang, X., Harvey, K. D., Hogg, W. D. and Yuzyk, T. R. (2001). Trends in Canadian streamflow. *Water Resources Research* 37(4): 987–998.

Zhang, X., Vincent, L. A., Hogg, W. D. and Niitsoo, A. (2000). Temperature and precipitation trends in Canada during the 20th century. *Atmos. Ocean* 38(3): 395–429.

LIST OF APPENDICES

Appendix 1: Household water use questionnaire

SOKOINE UNIVERSITY OF AGRICULTURE

Assessment of current water uses and demands

QUESTIONNAIRE FOR HOUSEHOLD HEADS

A. BACKGROUND INFORMATION

1. Name of district: --
2. Name of division: --
3. Name of ward: --
4. Name of village: --
5. Name of sub-village: --
6. Name of household head: --
7. Sex of household head: male: ( ); female: ( )
8. Age of household head: (years): ( )
9. Household size: male ( ); female ( ); children (under 18 yrs) ( )
10. Where you born in this village?

    Answer: Yes = 1

    No = 2 ( )
11. If the answer is no when did you migrate to this village (year)? ( )
12. Which reasons made you to migrate to this village?

Reasons: (1) --

(2) --

(3) --

B: WATER USES AND DEMANDS IN THE HOUSEHOLDS

13. What are the sources of water for domestic uses?

Source	Wet season			Dry season		
	Source	Name of source	Distance (km)	Source	Name of source	Distance (km)
Pipe system						
Perennial rivers						
Ephemeral streams						
Wells and boreholes						
Charco dam						
Rooftop rainwater harvesting						
Wetland						
Others (specify)						

14. Do you keep livestock?

Answer: Yes = 1
No = 2 ( )

15. If the answer is yes, how many livestock do you keep?

Cattle ( )
Goat ( )
Sheep ( )
Donkey ( )
Pig ( )

16. What are the sources of water for livestock use?

Source	Wet season			Dry season		
	Source	Name of source	Distance (km)	Source	Name of source	Distance (km)
Pipe system						
Perennial rivers						
Ephemeral streams						
Wells and boreholes						
Charco dam						
Rooftop rainwater harvesting						
Wetland						
Others (specify)						

17. Do you engage in irrigated agriculture?

Answer: Yes = 1
No = 2 ( )

18. If the answer is yes, in which seasons do you engage in irrigated agriculture?

Answer: Wet season only = 1

Dry season only = 2
Both wet and dry seasons = 3 ( )

19. Why don't you engage in dry season irrigated agriculture?

Reasons: (1) --

(2) --

(3) --

20. What are the sources of water for irrigated agriculture?

Source	Wet season			Dry season		
	Source	Name of source	Distance (km)	Source	Name of source	Distance (km)
Perennial rivers						
Ephemeral streams						
Wells and boreholes						
Charco dam						
Rooftop rainwater harvesting						
Wetland						
Others (specify)						

21. Which crops do you grow under irrigation during both the wet and dry seasons? Please mention them together with the size of the fields for the 2002/03 season.

Crop type	Wet season		Dry season	
	Crop	Cropped area (acre)	Crop	Cropped area (acre)
Rice				
Maize				
Tomatoes				
Onions				
Beans				
Sunflower				
Cassava				
Round potatoes				
Sugarcane				
Bananas				
Fruits (mango, avocado)				
Groundnuts				
Sweet potatoes				
Others (specify)				

22. After irrigating the fields where do you direct the drainage or excess water?

Answer: Directly returned to the river = 1

Left to spread in nearby bushes, grasslands etc.	=	2
Re-used for domestic uses, brick making, etc.	=	3
Others (specify)	=	4
	(	)

23. Do you engage in other economic activities during the wet season apart from agriculture?

Answer: Yes = 1
No = 2 ( )

24. If the answer is yes, mention the other activities

Activities: (1) --
(2) --
(3) --

25. Which activity earns you more money during the wet season?

Answer: --

26. Do you engage in other economic activities during the dry season apart from agriculture?

Answer: Yes = 1
No = 2 ( )

27. If the answer is yes, mention the other activities

Activities: (1) --
(2) --
(3) --

28. Which activity earns you more money during the dry season?

Answer: --

29. Do you engage in bricks making?
Answer: Yes = 1
No = 2 ( )
30. If the answer is yes what are the sources of water for brick making?

Type of water source	Source used (tick)	Name of source	Distance (km)
Pipe system			
Perennial rivers			
Ephemeral streams			
Wells and boreholes			
Charco dam			
Rooftop rainwater harvesting			
Wetland and swamps			
Others (specify)			

31. How many bricks did you manage to make this season (2002/03)

Answer: ( ) bricks

32. How much water is required for brick making?

Answer: Number of bricks ( )
Quantity of water (Number of buckets; each 20 litre) ( )

33. Do you engage in fishing?

Answer: Yes = 1
No = 2 ( )

34. If the answer is yes mention the sources of water for fishing and the type of fishing being practiced {e.g. using hooks (=1), using nets, traps (=2) blocking passage of water and catching fish using bare hands (=3)}

Type of water source	Wet season			Dry season		
	Source used (tick)	Name of source	Type of fishing	Source used (tick)	Name of source	Type of fishing
Perennial rivers						
Ephemeral streams						
Wetland						
Others (specify)						

35. Are there other uses of water?

Answer: Yes = 1
No = 2 ( )

36. If the answer is yes mention the other uses of water

Sno.	Other uses of water	
	Wet season	Dry season
1		
2		
3		
4		
5		

37. What water storage structures do you use in your house? Specify capacities

Storage structure	Wet season		Dry season	
	Capacity (litre)	Duration of storage (days)	Capacity (litre)	Duration of storage (days)
Water tanks				
Plastic drums				
Metallic drums				
Buckets				
Clay pots				
Cooking pots				
Others (specify)				

38. What are your demand preferences? Mention the first four in order of preference

Major livelihood activities		Demand type	Preference (rank)
Livelihood activity	Respondent's major activity (tick)		
Irrigated agriculture		Agriculture	
Livestock keeping		Livestock keeping	
Fishing		Fishing	
Brick making		Domestic	
		Environment (wetlands, swamps, rivers)	
		Hydropower generation	
		Brick making	

39. In case there is more than one source of water, what are your supply priorities? Please give reasons for your answer

Water use	Priority water source				Reason
	Piped system	Wells and boreholes	Flowing river	Charco dam and reservoir	
Domestic					
Irrigated agriculture					
Livestock keeping					
Fishing					
Brick making					

Others (specify)					

40. How many litres does the household use per day for various domestic chores?

Domestic use	Quantity (number of 20 litre buckets)	
	Wet season	Dry season
Drinking and cooking		
Bathing		
Laundry and cleaning		
Others (specify)		

41. How do you determine (criteria) that there is water shortage or scarcity for domestic, fishing, livestock, brick making or agricultural use?

    Answer: when:

i. Less than one-third (1/3) of the demand is met
ii. Less than one-half (1/2) of the demand is met
iii. Less than three-quarter (3/4) of the demand is met
iv. No demand is met (there is no water)
v. Others (mention)

Water use	Criteria	
	Wet season	Dry season
Domestic		
Fishing		
Livestock		
Agriculture		
Brick making		

42. How do you cope with water shortages for domestic use (copying strategies)?

    Strategies: (1) --

    (2) --

    (3) --

43. How do you cope with water shortages for irrigation (copying strategies)?

    Strategies: (1) --

    (2) --

    (3) --

44. How do you cope with water shortages for livestock use (copying strategies)?

    Strategies: (1) --

(2) --

(3) --

45. In case of water shortage, will you be willing to use less water than your requirement so that those located downstream can also get some water for their daily uses?

Answer: Yes = 1
No = 2 (   )

46. If the answer is no, what are the reasons?

Reasons: (1) --

(2) --

(3) --

47. If the answer is yes, what proportion of your water requirement will you be willing to reduce?

Answer: 1) One-quarter (1/4)
2) One-third (1/3)
3) One-half (1/2)
4) Two-thirds (2/3)
5) Three-quarters (3/4)
6) Other (specify) (   )

48. What do you think should be done so that the flow of water in the rivers can be restored to their natural levels during the dry season?

Actions: (1) --

(2) --

(3) --

(4) --

49. What do you think should be done so that the flow of water in the rivers can be restored to their natural levels during the wet season?

Actions: (1) --

(2) --

(3) --

(4) --

THE END
THANK YOU

Appendix 2: Questionnaire on indicators of hydrologic alteration

SOKOINE UNIVERSITY OF AGRICULTURE

QUESTIONNAIRE ON INDICATORS OF HYDROLOGIC ALTERATION

1. Name of respondent: ---
2. Title/Designation: ---
3. Organisation: ---
4. Profession/Occupation: ---

Introduction

Water plays a fundamental, pervasive, critical role in every economy and thus is important in almost all aspects of human endeavour. In his struggle for a better life, man has expended great efforts to tame the rivers for transportation, water supply, agriculture, tourism and power generation. However, through these non-natural processes, the natural flow and hydrologic regimes of a majority of the world's rivers have been substantially altered. For example, impacts due to the existence and pattern of operation of dams and reservoirs may include: (a) upstream change from river valley to reservoir, (b) changes in downstream water quality, and (c) changes in total volume of stream flow and its seasonal distribution. The Great Ruaha River in Tanzania has not escaped this trend. Extensive river regulation activities such as construction of hydropower plants and reservoirs, development of irrigated agriculture and diversion of water for livestock and domestic water supply have intensified since the 1970s.

Currently, the indicators of hydrologic alteration that are commonly used are based on streamflow characteristics at available stream gauge sites (gauging stations). The hydrologic alteration is assessed basing on the differences in streamflow regime characteristics between two defined time periods at a given stream gauge site. These indicators are:

(a) ***Magnitude of monthly discharge conditions*** (e.g. mean monthly discharges)

(b) ***Magnitude and duration of annual extreme discharge conditions*** (e.g. Number of zero flow days; annual maxima and minima

(c) ***Timing of annual extreme discharge conditions*** (e.g. Date of occurrence of annual maximum and minimum discharge);

(d) ***Frequency and duration of high and low flows***.

Duration of high and low flows - periods in which the hydrograph rises above or falls below a given percentile within each year

Frequency of high and low flows – Number of high and low flows within each year; and

(e) ***Rate and frequency of water conditions changes*** (e.g. frequency at which the hydrograph switches from a rising period to a falling period – no. of rises and no. of falls (and vice versa) within each year.

Q1 Are these indicators relevant to our (Usangu catchment) conditions? I.e. can our local water users (domestic, agriculture, livestock, hydropower, national parks, fishing) understand them?

Answer: Yes = 1
No = 2 (   )

Explain a bit about your answer

Q2 Are they adequate?

Answer: Yes = 1

No = 2 (   )

Explain a bit about your answer

Q2 If they are not adequate, what other relevant indicators should we use in order to assess alteration of the hydrologic properties or characteristics of the Great Ruaha River and its tributaries (consider the Usangu and Pawaga Plains, Ruaha National Park, Usangu Game Reserve or Mtera Dam) as a result of natural phenomenon (e.g. climatic change) and/or human activities (e.g. dams & reservoirs operations; water diversions for agriculture, livestock; and intensive conversions of land use in a catchment). How can we measure them?

Use the following table to answer this question. The first four have been done as examples.

Table A4.5 Relevant Indicators of Hydrologic Alteration and Methods/ways of measuring them

Sno	Indicator of hydrologic alteration	Method of measurement (if possible)
a	*Upstream change from river valley to reservoir*	*Measuring surface area, depth of water*
b	*Change in downstream water quality*	*Collecting water samples and analysing water quality parameters*
c	*Change in annual or monthly volume of streamflow*	*Flow gauging*
d	*Disappearance, appearance or change of size of wetlands*	*Remotely sensed images analysis and mapping of wetland areas*
Sno	Indicator of hydrologic alteration	Method of measurement (if possible)
1.		
2.		
3.		
4.		
5.		

THE END
THANK YOU

Appendix 3: Rating curve derivation for Lwanyo River

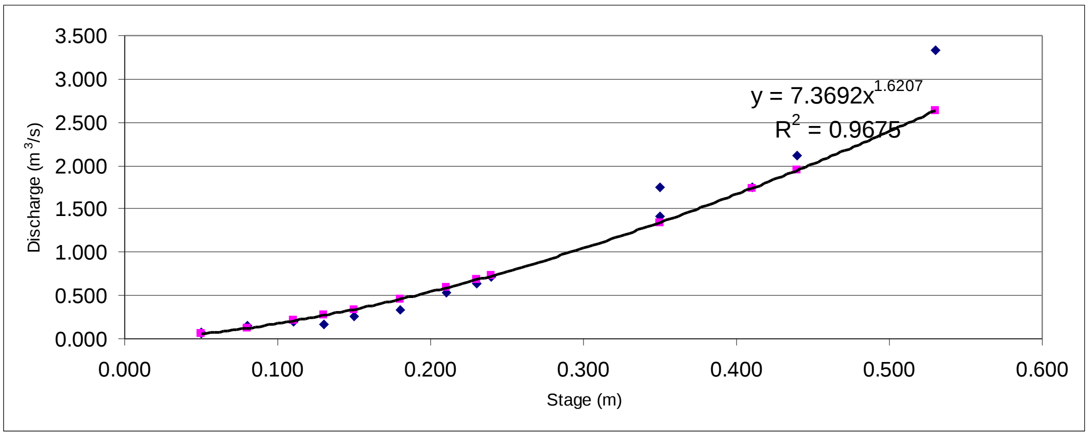
Q_r = k(h-h0)^x
k = 7.3692
x = 1.6207
h_0 = 0

The rating equation is:

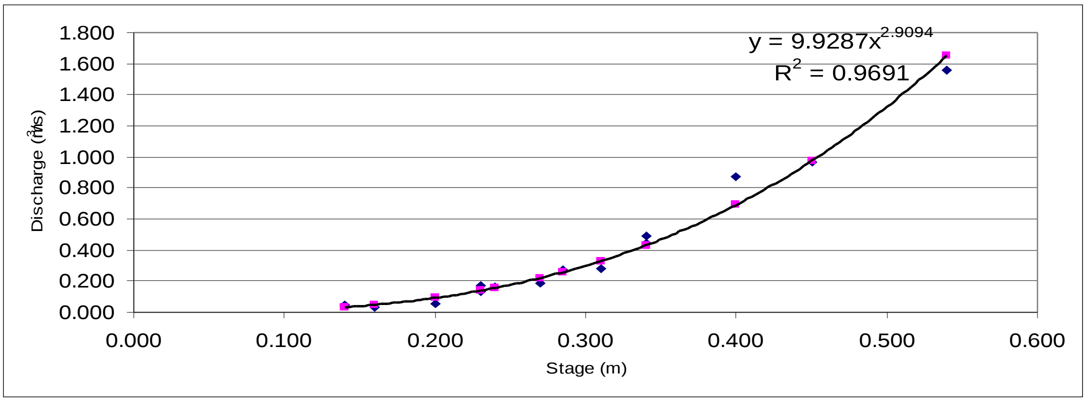
$$Q_r = 7.3692(h)^{1.6207}$$

Example of rating equation derivation for Lwanyo River at Majenje

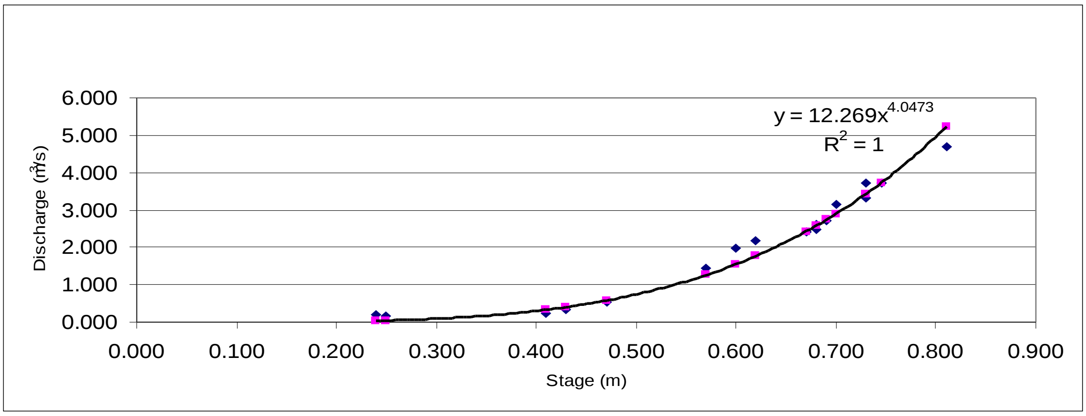
Sno.	Gauge height (h) (m)	Discharge Q_m (m^3/s)	Rating curve discharge Q_r (m^3/s)	(Q_r-Q_m)^2	sum((Q_r-Q_m)^2)
1	0.530	3.326	2.633627	0.479381	0.479381
2	0.440	2.115	1.947889	0.027926	0.507307
3	0.410	1.749	1.737237	0.000138	0.507445
4	0.350	1.417	1.344285	0.005287	0.512733
5	0.350	1.746	1.344285	0.161375	0.674107
6	0.240	0.721	0.729338	0.000070	0.674177
7	0.230	0.632	0.680726	0.002374	0.676551
8	0.210	0.537	0.587410	0.002541	0.679092
9	0.180	0.341	0.457552	0.013584	0.692677
10	0.150	0.252	0.340496	0.007831	0.700508
11	0.130	0.167	0.270015	0.010612	0.711120
12	0.110	0.201	0.205971	0.000025	0.711145
13	0.080	0.149	0.122930	0.000680	0.711825
14	0.050	0.066	0.057391	0.000074	0.711899
15	0.050	0.078	0.057391	0.000425	0.712323



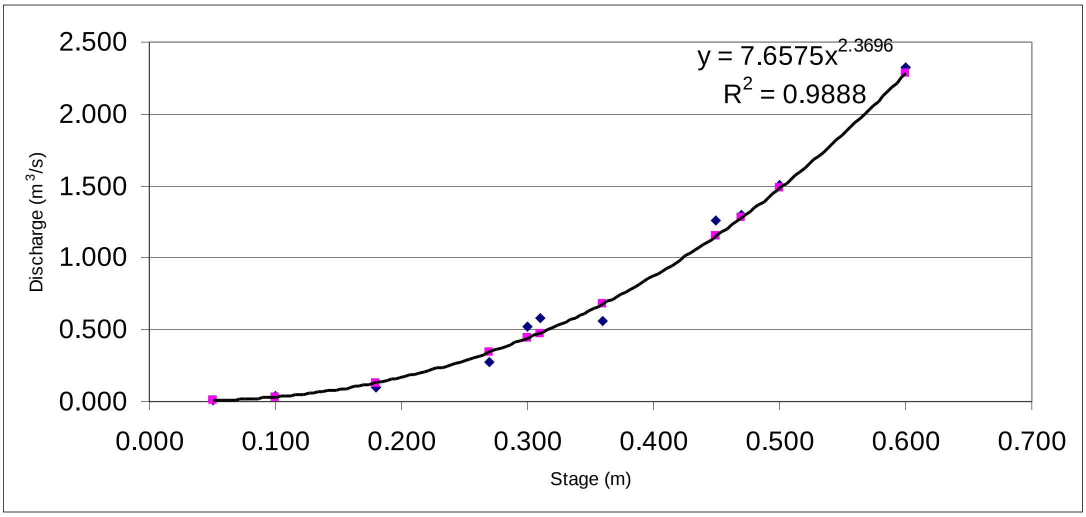
Appendix 3 (a) Rating curve at Mkoji River at Halanzi



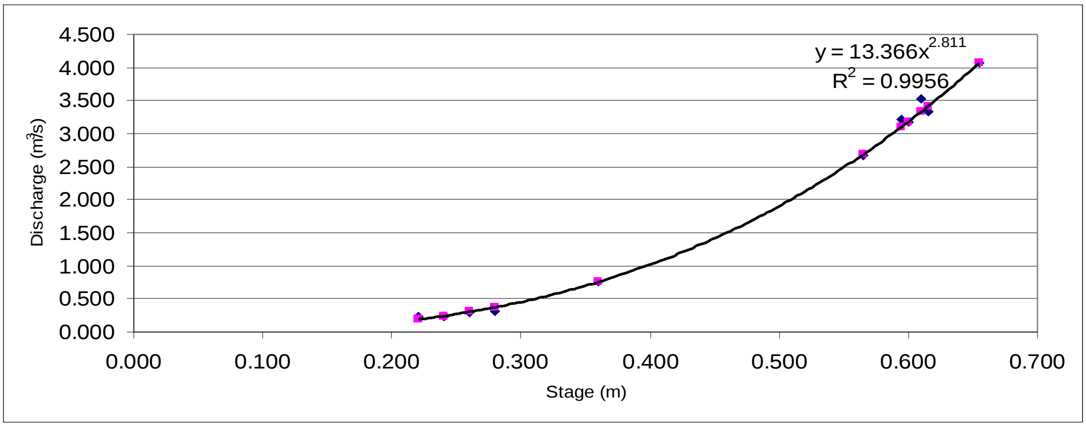
Appendix 3 (b) Rating curve at Mswiswi River at Wilima



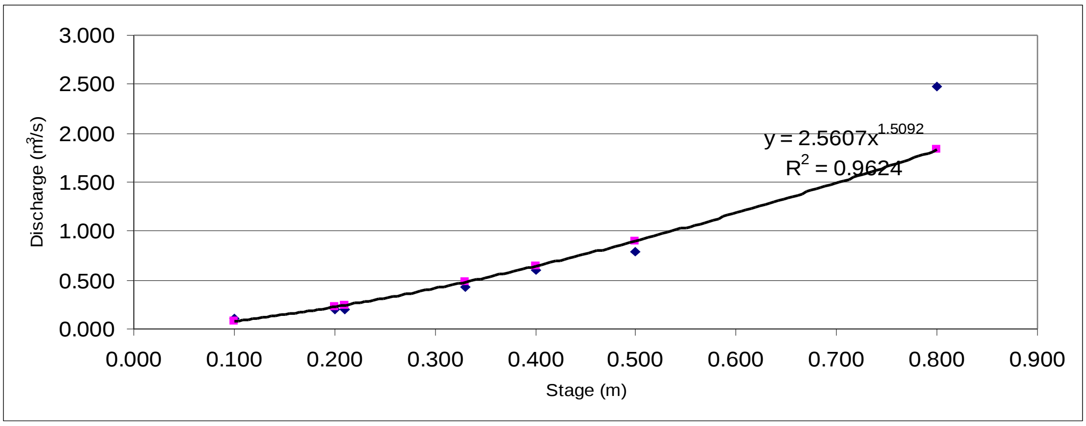
Appendix 3 (c) Rating curve at Mswiswi River at Azimio



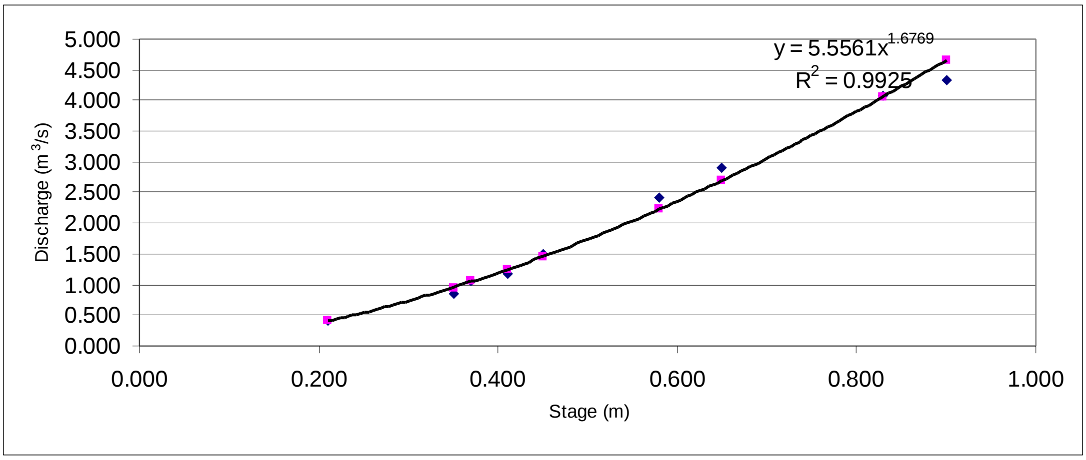
Appendix 3 (d) Rating curve at Lunwa River at Igurusi



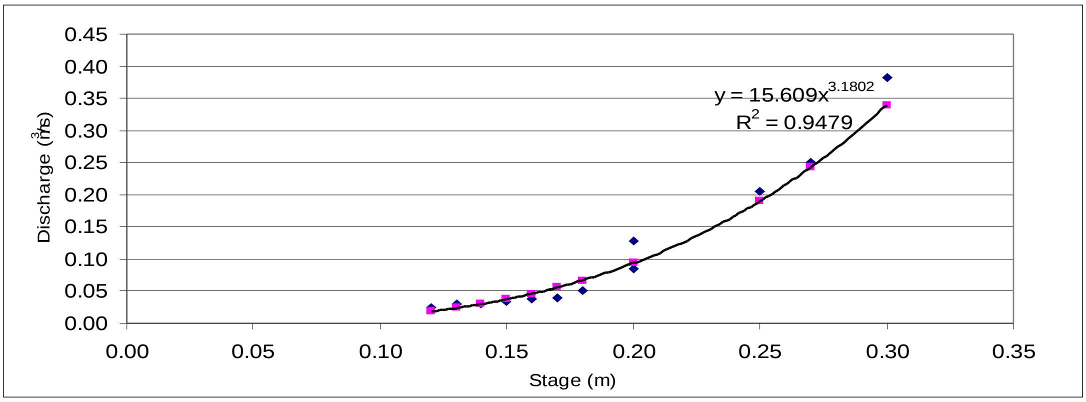
Appendix 3 (e) Rating curve at Kimani River at Ukwavila



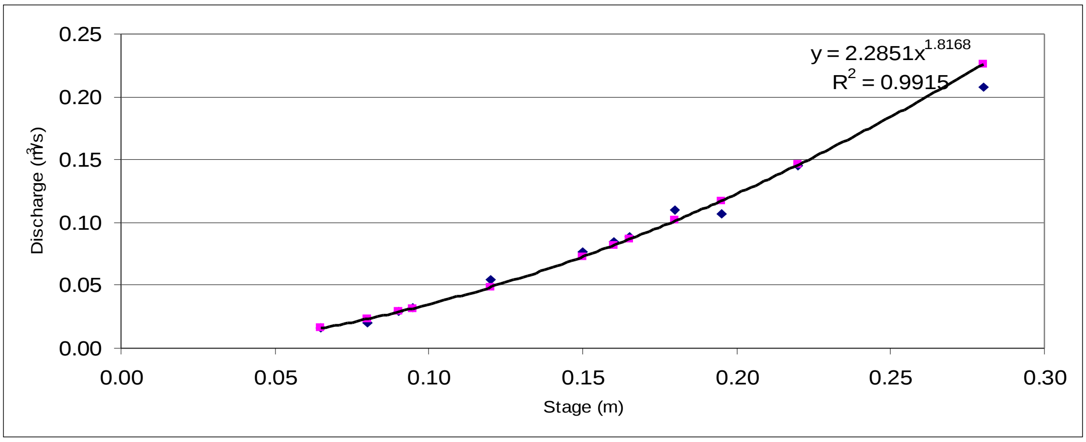
Appendix 3 (f) Rating curve at Mbarali River at Warumba



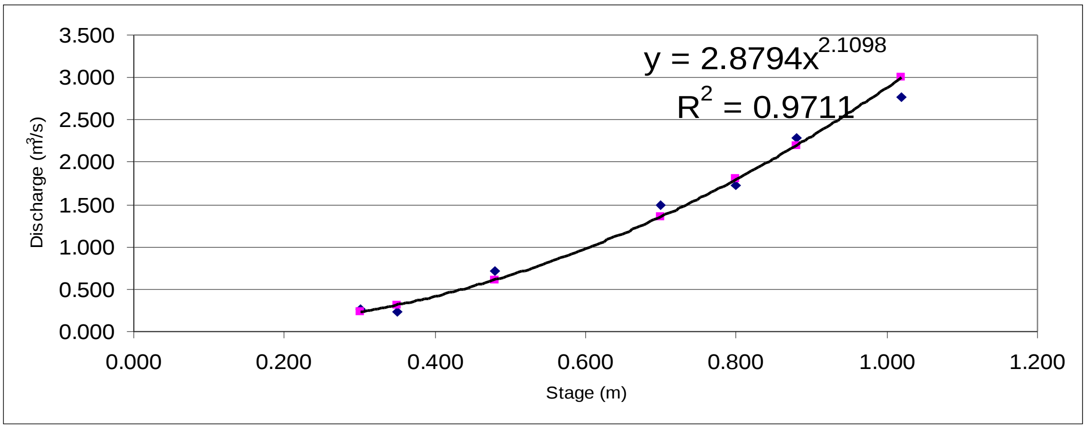
Appendix 3 (g) Rating curve at Uta River at Iyawaya



Appendix 3 (h) Rating curve at Luanda Majenje canal



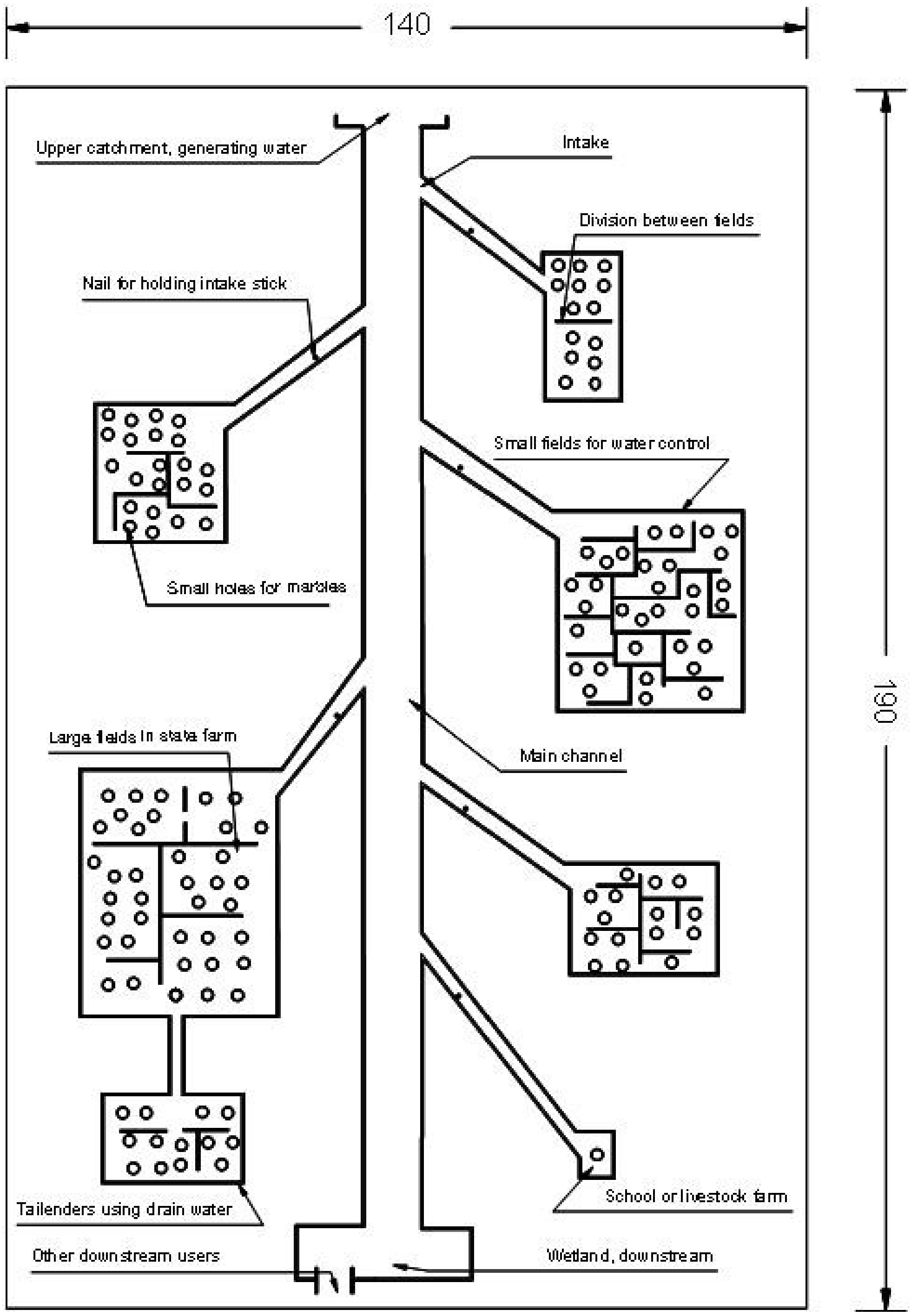
Appendix 3 (i) Rating curve at Mbuyuni canal



Appendix 4: Short description of the river basin game

The River Basin Game is a dialogue tool to aid the decision-making process and can be used by water users. It is a physical model representing the catchment in the form of a large wooden/iron sheet board. Physically, the river is represented to flow centrally between the upper catchment and the lowlands in the downstream (sometimes represented by a wetland). All along, there are several intakes leading water into irrigation systems and livestock watering points of varying sizes. Glass marbles act as the “flow of water” down the central channel, which represents the river. Irrigation intakes are represented by small sticks put across the central channel or river to capture the marbles as they ‘flow’. Once the marbles are ‘diverted by the weirs’ they flow through channels leading to small basins, which represent the crop fields. The crop fields are designed in such a way that they have holes the size of the marbles. Once the marbles reach these ‘fields,’ they easily rest in the holes. In order to assess how much water one got, the number of marbles is counted at the end.

In each of the two river basin game workshops, the game was played for two days and participants contributed in detail on: 1) individual strategies to search for water, money and livelihoods; 2) community actions required in order to allocate water equitably; 3) modifications and improvements to be undertaken on water abstraction intakes and conveyance canals in order to (i) reduce water losses and (ii) ensure that downstream users get their share of water; 4) strategies to increase productivity of water at the local user and sub catchment scales by using the little water available; 5) Importance and role of legislation and bye laws in facilitating sustainable water management (including proposing important clauses and provisions to be included in the bye laws); 6) The role, importance, necessity and shortcomings of water rights and water use fees; 7) Institutions required to oversee the proposed strategies (necessary for effective water management) and their possible roles; and 8) required improvements or changes on the procedures being followed before granting water rights and estimation and payment of water use fees.

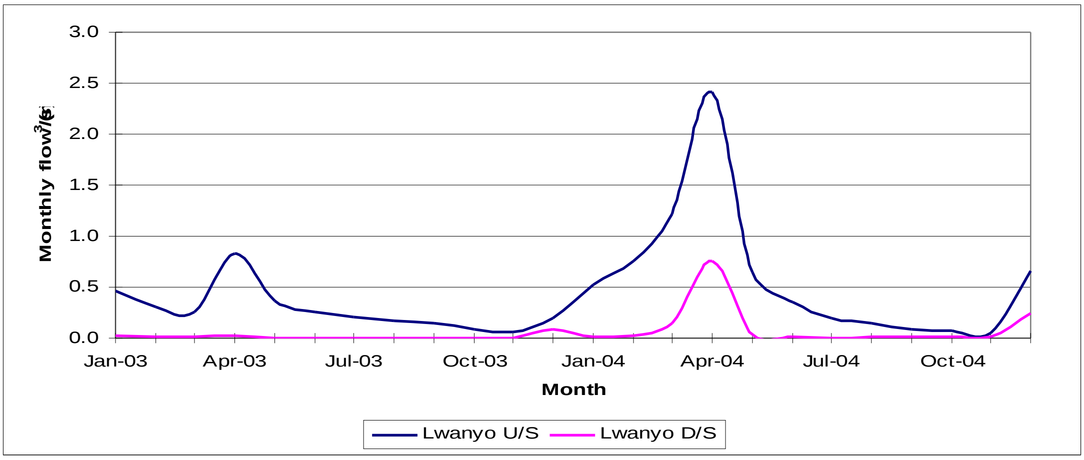


Dimensions: cm

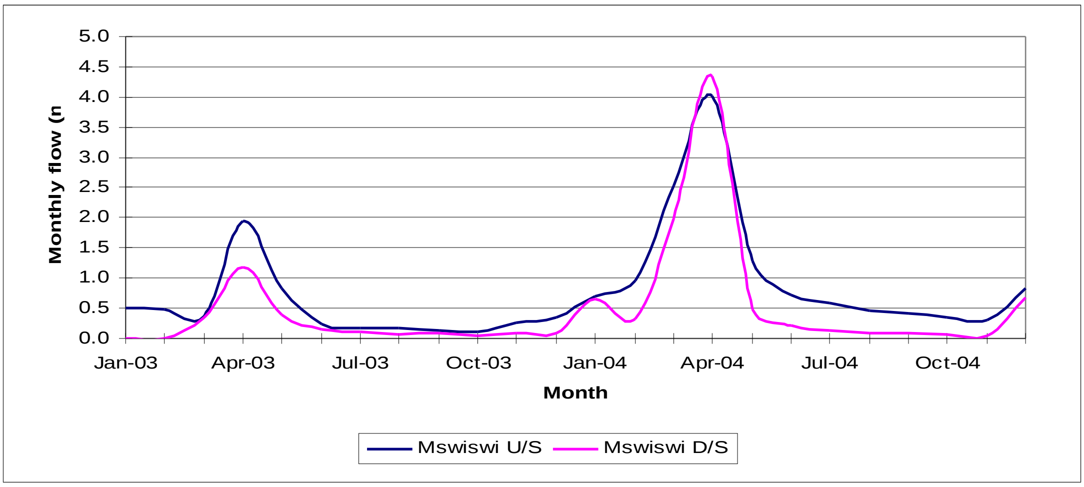
The river basin game table

Appendix 5: Monthly flow hydrographs at gauged points upstream and downstream of irrigation abstractions

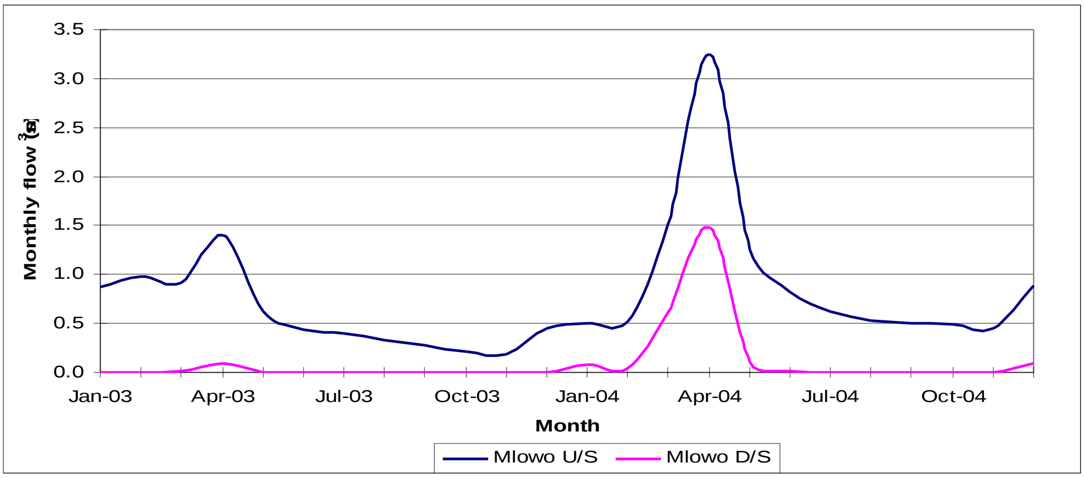
Appendix 5 (a): Monthly flow hydrograph for Lwanyo River



Appendix 5 (b): Monthly flow hydrograph for Mswiswi River



Appendix 5 (c): Monthly flow hydrograph for Mlowo River



Appendix 6: Location of studied water abstraction intakes